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Investigation of bio-desalination potential algae and their effect on water quality

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ABSTRACT

Alternative water sources should be considered when facing an increase in water demands and a decrease in freshwater supplies. Water desalination has become critical to meet increasing water demands, especially in water-stressed countries where water obtained by desalination far exceeds supplies from freshwater sources. This study aimed to investigate saline water desalination using marine algae. Factorial experiments were carried out based on a completely randomized design. Treatments were associated with four algae (*Dunaliella salina*, *Chlorella vulgaris*, *Nannochloropsis oculata*, and *Scenedesmus quadricauda*) considering different salinity (50–70 mS cm^{-1}) in three replicates (laboratory conditions). Moreover, electrical conductivity (EC) was daily measured. The results showed no significant difference in terms of desalination between *D. salina* algae and the others at EC of 50–70 mS cm^{-1}. However, a major effect was observed by increasing salinity. The results also revealed that the application of *D. salina* algae led to a significant reduction in chlorine, sodium, and bicarbonate levels under the same condition. The suitability of these desalination technologies was measured based on several criteria, including feed water quality level, energy source, removal efficiency, and energy requirement.

Keywords: Bio-desalination; *Dunaliella salina*; *Chlorella vulgaris*; *Nannochloropsis oculata*; *Scenedesmus quadricauda*; Saline water

1. Introduction

Water is considered a vital resource for the existence of life on the earth's surface. It is also necessary for economic and social development [1,2]. Freshwater accounts for only about 0.5% of the total global water supply, while seawater accounts for about 97% of it [3,4]. In many parts of the world, a huge amount of freshwater is required to be used for agricultural, industrial, and domestic purposes. Nowadays, nearly 25% of people suffer from inadequate freshwater supplies [5–7].

In the 21st century, the world's water challenges include lack of accessibility to freshwater, deterioration of water quality, a decline of financial resources, as well as allocation and fragmentation of water management [8,9]. Water scarcity causes to hamper economic development, and thus, devastates human health, degrades the environment, and foments political instability [3,4,10]. To cope with the increasing freshwater demand, it is now highly viable to find out some alternative freshwater sources. As an alternative solution, saltwater desalination has emerged as an essential method to sustain future generations across the globe.

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Desalination coincides with a general term for the process that removes dissolved solids and produces freshwater from feed waters such as seawater, brackish water, and inland water. The process also increasingly reclaims recycled water. Desalination describes a range of processes used for reducing the number of dissolved solids in water. Freshwater is defined as water containing less than 1,000 mg L^{-1} of salts or total dissolved solids (TDS) [11–13].

In recent years, a great deal of attention has been paid to the promise and prospects of desalination technology for alleviating the water scarcity crisis [7,14]. In its simplest form, the technology might substantially reduce water scarcity by making an almost inexhaustible stock of seawater and large quantities of brackish groundwater, which appear to be available as new sources of freshwater supply [15–17]. Several factors have the greatest effect on desalination costs, including feed water quality (salinity level), product water quality, energy costs, and scale economies [13–15].

In several regions across the world with local water basins depletions, communities have turned to alternative water sources, water recycling, water imports, and desalination [3]. Desalination is the process of removing excess salts and other dissolved chemicals from the seawater [5], which reduces salt concentrations at or below the World Health Organization's drinking water limit of 500 ppm [6]. Desalination has been around for centuries but has gained prominence in the last few decades.

Algae are taken into account as simple plant species, which have no stem, root, and chlorophyll content [5]. They range from small single-cell species to large and high-density species. They also have varied abilities to grow in different situations including various aqueous and dry environments [18]. Most alga species can properly grow in saline water and absorb substance dissolved in water [19]. In this way, salt in water (e.g., other nutrients) is absorbed into biomass by living creatures (plant or animal). Ultimately, the absorption ratio of salts will be reduced from water salinity [5,6]. In this case, some creatures are more likely to absorb water-soluble nutrients higher than their nutritional needs. This is the reason why they have more potential for reducing water salinity. Biological methods for desalination or water salinity reduction focus on using different species, including macrophyte (aquatic plants), microphyte (algae), and micro-organisms or a combination of them, which can be an effective way in reducing water salinity [14,17].

Upside down organic plants and algae can complete their life cycle in a wide range of salinity. Microalgae have been used for wastewater treatments in the third level for many years. Thus, nitrogen and phosphorus compounds are eliminated after lowering biological oxygen demand and chemical oxygen demand [20,21]. Many microalgae (e.g., *S. quadricauda* and *S. obliquus*) can use organic compounds under light conditions. These microalgae are considered as mixotrophic (in biology, it is introduced as the growth process of organs using a combination of organic matters and minerals) [22]. These microalgae apply a secondary treatment as an alternative for reducing the content of organic matters and eliminating nutrients [23,24].

Researchers used green *S. quadricauda* alga species to evaluate the efficiency of removing various nutrients in saline water [25–27]. They examined a continuous flow purification system. Saltwater was provided from the Red Sea (TDS was 40,000 ppm). Seaweed extract was added to each reactor for two consecutive reactors in 7 d. The removal efficiency was measured around 97% for total soluble solids, sodium, chloride, and phosphate at the output of the second reactor, while it was about 93% for nitrate and sulfate.

This research aimed to compare different species of microalgae, which has a considerable impact on the saline water desalination process. The detailed design concepts, desalination processes, and advantages and disadvantages of these technologies are beyond the scope of this research. Numerous studies have been carried out for finding suitable technologies throughout the world. However, we did not find any study designed for dry countries.

2. Materials and methods

2.1. Source of water

Sirjan Lake was considered for collecting a high salinity water sample. The water sample was taken in sterilized bottles and preserved for further studies. The analysis procedure was accomplished by transferring the source of water to the Central Lab, which is located at Islamic Azad University, Tehran, Iran.

2.2. Microalgae used for desalination

2.2.1. Dunaliella salina

The algae were classified as the *Chlorophyceae* category, the *Volvocales* order, and the *Chlorophyta* branch. Previously, the algae were placed in the family of *Polyblepharidaceae*; however, due to their similarity with *Chlamydomonas* algae, they were was placed in the *Chlamydomonadaceae* family [28,29]. *Dunaliella salina* species are widely distributed in Iranian ecosystems due to their different physicochemical characteristics [30]. The most resilient eukaryotic deals with salinity, which is found in many saline environments, including lakes and saline water lagoons. The salinity level is 3 M for *D. salina* (174 M), but critical salinity points are 0.5 M (29 M) and 5 M (290 M).

2.2.2. Chlorella vulgaris

Chlorella vulgaris is characterized as a genus of single-celled green algae belonging to the division-*Chlorophyta*. It has a spherical shape with a diameter of 2–10 μm without flagella. *C. vulgaris* contains green photosynthetic pigments as well as chlorophyll-a and b in its chloroplast. Photosynthesis multiplies it rapidly, and it requires carbon dioxide, water, sunlight, and a small number of minerals for reproduction.

2.2.3. Nannochloropsis oculata

Nannochloropsis oculata is one of the single-cell marine algae, belonging to the branch of *Chlorophyta* and the subbranch of *Eustigmatophyceae*.

2.2.4. Scenedesmus quadricauda

The alga is related to the *S. quadricauda* family. It is also considered as one of the significant single-cell algae, belonging to the *Chlorophyceae* family. The species of *S. quadricauda* and *S. obliquus* are among the major commercial species for the removal of some toxic cations such as cadmium from water sources. This can be beneficial for the industry [31].

2.3. Different methodology stages

First stage: Different types of microalgae and macrophyte species were found, which are effective for desalination processes. Moreover, efficiency and effectiveness were determined for each of these species based on library reviews.

Second stage: A laboratory-scale test was prepared to evaluate the effect of the selected algae on the reduction of salinity in water. Thus, the required principles were achieved for designing and using these kinds of algae in desalination.

Third stage: After transferring the water sample to the laboratory, the algae underwent electrical conductivity (EC), which is proportionate to their salinity (ranging from 50 to 70 mS cm^{-1}).

2.4. Algae sample and preservation conditions

The current research was carried out to apply green algae including *D. salina*, *C. vulgaris*, *N. oculata*, and *S. quadricauda*. The collected samples were placed in the reactor under laboratory conditions. A polyvinyl chloride (PVC) tank (5 L) was considered as a temporary medium concerning input and output tanks at the same speed (speed was adjusted with control valves). For each treatment, three replicates (three continuous systems) were considered. In each tank, 3 cc of the algae were added to water considering different salinity. The reactor was made of 10 L of transparent polyethylene bottles. The maximum supply of light is necessary for the optimal daily growth of algae in a reactor with an intensity of 3,500 ± 350 lux at 25°C ± 2°C. It is performed based on the light protocol, that is, 12 h of light and 12 h of dark [32]. Alternate water aeration was performed using an air pump, and EC was measured with an EC meter in 7 d (Horiba-meter model Es-14 E). The process was carried out to generate water flow and rotation, transfer the algae, and provide carbon dioxide and oxygen for photosynthesis and respiration, respectively. In addition to physical factors, the algae need a vital activity for the medium, including light, temperature, and aeration, which deals with micro and macro elements [33]. In this research, salt in water (e.g., other nutrients) was absorbed into biomass by living creatures (plant or animal) and without using food elements. Consequently, salinity was reduced by absorbing salts. In this regard, some creatures are more likely to absorb salt in water more than their nutritional needs, and therefore, they have more potential to reduce water salinity. At the end of each period, the amount of chlorine, sodium, and bicarbonate was measured. Afterward, the samples of water and algae were transferred to the laboratory. Then, the amounts of sodium, chlorine, calcium, magnesium, and bicarbonate were measured.

2.5. Algae separation method

There are different methods for separating microalgae, including polymer flocculation, tangential flow filtration, centrifugation filtration, as well as filtration ultra and micro-screening [34]. The choice of the separation method depends on the density and size of algae. In the liquid-solid filtration method, the fluid passes through a porous medium to trap suspended solids such as algae. In the centrifuge method, algae are exposed to centrifugal forces to compel solids to move through the liquid, and thus, the algae are separated. It should be noted that filtration and centrifuge methods are highly time-consuming and expensive.

The results showed that the cell wall of microalgae contained a negative electrical charge. It was due to the negative charge of acidic polysaccharides (pectin) in the cell wall composition of microalgae [35]. It should be noted that microalgae cells remain scattered in the environment, which can accumulate and become massed after neutralizing this negative charge. The ECF technique is characterized as an electrochemical method designed for producing coagulated metal ions from oxidizing metal electrodes. Electrolytes can be used to increase the reaction rate in the ECF technique [36,37]. In this method, the electric current is generated by installing two active electrodes such as an aluminum electrode. The electrodes are placed in the algae medium. In addition, the electrode acting as the anode pole is oxidized, and it plays a key role in the release of metal ions. Metal ions act as coagulants in the formation of algal masses. It is implied that the microalgae coagulation process can be used to calculate biomass by neutralizing electrical charge [38,39].

The soil samples were air-dried at 408°C, passed through a 2-mm sieve, and analyzed for bicarbonate-extractable (Colwell) P. Briefly, 1.0 g soil was extracted with 100 mL 0.5 M $NaHCO_3$, adjusted to pH 8.5, by shaking end-over-end for 16 h (Rayment and Higginson 1992).

2.6. Statistical analysis

This pattern contained factorial combinations based on a completely randomized design in three replicates. Statistical analysis was performed using the SAS statistical software package. The SAS procedure was considered to analyze variance, and thus, the statistical significance was determined for the treatment effects [40].

3. Results and discussion

3.1. Comparison of desalination capacity in different treatments

The collected data were analyzed to obtain variances and means, and also, compared to Duncan at the probability level of 0.01 (Table 1).

The effect of different algae on desalination capacity is shown in Fig. 1. The highest desalination was observed in *C. vulgaris* algae at EC of 50 mS cm^{-1}, and its desalination rate was 8.87 mS cm^{-1}. By decreasing EC to 70 mS cm^{-1}, the desalination rate significantly decreased in *C. vulgaris* algae. These treatments had the lowest absorbance at 2.07 mS cm^{-1}. By increasing EC from 50 to 70 mS cm^{-1},

Table 1
Variance analysis of desalination capacity and dry weight for the applied treatments (the values are mean square)

Source of variance	df	Desalination capacity	Dry weight
Type of algae (*A*)	3	267.44[b]	0.03[a]
Salinity (*B*)	1	7,093.47[b]	0.001[a]
A × *B*	3	28.43[b]	0.44[b]
Error	9	21.43	0.04

Significant at the level: [a]0.05 and [b]0.01.

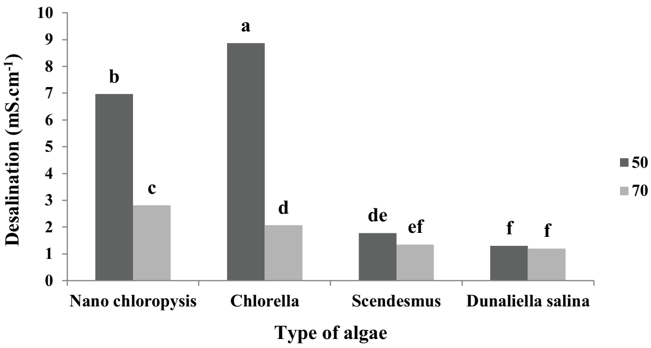

Fig. 1. Comparison between desalination capacity in different algae at electrical conductivities of 50 to 70 mS cm^{-1}. Different small letters above the columns indicate that the treatment means are significantly different at $p < 0.01$.

desalination dropped in all the algae. The amounts of desalination were not significantly different in *S. quadricauda* and *D. salina* at EC of 50 and 60 mS cm^{-1}.

However, the amount of desalination was significantly different in *N. oculata* algae at various EC levels. By increasing EC values from 50 to 70 mS cm^{-1}, the amount of desalination decreased from 6.97 to 2.81 mS cm^{-1} in the algae. The amount of desalination was not significantly different in *S. quadricauda* algae at various EC levels. The amounts of desalination were 1.78 and 1.35 mS cm^{-1} at EC of 50 and 70 mS cm^{-1}, respectively.

According to the results, the use of green algae leads to a reduction in water salinity [41]. This is an easy economic solution for environmental problems caused by saline water in plants. It can be mentioned that the growth of these species is highly effective in reducing salinity in desalination [25–27]. The growth of *N. oculata* species was successfully performed in saline water due to desalination used in its metabolism. Since *C. vulgaris* and *S. quadricauda* commonly exhibit great salt tolerance in their habitat, they are known as the most active algae in stabilization conditions [42].

Studies have shown that these algae can grow in saline water [43]. This type of desalination water is converted into its metabolism. In this method, salt in water can be absorbed and converted into biomass and other nutrients. Subsequently, water salinity is reduced by absorbing salts. In this regard, they are more likely to absorb salt in water more than their need. Therefore, they have more potential to reduce water salinity [24]. Microalgae have a high capacity for inorganic nutrient uptake, and can be used for mass culture in outdoor solar bioreactors. Unicellular green algae (e.g., *C. vulgaris* and *S. quadricauda*) have been widely used in a wide range of salt concentrations because they naturally colonize, have fast growth rates, and have high nutrient uptake capabilities. However, biomass harvesting is one of the major drawbacks of using microalgae in a wide range of salt concentrations [21].

A few studies have examined the effects of small increases of salinity on microbial organisms in Australian freshwater ecosystems. The available information indicates that small changes in salinity may have a small deleterious impact on the significant biological processes of algae. The reason is that water can adapt to small salinity changes, and that saltwater algae species can be replaced with other similar saltwater algae. It has been demonstrated that the algae are able to complete their life cycle in a wide range of salinity levels, even within the species. The application of these algae and microorganisms or their combination can be an effective way for desalting or reducing water salinity [14,17,44].

The highest dry weight was observed in *C. vulgaris* algae at EC of 50 mS cm^{-1}, considering the dry weight of 0.5 g. Moreover, by increasing EC from 50 to 70 mS cm^{-1}, the dry weight decreased in all the algae. The amounts of dry weight were not significantly different in *S. quadricauda* and *D. salina* at EC of 50 and 70 mS cm^{-1} (Fig. 2).

Since there was no considerable difference in terms of desalination and dry weight between *S. quadricauda* and *D. salina* at EC of 50 and 70 mS cm^{-1}, a new salinity range was set for these algae. This salinity range was defined as 50–140 for *D. salina*. The variance analysis results can be observed in Table 2.

D. salina algae were investigated at five different EC levels, including 50, 70, 100, 130, and 140 mS cm^{-1}. The results showed that by increasing the concentration from 70 to 130 mS cm^{-1}, the salt absorption of the algae significantly increased from 1.33 to 22.50 mS cm^{-1}. However, by increasing EC from 130 to 140 mS cm^{-1}, the salt absorption of the algae decreased to 9.11 mS cm^{-1}. At low concentrations of 50 and 70 mS cm^{-1}, the salt absorption was not significant in the algae.

According to the results of Fig. 3, the highest absorption was associated with a concentration of 130 mS cm^{-1} in *D. salina* algae. Moreover, a reduction was observed at 42.67 mS cm^{-1} (in 7 d) by providing environmental conditions in *D. salina* algae, including light, temperature, aeration, and EC. In this research, the purpose of reducing water salinity was to provide an economic condition for the procedure. As a result, the micro and macro elements used in the algal growth medium were not added to the incubator. The results demonstrated that by increasing EC from 50 to 130 mS cm^{-1}, the amount of desalination increased about seven times in the algae so that it changed from 1.33 to 22.5 mS cm^{-1}. However, by increasing EC from 130 to 140 mS cm^{-1}, desalination decreased in *D. salina*. The amounts of desalination were not significantly different in the algae at low EC of 50 and 70 mS cm^{-1} ($p \leq 0.05$). As shown in various studies, these algae are unmatched among photosynthetic organisms since they can tolerate extreme environmental conditions

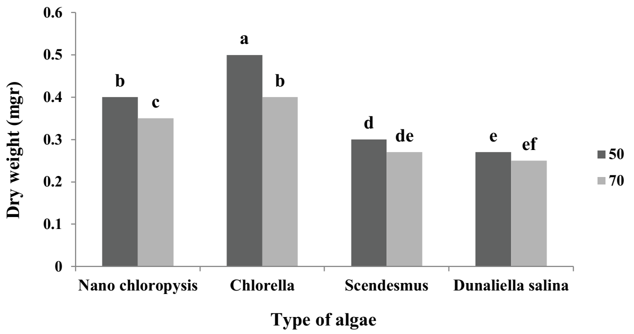

Fig. 2. Dry weight (mgr) comparison at electrical conductivities of 50–70 mS cm^{-1} in different algae. Different small letters above the columns indicate that the treatment means are significantly different at $p < 0.01$.

Table 2
Variance analysis of desalination and dry weight (mgr) for *Dunaliella salina* (the values are mean squared)

Source of variance	df	Desalination	Dry weight
Salinity	3	850.132^a	0.35^a
Error	3	0.26	0.001
CV	–	2.98	1.01

Significant at the level: ^{a}0.01.

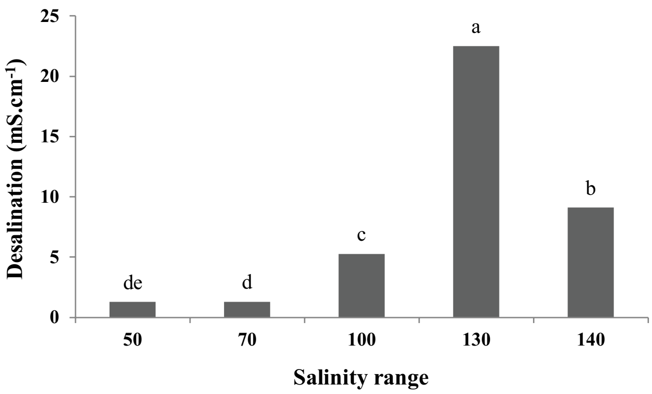

Fig. 3. Investigation of electrical conductivity (EC) reduced in *Dunaliella salina* algae after 7 d of growth. Different small letters above the columns indicate that the treatment means are significantly different at $p < 0.01$.

in terms of light intensity, temperature, food availability, and salinity levels. Light intensity and salinity are taken into account as two major environmental factors affecting *D. salina* algae. In this regard, *D. salina* can live in a dense environment. High salt concentrations lead to the production of reactive oxygen species through variation, which can be an effective way to absorb salt from the environment. Therefore, microscopic algae are used as a clean and renewable resource in the biotechnology industry [14,17].

The highest dry weight was observed at EC of 130 mS cm^{-1}, with a dry weight of 1.08 g (Fig. 4). Cation and

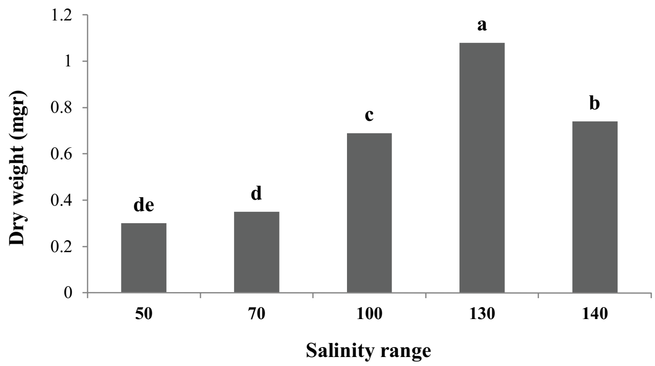

Fig. 4. Comparison between dry weight means (mgr). Different small letters above the columns indicate that the treatment means are significantly different at $p < 0.01$.

anions had a significant reduction. The dry weight gain was measured at the end of the test. The result indicated that these algae used elements of chlorine, sodium, and bicarbonate to grow and reproduce as nutrients. Depending on the number of algae for desalination in comparison with the amount of dry matter, the algae had the highest dry matter in salinity, with the highest salt content. The main environmental factors and chemical composition features affecting the growth of microalgae consist of light, food, pH, and temperature. Adjusting the above factors can greatly help microalgae to grow better. Light and salinity are considered significant factors, and their oscillation influences chlorophyll, carotenoids, and cell growth. Studies have shown that algae have a higher ability to use salinity. Moreover, algae significantly contribute to the growth and reproduction of the previously mentioned elements. This process is performed by reducing salinity through the absorption of salts and their use in the metabolism [26,27].

3.2. Comparison of ion absorption in different treatments

The following procedure was used to analyze the collected dataset. In this case, the obtained variances and means were compared to Duncan at the probability level of 0.01 (Table 3).

The chloride absorption in different treatments is shown in Fig. 5. The results indicated a significant difference in terms of chloride absorption between *C. vulgaris*, *N. oculata*, and *S. quadricauda* algae. The results also revealed that *S. quadricauda* algae had the highest chloride absorption value (2,168.65 mg L^{-1}). By decreasing EC to 70 mS cm^{-1}, chloride absorption significantly decreased in *C. vulgaris*, *N. oculata*, and *S. quadricauda* algae. The amounts of chloride absorption were not significantly different in *D. salina* at EC of 50 and 70 mS cm^{-1}.

Different studies have shown that the presence of compounds in the algal surface (e.g., amines, phosphates, sulfites, sulfhydryl, carboxyls, proteins, and saccharides) is activated in many respects such as ion exchange resins [45,46]. These compounds (e.g., amino groups) have a positive charge when combined with proteins. They can also absorb complex compounds, such as phenolic compounds, which absorb electrically charged electrons. However, these compounds

Table 3
Variance analysis of the ion absorption rate for the applied treatments (the values are mean squared)

Source of variance	df	Chloride	Sodium	Bicarbonate
Type of algae (*A*)	3	0.99^b	83.95^b	4.77^a
Salinity (*B*)	1	0.16^b	421.80^b	81.52^a
$A \times B$	3	0.18^a	38.44^b	7.34^a
Error	9	2.31	1.30	2.13

Significant at the level: ^{a}0.05 and ^{b}0.01.

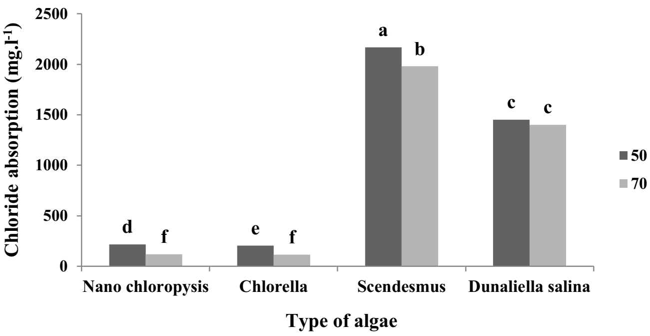

Fig. 5. Investigation of chloride absorption at electrical conductivities of 50 to 70 mS cm^{-1} in different algae. Different small letters above the columns indicate that the treatment means are significantly different at $p < 0.01$.

have a negative electrical charge [47]. Therefore, algae absorb chlorine from the environment, and thus, decrease its amount [48].

These algae are unmatched among photosynthetic organisms since they can tolerate extreme environmental conditions in terms of light intensity, temperature, food availability, and salinity levels [14,17]. Light intensity and salinity are considered as two major environmental factors affecting algae. Therefore, algae can live in a dense environment [26,27]. High salt concentrations lead to the production of reactive oxygen species through variation, which can be an effective way to absorb salt from the environment. Therefore, microscopic algae are used as a clean and renewable resource in the biotechnology industry [17,49].

In other words, it can be mentioned that algae lead to the reduction of chlorine by 718 mg L^{-1}. Algae-based systems have been developed for bio-desalination for three decades. Although these systems are potentially cheaper, more effective, and environmentally friendly than conventional treatment, they have failed to become a standard process [50,51]. As with algal biofuels, the main problem is the separation of cells from the liquid, which is an energy-intensive process [52–54]. According to the findings, algae in this group are likely to be presented in an active anion group. The results showed that chlorine adsorption increased, and thus, its amount decreased in the environment [47,48].

The effect of different algae on sodium absorption is depicted in Fig. 6. Based on the analysis results, sodium absorption was significantly different in *C. vulgaris*, *N. oculata*, and *S. quadricauda* algae. The results of the present

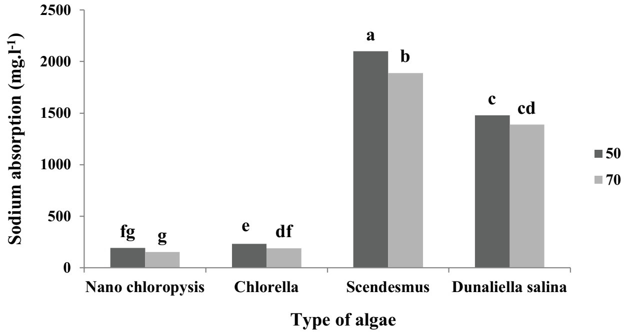

Fig. 6. Investigation of sodium absorption at electrical conductivities of 50 to 70 mS cm^{-1} in different algae. Different small letters above the columns indicate that the treatment means are significantly different at $p < 0.01$.

study indicated that sodium absorption was significantly higher in *S. quadricauda* algae (2,100.2 mg L^{-1}) than in the other algae. However, by decreasing EC to 70 mS cm^{-1}, sodium absorption significantly decreased in *C. vulgaris*, *N. oculata*, and *S. quadricauda* algae. The amounts of sodium absorption were not significantly different in *D. salina* at EC of 50 and 70 mS cm^{-1}.

Researchers found that the magnitude of anions showed easy uptake of the surface area and dry weight of algal cells [55]. It was the main factor affecting anion sorption and indicated favorable adsorption. Recently, researchers have become interested in biosorption using biomass-derived from freshwater, algae, marine seaweeds, and fungi. Many potential binding sites occur in algal cell walls and alginate matrices [23,56]. Existing ligands (e.g., the carboxyl group or other functional groups) cause to absorb cation in the cell wall of algae. As a result, a negative charge is generated and the attraction between negative charge and cation increases absorption on the cell surface. Ultimately, the cation is reduced in the environment [57,58].

The results of other researchers have demonstrated that an increase in the absorption of sodium by algae refers to the fact that surface openings of algae are opened and cations can enter grooves [25]. As a result, there are two stages for absorption in algae. The absorption of the first stage is related to active algal groups that are directly exposed to cations. The absorption of the second stage is relatively low and occurs over a long period of time since cations bond to surface groups [26,27].

Bicarbonate absorption for different treatments is shown in Fig. 7. There was a significant difference in terms of the amounts of bicarbonate between *C. vulgaris*, *N. oculata*, and *S. quadricauda* algae. By decreasing EC to 70 mS cm^{-1}, bicarbonate absorption significantly decreased in *C. vulgaris*, *N. oculata*, and *S. quadricauda* algae. The amounts of bicarbonate absorption were not significantly different in *D. salina* at EC of 50 and 70 mS cm^{-1}.

Carbon is taken into consideration as an essential factor for the growth of microalgae. In general, atmospheric CO_2 is considered as the carbon source of microalgae under cultivation [26,27]. However, it can be stated that metabolic efficiency and the combination of microalgae for the use of CO_2, bicarbonate, and carbonate as a carbon

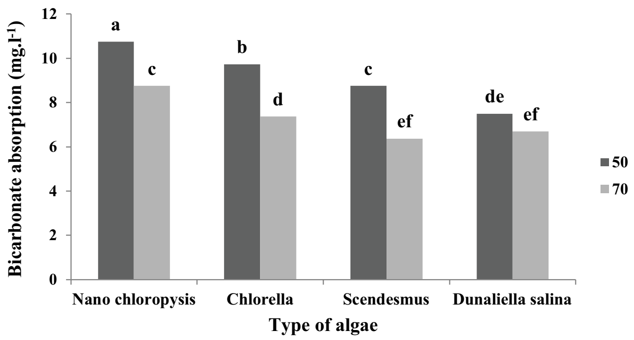

Fig. 7. Investigation of bicarbonate absorption at electrical conductivities of 50–70 mS cm^{-1} in different algae. Different small letters above the columns indicate that the treatment means are significantly different at $p < 0.01$.

source can vary from species to species [59]. The results indicated that the application of carbon was considered as one of the sources for the consumption of algae. Therefore, bicarbonate is used to supply carbon and reduces its amount in the environment [60]. Based on the results of other studies, different concentrations of sodium bicarbonate have a significant influence on the growth of two species of marine microalgae, and it is considered as a food source for the growth and development of algae [61].

4. Conclusion

In general, the results of this study indicated that the use of *D. salina*, *C. vulgaris*, *N. oculata*, and *S. quadricauda* would be an effective way of reducing salinity. The algae had high yields in high salinities and thus they can be used for reducing salinity, seawater from agricultural plants, and recycling plants. The results suggested using green algae for reducing water salinity. Fluctuations in physicochemical factors (e.g., salinity) have significant effects on the growth and biochemical composition of green algae. It can be stated that the growth of *D. salina* species is a highly effective method for absorbing salts in saline water, which leads to salinity reduction. The results are expressed without providing the food needed for the growth of algae, and salinity is further reduced by adding food. This procedure should be considered economically. The proposed system has a number of advantages including low cost, easy construction, and low performance and maintenance cost without the need for energy, and also, causes low environmental pollution. The use of algae is a new method for producing freshwater through the removal of salt from saline water. It is a cheap and effective tool for eliminating salinity, which itself contributes to ecological safety in aquatic ecosystems. In this method, water pollutants (i.e., nitrogen compounds, heavy metals, and phosphorus compounds) are simultaneously eliminated. In general, it can be argued that the production of algae biomass plays a significant role in producing biofuels, cosmetics, drugs, and protein substances.

Recommendation

There are few studies investigating biological methods for salinity reduction. Therefore, it is recommended to investigate and evaluate brown algae for salinity reduction. According to the results of this study, in addition to their low cost, the algae can be used in other areas and their growth can have economic justification. The use of these algae has been the subject of many studies in recent years due to economic reasons. However, limited studies have been performed on salinity reduction. It should be noted that this method is less expensive than other desalination methods. According to results obtained under indoor laboratory conditions, the algae led to a significant reduction of the salt content in the saline samples. In this regard, it is recommended to implement an outdoor project in this area. In this study, the algae were evaluated in 7 d and the procedure was carried out without adding nutrients needed for maximum growth. Thus, it is suggested to investigate the algae after adding nutrients to them. Further, an evaluation process should be developed to analyze results from the economic and technical points of view.

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