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ORIGINAL ARTICLE

Investigating the Nitrate Absorption Capacities of *Sargassum Polycystum* Biomass

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KEYWORDS

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ABSTRACT: Eutrophication caused by high nitrate levels in surface and subsurface water bodies is a major ecological concern. This process leads to the proliferation of algae and aquatic plants, which results in a reduction of dissolved oxygen and harm to aquatic organisms. Therefore, it is crucial to explore effective methods to remove nitrate ions from wastewater. In this study, the efficacy of *Sargassum polycystum* macroalgae as a biosorbent for nitrate ion removal was examined. The experiment investigated the impact of pH variations, initial biomass of *S. polycystum* algae, initial concentration of nitrate ions (50-300 mg L^{-1}), and contact duration on the nitrate removal process. The dried powder of *S. polycystum* algae was used in the experiment. The findings indicate that the seaweed *S. polycystum* has a high capacity to absorb nitrate ions from wastewater, with a maximum absorption capacity of 545.70 mg g^{-1} of seaweed. The optimal test conditions for nitrate removal were found to be pH of 6, initial biomass of 0.02 g L^{-1}, initial concentration of 300 mg L^{-1} nitrate ions, and contact duration of 60 minutes. Under these conditions, the nitrate removal rate was 52.8%. The results of this study suggest that *S. polycystum* macroalgae has a high potential for removing nitrate ions from wastewater. Overall, the use of *S. polycystum* as a biosorbent for nitrate removal can offer a cost-effective, eco-friendly, and efficient solution for mitigating eutrophication.

INTRODUCTION

Nitrate ions (NO_3^-) are a naturally occurring compound found in soil and water, and are an essential nutrient for plant growth. However, when nitrate levels become too high in surface and underground water sources, it can lead to contamination and pose a threat to human health [1]. High levels of nitrate in water sources are often attributed to agricultural activities, such as the use of fertilizers and manure. Other sources of nitrate contamination include sewage and industrial discharge, as well as atmospheric deposition from industrial and transportation emissions [2–4]. The presence of high levels of nitrate in water can have serious health consequences, especially for infants and pregnant women [5]. Nitrate can be converted into nitrite (NO_2^-) in the

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body, which can bind to hemoglobin in the blood and reduce its ability to carry oxygen [6]. This can lead to a condition known as methemoglobinemia, or "blue baby syndrome," which can be fatal if not treated promptly [7]. Furthermore, high nitrate levels in water can also contribute to the formation of harmful algal blooms, which can produce toxins that can harm human health and the environment [8,9]. Nitrate contamination can also have negative effects on aquatic ecosystems by promoting excessive plant growth, reducing oxygen levels, and altering the balance of aquatic species [10]. The World Health Organization (WHO) has set the maximum permissible concentration of nitrate ions in drinking water at 50 mg L^{-1} [11].

Therefore, in order to acquire water resources that meet global standards for quality, it is imperative to eliminate excessive levels of nitrate ions found in urban and agricultural wastewater through removal and reabsorption techniques. A variety of physical, chemical, and biological methods are available for this purpose [12]. Physical methods include processes such as ion exchange, adsorption, and reverse osmosis, which use specialized membranes or other materials to selectively remove nitrate ions from water [13]. Chemical methods include processes such as ion exchange, electrochemical reduction, and biological denitrification, which use chemicals or electrochemical reactions to convert nitrate ions into harmless compounds [14,15]. Biological methods include processes such as microbial denitrification, which utilizes naturally occurring bacteria to break down nitrate ions into nitrogen gas [16]. Using biological absorbents is a cost-effective way to isolate nitrate ions from water. Bacteria, fungi, and algae are among the three frequently employed bio-absorbents [17].

Over the years, extensive research has been conducted on bacteria and fungi due to their essential roles in numerous industries such as agriculture, food processing, biotechnology, and medicine [18]. These microorganisms have proven to be valuable sources of bioactive compounds, enzymes, and other biochemicals that can be utilized in different applications [19,20]. However, there has been limited research on the potential of macroscopic marine algae, also known as seaweeds, despite their immense potential in various industries [21,22]. Regarding the performance of biological adsorbents, several factors are particularly important in the efficiency of the adsorbent, including the pH of the solution, the initial concentration of ions, and the amount of biomass used in the adsorbent [23].

The pH can influence the surface charge of the adsorbent and the ionization state of the pollutants, which can affect the electrostatic interaction between them [24]. For example, in the case of heavy metals, the adsorption efficiency increases as the pH decreases due to the formation of metal hydroxides that can bind to the adsorbent surface. However, in the case of organic pollutants, the adsorption efficiency may decrease at low pH values due to the competition with H^+ ions for adsorption sites.

The adsorption capacity of the adsorbent is directly proportional to the concentration of the pollutant in the solution [25]. However, at high concentrations, the adsorption sites on the adsorbent surface can become saturated, reducing the adsorption capacity. Thus, the optimal concentration range should be determined to achieve maximum efficiency.

The amount of biomass used in the adsorbent is also a critical factor that can affect the efficiency of the process [26]. Increasing the amount of biomass can increase the number of available adsorption sites, leading to higher adsorption capacity. However, using too much biomass can increase the mass transfer resistance and reduce the accessibility of the adsorption sites, leading to lower adsorption efficiency.

Sargassum polycystum is a species of brown macroalgae commonly found in the tropical and subtropical waters of the Indo-Pacific region. It is a member of the genus *Sargassum*, which is known for its distinctive floating habit (Figure 1) [27,28].

Figure 1. *Sargassum polycystum*; the upper right inset providing a closer look at the branching pattern of the organism and the bottom left inset focusing on its vesicles.

It plays an important role in the marine ecosystem by providing habitat and food for a variety of marine organisms, including fish, crustaceans, and sea turtles [29]. In addition, it can also help to protect coastlines from erosion by absorbing wave energy. However, in recent years, large blooms of *S. polycystum* have become a problem in some regions, particularly in the on the northern coast of Egypt, especially along the Mediterranean Sea. This causes pollution and unsightly landscapes on the coasts of Egypt. Eutrophication is a process that occurs when an excess of nutrients, such as nitrogen and phosphorus, enter a water body, causing excessive plant growth, and the subsequent death of those plants as they decompose. This process can result in a decrease in oxygen levels in the water, which can have harmful effects on aquatic life, leading to what is commonly known as dead zones [10]. Therefore, utilizing these resources as biological absorbers to remove the common water pollution in this region would significantly benefit the endangered ecosystems in these areas. In this study, the efficacy of *S. polycystum* macroalgae as a biosorbent for nitrate ion removal was examined.

MATERIALS AND METHODS

Preparation of adsorbent

S. polycystum was collected from the coast of the Mediterranean Sea in Egypt at low tide and transported to the national institute of oceanography and fisheries of Egypt. Then the algae were washed and dried at 60^{o}C and powdered. To improve the efficiency of the algae powder and increase the contact surface area for ion absorption. To prevent the absorption of moisture during testing, absorbent materials were placed inside a desiccator beforehand. A desiccator is a container that is designed to maintain a low level of humidity inside by utilizing a drying agent such as silica gel or calcium chloride.

Preparation of solutions containing nitrates

KNO_3 salt was utilized to prepare a range of primary solutions with differing concentrations that were required for conducting the nitrate test. The concentrations included 50-300 mg L^{-1}. Once the primary solutions were created, 100 ml of each solution was used for each of the experiments. This ensured that the testing process was standardized, and the results obtained were comparable.

The absorption experiments

To explore how various factors impact the ability to absorb and remove nitrate ions, several parameters were examined, including varying pH levels (2-8), varying quantities of dry algae powder (0.02, 0.05, 0.1, 0.15, 0.2, 0.3, 0.4, 0.5 g), and different initial concentrations of nitrate ions (50-300 mg L^{-1}) during different contact durations. The first step in the experimental process involved testing the removal efficiency of nitrate ions in aqueous solutions with varying pH levels, with the aim of identifying the optimal pH for subsequent tests. Once the appropriate pH was established, the experiments continued by keeping this variable constant and testing the impact of different amounts of algae per liter as a bio-absorbent. In the third experiment, the concentration of nitrate ions was altered in separate solutions, spanning a range of 50-300 mg L^{-1}. The purpose of this variation in concentration was to determine the effect of varying levels of nitrate on the bio-absorbent capacity of the algae. The experiments consisted of multiple stages, with each stage being repeated three times to ensure accurate results. Furthermore, the impact of time on the reactions was also evaluated in this study. The measurements were conducted by taking samples from a 100 ml water volume at specific intervals: 10, 20, 30, 40, 50, and 60 minutes from the start of each experiment. To ensure the homogeneity of the solutions, they were subjected to centrifugation at 4500 rpm for 8 minutes at each sampling time.

Statistical analysis

In order to determine the concentration of nitrate ions in the samples, a spectrophotometer was utilized (purchased from Beijing Purkinje General Instrument Co.). The pH values of the samples were also measured and recorded using a portable pH meter (EZDO® H6341, Shanghai, China). Furthermore, the absorption capacity of *S. polycystum* algae biosorbent for nitrate was also calculated using the equation $q_e = (C_i - C_e)V/M$. In this equation, C_i and C_e are the initial and equilibrium (final) concentrations of nitrate in the solution (mg L^{-1}). V is the solution volume in L, and M is the mass of algae in g. The value of the percentage of nitrate ion absorption by the adsorbent was calculated using $100(C_i - C_e)/C_i$ [30,31].

RESULTS AND DISCUSSION

The aim of this study was to investigate various factors that could impact the absorption capacity and removal percentage of dissolved nitrate ion. These factors included the initial concentration of nitrate ion, the amount of algae biomass, and the pH level of the solution. The first step of the study involved testing different pH levels, including acidic, neutral, and alkaline environments, within a pH range of 2 to 8 to determine the optimal pH level. The experiment revealed that pH of 6 yielded the highest absorption capacity and removal percentage of nitrate ions (131.61 mg g^{-1}). However, beyond pH of 6, the absorption capacity decreased with an increase in pH (Figure 2).

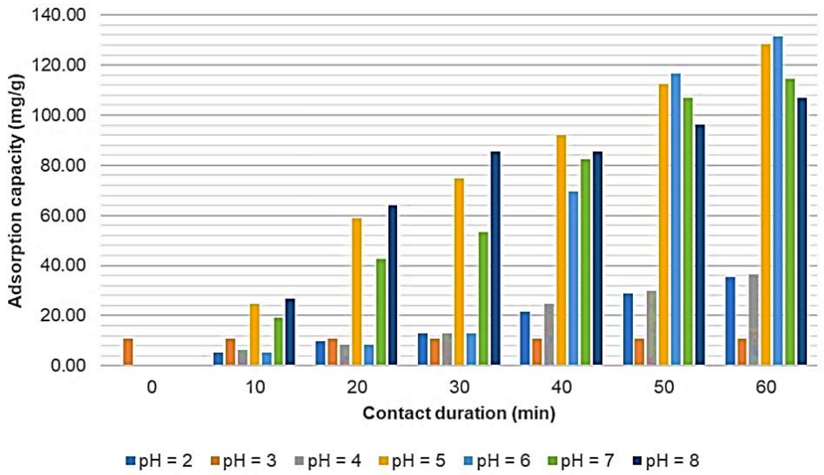

Figure 2. Nitrate adsorption capacity in different pH levels.

Various quantities of algae biomass were utilized to examine their adsorption capacity and efficiency in removing nitrate ions from solution. The findings demonstrated that the amount of algae biomass used played a crucial role in the removal of nitrate ions from the solution phase. As the amount of algae biomass increased in the solution tested, the nitrate ion absorption capacity decreased (Figure 3). The optimal amount of biomass for nitrate removal was determined to be 0.02 g L^{-1} since it resulted in the highest percentage of nitrate removal (78.11%) from the aqueous solution.

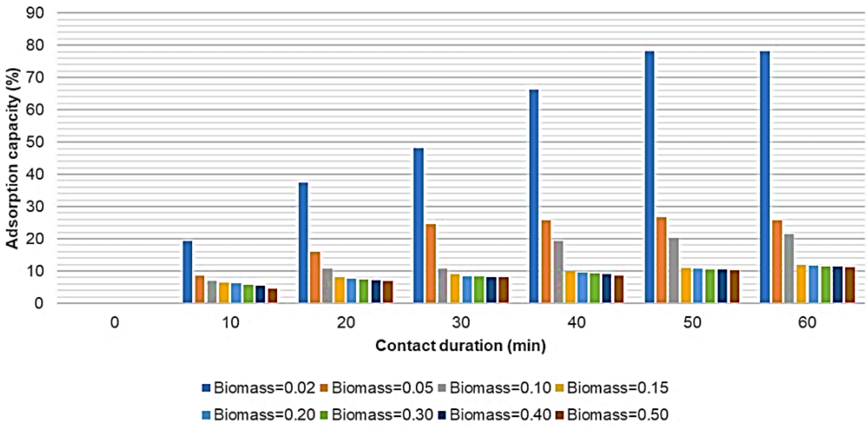

Figure 3. Nitrate adsorption capacity in different biomass levels.

However, at higher amounts of biomass in the test solutions, the accumulation and adhesion of biomass particles significantly diminished the ability of the algal cell wall to absorb nutrient ions within the solution. Therefore, at 0.50 g L^{-1} biomass, only 11.23% removal for nitrate was observed. Thus, it was concluded that 0.02 g L^{-1} was the optimal amount of biomass for nitrate removal. It is noteworthy that the absorption capacity and its results in absorption tests are more important than the results related to the removal percentage in determining an adsorbent's ability to clean polluted water.

The study also evaluated the impact of varying nitrate concentrations on adsorption capacity and removal percentage. The tests were conducted using initial nitrate concentrations ranging from 50 to 300 mg L^{-1}. The findings indicated that the absorption rate and removal percentage improved as the nitrate concentration increased in the test solutions. The absorption rate increased from 100 to 545.70 by increasing the initial concentration from 50 to 300 mg L^{-1}, and the highest nitrate absorption capacity of 545.70 was attained at the initial concentration of 300 mg L^{-1} (Figure 4). Furthermore, the maximum nitrate removal percentage of 52.8% was observed at the initial concentration of 300 mg L^{-1}.

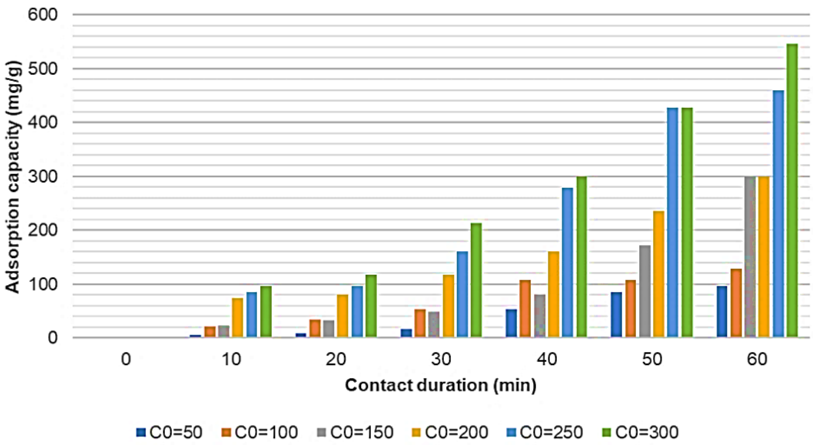

Figure 4. Nitrate adsorption capacity in different nitrate levels (C0).

Overall, the results suggest that the biological removal rate by algae is positively correlated with the concentration of ions in nutrient-containing solutions. Hence, increasing the concentration of ions in solutions can enhance the efficiency of biological nitrate removal by algae.

CONCLUSIONS

The primary objective of the current research was to examine the capacity of *S. polycystum* algae as a biosorbent to eliminate nitrate ions from water solutions. The ability of algae biomass to adsorb nutrients is influenced by various factors such as the level of negative surface charges in pH levels greater than 6 and the presence of chloride ions that compete with the nutrient ions in acidic pH levels due to the addition of hydrochloric acid. The research findings indicate that the tested algal biomass is effective in removing nitrate from natural waters and normal or neutral wastewater streams. However, any alterations in the pH level of the aqueous solutions from 6 will hinder the optimum absorption of nutrient ions from the solution. Therefore, it is crucial to maintain a pH level of 6 to ensure maximum nutrient uptake by the algae biomass in wastewater treatment processes. The most effective nitrate removal rate from water solutions occurred at a biomass concentration of 0.02 g L^{-1}, achieving a removal rate of 78.11%. However, at higher concentrations of biomass in the experimental solutions, the accumulation and attachment of biomass particles resulted in a significant decline in the ability of the algal cell wall to absorb nutrient ions, causing them to dissolve instead. The findings indicated that as the nitrate concentrations in the test solutions increased, both the adsorption capacity and removal percentage also increased. These results demonstrate that the algae's ability to biologically remove ions in nutrient-containing solutions is positively correlated with the concentration of those ions. Consequently, this method could be applied to treat polluted water solutions and wastewater streams with elevated nutrient levels. According to the findings of this investigation, *S. polycystum* demonstrates remarkable potential as a potent adsorbent for eliminating nitrate from water-based solutions.

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Conflict of interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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