Effect of heavy metals on duckweed growth

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ABSTRACT

In this study, three clones of the duckweed genus Lemna, collected from three different regions of Vietnam Binh Thuan Bac Giang and Ben Tre were used to evaluate the growth and development in a culture medium containing different concentrations of As\(^{3+}\), Cd\(^{2+}\), or Pb\(^{2+}\). During 14 days of incubation, the growth rate was determined daily by measuring the surface area of all plants of each sample. Experimental results show that the three Lemna clones could grow in nutrient medium contaminated by heavy metal at a concentration of 0.3-0.5 mg/L for As\(^{3+}\), 0.15-0.3 mg/L for Cd\(^{2+}\), and 0.15 mg/L for Pb\(^{2+}\). At these concentrations, the division rate of the treated clones was several times higher than that of the controls. The highest increase in the surface area was recorded for Lemna BTN (68.47 times higher when cultured in medium supplemented in 0.3 mg/L Pb\(^{2+}\) than under control conditions). The surface area of Lemna BTR cultured in a medium supplemented with 0.3 mg/L As\(^{3+}\) was 54.65 times higher than in medium without arsenic. The obtained results showed that Lemna BGG and Lemna BTR can tolerate arsenic and cadmium pollution while Lemna BTN tolerates lead pollution.

Keywords
Aquatic plants, duckweed, heavy metal, Lemna

1. INTRODUCTION

The process of industrialization and modernization has led to many serious environmental problems in the world. One of these issues is heavy metal pollution in water, which occurs not only in Vietnam but also in many other regions of the world. Human activities such as the use of access pesticides, mining, industrial production, transportation, aquaculture, etc. release heavy metals into the soil and water environment. These activities have caused hazardous pollution of freshwater systems (Schwarzenbach et al., 2004). Moreover, most heavy metals are toxic or carcinogenic and pose a threat to human health (Vidnodhini, Narayanan, 2009). Arsenic (As), cadmium (Cd), lead (Pb), zinc (Zn), and nickel (Ni), are considered toxic because they cause deleterious effects on plants, animals, and humans. Arsenic is a major environmental pollutant and is usually released from agricultural products, especially pesticides and herbicides (Singh et al., 2007, Abdul et al., 2015). According to Abdul arsenic has been associated with various organs. Cadmium, derived mainly from paint, plastics, fertilizer, and pesticides, can cause high blood pressure, while lead is toxic to the kidneys and the nervous system (Abdul, 2015). Lemna minor is one of the ideal aquatic plants that
can be used as a phytoremediator of various pollutants such as removing methylene blue (Imron et al., 2021). The maximum removal of Fe, Zn (88.18, 84.63 %) by L. minor at 100 ppm initial metal concentration after 20 days of incubation (Mohedano et al., 2021)

Many aquatic plants were reported that they can survive, grow and reproduce in contaminated environments. Metal-resistant organisms minimize the biological effects of metals in the soil or reduce the proteins to transport and absorb metals. Heavy metals are absorbed by root efflux transporters and promptly delivered to the vacuole or released out of the cell in non - accumulator species that can be exposed to metals. As a result, metal-resistant accumulator species detoxify metals in vacuoles via a tonoplast-carrying substance, whilst substantial amounts of metal are delivered to shoots and collected in ground-rising/collectible parts (Rascio & Navari-Izzo 2011; Lin & Aarts 2012).

Duckweeds are floating aquatic macrophytes, forming the family Lemnaceae a group of monocotyledonous flowering plants (Khellaf, 2009). Duckweeds can grow in an oxygen-deficient water environment and absorb essential nutrients such as PO₄ and NO₃, making them an effective wastewater treatment plant. Especially, duckweed has many advantages and potential over other groups of aquatic plants due to its very fast growth rate, small body size, and simple structure (Le et al., 2017). Therefore, duckweed is used to assess water quality and to remediate wastewater contaminated with heavy metals, ... (Piotrowska et al., 2010). Almost all duckweed species can absorb and accumulate heavy metals such as Cd, Cr, Pb, etc. in their body. Therefore, they have great potential to treat wastewater contaminated by heavy metals that result from tanning technology, and mining, thus reducing the occurrence of these metals in the food chain. In Vietnam, diverse duckweed species are distributed in most geographic regions of the country. So far, research on duckweeds as well as their applications for the treatment of water contaminated with heavy metals is limited.

Previous studies indicated that duckweed is effective phytoremediation for metal contamination in water, particularly effluent from industrial and agricultural processes. By increasing biomass and protein content in tissues, duckweed can cope with or reduce contaminants in wastewater (Mohedano et al., 2012; Saha et al., 2014). Increased protein concentration in duckweed could be due to increased synthesis of specific intense proteins (Sun et al., 2002), such as antioxidant enzymes, and heat shock proteins in response to a variety of intense conditions, including heavy metals and metal chaperones, which provide essential metal cofactors for targeting metalloproteins in various cellular compartments (Hall et al., 2002). This demonstrates that duckweed grows and develops using nutrients contained in wastewater. Furthermore, a plant is assumed to accumulate heavy metals as well as absorb them, while also having systems to protect itself against metal toxicity. After metal exposure, a rise in free amino acid concentrations has been linked to detoxification and metal reduction (Sharma & Dietz, 2006; Xu et al., 2012). Glycine, valine, methionine, phenylalanine, ornithine, proline, histidine, and glutamine accumulation in Chlorella vulgaris is linked to Cd complexity and tolerance (Chia et al., 2015). The accumulation of alanine, serine, phenylalanine, tyrosine, and threonine in the roots of Solanum nigrum revealed a high capacity for Cd accumulation and tolerance (Xu et al., 2012). Moreover, an increase in arginine synthesis causes an accumulation of polyamines, which are protective macromolecules such as polycations, negatively charged macromolecules in the cell (Alcázar et al., 2006). Organic acids, like citric and malic acids, are possible ligands for heavy metals and may thus play a role in cellular homeostasis tolerance, storage, and maintenance (Hall, 2002). It is also true in the case of heavy metal accumulation. Cd, Cu, and Zn are coordinated in hyperaccumulators by organic acids, which are often found in plant vacuoles (Küpper et al., 2009). The increased levels of malic and citric acid found in the leaves of the Cd-hyperaccumulator Solanum nigrum could be linked to the accumulation of Cd (Sun et al., 2006). Other metals, such as Pb, have no special function in plant physiological responses but can be taken by plants due to chemical properties that are comparable to important elements (Pais & Jones 2000). Additionally, arsenate and phosphate are chemically similar and arsenate is absorbed by plants using transporters that bear resemblance to phosphate transporters (Gusman et al., 2012). As a result, certain species improve their survival in the presence of arsenate by inhibiting phosphate transporters which alters the absorption kinetics (Meharg & Hartley, 2002).

Several studies showed heavy metal pollution in water, vegetables, and seafood in some areas of Vietnam. Nguyen (2016) and Testuro (2014) found that Cd and Pb were the main pollutants in surface...
sediments in the Red River basin. While As, Cr, and Hg concentrations were higher than the allowable limit in the Mekong Delta, Nguyen (2013) detected heavy metals (As, Cd, Cr, Pb) in oyster tissue in coastal areas of Can Gio and Le (2013) found high concentrations in rock oysters and green mussels in coastal Do Son (cite from Nguyen, 2020).

Robert Anthony Martienssen said at the International Conference on Duckweed Research and Application that “We’re interested in using or optimizing duckweed for use as a biomass for biofuel based on its ability to grow on wastewater and water in places which you would never imagine crops would grow”. This message showed that duckweed could become the potential crop for di-purpose applications (wastewater treatment and biofuel biomass).

The present study investigates the effect of As, Pb, and Cd on the three *Lemna* clones collected from three different regions in Vietnam to assess the tolerance to and survey their growth and development in water contaminated with these heavy metals.

2. MATERIALS AND METHOD

2.1. Plant material and culture medium

Three *Lemna* accession native to the Bac Giang (BGG), Binh Thuan (BTN), and Ben Tre (BTR) regions of Vietnam were collected from natural ponds and placed in 350-mL sterile glass jars containing 150 mL medium and covered with a plastic film and grown at 25±2°C, with a day-to-night cycle of 16:8 h (photon flux 40 µmol/m²s⁻¹) on N – medium (Appenroth et al., 1996). Different concentrations of arsenic (As³⁺) (0.1; 0.3; 0.5; 0.7; 0.9 mg/L), cadmium (Cd²⁺) and lead ions (Pb²⁺) (0.1; 0.15; 0.2; 0.25; 0.3 mg/L) were added into *Lemna* BGG. The heavy metal adsorption capacity of different duckweed accessions has been studied previously (Goswami et al., 2014b; Teixeira et al., 2014; Mechora et al., 2015; Nguyen, 2016; Bokhari et al., 2019b). The obtained result from this study on *Lemna* BGG was similar to *L. minor* cultured in a medium containing 0.5 mg/L As³⁺ which yielded the best arsenic absorption within the range of concentrations investigated (Goswami et al., 2014b). Moreover, at concentrations higher than 0.2 mg/L Pb²⁺, the growth of *Lemna* BGG was markedly inhibited. The absorption capacity for Pb²⁺ of different duckweed species has been studied and showed that each species has its absorption optimum, for instance, 1.51 mg/L for *L. gibba* (Bokhari et al., 2019b) or 0.2 mg/L for *L. minor* (Ucuncu et al., 2013). The obtained results for *Lemna* BGG are similar to that reported for *L. minor*.

The *Lemna* accession BGG could grow well at the concentration of As³⁺ and Cd²⁺ above 0.5 mg/L. Thus, *Lemna* BGG can grow in water strongly contaminated with arsenic and cadmium indicated by the faster growth rate (increase in surface area) in supplemented heavy metals medium than that of control (Table 1 and Fig. 1).

2.2. Surface area measurement

The surface area based on the total area of all fronds of a sample was determined by image analysis using ImageJ software. Plants were collected for two weeks every day and photographed at the same time. The number of fronds is also counted on the images.

2.3 Replication and Statistical Analysis

All experiments were repeated 3 times. Data were analyzed by Microsoft Excel 2013 and Image J software.

3. RESULTS AND DISCUSSION

3.1. The effects of As³⁺, Cd²⁺, and Pb²⁺ on the growth of *Lemna* BGG

There was a significant increase in biomass of the accession *Lemna* BGG grown in the presence of As³⁺ and Cd²⁺ compared to the control. The concentrations of heavy metals for the *Lemna* BGG line were 0.5 mg/L for As³⁺, 0.2 mg/L for Cd²⁺ and 0.15 mg/L for Pb²⁺. At these concentrations, the surface area increased many times higher than that of the control. The 42.23-fold at 0.5 mg/L As³⁺ (from 0.430 to 18.158 cm²), 40.81-fold at 0.2 mg/L Cd²⁺ (from 0.408 to 16.652 cm²) and 32.19-fold at 0.15 mg/L Pb²⁺ (from 0.545 to 17.153 cm²) (Table 2, chart 1). This proved that there was a positive effect of arsenic on the growth and development of *Lemna* BGG. The heavy metal adsorption capacity of different duckweed accessions has been studied previously (Goswami et al., 2014b; Teixeira et al., 2014; Mechora et al., 2015; Nguyen, 2016; Bokhari et al., 2019b).
Duckweed has a great ability to endure contaminants in the environment, as we can see by the minor damage (a small change in color and size of duckweed fronds (Fig.1)). In assessing the effectiveness of duckweed absorption and development in a contaminated environment, time length is also a significant consideration. Setting up an experiment for a short length of time can result in unfavorable developmental outcomes, however prolonging the time of the experiment can result in other outcomes (Ekperusi et al., 2019).

Metal removal was practically complete within the first 24 hours, according to earlier investigations (Axtell, 2003; Ucuncu, 2012). In a study of Pb accumulation in *L.minor*, Axtell discovered that the fastest accumulation (50–90%) occurred in the first...

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**Table 1. The increase in surface area (cm²) of the Lemna BGG accession cultured in medium supplemented with As³⁺, Cd²⁺, and Pb²⁺ ions for 14 days**

| Day | 0     | 0.1  | 0.2  | 0.3  | 0.5  | 0.7  | 0.9  | 0.15 | 0.25 | 0.3  | 0.15 | 0.2  | 0.25 | 0.3  |
|-----|-------|------|------|------|------|------|------|------|------|------|------|------|------|------|
|     | As³⁺ (mg/L) | Cd²⁺ (mg/L) | Pb²⁺ (mg/L) |
| D1  | 0.519 | 0.452 | 0.470 | 0.430 | 0.470 | 0.530 | 0.375 | 0.410 | 0.450 | 0.408 | 0.455 | 0.486 | 0.400 | 0.455 |
| D2  | 0.520 | 0.455 | 0.474 | 0.431 | 0.471 | 0.530 | 0.376 | 0.411 | 0.452 | 0.408 | 0.457 | 0.488 | 0.408 | 0.457 |
| D3  | 0.635 | 0.511 | 0.694 | 0.589 | 0.501 | 0.601 | 0.381 | 0.512 | 0.589 | 0.561 | 0.549 | 0.610 | 0.532 | 0.594 |
| D4  | 0.713 | 0.678 | 0.717 | 0.786 | 0.702 | 0.763 | 0.385 | 0.620 | 0.652 | 0.629 | 0.701 | 0.783 | 0.624 | 0.712 |
| D5  | 0.963 | 1.391 | 2.218 | 1.955 | 1.937 | 1.542 | 1.002 | 1.609 | 1.965 | 1.703 | 1.527 | 1.581 | 1.044 | 1.670 |
| D6  | 1.859 | 2.262 | 2.792 | 2.510 | 1.943 | 1.831 | 1.676 | 1.676 | 2.117 | 2.501 | 2.474 | 2.057 | 1.864 | 2.205 |
| D7  | 2.738 | 3.260 | 3.872 | 4.524 | 3.240 | 2.555 | 2.752 | 3.116 | 3.728 | 4.466 | 2.562 | 2.529 | 2.632 | 2.993 |
| D8  | 2.932 | 3.869 | 4.895 | 6.015 | 4.956 | 3.023 | 2.978 | 4.150 | 4.395 | 5.108 | 3.392 | 3.085 | 3.015 | 4.359 |
| D9  | 3.650 | 5.106 | 6.962 | 8.060 | 6.690 | 4.814 | 3.422 | 5.536 | 6.039 | 6.587 | 4.982 | 4.671 | 3.422 | 5.360 |
| D10 | 5.335 | 7.033 | 8.801 | 10.674 | 7.903 | 6.065 | 4.829 | 5.963 | 7.202 | 7.147 | 6.054 | 5.305 | 4.163 | 5.930 |
| D11 | 5.864 | 8.832 | 9.802 | 12.770 | 8.920 | 7.868 | 5.163 | 7.041 | 8.816 | 9.015 | 7.482 | 6.752 | 5.557 | 7.871 |
| D12 | 6.626 | 9.532 | 11.074 | 14.213 | 10.480 | 10.573 | 5.557 | 7.786 | 10.439 | 11.245 | 9.336 | 7.452 | 7.452 | 8.263 |
| D13 | 6.965 | 11.151 | 12.989 | 15.719 | 13.092 | 12.739 | 7.304 | 9.179 | 11.998 | 14.258 | 10.624 | 9.822 | 7.795 | 11.179 |
| D14 | 7.795 | 13.049 | 15.263 | 18.158 | 16.197 | 16.107 | 7.445 | 10.047 | 13.199 | 16.652 | 11.664 | 11.023 | 8.304 | 13.049 |

**Figure 1. The increase in surface area (times) during 14 days and the growth of Lemna BGG cultured in medium supplemented with As³⁺, Cd²⁺, and Pb²⁺ ions (mg/L) on day 1 and day 14**
24 hours (Axtell, 2003). In Pb removal, investigated *L.minor* obtained a total of 95% Pb removal, with 85% performed in the first 24 hours (Rahmani & Sternberg, 1999).

*L.gibba* reported that can remove heavy metals from untreated industrial/city wastewater in about 21 days. An increase in Ni, Pb, and Cd concentrations of plant tissues was detected in experiments. The difference between the initial concentration (at inoculation) and the final concentration (at day 21) was significant (p < 0.05) (at harvest) (Syeda *et al.*, 2019). When the initial and final concentrations of Cd, Pb, and Ni in *L. gibba* tissues were compared, the final values were several times higher than the starting concentrations. Heavy metal accumulation in the tissues of *L.gibba* produced the same results as reported by Megateli (Megateli *et al.*, 2009).

### 3.2. The effects of As³⁺, Cd²⁺, and Pb²⁺ on the growth of *Lemna BTR*

A similar growth rate between treatments was observed for the first 7 days, from the 8th day onwards, we noticed a large difference. Similar to the *Lemna BGG*, all treatments with arsenic ions yielded a higher growth rate than the control for *Lemna BTR*. The highest growth rate was observed at 0.3 mg/L (from 0.2 to 7.236 cm²), around 36 times)

| Day | 0     | 0.1   | 0.3   | 0.5   | 0.7   | 0.9   | 1.1   | 1.3   | 1.5   | 2.0   | 0.2   | 0.25  | 0.3   |
|-----|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| As³⁺ (mg/L) | 1.025 | 0.275 | 0.2   | 0.215 | 0.270 | 0.222 | 0.230 | 0.270 | 0.18  | 0.18  | 0.250 | 0.2   | 0.224 | 0.280 |
| Cd²⁺ (mg/L) | 1.026 | 0.277 | 0.221 | 0.277 | 0.224 | 0.261 | 0.274 | 0.182 | 0.18  | 0.264 | 0.220 | 0.285 | 0.238 | 0.252 |
| Pb²⁺ (mg/L) | 1.030 | 0.355 | 0.289 | 0.256 | 0.286 | 0.231 | 0.381 | 0.301 | 0.223 | 0.217 | 0.356 | 0.246 | 0.316 | 0.332 |

Table 2. The increase in surface area (cm²) of the *Lemna BTR* accession cultured in medium supplemented with As³⁺, Cd²⁺, and Pb²⁺ ions for 14 days.

Mohedano showed that the duckweed biomass level and protein content increased by 35% after being cultured in swine wastewater (Mohedano *et al.*, 2012) and Saha reported that duckweed after 21 days of experiment with wastewater from steel mills increased biomass by 30% (Saha *et al.*, 2014). However, there were also contrasting results of pollutants, and heavy metals causing negative effects (Saha *et al.*, 2014; Zhang *et al.*, 2014a, b, c) or growth inhibition. (Wang *et al.*, 2014a, b; Grijalbo *et al.*, 2016; Wang *et al.*, 2016) of duckweed depends on the concentration of pollutants and the toxicity level of the wastewater type. Furthermore, the success of heavy metal absorption by plants is associated with the ability of a specific phenotype and genotype of the plant to absorb and translocate heavy metals (Chen *et al.*, 2013).

Duckweed biomass and protein content increased by 35 percent after being grown in swine wastewater (Mohedano *et al.*, 2012), or by 30% following 21
days of experiment with wastewater from steel mills (Saha et al., 2014). However, there were also negative consequences from pollution, heavy metals or growth suppression of duckweed (Wang et al., 2014a, b; Grijalbo et al., 2016; Wang et al., 2016) is dependent on the contaminants present, and the wastewater toxicity level.

3.3. The effects of $\text{As}^{3+}$, $\text{Cd}^{2+}$, and $\text{Pb}^{2+}$ ions on the growth of Lemma BTN

Similar to experiments with the other two Lemma accessions, Lemma BTN also showed different responses to each concentration of metal ions added to the medium. The increase in surface area after treatments is shown in Table 4 and Fig. 3.

Figure 3 shows that the growth of Lemma BTN after heavy metal exposure differs from that of Lemma BGG and BTR.

The growth rate on media supplemented with arsenic did not change much compared to the control treatment. The maximum increase in the surface was achieved after the application of 0.5 mg/L arsenic which increased 47.48 times (from 0.213 to 10,113 cm$^2$) compared to the control which increased 34.88 times (from 0.201 to 7.011 cm$^2$) after 14 days of cultivation. Thus, the presence of arsenic (up to 0.9 mg/L) in the medium had only a little effect on the growth and development of Lemma BTN.

For the cadmium exposure, in the low concentration range (from 0.1 to 0.25 mg/L Cd$^{2+}$), the growth rate of Lemma BTN was significantly reduced and lower than that of the control. However, at a higher concentration (0.3 mg/L), the growth increased 39.12 times (from 0.255 to 9,976 cm$^2$), starting from day 7. The cadmium absorption for L. gibba species was recorded to be 0.74 mg/L. Therefore, the absorption capacity of metal ions of different Lemma accessions or species seems to be different (Bokhari et al., 2019b).

The Lemma accession BTN showed a was quite sensitive to lead and irregular surface increase with increasing concentration (similar to the medium with Cd$^{2+}$). At 0.1 mg/L Pb$^{2+}$, Lemma BTN showed
increased growth compared to the control, followed by a decrease at 0.15 - 0.2 mg/L to the control level, and again an increase at 0.25 mg/L. At 0.3 mg/L Pb²⁺, the surface area of the *Lemma BTN* reached its peak with 18.349 cm² after 14 days (68.47 times than at day 1). At least, no indication of growth inhibition by lead and this accession can easily live in environments with high lead concentrations. Similarly, Pb²⁺ absorption capacity was recorded for *L. gibba* at 1.51 mg/L (Bokhari et al., 2019b). Also, *Lemma BTN* has the potential to grow and absorb Pb²⁺ at high concentrations.

Axtell indicated *L. minor* ability to remove soluble Pb and Ni under different laboratory conditions (Axtell et al., 2003). The initial concentrations of Pb were 0.0, 5.0 and 10.0 mg/L and of Ni were 0.0, 2.5 and 5.0 mg/L in the experiment. Overall, *L. minor* removed an average of 76% Pb and 82% Ni from the medium. Similar results were reported while using duckweed (*L. minor* and *L. gibba*) in wastewater treatment to remove heavy metals under various laboratory tests (Loveson et al., 2013, Aurangzeb et al., 2014, Yılmaz & Abkublt, 2011). The removal efficiency of Cu, Ni, and Pb from wastewater was more than 60% for *L. minor* (58%, 68%, and 62% for Cu, Ni, and Pb respectively).

Basile determined that *L. minor* after 7 days treated with 10⁻⁴ M Zn could accumulate up to 58.800 mg/g metal in tissue, while with 10⁻⁴ M Pb can accumulate 22.533 mg/g metal, which is the reason that duckweed was supposed to be a potential subject for wastewater treatment (Basile et al., 2012; Syeda et al., 2016). In 2007, Keith exposed *L. minor* to an aqueous solution containing 125 mg/L Cu, 220 mg/L Cr, and 205 mg/L As in single and mixed forms, reported results showed that plants can remove 60% Cu, Cr and As when they are mixed, but when Cu (60 mg/L) is the only heavy metal in the solution, it could be removed up to 85%, over 7 days (Keith et al., 2007).

Even though duckweed is closely related and outstanding in the Lemnaceae family, different species have varying abilities to adapt to a variety of environmental contaminants or intensities. Although there may be a generic kind of metal absorption, absorption can also be species-specific. More research is needed to determine the absorption kinetics of various types of metal pollutants during macrophyte treatment. Due to a paucity of data to define the kinetics and reactions to certain metals in situ, it is unclear whether some plant species have an affinity for metal absorption (Ekperusi et al., 2019).

Table 3. The increase in surface area (cm²) of the *Lemma BTN* accession cultured in medium supplemented with As³⁺, Cd²⁺, and Pb²⁺ ions for 14 days

| Day | As³⁺ (mg/L) | Cd²⁺ (mg/L) | Pb²⁺ (mg/L) |
|-----|-------------|-------------|-------------|
| 0   | 0.201       | 0.211       | 0.216       |
| 0.1 | 0.213       | 0.225       | 0.225       |
| 0.3 | 0.225       | 0.253       | 0.253       |
| 0.5 | 0.254       | 0.279       | 0.284       |
| 0.7 | 0.248       | 0.299       | 0.301       |
| 0.9 | 0.239       | 0.255       | 0.321       |
| 1.1 | 0.265       | 0.265       | 0.345       |
| 1.5 | 0.248       | 0.284       | 0.304       |
| 0   | 0.257       | 0.254       | 0.285       |
| 0.1 | 0.265       | 0.265       | 0.301       |
| 0.2 | 0.249       | 0.295       | 0.301       |
| 0.3 | 0.268       | 0.301       | 0.301       |

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Bonanno evaluated the removal of different heavy metals (As, Cd, Cl, Cu, Hg, Mn, Ni, Pb, and Zn) by twenty distinct macrophytes in a living and industrial wetland. They demonstrate that metal absorption or translocation does not follow a predictable pattern among plant species. Although removal rates differed widely across the twenty species, *L. minor* had the greatest elimination rate (Bonanno et al., 2018). The transit and status of inorganic contaminants in duckweed, particularly metals, although processes such as methylation, chelation, sequestration, and chemical binding are primarily responsible for metal detoxification and conversion from harmful to less toxic forms are still unclear (Chandra, 2015).

4. CONCLUSIONS

From obtained results of three duckweed clones (BTR, BTN and BGG) gave different reactions on As\(^{3+}\) (0.1; 0.3; 0.5; 0.7; 0.9 mg/L) or Cd\(^{2+}\)/Pb\(^{2+}\) (0.1; 0.15; 0.2; 0.25; 0.3 mg/L) treatments. In details, Lemma BGG line has the potential to grow in medium supplemented with 0.5 mg/L As\(^{3+}\) or 0.3 mg/L Cd\(^{2+}\), while Lemma BTR line grew well in medium contained 0.3 mg/L As\(^{3+}\) or 0.15 mg/L Cd\(^{2+}\) or 0.2 mg/L Pb\(^{2+}\) and Lemma BTN line could grow well in medium contaminated by more than 0.3 mg/L of Pb\(^{2+}\).

This is the first investigation on heavy metals resistance of duckweed lines collected from different regions along Vietnam. The obtained data showed that duckweed in Vietnam could be used for wastewater treatment as reported by other international research groups. For further work, to survey the accumulation rate of these heavy metals in the three duckweed lines as well as increase the experiment scale to the pilot scale for practical application.

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