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Research Article

The Evaluation for *Salvinia* sp. Adaptation to Iron Concentration on Nutrient Solution and Tidal Swamplands Soil Growing Media

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Salvinia sp. is an alternative aquatic plant that is abundant in the swamplands and can be used for bioremediation of water contaminated with metals. The objectives of the experiment were (1) to evaluate the adaptation of *Salvinia* sp. to the iron (Fe) concentration in nutrient solution and tidal swampland soil growing medium and (2) to obtain Fe-adaptive *Salvinia* sp. as indicated by having rapid growth and high biomass. The experiment has been carried out in Cikabayan greenhouse IPB University, Bogor. *Salvinia* sp. was evaluated in a 4-liter plastic container with Hoagland nutrient solution that was supplemented with Fe based on the experimental treatments. The 10 accessions of *Salvinia* sp. were selected and evaluated using a pot filled with soil from tidal swampland. The results showed that increasing Fe concentration from 7 to 14 ppm in solution inhibited the growth, reduced the fresh weight, and delayed the doubling time of *Salvinia* sp. The selection of *Salvinia* sp. on 7 ppm Fe obtained 4 *Salvinia* sp. accessions with high biomass weights and fast doubling time, namely S. Kambat, Murung Karamat, Gambut, and Muning Tengah. Among the 4 accessions, the best two were S. Kambat and Murung Karamat with a fast doubling time of about 7.9 days and were adaptive in the tidal swampland.

1. Introduction

The decrease of productive and optimal agricultural land as a result of rapid land conversion to other purposes can be solved by maximizing the use of suboptimal or marginal land like tidal swamplands in Indonesia with an area of 8.92 million ha [1] as an alternative for plant cultivation. In order to increase plant productivity in tidal swampland, soil quality improvement is required such as soil amelioration [2]. The use of chemical fertilizers can be completely or partially replaced by the use of organic fertilizers or by the application of bioeffectors or biostimulants [2–5].

Previous studies showed the success of organic fertilizer to improve land quality, decrease toxic elements in soil, and increase plant yield. The results of the decomposition of organic fertilizer contribute to the macro and micronutrient status and increase the soil exchange capacity leading to high soil nutrient retention [6].

According to Jumberi and Alihamsyah, the application of straw compost to tidal swampland can reduce Fe and SO_4 levels [7]. However, there is still a limitation during the implementation of rice straw as organic fertilizer. Organic matter such as rice straw cannot be applied directly to the land in a fresh form because it can stimulate Fe toxicity in the plant [8]. Thus, the straw should be processed to be composted. In addition, there is a huge number of rice straws that should be prepared and it is difficult to find rice straws nearby the land. Therefore, there is a need to look for another alternative to organic matter for soil amelioration.

Aquatic plants have the potential to be used for phytoremediation of water contaminated with inorganic (nutrients, heavy metals) and organic pollutants because of their ability to absorb and bind elements that dissolve in the water [9–13]. The technology used in the phytoremediation of metal-contaminated environments should be effective, cost-effective, and environmentally friendly [14, 15]. Plants that can be used for phytoremediation must have characteristics such as native and quick growth rate, high biomass production, uptake of a large number and higher accumulation of heavy metals, ability to transport metals aboveground parts of the plant, and tolerance to metal toxicity mechanism [12, 16–18].

An alternative aquatic plant that is abundant in tidal swampland is *Salvinia* sp., which is used for bioremediation of water bodies that are contaminated. *Salvinia* sp. shows a high potential to use as an organic fertilizer because of its rapid growth, high biomass production [19, 20], and composition of macronutrients (N, P, K, Ca, Mg) [20]. However, there are still limited studies that highlight the use of *Salvinia* sp. to ameliorate the tidal swampland. Therefore, this study aimed (1) to evaluate the adaptation of *Salvinia* sp. to various Fe concentrations both in nutrient solution media (Hoagland) and tidal swampland soil and (2) to determine *Salvinia* sp. that are adaptive to Fe-rich condition and tidal swampland soil, as indicated by the rapid growth and high biomass.

2. Material and Methods

This study was conducted at Cikabayan greenhouse and Crop Production Laboratory, Faculty of Agriculture, IPB University, Bogor, Indonesia (Location: South Latitude: −6.55524011; East Longitude: 106.7222321; 185 m above sea levels), from June to December 2010. This study consisted of two stages, that is, (i) the evaluation of adaptation of 10 *Salvinia* sp. accessions to Fe concentration in nutrient solution and (2) the evaluation of adaptation of 4 selected *Salvinia* sp. accessions to Fe concentration in tidal swamp soil growing media.

2.1. The Evaluation of Adaptation of 10 Salvinia sp. Accessions to Fe Concentration in Nutrient Solution Media. *Salvinia* sp. is mostly found in tidal swampland and freshwater swampland in South Kalimantan. Therefore, to evaluate the adaptation of *Salvinia* to Fe toxicity, we collected *Salvinia* sp. (fresh plant) from the 2 agroecosystems types. There were 10 accessions of *Salvinia* sp. The collections consist of 4 accessions from freshwater swampland and 6 accessions from tidal swampland. One kilogram of fresh (live) *Salvinia sp.* is taken from its natural habitat and placed in a box filled with water. *Salvinia* is left in the greenhouse for 1 week to adapt before treatment.

This experiment was arranged in a factorial randomized complete block design (RCBD) with 2 factors, namely *Salvinia* accessions and Fe concentrations. There were 10 accessions of *Salvinia* sp. that were collected from some swamp areas in South Kalimantan and then tested in the Cikabayan greenhouse. The second factor was composed of 3 levels of Fe concentrations (in pH 4.5), namely 0.5 ppm Fe (control), 7 ppm Fe, and 14 ppm Fe. For every combination treatment, there were 3 replications. In total, there were 60 experimental units.

The Hoagland nutrient solution was prepared as *Salvinia* sp. growing media. The Hoagland nutrient solution (modified 1/5 concentration) used for this experiment consisted of 30.8 ppm N, 6.2 ppm P, 46.9 ppm K, 32.0 ppm Ca, 9.7 ppm Mg, 12.8 ppm S, 0.1 ppm Mn, 0.01 ppm Zn, 0.004 ppm Cu, 0.1 ppm B, and 0.002 ppm Mo. The Hoagland was put in a 4-liter plastic box. *Salvinia* sp. (fresh plant) was inoculated with as much as 50 g per 1 m^2 in that box. The solution surface in the plastic box was maintained at 10 cm above the base of the box for 4 weeks. To maintain the solution, the decline of the solution surface inside the box was refilled with Aquadest. The nutrient solution was renewed every 2 weeks (Figure 1).

Salvinia sp. growth rate was observed every week, starting from 1^{st} week after inoculation, by estimating the percentage of solution covered by *Salvinia* sp. Four weeks after inoculation, there were several variables observed, namely, fresh biomass, Fe content of *Salvinia* sp., acidity (pH), and Fe of surface water in the pots after 2 weeks, and doubling time [21]. Additionally, this also evaluated the content of N, P, K, and organic C of *Salvinia* sp. tissue.

$$\text{Doubling Time} = t \cdot \log 2 \cdot \left[\log\left(\frac{w_t}{w_0}\right)\right]^{-1}, \qquad (1)$$

where t is the duration of the experiment (days), w_t is the final weight, and w_0 is the initial weight.

2.2. The Evaluation of Adaptation of 4 Selected Salvinia sp. Accessions to Fe Concentration in Tidal Swampland Soil Growing Media. This experiment used growing media in the form of tidal swampland soil obtained from Blandean, Barito Kuala District, South Kalimantan Province. The 2^{nd} experiment only used 4 selected *Salvinia* sp. accessions from the previous experiment. This experiment was arranged in RCBD with selected accessions that consisted of 5 treatments, namely no *Salvinia* sp., *Salvinia* sp. accession-1, *Salvinia* sp. accession-2, *Salvinia* sp. accession-3, and *Salvinia* sp. accession-4. There were 3 replications for each accession. *Salvinia* sp. was planted in a 4 kg (dry basis) tidal swampland soil inside the plastic pot. Afterward, the soil overflowed with water for about 5 cm above the base of the box within 2 weeks. *Salvinia* sp. as much as 50 g per m^2 (wet basis) was used as the seedling for each pot.

The observed variables were (i) the growth rate that was noted from the water surface coverage of *Salvinia* sp. weekly, (ii) the weight of *Salvinia* sp. after 4 months of maintenance,

Figure 1: The evaluation of *Salvinia* sp. adaptation to Fe concentration in Hoagland nutrient solution media in a 4-liter plastic box within 4 weeks.

(iii) the content of Fe in plant tissue, and (iv) the acidity (pH) and Fe of surface water in the pots after 4 weeks.

2.3. Plant and Soil Sampling Analysis. The levels of N, P, and K of *Salvinia* plant tissue were analyzed by wet ashing using strong acid extraction $H_2SO_4 + HCLO_4$. Phosphorus levels were measured using the staining method using spectrophotometry, potassium and Fe levels were measured using atomic absorption spectrophotometry (AAS), and N levels were measured by the distillation method. Carbon levels were analyzed by the extraction of potassium dichromate + H_2SO_4 (Walkey and Black) and by titration.

Analysis of soil characteristics used in the study: acidity (pH) was measured using a pH meter with a ratio of 1 : 2.5 soil and water. Organic C was analyzed by potassium dichromate + H_2SO_4 (Walkey and Black) method, and total N was extracted with sulfuric acid + H_2O_2. Exchange bases (Ca, Mg, K, Na) were extracted with ammonium acetate 1 N pH 7.0, and Ca, Mg, K, and Na were measured with AAS. Exchangeable aluminum was extracted with KCl 1 N and then measured by titration method. Available P was analyzed by P Bray I method, P total and K total were extracted with 25% HCl, P was measured by spectrophotometer, K was measured with AAS, and cation exchange capacity (CEC) was analyzed by percolation method with ammonium acetate 1 N pH 7.0 and then measured by distillation. The pipette method was used to assess the texture, and sand, dust, and clay were weighed.

2.4. Data Analysis. Data obtained were subjected to analysis of variance (ANOVA), and further means of treatment effect were compared with testing using Duncan's multiple range test (DMRT) at a 95% confidence level. Data were analyzed using the SAS V.9 version program.

3. Results and Discussion

3.1. The Evaluation of Adaptation of 10 Salvinia sp. Accessions to Fe Concentration in Nutrient Solution Media. Ten accessions of tested *Salvinia* sp. were collected from some swampland in South Kalimantan (Table 1). All collected *Salvinia* sp. accessions were naturally grown. The pH of *Salvinia* sp. habitat was 4.13–4.50, and it was categorized as an acid soil solution. The high acidity in the soil increased the solubility of Fe leading to high Fe concentration in the soil solution, that is, 0.38–6.57 ppm Fe.

Table 1: Sampling locations and type of agroecosystem of 10 accessions *Salvinia* sp. in South Kalimantan.

No.	Sampling locations of *Salvinia* sp.	Type of agroecosystem
1.	Danau Ceramin	Freshwater swampland (FS)
2.	Muning Tengah	Freshwater swampland (FS)
3.	Tawar	Freshwater swampland (FS)
4.	Paharangan	Freshwater swampland (FS)
5.	S. Kambat	Tidal swampland (TS)
6.	Danda Jaya	Tidal swampland (TS)
7.	Gambut	Tidal swampland (TS)
8.	Belandean	Tidal swampland (TS)
9	Barambai	Tidal swampland (TS)
10	Murung Karamat	Tidal swampland (TS)

The greenhouse experiment was conducted to clarify *Salvinia* sp. growth rate and its tolerance to Fe in Hoagland natural solution. The growth rate of *Salvinia* sp. was implied from the percentage of water surface covered by *Salvinia* sp. and the weight of *Salvinia* sp. biomass. The low percentage of water surface covered by *Salvinia* sp. was found in the treatment with high Fe content (Figure 2).

Salvinia sp. in control treatment showed rapid growth in the 3rd week, as indicated by the increase of water surface covered by *Salvinia* sp. for about 1.7 times compared to the 2nd week. During the same period, *Salvinia* sp. in the treatment of 7 ppm Fe and 14 ppm Fe only showed an increase of about 1.3 and 1.1 times, respectively. In the 4th week, the percentage of water surface covered by *Salvinia* sp. in control, 7 ppm, and 14 ppm Fe treatment were varied in the range 84.5%–97%, 25.0%–80.0%, and 20%–30%, respectively (Figure 2).

The more the Fe content in a nutrient solution, the higher the growth inhibition for *Salvinia* sp. and the lower the *Salvinia* sp. biomass produced after 4 weeks of maintenance. The reduction of biomass as the effect of 7 ppm Fe was only 2.6 times, while in 14 ppm Fe treatment, the reduction increased up to 9.4 times compared to the control. The mean of *Salvinia* sp. biomass (fresh weight) in control was 78.0 g, while the mean of *Salvinia* sp. biomass (fresh

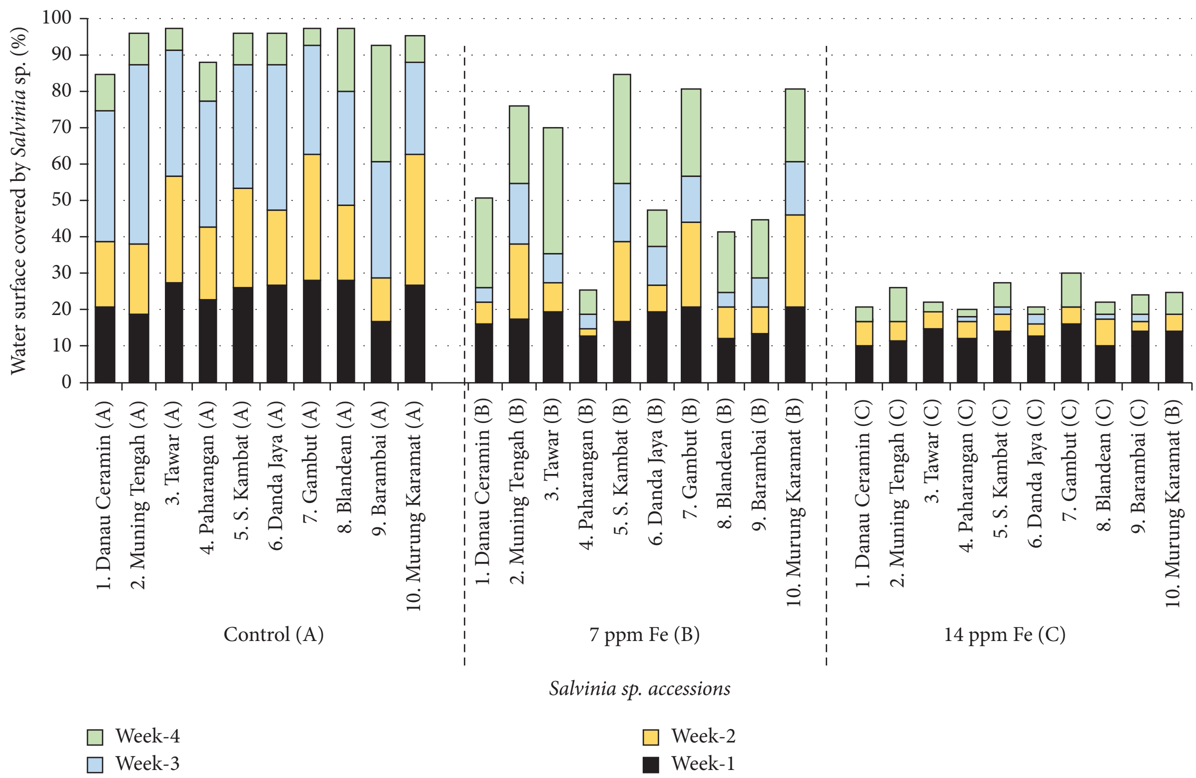

Figure 2: Water surface covered by *Salvinia* sp. during 4 weeks of maintenance in Hoagland nutrient solution medium enriched with various levels of Fe.

weight) in 7 ppm Fe and 14 ppm Fe were reduced to 29.5 g and 8.3 g, respectively. The range of *Salvinia* sp. biomass (fresh weight) in control, 7 ppm Fe, and 14 ppm Fe were 62.5–87.8 g, 12.6–60.9 g, and 6.2–11.8 g, respectively (Table 2).

In the control treatment, the biomass average of *Salvinia* sp. from tidal swampland was 79.6 g, while those from freshwater swampland was 75.6 g. In the treatment of 7 ppm Fe, the biomass average of *Salvinia* sp. from tidal swampland and freshwater swampland was 33 g and 24.4 g, respectively (Table 2). Among several *Salvinia* sp. accessions tested in 7 ppm Fe treatment, the highest biomass was found in the Gambut accession for about 60.9 g that was originated from the tidal swampland and Muning Tengah accession for about 43.2 g that was collected from freshwater swampland. At a concentration of 14 ppm Fe in solution, the biomass weight of *Salvinia* does not change significantly between all accessions from tidal swampland and freshwater swampland (Table 2).

The increase of Fe concentration in the Hoagland nutrient solution could prolong the doubling time of *Salvinia* sp. The doubling time of *Salvinia* sp. in control treatment varied from 4.6 to 5.9 days, while the presence of 7 ppm Fe and 14 ppm Fe made the delay of doubling time range from 6.0 to 16.1 days and 16.7 to 27.2 days, respectively (Table 3). In contrast, the absence of Fe in the control treatment showed a similar doubling time from one to another. Under 7 ppm Fe stress conditions, there were 4 varieties selected as the high varieties with good doubling time than others, that is, Muning Tengah (7.7 days), S. Kambat (7.5 days), Gambut (6.0 days), and Murung Keramat (8.6 days) (Table 3).

Table 2: Biomass (fresh weight) of *Salvinia* sp. after 4 weeks of maintenance in Hoagland nutrient solution medium enriched with various levels of Fe.

No.	*Salvinia* sp. accession	Fe treatment		
		Control	7 ppm	14 ppm
			g	
1	D. Ceramin (FS)	62.5 b	18.7 d	7.0 a
2	Muning T. (FS)	84.7 a	43.2 b	7.8 a
3	Tawar-2 (FS)	81.4 a	23.1 cd	6.5 a
4	Paharangan (FS)	73.8 ab	12.6 d	7.8 a
5	S. Kambat (TS)	87.8 a	43.6 b	11.0 a
6	Danda Jaya (TS)	76.4 ab	18.0 d	6.2 a
7	Gambut (TS)	87.1 a	60.9 a	11.8 a
8	Blandean (TS)	80.0 a	19.0 d	8.1 a
9	Barambai (TS)	63.0 b	20.8 cd	8.1 a
10	Murung K. (TS)	83.5 a	35.6 bc	9.0 a

Note. Mean followed by the same letters in the same column was not significantly different based on DMRT α 5%. FB, freshwater swampland; TS, tidal swampland.

The difference in terms of Fe addition treatment and *Salvinia* sp. accession caused a variation of pH and Fe concentration in the Hoagland nutrient solution. The increase of Fe concentration from 7 to 14 ppm caused the decline of pH from 5.3 to 5.0 (Table 4). Diverse *Salvinia* sp.

Table 3: The doubling time of *Salvinia* sp. (days) after 4 weeks of maintenance in some Fe treatments in Hoagland nutrient solution.

No.	*Salvinia* sp. accessions	Fe treatment (ppm)		
		Control	7	14
1	D. Ceramin (FS)	5.9 a	12.8 ab	24.2 abc
2	Muning T. (FS)	4.6 a	7.7 cd	22.4 bc
3	Tawar-2 (FS)	4.8 a	11.1 bc	27.2 a
4	Paharangan (FS)	5.2 a	16.1 a	22.1 c
5	S. Kambat (TS)	4.5 a	7.5 d	17.3 de
6	Danda Jaya (TS)	5.0 a	12.9 ab	26.3 ab
7	Gambut (TS)	4.5 a	6.0 d	16.7 ef
8	Belandean (TS)	4.8 a	12.7 ab	21.1 cd
9	Barambai (TS)	5.8 a	11.8 bc	21.2 cd
10	Murung K. (TS)	4.7 a	8.6 cd	20.0 cde

Note. Mean followed by the same letters in the same column was not significantly different based on DMRT α 5%. FS, freshwater swampland; TS, tidal swampland.

Table 4: The change of pH and Fe concentration in Hoagland nutrient solution after enriched with 7 and 14 ppm Fe during 2 weeks of *Salvinia* sp. growth.

No.	*Salvinia* sp. accessions	pH		Average	Fe		Average
		7*	14*		7*	14*	
	Control	4.8	4.6	4.7	6.1	11.8	9.0
1	D. Ceramin (FS)	5.4	5.0	5.2 a	4.9	10.2	7.5 a
2	Muning T. (FS)	5.4	4.9	5.1 ab	2.2	9.3	5.8 bc
3	Tawar-2 (FS)	5.2	5.2	5.2 a	3.1	9.1	6.1 bc
4	Paharangan (FS)	5.3	5.3	5.3 a	4.5	9.8	7.1 ab
5	S. Kambat (TS)	5.4	4.6	5.0 ab	2.6	8.9	5.7 c
6	Danda Jaya (TS)	5.4	5.2	5.3 a	3.6	9.5	6.5 abc
7	Gambut (TS)	4.9	4.7	4.8 b	2.1	5.6	3.9d
8	Belandean (TS)	5.3	5.2	5.3 a	2.6	8.5	5.5 c
9	Barambai (TS)	5.3	4.9	5.1 ab	4.1	8.8	6.4 abc
10	Murung K. (TS)	5.2	4.8	5.0 ab	3.4	8.4	5.9 bc
	Mean value	5.3 a	5.0 b		3.3 b	8.8 a	

Note. Mean followed by the same letters in the same column was not significantly different based on DMRT α 5%. 7*, treatment of 7 ppm Fe; 14*, treatment of 14 ppm Fe; FS, freshwater swampland; TS, tidal swampland.

accession stimulated the pH variation in the range of 4.8 to 5.3. Fe content in nutrient solution with 7 ppm Fe treatment was lower than those with 14 ppm Fe treatment, that is, 3.3 ppm <8.8 ppm. Moreover, the variation of Fe content in the observed nutrient solution was about 3.9–7.5 ppm Fe (Table 4).

The differences of remaining Fe in nutrient solution after culturing by diverse *Salvinia* sp. accessions indicated the difference of *Salvinia* sp. to absorb Fe in the nutrient solution. The absorption of Fe from the nutrient solution was also determined by the Fe saturation. In 7 ppm Fe treatment, *Salvinia* sp. could absorb 19.7–65.6% after 2 weeks of culture. In 14 ppm Fe treatment, the ability of *Salvinia* sp. to absorb Fe decreased in the range of 13.6–52.5% after a similar culture period (Table 4). The decline of Fe absorption was the result of *Salvinia* sp. growth inhibition in a more saturated 14 ppm Fe treatment (Tables 1–3).

The Fe content in *Salvinia* sp. tissue increased following the increase in Fe concentration in nutrient solution as a growing medium (Figure 3). The difference in *Salvinia* sp. accessions caused the variation of Fe levels in plant *Salvinia* sp. tissue. In *Salvinia* sp. tissue treated with 7 ppm Fe, the level of Fe was around 5295–11418 ppm, while in 14 ppm Fe treatment, the level of Fe was around 1875–30122 ppm (Figure 3).

The high content of Fe in *Salvinia* sp. tissue in 14 ppm treatment might cause distraction in plant metabolism that restricted the growth of *Salvinia* sp., as indicated by the low fresh weight of *Salvinia* sp. under 14 ppm treatment compared to those under 7 ppm treatment (Table 2).

Among 10 accessions, there were 4 accessions selected based on their performances in 7 ppm Fe treatment, namely S. Kambat, Murung Karamat, Gambut, and Muning Tengah. The nutrient content of the 4 selected accessions of *Salvinia* sp. is shown in Table 5. The results of the analysis of the nutrient content of *Salvinia* sp. showed that carbon organic levels ranged from 38.75 to 42.38%, nitrogen varied from 2.18 to 3.17%, phosphor ranged from 0.37 to 0.0.57%, potassium varied from 1.78 to 2.02%, and Fe ranged from 5295 to 8526 ppm (Table 5).

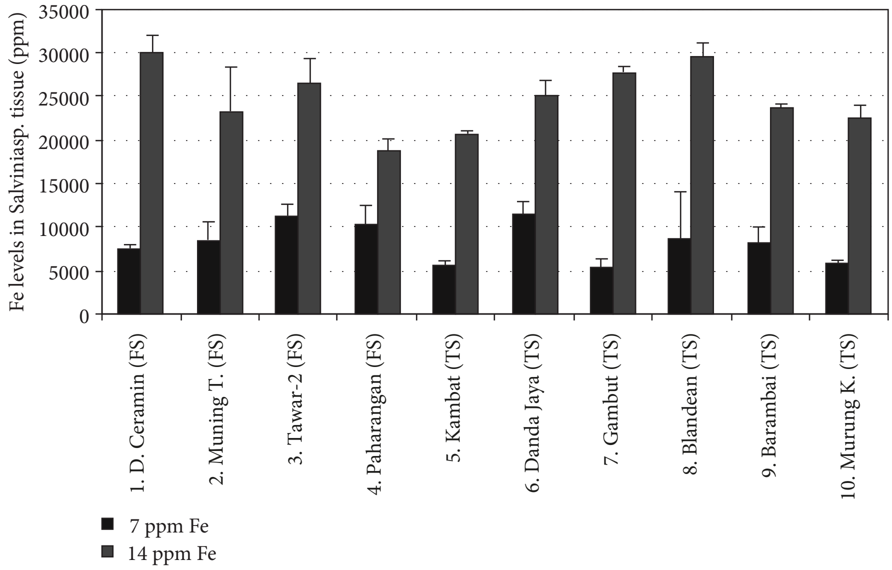

Figure 3: Fe levels in *Salvinia* sp. tissue that was cultured within 4 weeks in Hoagland nutrient solution enriched with 7 ppm Fe and 14 ppm Fe.

Table 5: Biomass; doubling time; and the content of carbon, nitrogen, phosphor, potassium, and iron in *Salvinia* sp. tissue in nutrient solution after enriched with 7 ppm Fe.

Salvinia sp. accession	BM (g)	DT (days)	C (%)	N (%)	P (%)	K (%)	Fe (ppm)
Muning Tengah (FS)	43.2	7.7	38.75	2.18	0.37	1.79	8526
S. Kambat (TS)	43.6	7.5	42.38	2.98	0.57	1.85	5545
Gambut (TS)	60.9	6	38.77	2.66	0.42	2.02	5295
Murung Karamat (TS)	35.6	8.6	38.19	3.17	0.37	1.78	5835

Note. BM, biomass of *Salvinia* sp.; DT, doubling time of *Salvinia* sp.; C, carbon; N, nitrogen; P, phosphorus; K, potassium; Fe, iron; FS, freshwater swampland; TS, Tidal swampland.

The results in Figure 2 and Tables 2 and 3 show that the level of Fe in solution affects the growth of *Salvinia* sp.; when the Fe concentration was higher, it blocked the growth and lowered the biomass weight of *Salvinia* sp. Some *Salvinia* sp. accessions showed better growth, this indicates the adaptability of some *Salvinia* sp. accessions. In the 7 ppm Fe concentration, the highest biomass was found in Gambut's accession for about 60.9 g (doubling time 6.0), S. Kambat 43.6 g (doubling time 7.5), and Muning Tengah's accession for about 43.2 g (doubling time 7.7).

This finding enriched the result of previous studies that only showed the ability of *Salvinia* sp. to adapt to heavy without any limitation of which Fe level *Salvinia* sp. could still be resistant [10, 21]. A previous more recent study by Rantjita et al. showed that *Salvinia molesta* could grow well in water that contaminated with heavy metal (Cu and Pb) less than 10 ppm, but it could not grow if the contaminants were Cr and Cd. In addition, *Salvinia* sp. also could clean the water waste from industry [22]. Hasan et al. showed that the dry biomass of *Salvinia* sp. could transfer 98% of nitrogen and phosphorus from cassava industry water waste [23].

According to the results of research by Mardelena and Napoleon, aquatic plants such as water hyacinth (*Eichornia crassive*), water lettuce (*Pistia straiotes*), and floating fern (*Salvinia natans*) can be used as phytoremediation materials for water contaminated by coal waste because of their ability to absorb heavy metals such as Fe and Mn. *Salvinia natans* is most effective in absorbing Mn metal compared to other aquatic plants. The use of *Salvinia natans* can reduce the levels of Fe 34.8% and Mn 36.0% after 10 days and 63.5% Fe and 42.8% Mn in 20 days [11]. The research results of Baroroh et al. showed that the water plants *Salvinia molesta* was able to remove Cu from a solution containing 2 ppm Cu as much as 96% and a solution containing 5 ppm Cu as much as 95% after 7 days without disrupting the plant growth [24].

In the rhizofiltration mechanism, plant roots play an important role because of their ability to produce a widespread root system and accumulate high concentrations of heavy metals [25]. According to Olguin and Sanchez-Galvan (2012), there are two mechanisms for the ability of plants or microorganisms to uptake metals, namely (1) adsorbing the metal onto their surface through passive mechanisms and (2) accumulating the contaminant at the intracellular level through metabolically active mechanisms [26]. Several environmental factors such as pH, solar radiation, nutrient availability, and salinity greatly influence the phytoremediation potential and growth of the plant [27, 28].

The response of plants to heavy metal toxicity was varied. Some plant species have the ability to accumulate large amounts of heavy metals without showing toxicity symptoms [27]. Some plant species were very sensitive to small amounts of heavy metals and other species were tolerant to high levels of heavy metals so that tolerant varieties could be used as phytoremediation agents in contaminated ecosystems [29]. The plant mechanism of phytoremediation accumulates contaminants through its roots and then translocates these contaminants to its upper body [14, 15]. The mechanism of plant tolerance to heavy metals might be due to the formation of phytochelatins in plant vacuolar [30]. Phytochelatins were low molecular weight peptides that contain cysteine, where their biosynthesis was driven by the presence of heavy metals [31].

Previous studies showed that *Salvinia* sp. can remove or absorb contaminants such as heavy metals, organic compounds, and inorganic nutrients from the environment. Begum and HariKrihsna reported that after 10 days of culture, *Salvinia* sp. was able to remove 88.8% Fe, 67% Cu, and 40.4% Ni in a nutrient solution that was added with 5 ppm of Fe, Cu, and Ni. *Salvinia* sp. could still grow normally, without showing any symptoms of toxicity in 5 ppm of Fe [32].

Salvinia sp. showed a great potential to absorb heavy metals from the environment by compartmenting them as a secondary defense against the environment [19]. The absorption of heavy metals by *Salvinia* sp. was conducted through biological and physical processes. Metals such as Cr and Pb were bound through physical processes such as absorption, ion exchange, and chelation, while Cd was bound through biological processes, namely intracellular absorption or transported via plasmalemma into cells [32]. The absorption of heavy metals could be done directly through leaf contact with the solution by considering the absorption capacity of the leaves [29].

3.2. The Evaluation of Adaptation of 4 Selected Salvinia sp. Accessions to Fe Concentration in Tidal Swampland Soil Growing Media. Research aims to get *Salvinia* that is adaptive on soils that have problems with high soil Fe (problematic soil with Fe toxicity in rice plants) and fast-growing *Salvinia* with high biomass as organic ameliorant in tidal swampland. Tidal swampland soil was obtained from tidal swampland and transferred into the pot as a growing medium for the present experiment. The results of the soil analysis showed that the soil was strongly acidic and contained a high C carbon organic content; a medium nitrogen content; and a low potassium, calcium, and magnesium content, but rich in sodium. The toxic elements in the form of Al and Fe were high in this silty clay-textured soil (Table 6).

The soils used in the experiment had high Fe content (1.626 ppm Fe), which might produce iron toxicity in plants. The resistance of a plant to Fe toxicity depends on soil Fe content and plant tolerance. The growth of 4 selected *Salvinia* sp. accession grown on tidal swampland soil medium in the pot was normal as indicated by the increase of the percentage of surface covered by *Salvinia* sp. from the 1st week to the 4th week. This finding highlighted the rapid growth of *Salvinia* sp. accessions from S. Kambat and Murung Karamat (origin of tidal swampland) rather than Gambut (origin of tidal swampland) and Muning Tengah (origin of the freshwater swampland (Table 7).

After growing for 4 weeks, the fresh weight of *Salvinia* per pot from S. Kambat was 31.44 g and the origin of Murung Karamat (30.28 g) was higher than that of *Salvinia* from Murung Karamat (18.54 g) and from Gambut accession (21.68 g). The fastest doubling time of *Salvinia* sp. was found in S. Kambat and Murung Karamat accessions for about 7.86 days, faster than Gambut for about 10.02 days, and Muning Tengah for about 10.92 days. The Fe content in *Salvinia* sp. tissue was not significantly different among the 4 tested accessions (Table 8).

There was no difference among the 4 accessions of *Salvinia* sp. in terms of surface water pH in tidal swampland soil after 4 weeks of culture. The acidity (pH) of the surface water in the pot ranged from 3.72 to 3.86 (Table 9).

Fe content of surface water in the pot after 4 weeks of culture differed among the 4 accessions of *Salvinia* sp., which ranged from 4.90 ppm Fe (S. Kambat) to 6.40 ppm Fe (Muning Tengah). However, these results were still below the Fe content in the control treatment (pot without *Salvinia* sp.) that was around 7.90 ppm Fe. Therefore, *Salvinia* sp. proved to reduce the Fe content ranging from 19 to 38%.

This finding highlighted the ability of *Salvinia* sp. to grow both on Hoagland nutrient solution and tidal swampland soil containing Fe. Not only to grow, *Salvinia* sp. was also able to remove (absorb) Fe in nutrient solution media. In addition, there was a variation in terms of adaptation observed among *Salvinia* sp. accessions. This finding showed that some *Salvinia* sp. from tidal swamplands were quite adaptive at 7 ppm Fe treatment. However, the increase of Fe concentration to 14 ppm inhibited all accessions of *Salvinia* sp. leading to the failure of adaptation and the decline of growth of about 86–92% compared to controls (Table 2).

The 4 accessions of *Salvinia* sp. are growing quiet well (Tables 7 and 8) on soil media from tidal swampland with very acidic soil (pH 3.9) and high Fe contain 1.626 ppm (Table 6). *Salvinia* sp. absorbs iron which is quite high with Fe tissue containing around 2441–2764 ppm after 4 weeks of growing in pots (Table 8). The presence of Fe absorption from the solution by *Salvinia* sp. caused a decrease in Fe content in solution (Table 9).

The condition of heavy metals such as high Fe in the soil or water can disrupt plant growth. Research results by Lubis et al., on tidal swampland in South Kalimantan with Fe soil contain 631 ppm; paddy IR.64 (sensitive varieties) showed severe symptoms of iron toxicity [33]. The Fe concentration in a solution ≥325 ppm showed severe symptoms of iron toxicity in the IR.64 variety, which caused inhibition of rice plant growth [34]. Iron toxicity in the rice plant experienced a decrease in morphophysiological performance as indicated by a decrease in plant height, length and width, number of leaves, and contents of chlorophyll and carotenoids [35]. Iron toxicity affects some characters of rice plants such as length of roots, leaves bronzing, photosynthesis and transpiration level, contents of soluble sugars, proteins, and starch [37].

Table 6: Characteristics of soil that originated from KP Blandean, Barito Kuala District, South Kalimantan Province.

Soil characteristics	Value	Criterion
pH (H_2O)	3.90	SA
Organic carbon (%)	5.86	H
N total (%)	0.26	M
P Bray I (ppm P_2O_5)	138.3	H
P total (mg $100\,g^{-1}$ P_2O_5)	124	H
K total (mg $100\,g^{-1}$ K_2O)	9.00	L
Exchangeable bases (me $100\,g^{-1}$):		
Ca	0.80	L
Mg	1.64	L
K	0.03	VL
Na	1.67	H
CEC (me $100\,g^{-1}$)	23.29	M
Al-dd (me $100\,g^{-1}$)	11.05	H
Fe available (ppm)	1626	VH
Texture (%):		
Clay	58	
Silt	40	Silty clay
Sand	2	

Note. SA, strongly acidic; *M*, moderate; VL, very low; *L*, low; *H*, high; VH, very high.

Table 7: The percentage of surface covered by *Salvinia* sp. after 4 weeks of maintenance in tidal swampland soil growing media.

Salvinia sp. accession	Surface covered by *Salvinia* sp. (%)			
	1st week	2nd week	3rd week	4th week
Muning Tengah	17.0 a	26.8 a	50.2 b	60.6 b
S. Kambat	18.8 a	29.6 a	59.6 a	84.4 a
Gambut	17.8 a	28.8 a	53.0 ab	72.2 ab
Murung Karamat	18.0 a	30. a	58.4 a	85.0 a

Note. Mean followed by the same letters in the same column was not significantly different based on DMRT α 5%.

Table 8: The fresh weight of *Salvinia* sp. biomass, the doubling time of *Salvinia* sp. plant, and the Fe content in *Salvinia* sp. tissue after 4 weeks of maintenance in soil growing medium that originated from tidal swampland.

Salvinia sp. accession	Fresh weight (g)	Doubling time (days)	Fe content (ppm)
Muning Tengah	18.54 b	10.92 a	2625 a
S. Kambat	31.44 a	7.86 b	2441 a
Gambut	21.68 b	10.02 a	2764 a
Murung Karamat	30.28 a	7.86 b	2624 a

Note. Mean followed by the same letters in the same column was not significantly different based on DMRT α 5%.

Table 9: The pH and Fe content of surface water in the pot after the culture of *Salvinia* sp. during 4 weeks in tidal swampland soil growing media.

Salvinia sp. accessions	pH	Fe (ppm)
Control (without *Salvinia* sp.)	3.86 a	7.90 a
Muning Tengah	3.78 a	6.40 b
S. Kambat	3.86 a	4.90 c
Gambut	3.77 a	5.54 bc
Murung Karamat	3.72 a	5.62 bc

Note. Mean followed by the same letters in the same column was not significantly different based on DMRT α 5%.

The presence of carboxylate groups on the cell surface provided a suitable area to bind metals (Olguin et al. [38]). *Salvinia* sp. biomass has a high ability to remove or bind metals as indicated by the size of the specific surface ($264\,m^2 \cdot g^{-1}$) that is mostly composed of carbohydrates (48.50%) and carboxyl groups ($0.95\,mmol \cdot g^{-1}$) [39]. Protein is an important ligand atom and also played an important role in metal absorption.

The biomass of *Salvinia* sp. indicated its ability not only to bind but also to absorb heavy metals. The high concentrations of lipids and carbohydrates on the plant surface acted as a weak cation exchange group that contributed to metal absorption through ion exchange reactions [40]. A previous study by Dhir and Kumar showed that the biomass of *Salvinia* sp. could be used as an adsorbent and it was more effective to bind heavy metals such as Ce, Ni, and Cd than other crop wastes such as rice straw and wheat straw. The heavy metals' binding efficiency of *Salvinia* sp. biomass, rice straw, and wheat straw were 60.0%, 57.1%, and 45.7%, respectively. The test was conducted at 10 days post-culture in a solution added with 35 ppm heavy metals. However, the extreme increase of heavy metal content in the solution could decline the efficiency of *Salvinia* sp. to bind heavy metals [41].

There are several mechanisms in environmental phytoremediation such as phytoextraction, phytostabilization, phytovolatilization, and rhizofiltration during the uptake of heavy metals in the plant [42]. Several advantages resulted from the usage of *Salvinia* sp. as important species for phytoremediation were (1) the large geographical distribution of *Salvinia* sp. within the tropic and subtropic region, (2) the high productivity of about 5.8–11.4 g dry matter per m^2 per days under Hoagland culture and 20–120 kg per Ha per days in natural conditions [37], (3) the broad water surface covered area (264 m^2 per g dry weight) and the high carboxylate ligand content (0.95 mmol H^+ per g biomass), (4) the high efficiency to remove nutrients or pollutants from wastewater, (5) the high metal removal rates per surface unit and the high metal returns after appropriate treatment [38], and (6) easy to harvest as leaves and it is possible to exploit the harvested biomass [19].

4. Conclusion

(1) The increase of Fe concentration in the Hoagland nutrient solution inhibited the growth, declined the fresh weight of *Salvinia* sp. biomass, and delayed the doubling time of the *Salvinia* sp. plant. The doubling time of *Salvinia* sp. treated with 7 ppm Fe was faster than those in 14 ppm Fe, that is, 6.0–16.1 days and 16.7–27.2 days, respectively.

(2) *Salvinia* sp. that was cultured for 2 weeks in 7 ppm Fe treatment could decline Fe concentration in nutrient solution for 19.7–65.6%.

(3) Selection in 7 ppm Fe treatment resulted in 4 adaptive *Salvinia* sp. accessions, namely Muning Tengah, S. Kambat, Gambut, and Murung Karamat with the doubling time in the range of 6.0–8.6 days. Further selection in soil growing medium originated from tidal swampland resulted in 2 accessions that showed rapid growth rate, namely S. Kambat and Murung Karamat with doubling time for about 7.9 days.

Data Availability

The data that support the research can be obtained from the corresponding author upon request.

Conflicts of Interest

All authors declare that there are no conflicts of interest in the writing and publishing of this article.

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