Experimental Investigation of Phytodesalination and Growth Rate of Duckweed (*Lemna minor*) in Saltwater Hydroponics

Swara Patel

Carrollwood Day School, 1515 W. Bearss Ave, Tampa, Florida, 33613, USA; swarap3109@gmail.com

ABSTRACT: Less than 1% of the Earth's water, a nonrenewable resource, is accessible as fresh water to us. Global warming, industrialization, and the growing human population exacerbate food and freshwater shortages. This investigation explores the potential of duckweed as a phytodesalinating agent for saltwater to address these issues. Duckweed (0.63 g) was grown hydroponically in different saline solutions (1%, 2%, and 3% salinity) and a commercial hydroponic nutrient solution (HS) as a control. Electrical conductivity (EC) and pH were measured every 3 days over 30 days, with spectrum (red/purple) grow lights on a 16/8 hour cycle. The average EC decrease for the 1% saline solution (SS) was 18.64% µS/cm, the 2% SS decreased by 9.09%, and the 3% SS decreased by 6.27% µS/cm, indicating effective desalination. Phytodesalination rate change (PRC) highlighted the most effective desalination date for each saline solution. A paired t-test was conducted to validate the significance of the desalination rates. Duckweed fresh weight increased by 1% and 2% in saline solutions but decreased by 3% due to the decay of duckweed. This research highlights duckweed's potential as a sustainable solution to alleviate water scarcity and food insecurity in a warming climate.

KEYWORDS: Earth and Environmental Science, Water Science, *Lemna minor*, Desalination, Electrical Conductivity.

Introduction

Duckweeds are small, aquatic macrophytes mostly found in stillwater bodies. Duckweed is a part of the family Lemnaceae, which are very small angiosperms. The duckweed family has five water-based species and is comprised of 38 species in total. These tiny plants have the ability to survive almost anywhere, including in incredibly salty conditions. Many of these genera are able to or have the potential for phytoremediation. This means that they can be used to clean up contaminated or polluted environments. Research studies have been conducted on the desalination and purification of septage, brackish, or agricultural wastewater. *Lemna minors*' rapid growth, prompt reproduction, and high nutrient and metal accumulation are all factors contributing to its phytoremediation potential.[1]

Duckweed is used in traditional East Asian cuisines as a popular breakfast choice. It is inexpensive, high in protein and omega-3 content, and has become a popular snack item. When grown in the right conditions, this superfood can contain up to 40% protein. Duckweed has a high fiber content, grows like a weed, and is good for the environment as it affects not only humans but animals, too. A high-quality protein source for humans may also be found in it since it has a perfect amino acid composition. As well as being high in minerals, vitamins, and antioxidants, duckweed also contains a variety of health-promoting properties. "The fastest-growing duckweed strain can produce about 20 g (when dried) per square meter per day using our current prototype. That's about 1.4 million pounds per hectare (2.47 acres) annually—50 times what you get from corn."[1] This aquatic macrophyte is the perfect candidate for hydroponic farming.

Hydroponics has recently become a popular choice for growing plants since it is efficient and cost-effective, it requires less space (vertical farming), and it has a reduced carbon footprint compared to soil farming. This technique uses no soil, instead relying on a nutrient-rich water solution to provide the plants with the nutrients they need. It eliminates the need for pesticides and herbicides. About 70% of our global freshwater is used for agriculture, and with the human population rapidly growing, we need to look for alternative solutions for irrigation. Saltwater hydroponics is another exciting area of research because of the possibility of using seawater as a water source for growing aquatic macrophytes. This is a method of hydroponic gardening that uses seawater instead of freshwater as a growing medium. Seawater contains many nutrients like K, Ca, and Mg that are useful for growing plants. It has been proven that by using saltwater hydroponics, plants uptake more nutrients than they had started with.[2] Saltwater hydroponics is an efficient and sustainable way to grow plants, as it utilizes the resources available in seawater.

About 70% of our global freshwater is used for agriculture, and with the human population rapidly growing, we need to look for alternative solutions for irrigation. Water is a nonrenewable resource that is being depleted at a rapid rate due to our ever-increasing population, and to solve this issue, we must come up with alternative solutions to combat this crisis. Desalination is the process of removing salts and other minerals from seawater or other saline sources to make them suitable for human consumption and other uses.[3] It is becoming increasingly important due to the rise in global water demand and the decline in freshwater sources.[4,5] With the world's population projected to reach 9.7 billion by 2050, the demand for freshwater is expected to increase significantly, making desalination an important source of clean and safe drinking water.[6] Currently, many desalination processes consume massive amounts

DOI: 10.36838/v7i6.92

of energy, are unsustainable, and are not beneficial to the environment. Natural desalination using plants will reduce the need for expensive, energyintensive desalination plants, as well as protect natural ecosystems. Additionally, these natural processes help to reduce the impact of climate change; plants will help to absorb and store carbon dioxide.[7] Using duckweed for saltwater hydroponics could be quite significant due to its role in phytodesalination and recycling. Saltwater hydroponics is especially beneficial for growing crops in arid climates, as it can be used to supplement the lack of fresh water.[8] Duckweed has the ability to absorb salts from salt water, which might make the water more suitable for reuse in other applications. Moreover, the water that duckweed is grown in can be recycled, reducing the impact of salts in downstream processes. Additionally, duckweed itself can provide a food source, adding another layer of utility to this technique. Overall, integrating duckweed into saltwater hydroponics might offer a practical approach to managing salinity and enhancing resource efficiency.

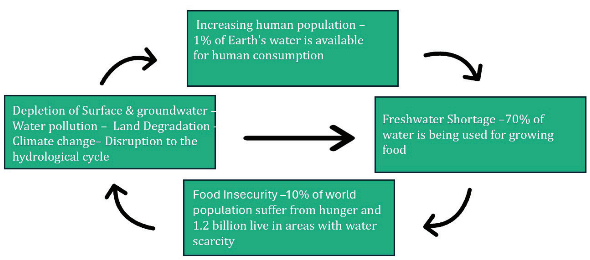

Figure 1: The exponential increase in the global population will demand an increase in food and freshwater consumption. Climate change due to human impact has disrupted the hydrological cycle, leading to a freshwater shortage, which can ultimately impact food cultivation.[9]

Problems -
- The water crisis is among the top 5 global risks in terms of impact on society. Fresh water is a limited resource; less than 3% of the world's water is fresh.[10]
- With the world's population projected to reach 9.7 billion by 2050, food production will need to be doubled to meet increasing demand.
- About 70% of our global freshwater is used for agriculture; any freshwater insecurity can exacerbate worldwide food insecurity.
- Climate change will continue to threaten food and freshwater availability by increasing resource scarcity and soil degradation. [11]

Current work -
- Current desalination techniques like distillation and reverse osmosis (RO) are expensive in terms of energy and technology and have climatological and hydrological constraints like emitting greenhouse gases. Producing 1 L of drinking water creates 1.6 L of salty brine. Waste brine released into oceans has a negative impact on the marine environment and its biodiversity due to chemicals, increased salinity, and temperature.

Need -
- Adopt the wider use of alternative water resources such as desalination of sea and brackish water.
- Develop alternate natural desalination techniques that are affordable, sustainable, and environmentally friendly.

Methods

Preparing the Jars:

Wash the 1L 15 mason jars with distilled water. Gather the 7.6 L Hoagland solution, label maker, 7.6 L distilled water, analytical weighing scale, and 5 g fine sea salt. Assemble the mason jars on the three-tier storage rack in 5 rows of three and label the first jar of each row: 1%, 2%, 3%, commercial hydroponic nutrient solution, Hoagland Solution (HS), and Distilled Water (DW). Then label each jar with replication 1, 2, or 3.

Creating Salt Solutions:

Take 3 large bowls and label them 1%, 2%, and 3%, respectively. Using a measuring cup pour six cups of HS into each bowl. Weigh 0.95 g of salt and dissolve into the bowl marked 1%; this will be the 1% solution. Weigh out 1.95 g of salt and dissolve into the bowl marked 2%; this is the 2% solution. Weigh out 2.95 g of salt and dissolve into the bowl marked 3%; this is the 3% salt solution.

Assembly and Sterilization:

Pour two cups of the 1% solution into the jars marked 1%. Repeat this step for the 2% and 3% solutions. Sterilize the materials with DW to avoid cross-contamination. Each jar should contain two cups of its respective salt solution. Pour 2 cups of DW into their respective jars. Pour 2 cups of HS into the jars labeled HS. Once all the jars are filled with their corresponding solution, measure 1/4 tsp (6.39 g) of the duckweed and place it into each jar.

Maintenance and Monitoring:

Turn the 3 LED full-spectrum grow light on and measure EC using an EC probe and pH using a pH meter. Continue to do this every three days for 30 days. The grow light should be turned on for 16 hours and turned off for 8 hours every day. If the water level starts to decline in the jars, add distilled water until they are filled up to the 2-cup mark. After 30 days, take the duckweed out of the jars with 2 chopsticks and weigh them. Data analysis will be conducted for the EC and pH data, as well as the fresh weight of duckweed.

Result and Discussion

6.39 g of Duckweed was grown hydroponically in 15 jars with 3 replications of 1%, 2%, and 3% saline solutions, Hoagland solution, and distilled water. Phytodesalination by duckweed was measured using an electrical conductivity probe every three days for 30 days. The 1% saline solution contained 0.95 g of salt, the 2% saline solution contained 1.95 g of salt, and the 3% saline solution contained 2.95 g of salt. The Hoagland Solution and distilled water served as the control group. A Generalized Linear Model (GLM) was developed to create a line of best fit for desalination in the 5 various solutions.

PDSR was calculated to highlight the effectiveness of the duckweed in terms of desalination as well as at what point the duckweed was working at maximum efficiency. The differences between the readings (every 3 days) for each replication were calculated and then averaged and the largest difference was the day at which the duckweed was performing the most efficiently. Table 1 shows the highest drop in pdsr for 1% during day 15, with the average drop (average of three replications) in the EC of 189.66 µS/cm. The pdsr for 2% was at its peak during day 21, with the average drop being 174.6 µS/cm. The phytodesalination rate change for the 3% solution was at its highest during day 24, and the average drop was 152.6 µS/cm. This indicates that duckweed can be changed when the pdsr is highest for each saline solution this was calculated through Table 2. As expected, the Hoagland solution had the highest growth of duckweed, ending at 43.76 grams. Followed by the 1% saline solution with the duckweed weight at 32.99 grams. This was closely followed by the 2% solution, which had duckweed growth of 26.9 grams. The 3% saline solution had a decrease in duckweed mass by 0.7 g, possibly due to the decay of the duckweed due to the high salinity of the solution or nutrition deficiency. From these readings, the past, and the fresh weight of duckweed, it can be inferred that duckweed is a potential candidate for desalinating seawater. However, it has to be changed every 21-24 days to avoid disintegrating. The tailed t-test was conducted (Table 3), and the fresh weight of the duckweed was measured for each solution respectively after the cycle of 30 days concluded (Table 4). A Generalized Linear Model was fitted, and the data provided a strong correlation to the model. By fitting a GLM with a logarithmic link function, it models the relationship between predictor variables (time) and the logarithm of the expected value of the response variable (electrical conductivity). This approach allows for nonlinear relationships and can better accommodate data that do not meet the assumptions of traditional linear regression. Over thirty days, the EC consistently dropped in each saline solution and the controls. As expected, the EC of the distilled water remained the same because it lacked NaCl. As per the data, the desalination rate (difference of the first and last reading) of duckweed measured in EC was the highest in the 1% saline solution (826 µS/cm) (Figure 2). This was followed by the decrease in EC in the 2% saline solution (677 µS/cm) and the 3% saline solution (609 µS/cm), indicating duckweed desalinated 1% saline solution the most.

The null hypothesis states that there is no statistically significant difference between the drop of desalination between the Hoagland solution and the three saline solutions. The alternate hypothesis states that there is a statistically significant difference between the Hoagland and 1, 2 & 3% saline solutions. All p-values were less than 0.05, meaning that the data was statistically significant, the null hypothesis was rejected, and the alternative hypothesis was accepted (Table 3). The drop in salinity in the 1%, 2%, and 3% solutions suggests that duckweed can effectively phytodesalinate water and grow in saltwater while providing an alternate food source.

Generalized Linear Model (GLM):

$g(\mu)=\eta=\log(\mu)$

- $g(\mu)$ is the link function that transforms the expected value of the response variable (μ) into the linear predictor
- μ is the expected value (mean) of the response variable
- η is the linear predictor, which is a linear combination of predictor variables (features) weighted by their coefficients

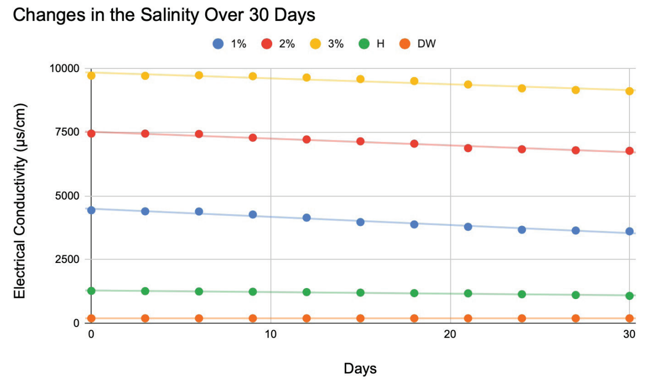

Figure 2: Phytodesalination by duckweed (*L. minor*) for different solutions over 30 days. This figure displays the various saline solutions decreasing in EC over the timeline of 30 days. The EC of the solutions was the highest in the 1% saline solution (826 µS/cm), followed by the decrease in EC in the 2% saline solution (677 µS/cm) and the 3% saline solution (609 µS/cm), the Hoagland solution dropped by 196 µS/cm indicating duckweed desalinated 1% saline solution the most (Figure 2).

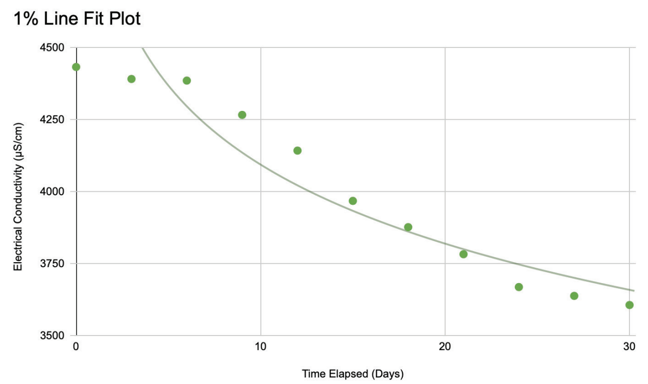

Figure 3: Phytodesalination rate of duckweed (*L. minor*) for the 1% saline solution. The GLM was used to create a trendline to demonstrate the relationship between the EC and the period of time. The 1% solution started at 4432 µS/cm and ended at 3606 µS/cm. The drop in salinity was the highest in the 1% saline solution, with an 826 µS/cm drop.

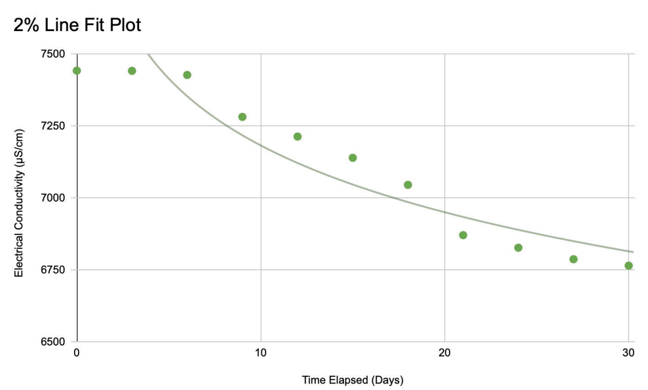

Figure 4: Phytodesalination rate of duckweed (*L. minor*) for the 2% saline solution. Using the GLM model, a trendline was created between the time elapsed and the EC. The 2% saline solution began at 7442 µS/cm and ended at 6764 µS/cm, with a 667 µS/cm drop in salinity over 30 days.

DOI: 10.36838/v7i6.92

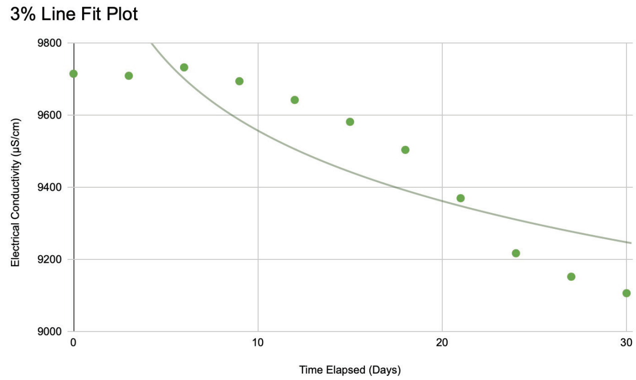

Figure 5: Phytodesalination rate of duckweed (*L. minor*) for 3% of the saline solution. This trendline was fitted using a GLM model to display the trend between the EC and the time elapsed. The 3% saline solution began at 9715 µS/cm and ended at 9106 µS/cm, with a 609 µS/cm drop over 30 days.

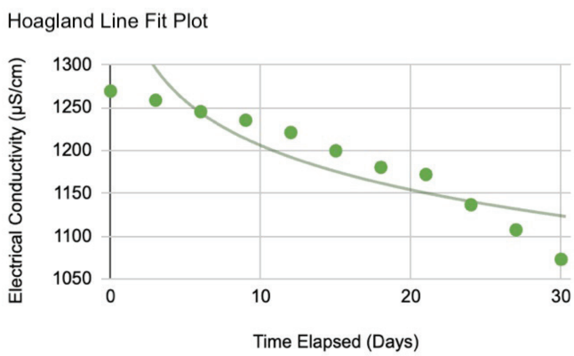

Figure 6: Phytodesalination rate of duckweed (*L. minor*) for Hoagland Solution. In this graph, the GLM was used to create a trendline between the EC and the time elapsed for the Hoagland solution, which was used as a control. The solution started at 1269 µS/cm and ended at 1073 µS/cm, creating a 196 µS/cm drop in the Hoagland solution over 30 days.

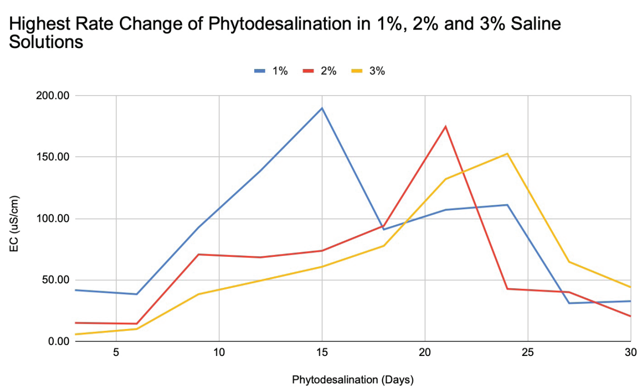

Figure 7: The highest rate of change in phytodesalination is 1%, 2%, and 3% Saline Solutions. This graph displays the highest desalination rate = the highest change in EC. This occurred during day 15, with the average drop (n=3) being 189.66 µS/cm. The pdsr (Phytodesalination Rate) for 2% was at its peak during day 21, with the average drop being 174.6 µS/cm. The phytodesalination rate change for the 3% solution was at its highest during day 24, and the average drop was 152.6 µS/cm. (Figure 7).

Table 1: Highest rate of change of phytodesalination in 1%, 2%, and 3% saline solutions every 3 days (µS/cm). The highest rate of phytodesalination in 1%, 2%, and 3% Saline Solutions is displayed by data in the table. Each italicized number represents the highest change in EC for each solution (n=3) that had desalinated over thirty days. Table 1 displays the highest drop in pdsr during day 15, with the average drop (average of three replications) and the EC of 189.66 µS/cm. The pdsr for 2% was at its peak during day 21, with the average drop being 174.6 µS/cm. The phytodesalination rate change for the 3% solution was at its highest during day 24, and the average drop was 152.6 µS/cm.

Days	Salinity		
	1%	2%	3%
3	41.67	15.00	5.67
6	38.33	14.33	10.00
9	92.67	70.67	38.33
12	138.67	68.33	49.33
15	189.67	73.67	60.67
18	91.00	94.00	77.67
21	107.00	174.67	132.00
24	111.00	42.67	152.67
27	31.00	40.00	64.67
30	32.67	20.33	44.00

Table 2: Phytodesalination by duckweed (*L. minor*) for different solutions over 30 days (µS/cm). Over 30 days, measurements were taken from each solution every three days (averages of three replications are shown). The duckweed measured in EC was the highest in the 1% saline solution (826 µS/cm), followed by the decrease in EC in the 2% saline solution (677 µS/cm) and the 3% saline solution (609 µS/cm), the Hoagland solution dropped by 196 µS/cm indicating duckweed desalinated 1% saline solution the most. (Figure 1 and Table 2).

Days	1%	2%	3%	H	DW
0	4432	7442	9715	1269	192
3	4391	7441	9709	1259	192
6	4385	7427	9732	1245	192
9	4266	7281	9694	1235	192
12	4142	7213	9642	1221	192
15	3967	7139	9581	1200	192
18	3876	7045	9504	1180	192
21	3782	6870	9370	1172	192
24	3668	6827	9217	1137	192
27	3638	6787	9152	1107	192
30	3606	6764	9106	1073	192

DOI: 10.36838/v7i6.92

Table 3: Paired 2-tailed T-Test Values. A paired t-test analysis of the phytodesalination rate was conducted for the saline solutions compared with the Hoagland solution. The null hypothesis states that there is no statistically significant difference between the drop of desalination between the Hoagland solution and the three saline solutions. The alternate hypothesis states that there is a statistically significant difference between the Hoagland and 1, 2 & 3% saline solutions. All p-values were less than 0.05, meaning that the data was statistically significant, and the null hypothesis was rejected, while the alternative hypothesis was accepted.

H vs 1%	p = 6.85 x 10^-12
H vs 2%	p = 4.618 x 10^-16
H vs 3%	p = 3.336 x 10^-18
1% vs 2%	p = 2.257 x 10^-18
1% vs 3%	p = 3.829 x 10^-18
2% vs 3%	p = 1.92 x 10^-16

Table 4: Changes in Fresh Weight of Duckweed (L. minor) After 30 days. As expected, the Hoagland solution had the highest growth of duckweed, ending at 43.76 grams. Followed by the 1% saline solution with the duckweed weight at 32.99 grams. Closely followed by the 2% solution, which had duckweed growth of 26.9 grams. The 3% saline solution had a decrease in duckweed mass by 0.7 g. duckweed growth of 26.9 grams. The 3% saline solution had a decrease in duckweed mass by 0.7 g.

	H	1%	2%	3%	DW
Beginning Weight (g)	6.39	6.39	6.39	6.39	6.39
End Average Weight (g)	43.76	32.99	26.9	6.32	13.1

Conclusion

The experimental results presented in this study demonstrate the remarkable ability of duckweed to effectively desalinate water across various saline concentrations. The data revealed a consistent decrease in electrical conductivity (EC) in all saline solutions tested, indicating the successful removal of salt from the water by duckweed. Notably, the highest desalination was observed in the 1% saline solution, (Figure 3) followed by the 2% (Figure 4) and 3% solutions (Figure 5). The Duckweeds' desalination of Hoagland was substantial as well (Figure 6). These findings underscore the efficacy of duckweed in reducing salinity levels, with the 1% saline solution showing the most substantial reduction.

Further analysis of peak phytodesalination rates (PDSR) revealed that the timing of maximum desalination efficiency varied among the different saline solutions (Figure 7). The 1% solution exhibited its highest PDSR on day 15, followed by the 2% solution on day 21 and the 3% solution on day 24. This variation suggests that duckweed's desalination efficiency is influenced by the salinity level of the solution and reaches its peak during specific growth stages. The study also investigated the impact of saline conditions on duckweed growth, measured by fresh weight. While the Hoagland solution supported the highest growth, followed by the 1% and 2% saline solutions, the 3% saline solution resulted in a slight decrease in duckweed mass. This decrease highlights the adverse effects of high salinity on plant growth and emphasizes the importance of maintaining optimal salinity levels for sustained growth and desalination performance. Statistical analysis confirmed significant differences in desalination rates between the Hoagland solution and the saline solutions, with all p-values below 0.05. This statistical evidence supports the effectiveness of duckweed in desalinating water across a range of saline concentrations. This investigation into the phytodesalination capabilities of duckweed has yielded compelling results. Over 30 days, a consistent reduction in electrical conductivity was observed across saline solutions of varying concentrations, indicative of successful desalination. Notably, duckweed demonstrated the highest desalination rate in the 1% saline solution, followed by the 2% and 3% solutions. This highlights the efficacy of duckweed as a natural desalination agent, particularly in moderate salinity conditions. Furthermore, this study elucidated the growth dynamics of duckweed in different nutrient environments. The highest growth was observed in the Hoagland solution, underscoring the potential of duckweed as a nutrient-rich food source in addition to its desalination capabilities. This dual functionality positions duckweed as a versatile bioresource with significant implications for sustainable agriculture and food security.

Previous studies have primarily focused on specific applications of duckweed, such as phytodesalination or nutrient uptake in agricultural settings. In contrast, this research extends beyond these isolated investigations to examine the broader implications of duckweed-based systems in closed-loop hydroponics. By employing a Generalized Linear Model (GLM) to analyze dynamic changes over a 30-day experimental period, the intricate relationships between duckweed growth, nutrient absorption, and desalination efficiency are elucidated. The findings in this study reveal consistent decreases in electrical conductivity (EC) across all saline solutions, indicating the efficacy of duckweed in desalinating water. Furthermore, the variation in duckweed's fresh weight across different solutions underscores its adaptability to saline conditions. Statistical analysis confirms significant differences in desalination rates between saline and control solutions, highlighting the effectiveness of duckweed-based systems in restoring water quality.

Environmental benefits:

Saltwater hydroponics reduces the demand for large spans of land and minimizes soil consumption, thereby preserving vital ecosystems. Additionally, this method enhances water conservation by efficiently utilizing water resources, mitigating the environmental impact associated with traditional farming practices. The closed-loop nature of hydroponic systems ensures that water is continually circulated, minimizing wastage. Also, reduced reliance on soil diminishes the need for chemical fertilizers, limiting soil and water pollution.

Furthermore, saltwater hydroponics is cost-effective, as it optimizes resource utilization and minimizes input costs, making it an economically viable and sustainable choice for modern agriculture

DOI: 10.36838/v7i6.92

Applications:

Phytodesalination - Saltwater can be utilized to grow halophytes (duckweed). This method will utilize an abundant supply of salt water to cultivate food without negative ecological impact. Desalinated saltwater solutions can be recycled and reutilized, thereby minimizing wastage and providing a sustainable water management system.

Increased food production - This method uses 90% less water than traditional agriculture practices. Precise farming maximizes the yield of crops and quicker growth. It is essential for arid farming where food scarcity, climate, and poor soil quality pose a great challenge. Food in space: Duckweed is high in protein and contains powerful antioxidants like lutein and zeaxanthin. It reduces inflammation and supports eye health.

The engineering applications derived from current research findings are multifaceted and far-reaching. Phytodesalination systems, leveraging the natural desalination capabilities of duckweed, offer a cost-effective and environmentally friendly approach to remediating saline water sources. Smart irrigation technologies incorporating duckweed-based systems can optimize water use efficiency and mitigate the impacts of water scarcity in agriculture. Furthermore, the integration of duckweed into hydroponic farming systems holds promise for enhancing food production while minimizing environmental impact. By harnessing the innate abilities of duckweed to thrive in aquatic environments and absorb nutrients, hydroponic systems can revolutionize agricultural practices and contribute to sustainable food production.

Future Applications:

As the global population burgeons and environmental challenges escalate, the imperative to explore sustainable solutions for water and food security becomes increasingly evident. Duckweeds, with their multifaceted capabilities and adaptability, offer promising avenues for tackling these pressing issues. More species and specific genera of Duckweed can be used to resolve this issue Through interdisciplinary research and innovative applications, duckweeds can provide valuable insights and solutions to the quest for a more sustainable and resilient future. By delving deeper into the intricacies of duckweed biology, ecology, and applications, researchers can unlock new opportunities for environmental stewardship and agricultural sustainability. Through collaborative efforts across disciplines, including biology, ecology, environmental science, and agricultural engineering, the potential of duckweed can be fully realized. With continued exploration and innovation, duckweeds have the potential to revolutionize how society approaches water management, food production, and environmental conservation on a global scale.

Acknowledgments

I am deeply grateful to my mentor, Ms. Alexandra Smith, for her guidance and support throughout the project. Her assistance included advice on experimental design and statistical analysis. I thank my brother for providing his expertise in data and statistics.

References

1. Fertig, W. *Common duckweed.* www.fs.usda.gov.https://www.fs.usda.gov/wildflowers/plant-of-the-week/lemna_minor.shtml. (accessed Dec 10, 2023).
2. Mohd Nani, S. Z.; Majid, F. A. A.; Jaafar, A. B.; Mahdzir, A.; Musa, M. N. Potential Health Benefits of Deep Sea Water: A Review. *Evidence-based Complementary and Alternative Medicine: eCAM* 2016, 2016. https://doi.org/10.1155/2016/6520475
3. *2.1 Desalination by reverse osmosis.* Oas.org. https://www.oas.org/dsd/publications/Unit/oea59e/ch20.htm. (accessed Dec 14, 2023).
5. *Growing Food Without Soil: A Guide to Hydroponics*. Lakewinds Food Co-op. 2020. https://www.lakewinds.coop/blog/growing-food-without-soil-a-guide-to-hydroponics/. (accessed Dec 10, 2023).
6. Bates, Todd. *Could duckweed feed the world? phys.org.* https://phys.org/news/2019-08-duckweed-world.html. (accessed Dec 10, 2023).
7. Prado, A.; Ángel Molina-García; Juan Pascual García; F. Vera-García. Desalination, Minimal and Zero Liquid Discharge Powered by Renewable Energy Sources: Current Status and Future Perspectives. *Renewable & Sustainable Energy Reviews* 2023, 187, 113733–113733. https://doi.org/10.1016/j.rser.2023.113733. (accessed Dec 10, 2023).
8. Alley, William M. *Desalination | U.S. Geological Survey*. Water Science School. www.usgs.gov. https://www.usgs.gov/special-topics/water-science-school/science/desalination. (accessed Dec 10, 2023).
9. *Hydroponics | National Agricultural Library.* Usda.gov. https://www.nal.usda.gov/farms-and-agricultural-production-systems/hydroponics. (accessed Dec 10, 2023).
10. *Seawater Hydroponics | Garden Culture Magazine.* Garden Culture Magazine. https://gardenculturemagazine.com/seawater-hydroponics. (accessed Dec 10, 2023).
11. *9 Advantages of Seawater Desalination Systems*. Pure Aqua. Inc. https://pureaqua.com/blog/9-advantages-of-seawater-desalination-systems. (accessed Dec 14, 2023).
12. Shrestha, A.; Dunn, B. *Hydroponics - Oklahoma State University.* extension.okstate.edu. https://extension.okstate.edu/fact-sheets/hydroponics.html. (accessed Dec 14, 2023).
13. *2.1 Desalination by reverse osmosis.* Oas.org. https://www.oas.org/dsd/publications/Unit/oea59e/ch20.htm. (accessed Dec 14, 2023).
14. *Material Safety Data Sheet - Fisher SCI*, fscimage.fishersci.com/msds/91199.htm. (accessed Dec14, 2023).

Authors

Swara, a 16-year-old researcher from Carrollwood Day School in Tampa Bay, Florida; embodies a profound commitment to improving the environment for all living beings. Her journey into the world of science began in second grade with a project investigating the effects of yogic breathing on cognitive performance. Since then, her passion for scientific inquiry has only deepened, leading her to explore innovative solutions to challenges such as terraforming Mars and addressing water insecurity. With aspirations to pursue environmental engineering, focusing on water engineering, climate, and sustainability, Swara aims to contribute to innovative advancements in these critical areas.