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Arsenic Biosorption by the Macroalgae *Chondracanthus chamissoi* and *Cladophora* sp.

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Abstract: The biosorption of arsenic (As) with macroalgae has aroused much interest as a clean and low-cost technology. To evaluate arsenic biosorption by *Chondracanthus chamissoi* and *Cladophora* sp., approximately 5 kg of algae was collected from Huanchaco's beach and Sausacocha lake (Huamachuco), La Libertad. As biosorption was carried out in four column systems, with 2 g of algae pellets each, circulating As solutions of 0.25 and 1.25 ppm, respectively, at 300 mL/min cm^2. As concentration was determined at 3 and 6 h of treatment by flame atomic absorption spectrophotometry. Data were analyzed using Student's t-test with 95% confidence. At 6 h, *Chondracanthus chamissoi* presented an As biosorption of 95.76% in a 0.25 ppm mg/L solution and 85.33% in a 1.25 mg/L solution. *Cladophora* sp., at 6 h, presented an As biosorption of 95.76% in a 0.25 mg/L solution and 42.03% in a 1.25 mg/L solution. It was concluded that *Chondracanthus chamissoi* achieves higher percentages of biosorption than *Cladophora* sp. in solutions of 1.25 mg/L As ($p < 0.05$), and that there is no significant difference between the biosorption percentages of *Chondracanthus chamissoi* and *Cladophora* sp. in a 0.25 mg/L solution of As at 6 h of treatment ($p > 0.05$).

Keywords: biosorption; arsenic; heavy metals; *Chondracanthus chamissoi*; *Cladophora* sp.

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1. Introduction

The release of heavy metals into the environment, whether due to natural phenomena or anthropogenic activities, such as mining, agriculture, and industries, among others, leads to serious impacts, due to their bioaccumulation and high toxicity, since these metals are not removed from ecosystems by natural processes [1,2]. Among these heavy metals, one of the most abundant in nature is arsenic (As) [3]; this mineral is a highly toxic metalloid, and it is released into the environment, especially in water bodies, as a result of mining and other industrial activities [4]. Thus, arsenic contamination in the environment is frequently observed in soils, sediments, and water with values above 10 µg/L (maximum concentration established in 2006 according to the EPA); in this regard, the concentration of arsenic reference is, on average, below 1 µg/L [5,6].

Likewise, various adverse effects of arsenic on humans have been observed when drinking contaminated water, as well as through inhalation and direct contact with the skin, and it is estimated that 70–90% of inorganic arsenic is absorbed by the gastrointestinal tract and reaches through the blood mainly to the liver, kidneys, lungs, and bladder and, secondly, to muscle and nerve tissue, thus promoting the appearance of different diseases, including cancer [3,7–9]. In this context, it should be noted that the toxicity of this metalloid varies, according to the oxidation state and chemical presentation (organic or inorganic), with inorganic As being more toxic than organic [4]. The most common form of As is As (V) or arsenate and As (III) or arsenite, depending on the pH and the oxidation-reduction

conditions. [8] As (III) is found as H_3AsO_3 and its corresponding dissociation products (H_4AsO_{3+}, H_2AsO_{-3}, $HAsO_3{}^{-2}$, and $AsO_3{}^{-3}$), which, under oxidizing conditions, are dominant at alkaline pH. However, the uncharged form of As (III) [$As(OH)_3$] is dominant in reduced and anoxic environments, thus being the most toxic and difficult to remove. For its part, As (V) is present in the form of H_3AsO_4 and its corresponding dissociation products (H_2AsO_{4-}, $HAsO_4{}^{-2}$, and $AsO_4{}^{-3}$), thus being dominant under oxidizing conditions at acidic pH in aqueous and aerobic environments [10].

As (III) is more toxic than As (V), because it inhibits the activity of metabolic enzymes by binding to its sulfhydryl group, causing highly negative effects on organisms [7]. Taking this problem into account, various techniques have been developed to remove the different forms of As from water, such as oxidation, membrane techniques, coagulation-flocculation, ion exchange, and adsorption with artificial or natural materials [11]. However, these methods have some disadvantages, such as the high cost and complexity of the technique, which are not always accessible for some regions of developing countries [12]. Thus, a series of clean alternatives have emerged to treat environments contaminated with As, with bioremediation being one of these technologies, which proposes the use of microorganisms (bacteria, fungi, yeasts, and microalgae) and superior organisms, such as macroalgae and plants, which have been widely studied for their ability to capture and accumulate pollutants [13]. Among other biotechnological techniques that are presented as an alternative to conventional methods, biosorption has become very important [14].

The biosorption technique is based on using dead and inactive biomass to recover heavy metals from aqueous solutions; this is a metabolically passive mechanism that is affected by chemical, physical, and biological factors [14,15]. Ion exchange is one of the main mechanisms of biosorption, and it occurs between metal ions from the environment and main functional groups present in cell walls [16]. This technology has very significant advantages, such as low cost, high availability, good profitability, easy handling, and efficiency, when metals are in low concentrations [17]; above all, it is clean and environmentally friendly technology. Thus, biosorption with macroalgae is a technology that can be applied in the treatment of contaminated water bodies. In this case, they are used as dry biomass and behave as very efficient biosorbents because they have a large number of functional groups, which have an affinity for dissolved cationic metals [18]. It has been shown that the macroalgae of marine origin are more efficient than bacteria and fungi in the biosorption of some metals [14]. In this context, it is worth mentioning that the cell wall of algae is composed of polysaccharides, proteins, and lipids that contain functional groups, such as carboxyl (-COOH), hydroxyl (-OH), phosphate (O_4P^{-3}), amine (-NH_2), and the sulfhydryl group (-SH), that give the cell surface a negative charge, which favors the adsorption of metals [19,20]. Among these polysaccharides are the alginates from brown or brown algae, which have a high affinity for metal ions [19].

There are various species of macroalgae that are used in the biosorption of heavy metals [16,18,19,21], among these are the macroalgae *Chondracanthus chamissoi* (red algae) and *Cladophora glomerata* (green algae), which have been investigated for the biosorption of heavy metals, such as Pb (II) and Cd (II) for *Chondracanthus*, as well as the biosorption of Cr (III) in the case of *Cladophora* [22,23]. In this regard, Christobel and Lipton (2022) evaluated the capacity of various macroalgae, including the red algae *Gracilaria corticata*, for the removal of Arsenic (As) from an aqueous solution; the results indicated that the optimum pH was 6, removal of arsenic was 90.2%, and maximum biosorption capacity was 2.21 mmol/g; on the other hand, the FTIR analysis revealed the presence of amino, carboxyl hydroxyl, and carbonyl groups on the surface of the biomass cells. From this, it was concluded that the biomass of macroalgae represents an ecological alternative for the treatment of water with arsenic [24].

In recent years, in Peru, there have been serious problems of contamination of rivers, lakes, and seas, due to the activity of mining projects and informal mining [25–27]. One of the contaminants is As, which, as mentioned above, affects both environmental and public health. Therefore, considering that algae are a very abundant resource on the Peruvian

coast, this research is proposed with the objective of evaluating the Arsenic biosorption by macroalgae, *Chondracanthus chamissoi*, and *Cladophora* sp. from Huanchaco's beach and Sausacocha lake (Huamachuco), La Libertad (Peru). This technology can be included as a sustainable strategy for bioremediation of aquatic environments contaminated with As.

2. Materials and Methods

2.1. Algae Harvesting

Approximately 5 kg of each macroalgae were collected, which were placed in first-use polyethylene bags, labeling each bag with information on the place, date, and time of sampling.

2.1.1. Harvesting of *Chondracanthus chamissoi*

Algae of the species *Chondracanthus chamissoi* were collected on the coast of Huanchaco beach, Trujillo province, La Libertad Region, Peru. Two sampling points were considered, and each sampling point was referenced by satellite GPS. The first point was located on Huancarute beach, whose GPS coordinate was UTM 17 L 0706774 9106047; the second point was on the Huanchaco beach pier, with coordinates UTM 17 L 0707042 9106509.

2.1.2. Collection of *Cladophora* sp.

The algae *Cladophora* sp. was collected on the outskirts of the Sausacocha lake pier, which is located 10 km northeast of Huamachuco, Sánchez Carrión Province, La Libertad Region, Peru, at 7°47′45.28″ south latitude and 77°59′27.20″ west longitude.

2.2. Transfer of Samples

The samples were placed in coolers, which contained ice packs to maintain the cold chain between 4 to 8 °C, and were transferred to the laboratory of the Institute of Research in Science and Technology of the César Vallejo University.

2.3. Identification of the Genus and Species of Algae

The identification of the algae was carried out using the dichotomous keys for the identification of algae, proposed by the Faculty of Natural Sciences of the National University of La Plata, Argentina [28].

2.4. Production of Algae Pellets

The algae were worked separately, taking portions of between 500 and 600 g, and washed 3 times with distilled water; later, they were placed in trays containing 1000 mL of HNO_3 at 0.1 N for one hour to achieve protonation. After this time, the algae were removed, and the excess liquid was allowed to drain for 15 to 20 min. Finally, pellets of 4 to 5 mm in diameter were manually formed. The pellets were dried in an oven at 45 °C for 24 h and stored until use.

2.5. Preparation of as Solutions

Starting from a 1000 mg/L standard solution of As_2O_3, in the arsenite state (pH 7.5) [10], they were prepared 1000 mg/L solutions at concentrations of 0.25 and 1.50 mg/L.

2.6. Enabling the System for Biosorption

The equipment for As biosorption consisted of a column system (3 graduated cylindrical polyethylene tubes), connected in series, as shown in Figure 1, attached to an universal support with two universal metal clamps, and connected to two between each other by polyethylene hoses of 0.5 cm in diameter. The third column empties into an Erlenmeyer flask, which, in turn, was connected to a continuous recirculation pump of 4.5 volts, with a flow rate of 12 to 13 L/h, which was connected to the upper container by means of a 0.5 cm diameter silicone hose (Figure 1).

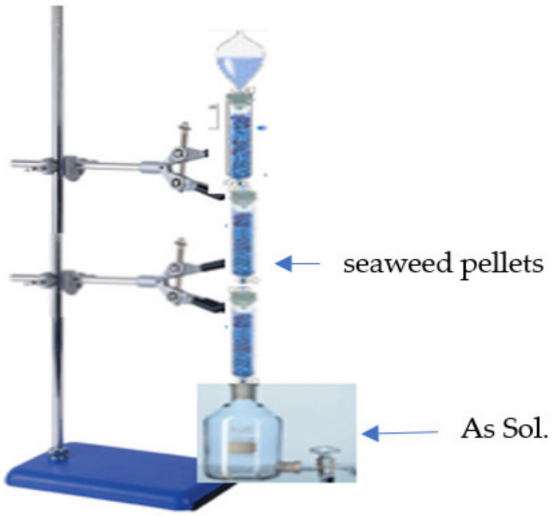

Figure 1. Scheme of the biosorption system.

2.7. Identification of Functional Groups on the Surface of Algae

It was carried out by Fourier transform infrared spectroscopy (FTIR) analysis [29]; the analyses were performed in duplicate, using Shimadzu FTIR equipment (Japan), model IRAffinity-1, in the range of wave numbers from 400–4000 cm^{-1}.

2.8. Evaluation of the as Biosorption by Algae

We worked with 4 experimental systems for biosorption, with different concentrations of As, as shown below:

System 1: 0.25 mg/L As solution + 2 g of *Chondracanthus chamissoi* pellets.
System 2: Solution 0.25 mg/L of As + 2 g of *Cladophora* sp. pellets.
System 3: Solution 1.50 mg/L of As + 2 g of *Chondracathus chamissoi* pellets.
System 4: Solution 1.50 mg/L of As + 2 g of *Cladophora* sp. pellets.

Two liters of the respective arsenite solution were circulated in each of the columns, at a circulation volume of 300 mL/min/cm^2. Samples of the circulating fluid were taken at 3 and 6 h from the start of circulation.

The initial pH for the systems was 7.50 ± 0.02. After six hours of treatment, the pH was reduced to 2.50 ± 0.09 in the systems with *Chondracanthus chamissoi* and 4.21 ± 0.07 in those with *Cladophora* sp.

The collected samples were preserved at a pH of less than 2, until they were sent to the LABICER Laboratory of the Faculty of Sciences of the National University of Engineering, where the concentration of As in each of the solutions was determined by the flame atomic absorption spectrophotometry method, using the SHIMADZU AA 700 atomic absorption spectrophotometer, with a detection limit of 0.01 mg/L.

The biosorption of As was determined in percentage, using the following formula:

$$\% \text{ biosorption (As)} = ([\text{As T0}] - [\text{As T1}]) \times 100 \,/\, [\text{As T0}] \quad (1)$$

where:

[As T_0] = Initial concentration of As (mg/L).
[As T_1] = Final concentration of As (mg/L).

We worked with the data in the following Table 1:

Table 1. Arsenic concentrations at the beginning and after 3 and 6 h of treatment with *Chondracanthus chamissoi* and *Cladophora* sp, from As solutions of 0.25 and 1.50 mg/L.

Solution 0.25 mg/L		
As Concentration (mg/L)	***Chondracanhtus chamissoi***	***Cladophora* sp.**
Initial	0.25 mg/L	0.25 mg/L
At 3 h	0.20 mg/L	0.15 mg/L
At 6 h	<0.01 mg/L	<0.01 mg/L
Solution 1.50 mg/L		
Initial	1.50 mg/L	1.50 mg/L
At 3 h	1.31 mg/L	1.31 mg/L
At 6 h	0.22 mg/L	0.87 mg/L

2.9. Visualization of the Surface of Sorbents by Scanning Electron Microscopy (SEM)

A high-resolution scanning electron microscope (Schottky) was used, with X-rays and backscattered electron diffraction. The patterns (Quanta 400 FEG ESEM/EDAX Genesis X4M) were analyzed in XPS and performed at the Universidad Privada Antenor Orrego. The samples were covered with a thin film of Au/Pd, by cathodic sputtering, for 90 s, as well as a current of 15 mA, using the SPI module sputter coater equipment. SEM images and EDS spectra (energy dispersive X-ray spectroscopy) [29]. We worked both for the algae and As solution at the beginning and after the biosorption process.

2.10. Analysis of Data

The means of the bioadsorption percentages of As by the algae *Chondracanthus chamissoi* and *Cladophora* sp were compared using Student's *t*-test with 95% confidence.

2.11. Ethical Aspects

The authenticity of the data, respect for intellectual property, and care for the environment through proper disposal of arsenic-contaminated waste were considered. Likewise, the criteria established by the law for the conservation and sustainable use of biological biodiversity [30] were considered.

3. Results

3.1. Biosorption Percentage of Macroalgae Using a 0.25 and 1.50 mg/L as Solution

When working with a 0.25 mg/L As solution, at 3 h, a significant difference was observed between the biosorption percentages of both algae ($p < 0.05$); however, these percentages were equal at 6 h ($p > 0.05$), reaching a value of 95.76%, which indicates that these algae are suitable for the biosorption of As, and the optimal time for biosorption at this concentration is 6 h, as can be seen in Figure 2.

Figure 3 shows that at 6 h *Chondracanthus chamissoi* reaches a biosorption of 85.33%, unlike *Cladophora* sp., which reaches 42.03%, which indicates that *Chondracanthus* has a higher biosorption percentage than *Cladophora*, when working with a 1.50 mg/L As solution.

3.2. Comparison of the Biosorption Percentage of Chondracathus Chamissoi and Cladophora sp.

When working with low concentrations of As (0.25 mg/L), both algae reach a biosorption of approximately 96% at 6 h ($p > 0.005$), while, when working with a 1.50 ppm As solution, *Chondracanthus chamissoi* has a higher biosorption (85.33%) than *Cladophora* sp. at six hours of treatment ($p > 0.05$), as shown in Table 1.

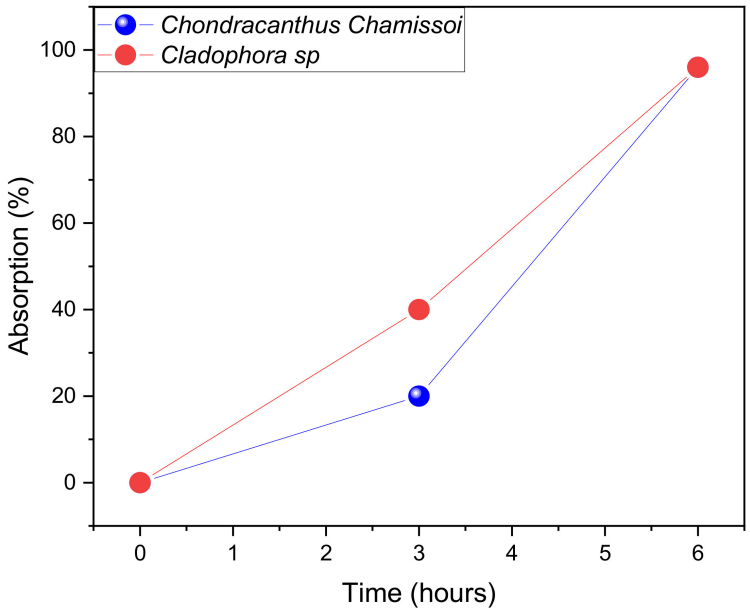

Figure 2. Biosorption percentage of *Chondracanthus chamissoi* and *Cladophora* sp. in a 0.25 ppm arsenic solution for 6 h.

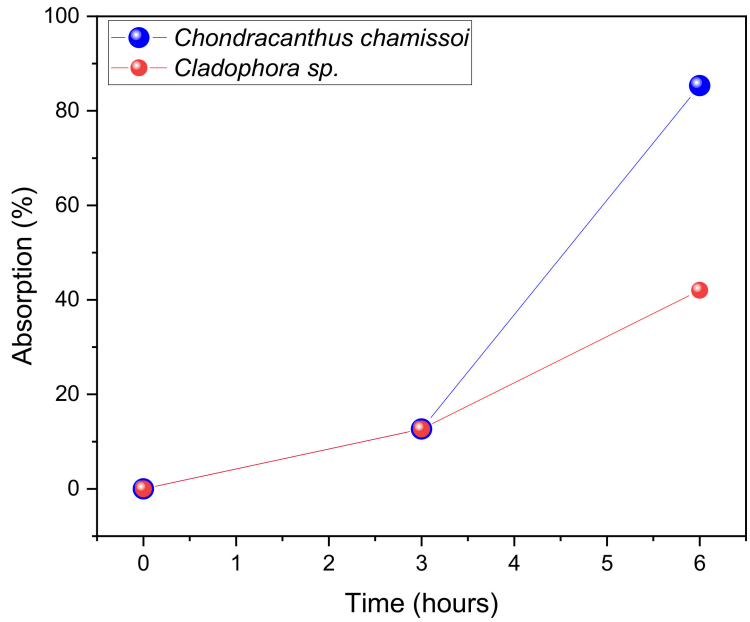

Figure 3. Biosorption percentage of *Chondracanthus chamissoi* and *Cladophora* sp. in a 1.50 ppm arsenic solution for 6 h.

3.3. Identification of Functional Groups

Figure 4 shows the FTIR absorbance spectra of the As solution used as a sample (blue line) and of the algae (*Chondracathus chamissoi* and *Cladophora* sp.) after being used as sorbent, where it can be observed is the spectrum in the 3350 cm^{-1} peaks belongs to the stretching of the protein (N-H), the peak observed in the range of 2930 cm^{-1} belongs to the stretching of the lipids and carbohydrates present, and the peak of 1620 cm^{-1} belongs to the protein amine (C=O) and carbohydrate absorption bands by C-O-C of polysaccharides between 1400 to 1030 cm^{-1} [31–33].

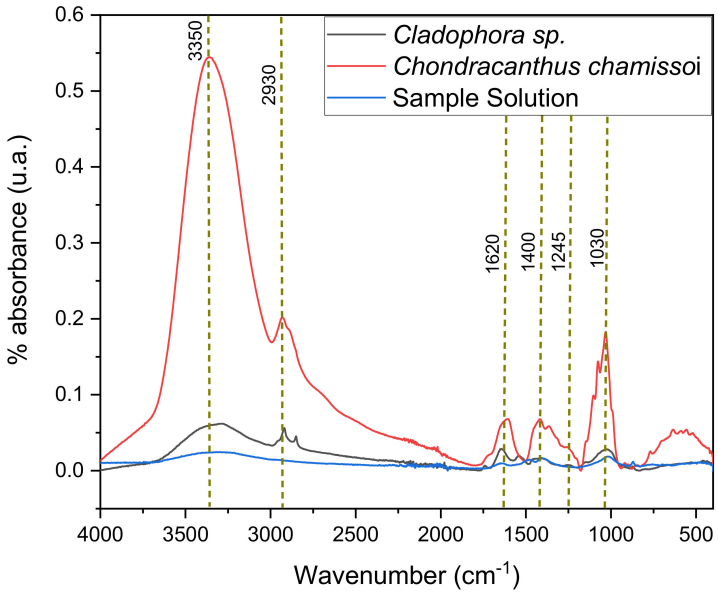

Figure 4. FTIR spectrophotometry of the solution of As and algae used in the biosorption process.

3.4. Visualization of the Surface of Sorbents during as Biosorption by Scanning Electron Microscopy (SEM)

In Figure 5, the initial and final micrographs of the *Chondracathus chamissoi* and *Cladophora* sp. are shown. In Figure 5a,b, the micrographs of the *Chondracathus chamissoi* algae are observed, where a rough surface is clearly noted in the initial state, while, after being used as a filter, small adhesions of particles of approximately 20 µm are observed; on the other hand, the micrographs of Figure 5c,d belong to the algae *Cladophora* sp,. in which a rough cracked surface is observed in its initial state, while, in the end, larger white particles (approximately 50 µm) are observed.

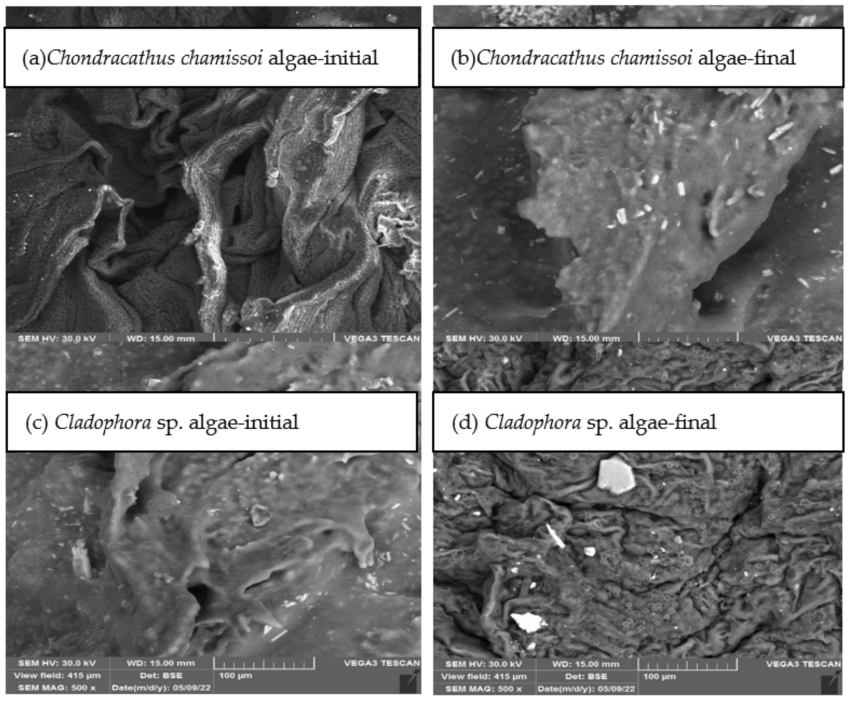

Figure 5. Micrographs of the algae *Chondracathus chamissoi* and *Cladophora* sp. initial and final observed by scanning electron microscopy (SEM).

4. Discussion

The present investigation was carried out with the objective of evaluating the arsenic biosorption of *Chondracathus chamissoi* and *Cladophora* sp., as an alternative to remediate aquatic environments contaminated with Arsenic. As can be seen in Figure 2, when working with a low concentration of As (0.25 mg/L), at 3 h, the difference between the biosorption percentages is significant ($p < 0.05$); however, at 6 h, both algae reach the same biosorption percentage ($p > 0.05$). In this case, the final concentration of As was less than 0.01 mg/L, both *for Chondracathus chamissoi* and *Cladophora* sp., which is below the value allowed by both the EPA and WHO (0.01 mg/L). [10,34] This indicates that both algae have the potential to remediate contaminated water bodies with low concentrations of As, and the optimal time for biosorption is 6 h. What was observed in this research corroborates what was established by Ahmad et al., (2018), i.e., that the contact time of the biosorbent influences biosorption, and the optimal time is the time in which all the active sites of the biomass are occupied [31]. This time is different for each biosorbent, being 60 min for red macroalgae and 300 min for the mass of immobilized algae. In this research, algae pellets were used, so optimal adsorption was reached after six hours (360 min). Physical treatments of algae biomass, such as crushing and drying, to which they are subjected for the formation of pellets, generally leads to a higher level of biosorption of metal ions, since, according to Zeraatkar et al., (2016), the destruction of the dead cell membrane provides a greater surface to increase the biosorption, due to the greater number of exposed functional groups, and the biosorption also depends on the number of functional groups in the cells of algae, as well as their accessibility for the union of metal ions [19].

On the other hand, when working with a 1.50 mg/L As solution, it was observed that, at 3 h, both algae have the same biosorption percentage (12.66%) ($p > 0.05$); however, at 6 h, it can be seen that there is a significant difference in biosorption percentages, with the percentage being higher (85.33%) for *Chondracanthus chamissoi* ($p < 0.05$). In this case, the final concentrations obtained at 3 and 6 h, for both *Chondracathus chamissoi* and *Cladophora* sp., were above the values allowed by the EPA and WHO [10,34], so it is possible that a longer treatment time is required under these conditions to achieve a greater removal of As. The biosorption is also affected by the metal ion concentration. Generally, a high metal concentration induces a high biosorption at the beginning, due to the availability of free active sites; then, a state of equilibrium is enduced as the active sites are being occupied [17], and this may be the reason why, when working with 1.50 mg/L As, *Chondracanthus chamissoi* only reached 85.33% (compared to 96% reached with solution 0.25 mg/L As), while, for *Cladophora* sp., it had a biosorption of 42.03%, as can be seen in Table 2. When working with low concentrations of As, both algae reached a biosorption of 96% at 6 h, while, when working with the 1.50 mg/L solution, the one with the highest biosorption was *Chondracanthus chamissoi* (85.33%). In this case, the value of significance less than 0.05 indicates that there is a highly significant difference between the means of the biosorption percentages of the algae evaluated, which allows us to affirm that, when working with high concentrations of As, *Chondracanthus chamissoi* has better biosorption than *Cladophora* sp. Yipmantin et al., (2011), and showed that the presence of alginates in the cell wall of *Chondracanthus* explains its high efficiency for the biosorption of metals through complexation or ion exchange in carboxylic acid groups (glucuronic and mannuronic acid) [22]. Likewise, *Cladophora* sp. has a very high capacity to bind metals, due to the presence of polysaccharides, proteins, or lipids on the surface of the cell walls, which contain amino, carboxyl, thioether, and sulfhydryl functional groups, as well as imidazole group of histidine, oxygen, phosphate, phenolic, phosphoryl, sulfuryl, and carbohydrate that act as binding sites for metals. In addition to the aforementioned functional groups. These functional groups play an important role in the removal of heavy metals from aqueous solutions [19,35–37].

Table 2. Comparison of means of the biosorption percentages of *Chondracathus chamissoi* and *Cladophora* sp. at 3 and 6 h of treatment in As solutions at concentrations of 0.25 and 1.50 mg/L.

	3 h			**6 h**		
In As solution 0.25 mg/L						
Alga	Mean	Standard deviation	Significance (*t*-test)	Mean	Dev. Standard	Significance (*t*-test)
Chondracanthus chamissoi	20.40	0.4	<0.05	95.76	0.48	>0.05
Cladophora sp.	40.27	0.23		95.76	0.48	
In As solution 1.50 mg/L						
Chondracanthus chamissoi	12.66	0.051	>0.05	85.33	1.33	< 0.05
Cladophora sp	12.66	0.06		42.03	0.92	

In the macroalgae used in the adsorption process, the presence of these functional groups was demonstrated by analyzing the absorbance spectra by Fourier transform infrared spectroscopy (FTIR) analysis, which is widely used to identify and quantify the functional groups on the surface of brown, green, and red algae [38]. A peak of 3350 cm^{-1} pertaining to protein stretching (N-H), a peak in the range of 2930 cm^{-1} pertaining to lipid and carbohydrate stretching, and a peak of 1620 cm^{-1} pertaining to protein stretching (N-H) were observed. For the amine protein (C=O), bands of carbohydrate absorption by C-O-C of polysaccharides between 1400 and 1030 cm^{-1} were also observed. The number of absorption bands shown in the infrared spectrum indicates the complex nature of the observed biomass [29].

Changes in the surface of the sorbents during the binding of As ions to active sorption sites present on the surface of algae walls were observed by scanning electron microscopy (SEM). In the SEM micrographs shown in Figure 5, it can be seen that the surface of the cells that are in contact with arsenic (at the end of the process) show a slightly rougher surface than the cell surface of the initial sample. In the case of *Cladophora* sp., the surface was scattered, with rough and deep grooves. These changes were probably due to strong cross-linking between the metalloid and charged chemical groups on the cell wall polymer [39]. As is known, the main mechanism for the biosorption of metal ions by the biomass of macroalgae is the exchange of light metal ions, such as calcium, magnesium, sodium, and potassium, which are naturally bound to the functional groups of the algae by the ions metals from contaminated water [35]; in this case, these ions are exchanged for As ions [36,40].

Another factor that influences the biosorption processes is the pH, since it influences the surface charge of the adsorbent, as well as the way in which the adsorbate species are present in the solution [29,38]. In this case, the biosorption process began by circulating As solutions with a pH of 7.5, a slightly alkaline pH, where the H_3AsO_3 and H_2AsO_3- forms predominate; it is likely that during the first three hours a high percentage of sorption was not achieved because, during this time, arsenite oxidation occurred when reacting with oxygen and water through $2HAsO_2 + 2H_2O + O_2 \rightarrow 2HAsO_4^{-2} + 4H^+$ [10], which would increase the binding of As molecules to the sorbent surface, which is visualized as a higher percentage of sorption at 6 h of treatment. It is important to consider that the pH increases the biosorption of metal ions, since the protonation and deprotonation of functional groups are controlled by the pH of the medium. When the pH is low, the carboxylic groups, being acidic, are in the protonated state, due to the excess of H^+ and H_3O^+ ions; so, the repulsive forces of these protonated groups with positively charged heavy metal ions are responsible for the smaller amount of sorption [16].

When the pH increases, functional groups, such as amine, carboxyl, and hydroxyl groups, are exposed by deprotonation, which enhances the electrostatic attraction of heavy metals, due to their negative charge. However, care must be taken because, if the pH increases too much, the formation of anionic hydroxide compounds occurs and precipitation

occurs, which is one of the causes of low biosorption percentage [16]. In this investigation, the algae were pretreated with HCl, since the pretreatment with acids helps to improve the biosorption capacity, due to the fact that, in the protonated form, there is the release of H^+ that favors the exchange for heavy metals in solution.

The adsorption technique is considered one of the most feasible, with high efficiency, high effectiveness, and ease of operation, as well as low profitability, since the material used as adsorbent can be regenerated and formation of sludge is prevented [40]. The advantage of using dead biomass of algae in metal bioremediation processes is that it is less expensive, since it is not required to add nutrients for the growth or maintenance of algae, and changes in pH affect it less than when live algae are used, so they allow for working with a higher pH than that used for live algae, and it can be modified by means of activation methods to improve its performance [41–43]. Furthermore, the dead biomass used as biosorbent is not affected by heavy metal toxicity. In this case, the algae pellets can be reused, so this research offers a clean and sustainable alternative for the treatment of arsenic-contaminated water bodies. However, this research had some limitations, such as the lack of resources to complement the SEM observation with EDX tests to confirm the presence of the metalloid on the sorbent surface; likewise, only the FTIR test was performed at the end of the process, so it is recommended that, in future research, this test be performed before and after the biosorption process to make a comparison, as well as that the EDX tests be performed to complement the observations with SEM.

5. Conclusions

It was shown that *Chondracanthus chamissoi* has a good As biosorption, which is higher when working with low concentrations of As; in this case, 95.76% was reached with 0.25 mg/L, while, in more concentrated solutions of As (1.50 mg/L), the biosorption reaches 85%, which indicates the potential of this macroalga to be used in As bioadsorption processes from water contaminated with this metal. *Cladophora* sp. has a good bioadsorption capacity in solutions with a low concentration of As; in this case, 0.25 mg/L, where it reached 95.76%, but the same did not occur when working with a solution at 1.50 mg/L of As. In both cases, the highest arsenic biosorption was reached after 6 h, and no significant difference was found between the means of the biosorption percentages of these macroalgae when working with an As solution of 0.25 mg/L ($p > 0.05$), for which, it can be inferred that *Cladophora* sp. can be used in biosorption processes in water bodies contaminated with low concentrations of As.

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