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Concentration of chemical elements in dry mass of *Pontederia crassipes* Mart. for use as organic fertilizer in small-scale crops

Concentración de elementos químicos en masa seca de *Pontederia crassipes* Mart. para uso como abono orgánico en cultivos de pequeñas extensiones

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RESUMEN

Antecedentes: la creciente demanda y coste de producción de fertilizantes inorgánicos motivan a los investigadores a explorar nuevos medios para la obtención de abonos orgánicos. *Pontederia crassipes* Mart., es una planta acuática invasora que crece en una laguna de agua dulce (La Turbina), en Ciego de Ávila, Cuba. Es extraída del agua y depositada en las orillas de la laguna, afectando el valor estético del sitio. **Objetivo:** determinar la concentración de elementos químicos en la masa seca de *P. crassipes* (en su condición de crecimiento flotante y emergente), para recomendar su posible uso como abono orgánico o sustrato mezclado, en cultivos de pequeñas extensiones. **Método:** para el análisis de la mayoría de los elementos químicos, tanto en el agua de la laguna, como en la masa seca de *P. crassipes*, se empleó espectrometría de emisión óptica de plasma acoplado inductivamente. **Resultados:** el agua de la laguna se caracterizó por alta concentración de Ca. En la masa seca de *P. crassipes* (flotante y emergente) tuvo mayor concentración (mg g^{-1}) el Ca, N y K, seguidos del Na y Al. Los metales pesados tuvieron concentraciones inferiores a los límites máximos permisibles para abonos orgánicos y sustratos de cultivos. Los ocho elementos químicos cuantificados en el agua de la laguna (Ca, Cu, K, Mg, Na, P, S y Zn) mostraron bioconcentración en *P. crassipes* (flotante). Siete elementos químicos mostraron traslocación en *P. crassipes* (B, Ca, K, N, Na y Sr). **Conclusiones:** La masa seca de *P. crassipes* puede utilizarse como fertilizante orgánico o como sustrato mezclado para cultivos de pequeñas extensiones. *P. crassipes* (flotante) puede fitoestabilizar y fitoextraer elementos químicos en la laguna artificial de agua dulce La Turbina.

Palabras clave: Cuba, elementos químicos, lagunas, especie invasora, Liliopsida.

ABSTRACT

Background: the increasing demand and production costs of inorganic fertilizers motivate researchers to explore new ways to obtain organic fertilizers. *Pontederia crassipes* Mart., is an invasive aquatic plant that grows in a freshwater lagoon (La Turbina), in Ciego de Ávila, Cuba. It is extracted from the water and deposited on the shores of the lagoon, affecting the aesthetic value of the site. **Objective:** to determine the concentration of chemical elements in the dry mass of *P. crassipes* (in its floating and emerging growth condition), to recommend its possible use as organic fertilizer or mixed substrate in small area crops. **Method:** for the analysis of most of the chemical elements, both in the lagoon water and in the dry mass of *P. crassipes*, inductively coupled plasma optical emission spectrometry was used. **Results:** the water of a lagoon was characterized by high concentration of Ca. In the dry mass of *P. crassipes* (floating and emergent), Ca, N, and K had the highest concentrations (mg g^{-1}), followed by Na and Al. Heavy metals had concentrations below the maximum permissible limits for organic fertilizers and substratum of the crop. The eight chemical elements quantified in the lagoon water (Ca, Cu, K, Mg, Na, P, S, and Zn) showed bioconcentration in *P. crassipes* (floating). Seven chemical elements showed translocation in *P. crassipes* (B, Ca, K, N, Na, and Sr). **Conclusions:** The dry mass of *P. crassipes* can be used as organic fertilizer or as a mixed substrate for small-scale crops. Floating *P. crassipes* can phytostabilize and phytoextract chemical elements in the La Turbina artificial freshwater lagoon.

Keywords: Cuba, chemical elements, invasive species, lagoons, Liliopsida.

INTRODUCTION

Globally, the demand and the costs of producing inorganic fertilizers are rising (Tang *et al*., 2022). This demand increase motivates the search for alternatives to obtain organic fertilizers at lower costs and friendly to the environment. A possible solution may be to include organic fertilizers produced from the biomass of invasive aquatic plants (Begum *et al*., 2022; Rattanawong *et al*., 2022), but the feasibility of this particular approach is still under investigation for several species (Dissanayaka *et al*., 2023). This is largely because the use of biomass from any plant species for producing organic fertilizers depends on growth rate, local regulations, the availability of technology for biomass utilization, and most importantly, the chemical composition of the plant tissues used.

Pontederia crassipes Mart. is an aquatic plant native to the Amazon (South America), but its proliferation has spread worldwide (Ito *et al*., 2020). Recognized as invasive, harmful, and transformative for Cuba (Oviedo & González-Oliva, 2015) and in many other parts of the world (Lowe *et al*., 2004). Despite its invasive behavior, then it is considered among the most important aquatic plant species in the world, possibly because it has the potential for use in agriculture (Ramírez *et al*., 2021; Begum *et al*., 2022; Hernández-Fernández *et al*., 2024a). Despite this, this species is a phytoaccumulator (Muthusaravanan *et al*., 2020) and phytostabilizer, specifically, for cadmium (Cd) and zinc (Zn) (Sricoth *et al*., 2018), heavy metals that have maximum permissible limits in the organic fertilizers and crop substrates, according to (Reglamento (UE), 2019) and the criteria of Muñiz-Ugarte (2022).

Pontederia crassipes, found in the artificial freshwater lagoon La Turbina in Ciego de Ávila, Cuba, exhibits two growth forms: as a floating macrophyte (not attached to the substrate) and as an emerging macrophyte (attached to the substrate) (Valero-Jorge *et al*., 2025). The distribution of this plant in the lagoon's recreational nautical activities, leading to its extraction and either deposition on the shores or transport to landfills as its final destination. Physicochemical and microbiological studies indicate that the water of La Turbina is highly contaminated due to anthropogenic pressure from wastewater discharge (Hernández-Fernández *et al*., 2024b). However, the concentrations of other chemical elements in the lagoon water, particularly heavy metals, remain unknown.

Taking into account the above, this work aims to determine the concentration of chemical elements in the dry mass of the invasive aquatic plant *P. crassipes* (in its floating and emerging growth condition) and recommend its possible use as organic fertilizer or mixed substrate in small-area crops.

MATERIAL AND METHODS

Study area. The study was carried out in the municipality of Ciego de Ávila, province of the same name, which is located in the central region of Cuba, between the provinces of Sancti Spíritus and Camagüey.

In January 2022, 90 *P. crassipes* (floating) and 90 *P. crassipes* (emergent) plants were collected from the La Turbina artificial freshwater lagoon (21°50'51"N-78°45'43"W). When the water volume of the lagoon is high, *P. crassipes* floats thanks to the globose petioles that fill with air inside, and is a floating macrophyte. When the water volume of the lagoon is low, the petiole of *P. crassipes* elongates and the roots adhere to the substrate, becoming an emerging macrophyte (Niño-Sulkowska & Lot, 1983). In the La Turbina artificial freshwater lagoon, the water volume practically does not fluctuate. There are shallow areas towards the shores where *P. crassipes* (emergent) predominates, and deeper areas towards the center of the lagoon where *P. crassipes* (floating) predominates. Wind direction and human intervention determine the spatiotemporal distribution of *P. crassipes* (Valero-Jorge *et al*., 2025).

Determination of the concentration of chemical elements in the La Turbina freshwater lagoon. Five water samples were taken (1 L at a depth), where *P. crassipes* predominates (Hernández-Fernández *et al*., 2023). To determine the concentration (mg ml^{-1}) of 25 chemical elements, including aluminum (Al), boron (B), barium (Ba), beryllium (Be), bismuth (Bi), calcium (Ca), cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), iron (Fe), gallium (Ga), potassium (K), lithium (Li), magnesium (Mg), manganese (Mn), sodium (Na), nickel (Ni), phosphorus (P), lead (Pb), sulfur (S), selenium (Se), strontium (Sr), thallium (Tl), and zinc (Zn), 2 ml of each sample was taken and 1.5 ml of nitric acid was added. After 10 minutes, 11.5 ml of ultrapure water was added (resulting in a total of 15 ml). The solutions were then filtered (0.45 µm pore size) and stored in vials at 4 °C before final analysis. Samples were analyzed using Inductively Coupled Plasma-Optical Emission Spectrometry (ICP-OES) (iCAP 6000 ICP Spectrometer, Thermo Fisher Scientific, Waltham, MA, USA).

Morphological characteristics of *P. crassipes* (floating and emergent). The number of stolons was determined, and the number of leaves was counted for each main plant. Three middle-aged leaves were selected, and the length (cm) was measured from the base of the petiole to the apex. The width was measured across the beam, from edge to edge, down the center of the leaf. The longest root (cm) was measured. Measurements were taken with a ruler.

Determining the concentration of chemical elements in the leaves and roots of *P. crassipes* (both floating and emergent). Specimens of *P. crassipes* were washed with running water and then rinsed with distilled water before being placed in a drying oven set at 70 °C ± 1 °C for 48 hours. After drying, the samples (5 g) were ground to approximately 2 µm in size.

The concentration of 26 chemical elements (Al, B, Ba, Be, Bi, Ca, Cd, Co, Cr, Cu, Fe, Ga, K, Li, Mg, Mn, N (Nitrogen), Na, Ni, P, Pb, S, Se, Sr, Tl, Zn) was determined in dry mass (DW) samples on leaves and roots of *P. crassipes* (floating and emergent). For the plant material, the samples were analyzed three times (total = 9 samples).

Except for the N analysis, 100 mg of the ground powder was incinerated for 8 h in a muffle furnace at 480 °C. After cooling to room temperature, 1.5 ml of nitric acid 1:3 HNO_3 (HNO_3 super-quality Rotipuran® Supra 69 %, and ultra-pure water (v/v)) was added to the samples; after 10 min, 13.5 ml of ultrapure water was added. The solutions were then filtered (0.45 µm pore size) and stored in vials at 4 °C before final analysis. Samples were analyzed by inductively coupled plasma-optical emission spectrometry (ICP-OES) (iCAP 6000 ICP Spectrometer, Thermo Fisher Scientific, Waltham, MA, USA). Total Nitrogen (NT) in the plant samples was determined, by the salicylic acid-thiosulfate modification of the Kjeldahl method, which includs NO_3-N and NO_2-N (Dhaliwal *et al*., 2014).

The concentration (mg g^{-1}) of N, P, K, Ca, Mg, and S, was analyzed in a general way, taking into account that when using the DW of *P. crassipes* as a fertilizer or cultivation substrate. It is difficult to separate the leaves from the roots, as well as the specimens with floating growth from those with emergent growth.

Bioconcentration Factor (BCF) and Translocation Factor (TF). The Bio-concentration factor (BCF) shows the relationship between the accumulation of the chemical element in the plant's biomass and in the water (Ali *et al*., 2013; Yadav *et al*., 2018; Bello *et al*., 2018). The BCF of the studied plants (*P. crassipes* floating) was calculated using their DW as a base (equation 1):

$$BCF = \frac{C_{plant}}{C_{water}} \quad (1)$$

Where: C_{plant}: concentration of the chemical element in the plant (mg g^{-1}). C_{water}: concentration of the chemical element in the lagoon water (mg ml^{-1}).

The translocation factor (TF) is the quotient between the concentration of the metal in the aerial organs (leaves) and the root of the plant (Bello *et al*., 2018). The translocation factor indicates the efficiency of the plant in translocating the accumulated chemical elements from its roots to shoots (Ali *et al*., 2013). The translocation factor was determined in in floating and emergent samples (equation 2):

$$TF = \frac{C_{leaves}}{C_{root}} \quad (2)$$

Where: C_{leaves}: concentration of the chemical element in leaves (mg g^{-1}). C_{root}: concentration of the chemical element in the root (mg g^{-1}).

Statistical analysis. The chemical elements quantified in the leaves and roots of the *P. crassipes* plant (floating and emergent) were processed using the Statistical Package for Social Sciences (Version 21 for Windows, SPSS Inc.). The adjustments datat-testdistribution (Kolmogorov-Smirnov) and the homogeneity of variances (Levene) were checked. The different variables were evaluated using one-way parametric analysis of variance (ANOVA) tests. When differences were significant ($p \leq 0.05$) for the ANOVA test, the means of the treatments were analyzed using Tukey's significant difference procedure.

RESULTS

Chemical elements found in the La Turbina freshwater lagoons. Of the 25 chemical elements examined in La Turbina, only eight exhibited quantifiable concentrations. The order of these eight elements is as follows: Ca>Na>K>Mg>P> Cu = S>Zn (table 1).

Morphological characteristics of *P. crassipes* (floating and emergent). For all the morphological characters studied, except for the average number of stolons, *P. crassipes* (emergent) had a higher value than *P. crassipes* (floating) (table 2).

Determination of the concentration of chemical elements in leaves and roots of *P. crassipes* (floating and emergent). Of the 26 chemical elements studied in the leaves and roots of *P. crassipes*, 24 were quantified (beryllium (Be) and thallium (Tl) were not detected). Those with the highest concentrations were macronutrients Ca, N and K (fig. 1 A). Other elements with high concentrations were Al and Na. Theywere followed in concentration by the micronutrients Fe and Mn. (fig. 1 B). Heavy metals and other chemical elements were determined in lower concentrations (fig. 1 C).

For *P. crassipes* (floating), the order of the dominant elements was as follows: Ca>N>K>Na>Al>P>Mg>S in the leaves, and Ca> N>Al>-Na>K>S>Fe>P>Mg>Mn in the roots. In emergent plants, the order of the seven dominant elements was as follows: K>Ca>N>Na>P>Mg>S>Al in the leaves, and Ca>N>Na>K>Al>S>Fe>Mg>P>Mn in the roots.

The plants showed the following total concentrations of macronutrients: N: 19.49 ± 0.8 mg g^{-1}, K: 14.56 ± 1.20 mg g^{-1}, Ca: 24.15 ± 0.44 mg g^{-1}, P: 1.93 ± 0.06 mg g^{-1}, Mg: 1.75 ± 0.07 mg g^{-1} and S: 3.40 ± 0.35 mg g^{-1}.The total concentration of Pb: 0.005 ± 0.0004 mg g^{-1}, Cu: 0.034 ± 0.01 mg g^{-1}, Zn: 0.032 ± 0.01 mg g^{-1}, Cd: 0.00015 ± 0.00002 mg g^{-1} and Mn: 0.80 ± 0.04 mg g^{-1}.

Bioconcentration Factor (BCF) and Translocation Factor (TF). The eight elements that presented quantifiable concentrations in the water (Ca, Cu, K, Mg, Na, P, S and Zn) have a BCF greater than 1 in floating plants (table 3). Translocation was detected in seven chemical elements. The chemical elements that show translocation in (floating and emergent plants) were: B, Ca, Cu, K, N, Na and Sr. Na showed translocation only in *P. crassipes* floating form. Ca and Cu shows translocation only in *P. crassipes* emergent form (table 3).

DISCUSSION

The chemical elements with the highest concentrations in the La Turbina lagoon water are also among those found in the leaves and roots of *P. crassipes* (floating and emergent) (Ca, Na, K) (figs. 1 A and B). These elements exhibit a high bioconcentration in *P. crassipes* (floating) (table 3). These results indicate that, to accurately estimate the fraction of bioavailable metal in the aquatic environment, it is essential to determine it in the organisms inhabiting this ecosystem (Ehlers & Luthy, 2003). The plants reflect the prevailing environmental conditions in the aquatic ecosystem (Honmura, 2000).

According to Hernández-Fernández *et al*. (2024b), the water quality in the La Turbina freshwater lagoon is poor. It has a high concentration of organic matter linked to wastewater discharges from nearby homes and decay plants that end up at the bottom of the lagoon.

The morphological characteristics observed in *P. crassipes* reflect the environmental conditions the plants are exposed and the extent of their population in La Turbina lagoon, as described by Valero-Jorge *et al*. (2025). These criteria are supported by Niño-Sulkowska and Lot (1983) as well as Coetzee *et al*. (2017). Specifically, *P. crassipes* (emergent) did not reach the average leaf length indicated by Coetzee *et al*. (2017) (1 m), whereas the average leaf width did correspond to what these authors determined (<30 cm). There are no references to the morphological characteristics of this species in other regions of Cuba.

The Pb, Cu, Zn and Cd, are considered among the most dangerous heavy metals (Méndez *et al*., 2009; Muthusaravanan *et al*., 2018). Zn and Cu, together with Mn, are also considered within micronutrients since they are required elements, in small amounts, for specific functions of plants (Latimer, 2009).

The highest concentrations of Pb were determined in the roots of *P. crassipes* (floating) and *P. crassipes* (emergent), compared to those found in the leaves. This result aligns with findings by Maddock *et al*. (1988), Vesk & Allaway (1997), and Lima-Cazorla *et al*. (2005), who also detected higher concentrations of these elements in the roots of *P. crassipes*.

Table 1. Chemical elements quantified in the artificial freshwater lagoon La Turbina in Ciego de Ávila, Cuba (averages ± SE).

Chemical elements quantified	mg ml^{-1}
Ca	0.057 ± 0.00
Cu	0.001 ± 0.00
K	0.01 ± 0.00
Mg	0.004 ± 0.00
Na	0.054 ± 0.00
P	0.002 ± 0.00
S	0.001 ± 0.00
Zn	0.0006 ± 0.00

Table 2. Morphological characteristics of *Pontederia crassipes* (floating and emergent) in the artificial freshwater lagoon La Turbina in Ciego de Ávila, Cuba (averages ± SE).

Morphological characteristics	*P. crassipes* (floating)	*P. crassipes* (emergent),
Number of stolons per plant	1.9 ± 0.47	1.6 ± 0.46
Number of leaves	7.1 ± 0.91	9.2 ± 0.82
Length of the leaves	28.8 ± 4.90 cm	55.0 ± 6.37 cm
Width of the leaves	8.5 ± 0.85 cm.	11.8 ± 0.89 cm
Length of the major root	9.6 ± 2.12 cm	12.9 ± 1.58 cm

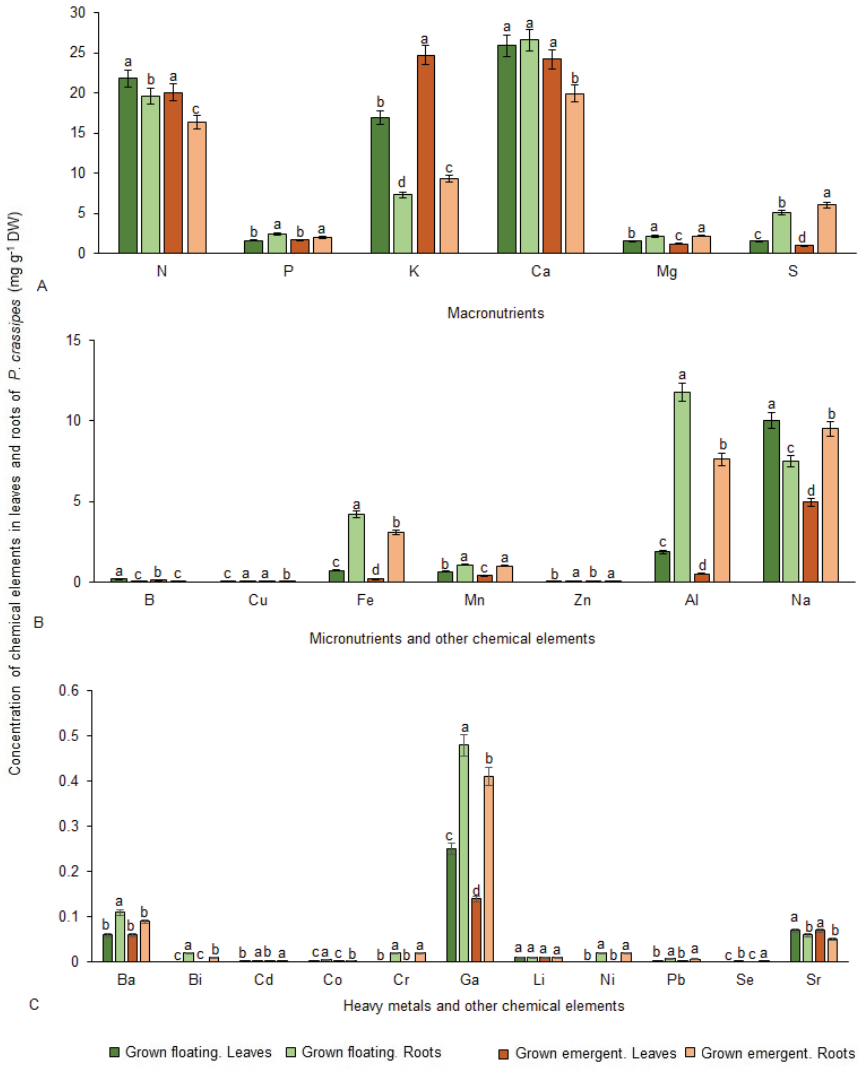

Figure 1. Chemical elements quantified in leaves and roots of *Pontederia crassipes* plant (floating and emergent) (mg g^{-1} DW, averages ± SE). Unequal letters have statistically significant differences (ANOVA of a factor, Tukey, $p \leq 0.05$, $n = 9$).

The Zn and Cd concentrations were the same in the roots of *P. crassipes* floating and emergent and were higher than those found in leaves. Lima-Cazorla *et al.* (2005) detected higher concentrations of Zn and Cd in the roots of *P. crassipes*. In the present study, Cd was found in the leaves at very low concentrations and also in the roots (Lima-Cazorla *et al.*, 2005). This behavior suggests that Cd moves toward the higher organs of the plants (Lu *et al.*, 2004), but at lower concentrations than those detected in the roots (Lima-Cazorla *et al.*, 2005). However, according to the TF results, Cd is not translocated from the roots to the leaves in *P. crassipes* (floating and emergent), nor is Zn or Pb (table 3).

According to Reglamento (UE) (2019), an organic fertilizer and crop substratum cannot have a concentration of Pb greater than 0.12 mg g^{-1}, Cu greater than 0.3-0.2 mg g^{-1}, Zn greater than 0.8-0.5 mg $g^{-1,}$ and Cd greater than 0.0015 mg g^{-1} in DW. Muñiz-Ugarte (2022) considered a limit of 0.15 mg g^{-1} for fertilizer and 0.3 mg g^{-1} for Pb in substratum, while Rodríguez-Alfaro *et al.* (2022) suggested values lower than 0.14 mg g^{-1} for organic fertilizer. Muñiz-Ugarte (2022) proposed that, for Cuba, Cd should not exceed 0.003 mg g^{-1} for fertilizer and 0.008 mg g^{-1} for substratum. The chemical elements (Pb, Cu, Zn, and Cd) present in the DW, derived from the invasive aquatic plant *P. crassipes* in the La Turbina lagoon, have concentrations below the maximum permissible limits established internationally and nationally for organic fertilizers and crop substratum (Reglamento (UE) 2019; Rodríguez-Alfaro *et al.*, 2022; Muñiz-Ugarte, 2022). However, Muñiz-Ugarte (2022) states that the issue of heavy metals in soils, substrates, and organic fertilizers in Cuba requires more studies, as the current permissible limits do not constitute a Cuban Standard.

The DW from *P. crassipes* had a nitrogen (N) concentration within the range specified by Honmura (2000) (between 15.0 mg g^{-1} and 35.0 mg g^{-1}) and was higher than that reported by Tucker & Debusk (1983) (0.02 mg g^{-1}) for this species. However, it exhibited a lower concentration of phosphorus (P) compared to the range provided by Honmura (2000) (between 5.0 mg g^{-1} and 10.0 mg g^{-1}) and Sondang *et al.* (2021) (6.0 mg g^{-1}), yet higher than that recorded by Tucker & DeBusk (1983) (0.006 mg g^{-1}). Furthermore, the potassium (K) concentration was also below that reported by Sondang *et al.* (2021) (20.0 mg g^{-1}) and the range specified by Honmura (2000) (between 20.0 mg g^{-1} and 50.0 mg g^{-1}) for this species. The magnesium (Mg) concentration in *P. crassipes* did not reach the range indicated by Honmura (2000) (between 2.0 mg g^{-1} and 4.0 mg g^{-1}).

Chemical elements detected in the La Turbina freshwater lagoon presented quantifiable concentrations that showed a BCF greater than one. Based on the values obtained from the BCF, *P. crassipes* (floating) has a greater capacity to bioaccumulate S, P, and K, demonstrating its nature as phytoaccumulator (Muthusaravanan *et al.*, 2020). The BCF of Cu and Zn had values greater than 1, indicating that *P. crassipes* (floating) could concentrate certain metals from the water. This may provide evidence of the phytoremediation and phytoextraction potential of the species (Nouri *et al.*, 2011; Alexandre *et al.*, 2025; Boanyah & Bondzie-Quaye, 2025). This illustrates the relationship between the accumulation of chemical elements in the plant biomass and in the water. These results confirm that *P. crassipes* (floating) is a hyperaccumulator plant. According to Cluis (2004), hyperaccumulator plants have a bioconcentration factor greater than one, sometimes reaching values between 50 and 500. In this study, *P. crassipes* (floating) demonstrated even higher values (1210, 1005, and 3305) (table 3).

Translocation was detected in only six chemical elements in *P. crassipes* (floating and emergent). The chemical elements that did not show translocation had a higher concentration in the roots of *P. crassipes* (floating and emergent) than in the leaves. B, K, N, and Sr had a higher concentration in the leaves than in the roots. In the roots of *P. crassipes* (floating), the highest concentrations of Cu were compared to those obtained in *P. crassipes* (emergent) (figure 1). In *P. crassipes* (emergent), the highest concentration of Cu was obtained in the leaves, indicating that this element is not always immobile (Vesk & Allaway *et al.*, 1997) and demonstrates translocation here (table 3). Na had a higher concentration in the leaves than in the roots of *P. crassipes* (floating) (fig. 1), where it exhibited translocation (table 3), whereas in *P. crassipes* (emergent), a higher concentration was detected in the roots than in the leaves (fig. 1), where it did not show translocation. Ca had equal concentration in the leaves and roots of *P. crassipes* (floating) (fig. 1), where it did not show translocation (table 3), while in *P. crassipes* (emergent), a higher concentration was observed in the leaves than in the roots (fig. 1), where translocation occurred (table 3). This indicates the efficiency of the plant in translocating the accumulated chemical elements from its roots to shoots (Ali *et al.*, 2013).

Table 3. Bioconcentration factor (BCF) in *Pontederia crassipes* (floating) for the elements quantified in water. Translocation factors (TF) in *P. crassipes* (floating and emergent) in La Turbina lagoon.

Chemical elements	Bioconcentration factor (BCF) Elements quantified in water	Translocation factors (TF)	
	Floating	Floating	Emergent
Al		0.16	0.07
B		6.00	3.40
Ba		0.55	0.67
Bi		0.10	0.00
Ca	460.3	0.97	1.21
Cd		0.50	0.33
Co		0.20	0.33
Cr		0.05	0.15
Cu	40.0	0.60	2.00
Fe		0.17	0.06
Ga		0.52	0.34
K	1210.0	2.32	2.65
Li		1.00	1.00
Mg	455.0	0.73	0.54
Mn		0.61	0.44
N		1.11	1.22
Na	162.3	1.34	0.52
Ni		0.25	0.15
P	1005.0	0.65	0.85
Pb		0.03	0.03
S	3305.0	0.29	0.16
Se		0.00	0.00
Sr		1.17	1.40
Zn	58.3	0.75	0.50

NOTE: BCF: bioconcentration factor. When the BCF is higher than 1, the plant concentrates the chemical element from water (Ali *et al.*, 2013, Yadav *et al.*, 2018). When TF are higher than 1, the plant trans-locates the chemical element from roots to leaves (Ali *et al.*, 2013; Bello *et al.*, 2018).

Plants with a high BCF value and low TF value are suitable for phytostabilization, while plants with BCF and TF values both greater than one are applicable for phytoextraction (Nouri *et al*., 2011). According to the findings of this study, *P. crassipes* (floating) is suitable for the phytostabilization of Ca, Cu, Mg, P, S, and Zn, as well as for phytoextraction of Na and K. These results may vary depending on the environmental conditions in which the plants grow and their growth condition (floating and emergent).

The concentration of chemical elements found in the dry mass of the invasive aquatic plant *P. crassipes* (both floating and emergent) from the La Turbina artificial freshwater lagoon in Ciego de Ávila indicates that this dry mass can be regarded as an organic fertilizer or used as a mixed substrate for small-scale crops. It contains both macronutrients and micronutrients essential for crop growth. Its concentrations of heavy metals (Pb, Cu, Zn, and Cd) are below the maximum permissible limits set nationally and internationally for organic fertilizers and crop substrates. Additionally, the capacity of *P. crassipes* (floating) as a phyto-stabilizer and for the phytoextraction of chemical elements present in the La Turbina artificial freshwater lagoon was demonstrated. The concentration of chemical elements in the dry mass of *P. crassipes* may vary depending on the environmental conditions of the ecosystem where the plant grows, as well as the time of year (rainy or dry).

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