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Phytoremediation Potential of Macrophytes from Calcium Fortified Ground Water under Laboratory Condition to Improve Water Quality

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ABSTRACT

To select the best macrophyte for the phytoremediation of calcium from Ca-fortified ground water and inland saline water, 1 week screening was done for *Eichhornia crassipes, Salvinia molesta* and *Lemna minor* by using four effective concentrations of Calcium viz., 200, 400, 600 and 800 mg L^{-1}. Experiment was done in triplicate. Water samples were collected at one day interval and plant samples at the end of experiment. The Calcium uptake concentration was found significantly ($p<0.05$) higher for *E. crassipes* on 6^{th} day (5.37%) of experiment at effective concentration 800 mg L^{-1}, followed by *S. molesta* (4.87%) and *L. minor* (4.13%). Further experiment was conducted for 1 month for water quality analysis and testing the Calcium uptake, and found that there was significant improvement in water quality parameters. The finding of this study will serve baseline information for treatment of inland saline water to make it useful for various agricultural and aquaculture applications.

Keywords Calcium, Phytoremediation, Inland saline water, Free floating macrophytes.

INTRODUCTION

The groundwater is a natural and renewable resource for day-to-day human activity. Globally, 65% of groundwater is used for drinking purposes, 20% for irrigation and livestock and 15% for industry and mining (Saeid *et al.* 2018) and approximately one-third of the world's population primarily relies on groundwater for drinking purpose (Karunanidhi *et al.* 2022). Due to intensive use of natural resources and increased human activities pushed the groundwater quality under great threat and deterioration. Increasing exploitation of groundwater, rapid urbanization and industrialization, over-application of chemical fertilizers and pesticides for higher plant growth, animal waste and improper drainage systems are important human-induced activities, which damage the natural occurrence of the chemical quality of groundwater and consequently not only affect human health but also reduce crop production (Deepali *et al.*

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2015, Rahmati *et al.* 2015, Li *et al.* 2016, Kouakou *et al.* 2017, Wagh *et al.* 2019). Generally, once the groundwater quality deteriorated or becomes an inferior type due to the contamination of geogenic and non-geogenic hazards, it will not be suitable for any purposes (Subba Rao *et al*. 2021). World-widely, more than 900 million hectares (mha) of land, accounting for nearly 6% of the world's total land area and approximately 20% of the total agricultural land is affected by salinity (Chinchmalatpure 2017). While comparing with Indian scenario the total degraded land due to salinity and sodicity is estimated to be 6.74 M ha in India. All over India, Gujarat has maximum salt affected soil of 2.2 mha followed by Uttar Pradesh (1.3 mha) and Maharashtra (0.6 mha) (Chinchmalatpure 2017).

Salinity mainly caused either through natural or human-induced processes leads to the accumulation of dissolved salts in the soil water up to an extent that may inhibit plant growth. Water hardness is one of the major problems of inland saline water and is a very important property of any ground water from its utility point of view or aquaculture point of view. The Calcium (Ca^{2+}) and magnesium (Mg^{2+}) are the two important ions responsible for the total hardness of the water. There is variation in water hardness of ground water in different places of Haryana as reported by various researchers viz., at Hisar city 100-900 ppm of $CaCO_3$ (Kumar *et al.* 2016), at Sonipat 50-1200 ppm of $CaCO_3$ (Kumar *et al.* 2019), at Rohtak 503-1005 ppm of $CaCO_3$ (Sangeeta *et al.* 2013). Similarly, there is difference in Calcium concentration in various places of Haryana as reported by many researchers viz., at Ambala district 150-200 ppm (Gupta *et al.* 2009), at Jind district 24-109 ppm (Singh *et al.* 2012), at Rohtak district 120-371 ppm (Sangeeta *et al.* 2013), at Karnal district 108.11–394.60 ppm (Singh *et al.* 2017). According to the ICMR and BIS standards the permissible limit for total hardness is 300 ppm of $CaCO_3$ fish culture. In the state of Haryana, inland saline water has salinity from 10-35 ppt with high water hardness due to presence of $Ca^{2+}$and Mg^{2+}ions in large amount. This area is more suitable for the shrimp culture.

Phytoremediation is a plant-based technique, which essentially involves the use of plants and plant materials to extract and remove elemental pollutants or lower their bioavailability in soil. Plants have the capabilities to absorb ionic compounds in the soil even at low concentrations through their root system. Plants outspread their root system into the soil matrix and form rhizosphere ecosystem to concentrate or accumulate heavy metals and modulate their bioavailability, thereby reclaiming the polluted soil and stabilizing soil fertility (Jacob *et al.* 2018, Dal Corso *et al.* 2019). Phytoremediation technique involves several mechanisms including degradation, accumulation, dissipation, and immobilization to degrade, remove or immobilize the pollutants. Depending upon the contaminants, plants utilize one or more of these mechanisms to reduce their concentrations from soil/sediment and water. For examples, plants uptake and accumulate the heavy metals in their tissues (Mahar *et al.* 2016) and degrade the organic pollutants (Saleem *et al.* 2020) reducing their toxicity from soil and water resources. Phytoremediation is a low-cost and environmental–friendly technique as it utilizes green plants to contain, sequester or detoxify contaminants from contaminated soil/sediment and water (Ashraf *et al.* 2019). There are various advantages of using this plant-based technique (phytoremediation), which comprise : (i) Economically feasible- phytoremediation is an autotrophic system, using solar energy, therefore, simple to manage, and the cost of installation and maintenance is low, (ii) Environment and eco-friendly–it can minimize exposure of the pollutants to the environment and ecosystem, (iii) Applicability it can be applied over a large-scale field and can easily be disposed, (iv) It prevents erosion and metal leaching through stabilizing heavy metals, reducing the risk of transportation of contaminants, (v) It can also help to improve soil fertility by releasing several organic matters to the soil (Jacob *et al.* 2018). Some of the free-floating aquatic plants are well recognized for their capability to eliminate the metals Water hyacinth, duckweed and water lettuce are the most frequently used free-floating plants as phytoremediator of heavy metals from wastewater (Anaokar *et al.* 2018, Chen *et al.* 2018).

Common desalination methods are either physical or electro-chemical. These techniques are mainly based on principle of ion exchange, filtration or separation and adsorption which are energy

Table 1. Experimental set-up for calcium removal efficiency of available macrophytes.

Plant/effective concentration		200 mgL^{-1} (R_1)	400 mg L^{-1} (R_2)	600 mg L^{-1} (R_3)	800 mg L^{-1} (R_4)
No plant	(P_0R_0)	P_0R_1	P_0R_2	P_0R_3	P_0R_4
Plant 1	(P_1R_0)	P_1R_1	P_1R_2	P_1R_3	P_1R_4
Plant 2	(P_2R_0)	P_2R_1	P_2R_2	P_2R_3	P_2R_4

consuming and costly. Phytoremediation is a green strategy that uses hyper-accumulator plants and their rhizospheric micro-organisms to stabilize, transfer or degrade pollutants in soil, water and environment (Liu *et al.* 2020). This technology is considered as well-efficient, cheap and adaptable with the environment (Nedjimi 2020). From inland saline water using macrophytes is not attempted by researcher earlier for Calcium removal. Therefore, the present study is conducted to study physico-chemical parameters of the water treated with available macrophytes on calcium removal efficiency from calcium fortified ground water.

MATERIALS AND METHODS

Experimental design and experimental Set-up : The experiment was carried out at wet laboratory of ICAR-Central Institute of Fisheries Education, Mumbai, India. In this study, the free-floating perennial aquatic plant *E. crassipes*, free-floating aquatic fern with creeping stems, branched, bearing hairs on the leaf surface papillae but without true roots *S. molesta* and free-floating, fragile, tiny aquatic plant *L. minor* was used for phytoremediation of Calcium from calcium fortified water. The *E. crassipes* was collected from Powai Lake (Mumbai), *S. molesta* from Ernakulum (Kerala) and *L. minor* from ICAR-CIFE Aquaculture wet-laboratory and were transferred to the wet laboratory in polyethylene bags. Prior to the start of the experiment all these plants were acclimated to the experimental conditions and grown for 2-3 weeks in circular FRP tanks containing freshwater to obtain the required quantity for the experiments.

Five treatment having distinct effective concentrations of the calcium at R_0 = Tap water (without Ca), R_1 = 200 mg L^{-1}, R_2 = 400 mg L^{-1}, R_3 = 600 mg L^{-1} and R_4 = 800 mg L^{-1} has been taken in glass aquarium (45 × 30 × 30 cm³) tanks of 40.5 L capacity each for the phytoremediation study (Table 1 and Plate 1) following a Completely Randomized Design (CRD). Treatments included P_0 = No plant, P_1 = *E. crassipes,* P_2 = *S. molesta* and P_3 = *L. minor* each treatment have three replicates. Stock solution of graded level of Calcium has been prepared separately for desired effective concentration (i.e., 200, 400, 600 and 800 mg L^{-1}) by dissolving 500, 1000, 1500 and 2000 mg L^{-1} of Calcium carbonate powder (Merck) respectively. The 17 L solution poured in each tank and water level kept at 13 cm. Selected healthy, washed and cleaned plants of *S. molesta* and *E. crassipes* were introduced respectively at the rate of 100 g and 500 g to cover the water surface of aquarium tanks as per the experimental design layout. Control tanks were set up for each treatment to find out the removal of Calcium through surface of glass aquarium tanks (adsorption mechanism) by maintaining the same effective concentration of Calcium (i.e., 200, 400, 600 and 800 mg L^{-1} respectively). Matured tap water was used for the preparation of different effective

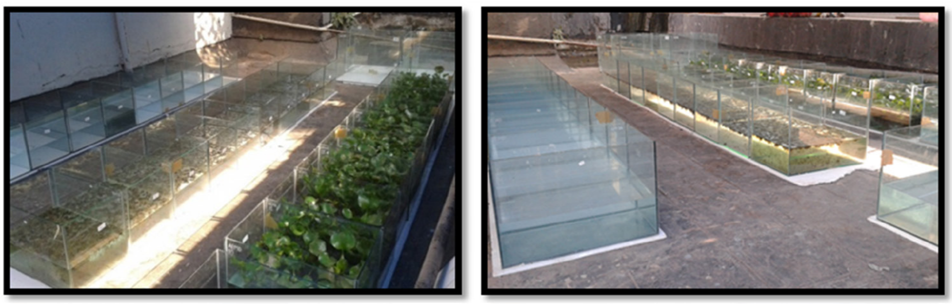

Plate 1. Experimental setup for phytoremediation of calcium from calcium fortified water.

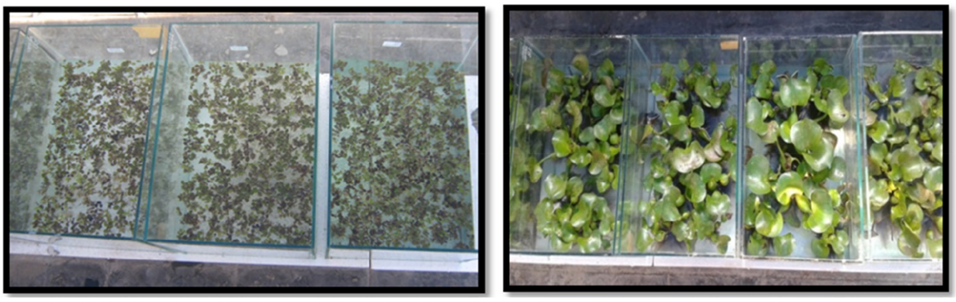

Plate 2. Phytoremediation using *Salvinia molesta* and *Eichhornia crassipes*.

concentration of Calcium. All the aquarium tanks were properly washed, cleaned and dried before use. Matured tap water was added per day to maintain the same level in each aquarium tank. All aquarium tanks were covered partially by using tarpaulin sheet to minimize water loss through evaporation.

Sample collection and preparation

Water sample

Each alternative day water samples 50 ml each were collected at alternate day in polypropylene bottles from each aquarium tank in triplicates for Calcium removal study. All the bottles were cleaned by soaking in dilute hydrochloric acid for 7-8 hrs and washed with distilled water and dried before use. Water samples were filtered by using Whatman paper No.1 and then used for Calcium analysis by Flame photometer. For water quality parameter (temperature, dissolved oxygen, nitrate-N, ammonia-N, available phosphorus) analysis water samples were collected in different sample bottles separately, which were carried out on the day of sample collection (Plates 2–3).

Plant sample

Plants were collected randomly from each aquarium tank at the end of experiment (Plates 2–3). All the samples were air-dried at room temperature for 2-3 days then, dried in hot air oven at temperature 105˚C for 3-5 hrs to attain a constant weight and ground to powder using glass mortar and pestle. The finely ground material (powder) was stored in sealed polyethylene bags with proper labelling and was kept at room temperature for further study.

Plate 3. Water and plant sample collection after phytoremediation.

Estimation of moisture content from macrophytes

The moisture content analysis of the macrophytes was carried out separately for each species before starting of the experiments and it was determined by drying a known quantity of macrophytes in air for three to four days and then in a hot-air oven at 105˚C till attaining a constant weight. The difference in weight of the samples represented the moisture content, which was calculated using the following formula :

$$\% \text{ Moisture} = \frac{\text{Fresh weight} - \text{Dry weight}}{\text{Fresh weight}} \times 100$$

Calcium content analysis from water and plant samples

Calcium content analysis from water samples were collected and filtered by using Whatman No. 1 filter paper and stored in polypropylene bottles. Filtration was done to get rid of any suspended solids which could chock the nebulizer of flame photometer. (Elico, India) and results were expressed in mg L^{-1} after multiplying with dilution factor.

Calcium content analysis from plant sample

The replicates of dried powdered plant samples were digested by using open digestion method on hot plate. In 100 ml conical flask 0.5 g of sample was transferred and to it 10 ml mixture of (4:1 ml) concentrated nitric acid and hydrogen peroxide acid was added and kept on hot plate at 100˚C till colorless solution obtained. Finally, sample subjected to Calcium analysis by using flame photometer (Elico, India) at wave length 422.7 nm. The results were expressed in mg L^{-1} on dry weight basis.

Water quality parameters

The water quality parameters (temperature, pH, dissolved oxygen, free carbon dioxide, ammonia-nitrogen, nitrate-nitrogen, available phosphorus, total alkalinity, total hardness and potassium were estimated on 7 days interval from each aquarium tank by following the standard procedures of APHA (2017).

Statistical analysis

For all the above experiments, the data were analyzed by using SPSS 16.0 software. One-way ANOVA were carried out for each experiment to find out the significance difference between treatments with selected macrophytes. All data were presented as mean ± SE and statistical significance was determined at $p<0.05$.

RESULTS

The Calcium uptake was significantly affected by all macrophytes. The level of Calcium uptake was higher (<0.05) by *E. crassipes* in case of 200 mg L^{-1} effective concentration on second day compare to control and other treatment group. Similarly, there was significant uptake of Calcium were observed by all macrophytes treatment group at 800 mg L^{-1} effective concentration on 6th day, but the significantly higher uptake of Calcium was observed in case of *E. crassipes* treated group. On the fourth day sampling the Calcium uptake was significantly higher in all macrophyte treated group as compared to control. Higher percentage uptake of Calcium observed by *E. crassipes* (5.88% and 6.88%) at 800 mg/l and 400 mg/l treated groups (Figs. 1–3).

Changes in water quality parameters in the different treatment after one month of the time period given in Tables 2–3. The total alkalinity was found to be varied significantly among the treatments ($p<0.05$). The higher reduction in total alkalinity was 43.43% in P_2R_4, 34.65% in P_1R_2 compare to control 5.90% in P_0R_0. There was significant decrease in total hardness. The reduction in total hardness was 22.56% in control, 47.10% in P_1R_4 and 48.15% in P_2R_4. The dissolve oxygen level increased significantly among the treatment group. The increase in DO was observed 13.33% in P_0R_2, 16.67% in P_1R_3 and 38.10% in P_2R_4. Free carbon dioxide level was observed vary significantly among the treatment group. Tank with *S. molesta* and *E. crassipes* treatment group reduced 100% CO_2 at all concentration compare to control. The pH value was also varied from 7-7.4 in control tank, to 7-8.6 in treatment tanks with *S. molesta* and *E. crassipes.* The ammonia level was significant decrease 86.36% in P_2R_4, 71.11% in P_1R_4 compare to control 31.71% in P_0R_2. Similarly, the higher reduction in nitrate-N was 91.27% in P_2R_4, 82.26% in P_1R_3 compare to control 7.87%. Similarly, the phosphorus level was also decreased significantly 12.07% in control, 57.41% in P_1R_4 and 83.33 % in P_2R_4. The higher reduction in potassium was observed significantly 79.63% in P_2R_4, 57.41% in P_1R_4 compare to control 10.53% in P_0R_2 (Table 3).

DISCUSSION

Now a day's contamination of aquatic habit by heavy metal is one of the major serious problems. Phytoremediation is a process by which using aquatic plant for the uptake and absorption or detoxify of this metal or pollutant. One of the major issues for managing water resources for food security and environmental health is a global challenge. The control of nutrient pollution sources is widely understood to be an essential component to manage this pollution is a floating aquatic plant. In this experiment some of the macrophyte use for the detoxify the Calcium in aquatic environment. The present study the Calcium level was significantly decreased were obtained within this period by *E. crassipes* i.e., on 4th (5.06%) and 6th day (5.37%) of experiment. Al-Homaidan *et al.* (2014) reported that Cu biosorption was found to be at a maximum (90.6%), within short periods of contact time i.e., 90 min., which was decreases with increasing biomass and time period. Since,

Table 2. Changes in water quality parameters the different treatment after one month of the time period. Abbreviation : TA-Total alkalinity, TH-Total hardness, DO-Dissolve oxygen.

Treatments/ Parameters	TA (mg/L) Initial	Final	% reduction	TH (mg/L) Initial	Final	% reduction	Tap water + treatment DO (mg/L) Initial
P_0R_0	166	156.21	5.90	99	84.33	14.82	3
P_0R_1	166.66	162	2.80	98.66	87	11.78	3
P_0R_2	166.11	157.33	5.29	101	82	19.19	3
P_0R_3	167	158	5.39	105.33	90	15.48	3
P_0R_4	165.33	156.33	5.44	107.33	85	22.56	3
			Salvinia sp. + treatment				
P_1R_0	166.66	125.33	24.80	98.33	76	22.56	4.1
P_1R_1	164.66	114	30.77	98	73	25.25	4
P_1R_2	165.26	108	34.65	101.33	69.33	32.32	4.3
P_1R_3	166	111.33	32.93	106.33	66.66	40.07	4.2
P_1R_4	166.12	109.33	34.19	107.63	61	47.10	4.2
			Eichhornia sp. + treatment				
P_2R_0	166.66	121.33	27.20	99.02	73.33	25.95	4.2
P_2R_1	167	97	41.92	97.98	69	29.27	4.1
P_2R_2	166.21	104	37.43	102.33	65	37.71	4.3
P_2R_3	165.33	103.33	37.50	105.73	68.66	37.44	4
P_2R_4	166.16	94	43.43	106.33	58.66	48.15	4.2

Table 2. Continued.

Treatments/ Parameters	Tap water + treatment DO (mg/L) Final	% increase	CO_2 (mg/L) Initial	Final	% reduction	pH Initial	Final	% increase
P_0R_0	3.3	10.00	3.3	2.6	21.21	7	7.2	2.86
P_0R_1	3.3	10.00	3.1	2.6	16.13	7.1	7.2	1.41
P_0R_2	3.4	13.33	3.4	2.6	23.53	7.2	7.3	1.39
P_0R_3	3.3	10.00	3.6	2.6	27.78	7.2	7.3	1.39
P_0R_4	3.3	10.00	3.6	2.6	27.78	7.3	7.4	1.37
				Salvinia sp. + treatment				
P_1R_0	4.2	2.44	3.3	2.6	21.21	7	7.2	2.86
P_1R_1	4.4	10.00	3.6	0	100.00	7.1	7.2	1.41
P_1R_2	5	16.28	2.6	0	100.00	7.2	7.4	2.78
P_1R_3	4.9	16.67	2.6	0	100.00	7.3	8.1	10.96
P_1R_4	4.7	11.90	2.6	0	100.00	7.4	8.2	10.81
				Eichhornia sp. + treatment				
P_2R_0	4.9	16.67	3.3	2.6	21.21	7	7.2	2.86
P_2R_1	5.6	36.59	2.6	0	100.00	7.1	7.2	1.41
P_2R_2	5.5	27.91	2.6	0	100.00	7.2	7.4	2.78
P_2R_3	5.2	30.00	2.6	0	100.00	7.3	8.1	10.96
P_2R_4	5.8	38.10	2.6	0	100.00	7.4	8.6	16.22

Table 3. Changes in water quality parameters in the different treatment after one month of the time period. Abbreviation: AP-Available Phosphate.

Treatments/ Parameters	Ammonia- N (mg/L) Initial	final	% reduction	Nitrate-N (mg/L) Initial	Final	% reduction	Tap water + treatment AP (mg/L) Initial	Final
P_0R_0	0.043	0.033	23.26	0.128	0.121	5.47	0.59	0.52
P_0R_1	0.042	0.031	26.19	0.125	0.118	5.60	0.57	0.53
P_0R_2	0.041	0.028	31.71	0.127	0.119	6.30	0.58	0.51
P_0R_3	0.044	0.032	27.27	0.127	0.117	7.87	0.57	0.51
P_0R_4	0.042	0.029	30.95	0.126	0.117	7.14	0.56	0.52
Salvinia sp. + treatment								
P_1R_0	0.041	0.023	43.90	0.127	0.043	66.14	0.54	0.45
P_1R_1	0.044	0.019	56.82	0.126	0.024	80.95	0.55	0.18
P_1R_2	0.044	0.021	52.27	0.129	0.026	79.84	0.53	0.12
P_1R_3	0.046	0.017	63.04	0.124	0.022	82.26	0.57	0.16
P_1R_4	0.045	0.013	71.11	0.126	0.025	80.16	0.53	0.17
Eichhornia sp. + treatment								
P_2R_0	0.042	0.021	50.00	0.127	0.041	67.72	0.55	0.42
P_2R_1	0.043	0.012	72.09	0.123	0.012	90.24	0.52	0.11
P_2R_2	0.041	0.008	80.49	0.129	0.015	88.37	0.55	0.11
P_2R_3	0.045	0.015	66.67	0.125	0.012	90.40	0.57	0.12
P_2R_4	0.044	0.006	86.36	0.126	0.011	91.27	0.54	0.09

Table 3. Continued.

Treatments/ Parameters	Tap water+treatment AP (mg/L) % reduction	Potassium (mg/L) Initial	Final	% reduction	Temperature (˚C) Initial	Final	% increase
P_0R_0	11.86	5.8	5.2	10.34	23.6	25.2	6.78
P_0R_1	7.02	5.9	5.3	10.17	23.3	25.1	7.73
P_0R_2	12.07	5.7	5.1	10.53	23.7	25.4	7.17
P_0R_3	10.53	5.7	5.3	7.02	23.4	25.3	8.12
P_0R_4	7.14	5.6	5.1	8.93	23.6	25.1	6.36
Salvinia sp. + treatment							
P_1R_0	16.67	5.5	3.9	29.09	23.5	25.1	6.81
P_1R_1	67.27	5.6	2.5	55.36	23.7	25.3	6.75
P_1R_2	77.36	5.8	2.8	51.72	23.8	25.2	5.88
P_1R_3	71.93	5.6	2.5	55.36	23.7	25.4	7.17
P_1R_4	67.92	5.4	2.3	57.41	23.5	25.4	8.09
Eichhornia sp. + treatment							
P_2R_0	23.64	5.9	3.8	35.59	23.7	25.3	6.75
P_2R_1	78.85	5.2	1.5	71.15	23.5	25.1	6.81
P_2R_2	80.00	5.6	1.3	76.79	23.8	25.6	7.56
P_2R_3	78.95	5.5	1.8	67.27	23.5	25.3	7.66
P_2R_4	83.33	5.4	1.1	79.63	23.6	25.3	7.20

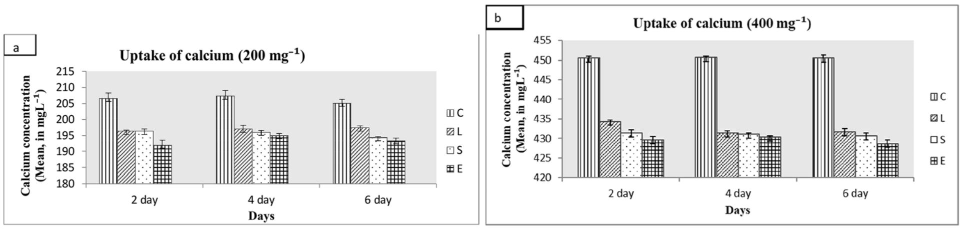

Fig. 1. a and b showing uptake of calcium from 200 and 400 mg L^{-1} respectively by *L. minor* (L), *S. molesta* (S) and *E. crassipes* (E), (Mean ± SE).

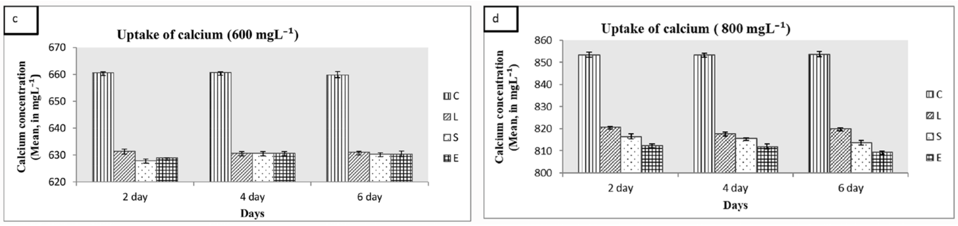

Fig. 2. c and d showing uptake of calcium from 600 and 800 mg L^{-1} respectively by *L. minor* (L), *S. molesta* (S) and *E. crassipes* (E), (Mean ± SE).

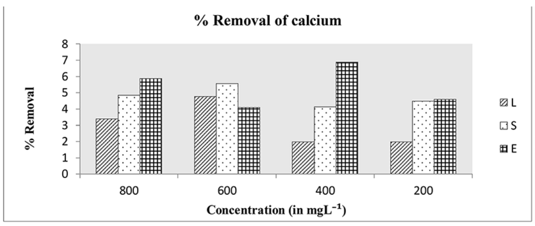

Fig. 3. Percentage uptake of calcium from different treatments.

the process of biosorption became slow during the later stage because during the early stage of Cu biosorption a huge number of unmanned surface sites were available for biosorption compared to that in the later stages, when the rest of the site surface vacancies were probably unapproachable or deeper in the cell membranes. The 98.5%., 85.0%, 99.8%, 99.5% and 95.0% removal of Calcium (Ca), Copper (Cu), Chromium (Cr), Cadmium (Cd) and Lead (Pb) respectively was recorded by Showqi *et al.* (2017) in duckweed, *Lemna minor* L. from waste water within 15 days of outdoor experiment and subsequently these elements exhibited an increasing concentration in the plant body. *Pistia stratiotes* was capable to eliminate the metals such as cadmium (Cd), Iron (Fe) and Zinc (Zn), about 76%, 83%, 79% respectively within 15 days of exposure of wastewater (Tan *et al.* 2023). At an effective concentration of 800 mg L^{-1}, the higher percentage Calcium removal was obtained by *E. crassipes* (5.02%) followed by *S. molesta* (4.55%) and *L. minor* (4.05%) on 2nd day. Similar decreasing trend of percentage Calcium removal with increasing experiment days shown by these macrophytes i.e., *E. crassipes*, *S. molesta* and *L. minor*, 5.06%, 4.63% and 4.40% on 4th day and 5.37%, 4.87% and 4.13% on 6th day respectively. The phytoremediation potential of three aquatic macrophytes, water hyacinth (*Eichhornia crassipes*), water ferns (*Salvinia minima*), duckweeds (*Lemna minor, Spirodela intermedia*), water lettuce (*Pistia stratoites*), were reported by several researchers for removal of heavy metals such as Fe, Zn, Cu, Cr, and Cd from the contaminated environment (Gunathilakae *et al.* 2018, Iha *et al.* 2015, da-Silva *et al.* 2017, Daud *et al.* 2018, Abbas *et al.* 2019).

There was significant decrease in total alkalinity and total hardness in treatment tanks with *S. molesta* (from 166.66 to 108 mg L^{-1}) and *E. crassipes* (166.66 to 94 mg L^{-1}) during the experimental period. The reduction was due to utilization of Calcium and partial utilization of bicarbonate ions by the plants for their body formation and development. There was significant decrease in CO_2 concentration i.e., (from 4 to 0 mg L^{-1}) in presence of *S. molesta* and *E. crassipes* and it was due to higher rate of CO_2 consumption in photosynthesis. There was significant decrease in available phosphorus (0.31 to 0.05 mg L^{-1}), ammonia-N (0.057 to 0.006 mg L^{-1}) and nitrate -N (0.75 to 0.009 mg L^{-1}) in treatment tanks with *E. crassipes* during the experimental period. The cause of reduction in available phosphorus was utilization by the plants as a nutrient. Shah *et al.* (2014) reported that *Eichhornia crassipes* had higher nutrient removal efficiency (40.34% N reduction from 2.42 mg/L to 1.45 mg/L) as compared to other aquatic macrophytes like, *Pistia stratiotes* L. (17.59% N reduction from 2.37 mg/L to 1.95 mg/L) and *Myriophyllum aquaticum* Verdc) (14.45% N reduction from 2.42 mg/L to 2.09 mg/L). *Eichhornia crassipes* had better nutrient removal potential than *Salvinia natans* for NO_3^- , Total Nitrogen and PO_4^{3-} (Kumari and Tripathi 2014). Loan *et al.* (2014) also suggested that the higher bio-remediation capability of *Eichhornia crassipes* to remove ammonia-N and PO_4^{3-} compared to *Ipomoea aquatica*. Similar, findings reported by Qin *et al.* (2016) reported that *Eichhornia crassipes* showed higher nitrogen removal efficiency than *Pistia stratiotes* L. Alligator weed showed 100% ammonia removal and 85% phosphate removal efficiency when treated with industrial wastewater, while pennywort capable to remove only 28% of ammonia from same industrial wastewater (Raza *et al.* 2023). There was decrease in ammonia-N and nitrate-N due to uptake by plants (*E. crassipes* and *S. molesta*). There was significant decrease in potassium level in treatment tanks with plants. The reduction in potassium can be attributed to its uptake and adsorption by plants (*S. molesta* and *E. crassipes*) for its growth and other physiological functions like production of ATP, stomatal activity (closing and opening of stomata), and enzyme activation. When all local weeds viz., water lettuce, alligator weed, pennywort and duckweed were combinedly used as phytoremediation agents for the removal of pollutants, resulted in 51% removal of sulphate from household wastewater, and water lettuce resulted in 79% removal of potassium from industrial wastewater (Raza *et al.* 2023). Similarly, Saidin *et al.* (2014) reported 90.05% reduction in potassium level of domestic wastewater by using caladium (*Colocasia esculenta*).

There was significant increase in DO level in treatment tanks with *S. molesta* (4.1 to 4.7 mgL^{-1}) and *E. crassipes* (4.2 to 5.8) during the experiment period. All the wastewater samples collected from Sukinda chromite mines area of Orissa (India) were initially devoid of dissolved oxygen (DO), after phytoremediation experiment by using water hyacinth, there was increase in the DO level as indicated by reduction of 50% biochemical oxygen demand (BOD) and 34% chemical oxygen demand (COD) in the wastewater (Saha *et al.* 2017). The reduction in BOD and COD can result in an increase in DO concentration of wastewater. This might be due to the occurrence of plants in wastewater and their high photosynthetic activity resulted in decline of free CO_2 level in wastewater. In turns, this leads to the creating aerobic conditions in wastewater which favor the aerobic bacterial activity to reduce the BOD and COD. Ravi *et al.* (2017) reported that there was significant increase in DO level from 5.8-6.8 mg/l of first cycle at salinity 7.5 ppt, of an integrated system incorporating *E. crassipes* for the phytoremediation of Calcium from inland saline water. The pH value had increased from 7 to 8.2 and 7 to 8.6 in treatment tank with *S. molesta* and *E. crassipes* respectively compare to the control tank (7 to 7.4). Hounkpe *et al.* (2022) observed that pH was increased from 5 to 7.1 during the treatment, when water hyacinth was used as phytoremediator to treat domestic wastewater pond. Their findings suggested that the optimum influent pH for the growth of plants and the removal of nutrients and organic matters in water hyacinth ponds is within pH 6.4 to pH 7.1. The water temperature was observed in the range 23.3 to 25.6ºC. Ziegler *et al.* (2023) reported that the optimum temperatures for the normal growth of many duckweed species and clones were found to vary between 20ºC and 30ºC. Under natural environments, the optimal temperature range for growth of water hyacinth (*E. crassipes*) is between 25°C and 30°C, and growth is insignificant at temperatures below 10 °C or above 40°C (Neves de Lima *et al.* 2022).

CONCLUSION

The present study results suggested that *E. cras-*

sipes was better than *S. molesta* and *L. minor* in terms of Calcium removal efficiency from aquatic environment. This experiment also revealed that all macrophytes are very active at lower concentration compare to higher concentration. The water quality parameter was significantly improving viz., TH, TA, CO_2, available phosphorus, ammonium-N, nitrate-N, potassium, pH and DO in different treatment treated with *E. crassipes, L. minor* and *S. molesta*. The finding of this study will provide the baseline information for treatment of inland saline water which can be further useful for various agricultural as well as aquaculture purposes for fish, shrimp and another aquatic organism.

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