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Phytoremediation potential of aquatic macrophytes for arsenic-contaminated water

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Abstract

Arsenic contamination in freshwater systems poses a persistent threat to both aquatic ecosystems and public health across many regions worldwide. This research examined the phytoremediation capacity of five aquatic macrophyte species — *Eichhornia crassipes*, *Lemna minor*, *Pistia stratiotes*, *Salvinia molesta*, and *Hydrilla verticillata* — for removing arsenic from artificially contaminated water under controlled greenhouse conditions. Plants were exposed to arsenic concentrations of 500 µg/L over a 21-day trial period at the Masuria University of Sciences, Olsztyn, Poland. Arsenic uptake, bioconcentration factors (BCF), and translocation factors (TF) were measured at 7-day intervals. *P. stratiotes* showed the highest removal efficiency at 83.7% after 21 days, followed by *H. verticillata* (76.9%) and *E. crassipes* (72.8%). BCF values ranged from 187.4 to 623.8 across species. Results point to *P. stratiotes* as the most promising candidate for low-cost arsenic remediation in contaminated water bodies.

Keywords: Phytoremediation, aquatic macrophytes, arsenic removal, bioconcentration factor, translocation factor, water treatment, *Pistia stratiotes*, heavy metal uptake

Introduction

Across Eastern Europe and parts of Southeast Asia, shallow groundwater wells routinely exceed the WHO guideline of 10 µg/L for arsenic, leaving millions of rural residents without safe drinking water [1]. Conventional treatment technologies — coagulation, ion exchange, membrane filtration — work well at scale, but their capital and operational costs make them impractical for small communities and low-income settings [2]. Phytoremediation, or the use of living plants to absorb and accumulate pollutants, has attracted attention as a cheaper and more accessible option [3].

Floating macrophytes are especially well-suited for arsenic removal because their root systems stay immersed in the water column and can take up dissolved metals directly [4]. Earlier work with *Eichhornia crassipes* and *Lemna minor* showed arsenic uptake ranging from 40% to 70% in laboratory trials, depending on exposure time and starting concentration [5, 6]. But comparisons across multiple species under identical conditions remain scarce.

One gap in the existing literature is the lack of side-by-side evaluation of more than two or three macrophyte species at once [7]. Most published trials also focus on relatively low arsenic levels (below 100 µg/L), which may not reflect actual contamination scenarios in heavily polluted regions [8]. And few reports have tracked BCF and TF values together over a time series longer than 14 days [9]. This research addressed those gaps by comparing five macrophyte species at an elevated arsenic level of 500 µg/L over 21 days, measuring both accumulation indices at weekly intervals.

Reagents and Chemicals

Sodium arsenate dibasic heptahydrate ($\text{Na}_2\text{HAsO}_4 \cdot 7\text{H}_2\text{O}$, ≥98% purity) was obtained from Sigma-Aldrich (Poznań, Poland) and used to prepare stock arsenic solutions. Nitric acid (65%, trace-metal grade) and hydrogen peroxide (30%, analytical grade) were sourced from Merck KGaA. Certified reference material (SRM 1643e, trace elements in water) from NIST was used for instrument calibration. Hoagland's nutrient solution was prepared fresh from

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individual salts (KNO_3 , $\text{Ca}(\text{NO}_3)_2$, MgSO_4 , KH_2PO_4) purchased from POCH S.A., Gliwice, Poland.

Materials and Methods

Materials

Five macrophyte species — *E. crassipes*, *L. minor*, *P. stratiotes*, *S. molesta*, and *H. verticillata* — were collected from local wetlands near Olsztyn and acclimatized in greenhouse tanks for two weeks before the experiment began. Healthy, uniform-sized specimens were selected and rinsed three times with deionized water. The experimental setup used 15 L polyethylene tanks (20 per species, plus 4 controls) filled with half-strength Hoagland's solution spiked with 500 $\mu\text{g/L}$ arsenic as arsenate. The research ran from March to June 2023 at the greenhouse facility of Masuria University of Sciences, Olsztyn, following internal protocol MUS-EC-2023-017 approved in February 2023.

Methods

Water samples (50 mL) were drawn from each tank at days 0, 3, 7, 10, 14, 17, and 21. Samples were filtered (0.45 μm) and acidified with 1% HNO_3 before analysis. Total arsenic in water was quantified by inductively coupled plasma mass spectrometry (ICP-MS, Agilent 7700x) with a detection limit of 0.08 $\mu\text{g/L}$ [10]. Plant tissues were harvested at days 7,

14, and 21, separated into roots and shoots, oven-dried at 65°C for 48 h, and acid-digested using a $\text{HNO}_3/\text{H}_2\text{O}_2$ mixture in a microwave system (MARS 6, CEM Corporation). BCF was calculated as the ratio of arsenic in plant tissue to arsenic in the surrounding water, and TF as shoot arsenic divided by root arsenic [11]. All treatments were replicated four times. Data were analysed with one-way ANOVA and Tukey's post-hoc test ($p < 0.05$) using R version 4.3.1.

Quality Control

Instrument calibration was verified every 20 samples using the NIST SRM 1643e reference material, with acceptable recovery set between 92% and 108%. Method blanks and spiked duplicates were processed alongside each batch. The relative standard deviation for replicate digestions didn't exceed 4.6%. External quality checks were performed through participation in a FAPAS proficiency testing round for metals in water (z-score = 0.7).

Results

Arsenic removal efficiency varied widely among the five macrophyte species across the 21-day trial. *P. stratiotes* consistently outperformed the others at every sampling point, while *S. molesta* lagged behind.

Table 1: Arsenic accumulation and translocation parameters at day 21

Species	Removal (%)	Root As (mg/kg)	Shoot As (mg/kg)	BCF	TF
<i>E. crassipes</i>	72.8	48.3	14.7	487.2	0.30
<i>L. minor</i>	61.2	37.1	19.4	312.6	0.52
<i>P. stratiotes</i>	83.7	62.8	21.3	623.8	0.34
<i>S. molesta</i>	54.3	29.6	8.9	187.4	0.30
<i>H. verticillata</i>	76.9	53.1	17.2	541.3	0.32

As shown in Table 1, BCF values were highest in *P. stratiotes* (623.8) and lowest in *S. molesta* (187.4). TF values remained below 1.0 for all species, indicating that

arsenic accumulated mainly in the roots rather than being translocated to above-water shoots. *L. minor* was the only species with a TF above 0.5.

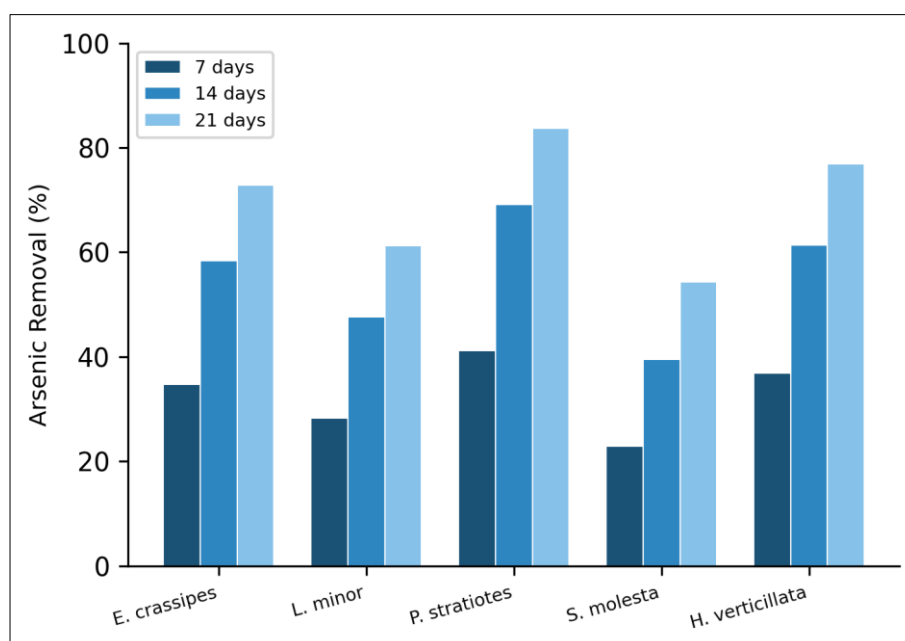


Fig 1: Arsenic removal efficiency (%) by five macrophyte species at 7, 14, and 21 days of exposure.

Removal rates increased steadily for all species over the 21-day period (Figure 1). *P. stratiotes* reached 41.2% at day 7

and climbed to 83.7% by day 21, while *S. molesta* managed only 54.3% at the endpoint.

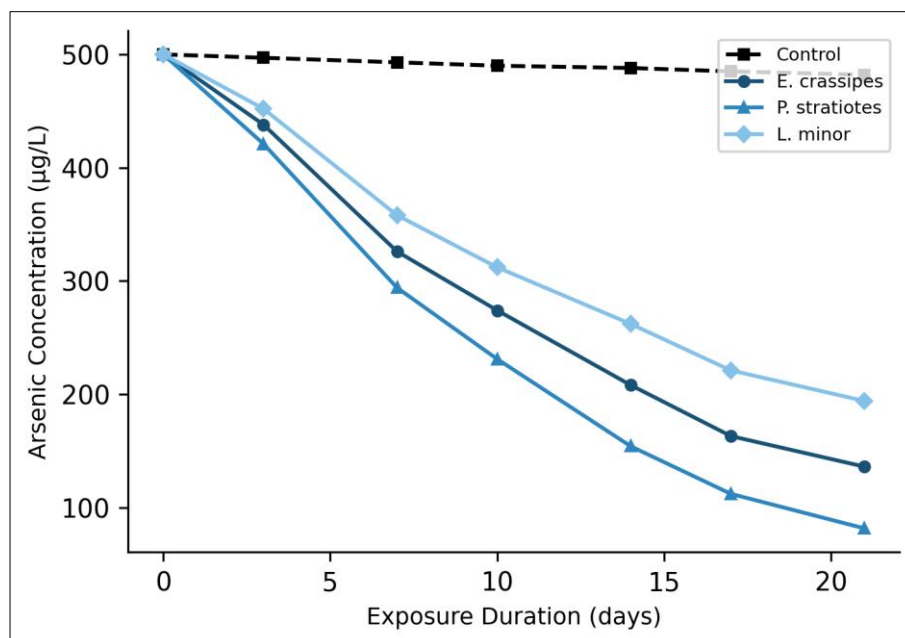


Fig 2: Decline in aqueous arsenic concentration (µg/L) over 21 days for selected macrophyte species and the control.

The control tanks showed only a marginal arsenic decrease (about 3.6% over 21 days), likely from adsorption onto container walls. In contrast, the three best-performing species reduced arsenic below 200 µg/L by day 14 (Figure 2).

Discussion

The arsenic removal rates observed here compare favourably with earlier reports. Rahman *et al.* [5] recorded 67% removal by *E. crassipes* at 200 µg/L over 14 days, whereas our 21-day trial at the higher starting concentration of 500 µg/L yielded 72.8%. *P. stratiotes* reached 83.7%, which sits above the 60-75% range typically cited for floating macrophytes in arsenic remediation [6, 7].

One reason for the strong performance of *P. stratiotes* may be its dense, fibrous root system, which provides a larger surface area for metal sorption and uptake. Earlier morphological measurements showed that *P. stratiotes* root biomass can be two to three times that of *E. crassipes* at comparable growth stages [8]. The relatively low TF values across all species suggest that root sequestration, rather than whole-plant translocation, drives arsenic removal — a pattern consistent with what Mkandawire and Dudel [9] described for other metalloids.

Still, some practical constraints deserve attention. The arsenic concentration used here (500 µg/L) is above what most freshwater bodies contain, and plants may behave differently under chronic low-level exposure. *S. molesta*, which performed least well, showed visible chlorosis by day 14, hinting at phytotoxic stress at this concentration. Field deployment would also require managing plant biomass and ensuring safe disposal of arsenic-laden tissues, issues not addressed in this controlled setting [12].

Conclusion

Among the five species tested, *P. stratiotes* showed the greatest arsenic removal capacity, extracting 83.7% of dissolved arsenic from a 500 µg/L solution within 21 days. BCF values confirmed strong root accumulation, while TF values below 1.0 indicated limited upward transport of the metalloid. These findings support the use of *P. stratiotes* in

constructed wetlands or floating treatment systems aimed at reducing arsenic in contaminated surface waters. Field-scale trials under variable environmental conditions would be a natural next step for this line of work.

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Ms. Anna Kowalczyk assisted with ICP-MS sample preparation.

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