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THE EFFECT OF GIBBERELLIC ACID (GA_3) ON GROWTH, PHOTOSYNTHETIC PIGMENTS, AND METAL BIOSORPTION IN THE WATER FERN *Salvinia natans* (L.) All. UNDER ZINC STRESS

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Aim. This study investigates the impact of exogenous gibberellic acid (GA_3) on growth, photosynthetic pigment content, and zinc biosorption by sporophytes of the water fern *Salvinia natans* L. at both the initial and final stages of ontogeny.

Methods. The ability of *S. natans* sporophytes to remove zinc from the aquatic environment was assessed by analyzing water samples post-cultivation using a portable Macherey-Nagel PF-12 Plus photometer. Photosynthetic pigments were extracted with 100% acetone and quantified using a Jenway UV-6850 spectrophotometer (UK) at wavelengths of 662, 664, and 440.5 nm, with acetone serving as the control.

Results. At both the intensive growth stage and the phase of sorus formation and spore maturation, exogenous GA_3 enhanced fresh and dry biomass accumulation in *S. natans* sporophytes, increased chlorophyll content, and alleviated the adverse effects of zinc sulfate. These morphological and physiological improvements were more pronounced in mature sporophytes. The study also confirmed the ability of *S. natans* sporophytes to biosorb zinc ions from the aquatic environment, with zinc uptake in young sporophytes increasing by 10% upon GA_3 application.

Conclusions. During its intensive growth phase, *S. natans* effectively removes zinc compounds from water, demonstrating its potential for phytoremediation. Exogenous GA_3 (10^{-6} M) mitigates the toxic effects of zinc (10 mg L^{-1}), enhancing growth and photosynthetic pigment content. Observable phenotypic changes in response to zinc toxicity further suggest that *S. natans* could serve as a bioindicator of water pollution.

Key words: *Salvinia natans*, zinc, gibberellins, growth, photosynthetic pigments, biosorption .

Phytoremediation is a cost-effective and environmentally friendly approach to mitigating anthropogenic pollution. A critical aspect of phytoremediation is selecting plant species capable of efficiently removing pollutants from the environment [1]. Alongside macrophytes such as water hyacinth (*Eichhornia crassipes* (Mart.) Solms), water lettuce (*Pistia stratiotes* L.), and duckweed (*Lemna* L.), species of the genus Salvinia exhibit a remarkable ability to hyperaccumulate contaminants, making them suitable candidates for the remediation of polluted water bodies [2].

Specific species within the Salvinia genus have been shown to absorb various heavy metals (HMs). *Salvinia herzogii de* la Sota accumulates cadmium (Cd) and chromium (Cr) [3]; *Salvinia*

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minima Baker absorbs Cd, nickel (Ni), lead (Pb), and zinc (Zn) [4]; and *Salvinia natans* (L.) All. has been found to accumulate Cr, iron (Fe), Ni, copper (Cu), Pb, Cd, Zn, cobalt (Co), and manganese (Mn) [5–7]. In recent years, due to climate change, the range of *S. natans* in Europe has expanded significantly, leading to a prolonged sporophyte vegetation period and an increase in the number of generations per year from two or three to five or more [8, 9]. *S. natans* is known for its robust antioxidant system and resilience to osmotic stress [10]. The physiological and biochemical adaptations of Salvinia species allow them to mitigate the toxic effects of heavy metal accumulation [11]. Previous studies have reported that *S. natans* sporophytes can accumulate 6–9 mg/g DW of Cr, Fe, Ni, Cu, Pb, and Cd, and up to 4 mg/g DW of Co, Zn, and Mn [6, 10].

Zinc is an essential micronutrient involved in enzyme activation and the metabolism of proteins, lipids, nucleic acids, and carbohydrates. It serves as a cofactor for numerous enzymes and is a key component of various transcription factors [12]. However, excessive Zn levels lead to anthocyanin overproduction, photosynthesis inhibition, chlorosis, and necrosis, ultimately suppressing plant growth [13]. Zn^{2+} toxicity primarily arises from its interference with metal ion transport in chloroplasts, replacing essential elements such as Mn^{2+}, Ca^{2+}, and Mg^{2+} while blocking Fe^{2+}, Mn^{2+}, and Cu^{2+} uptake, resulting in nutrient deficiencies [14]. Although Zn is not a redox-active metal, it can still induce oxidative stress by depleting glutathione, binding to protein sulfhydryl groups, inhibiting antioxidant enzymes, or triggering the production of reactive oxygen species (ROS) [15].

Plant responses to heavy metal-induced stress involve hormonal regulation. Under HM stress, levels of stress-related hormones such as abscisic acid, salicylic acid, brassinosteroids, ethylene, and jasmonates increase. In contrast, growth-promoting hormones such as auxins, cytokinins, and gibberellins decrease, leading to growth inhibition but improving plant survival under adverse conditions [16].

One potential strategy to alleviate environmental stress is the application of exogenous plant growth regulators [17]. However, the hormonal system of hydrophytic ferns, including those of the Salviniaceae family, remains poorly studied [18,19]. Gibberellins, a diverse group of diterpenoid tetracyclic compounds, play a crucial role in regulating numerous physiological processes [20]. They help mitigate both abiotic and biotic stress effects [21, 22]. Under pollution and HM toxicity, gibberellins function as signaling molecules, promoting growth, enhancing immunity, stabilizing ontogenetic processes, and counteracting stress-induced damage [23].

Additionally, gibberellins regulate oxidative stress by reducing ROS accumulation and influence metal ion transport by modulating transporter protein expression [24]. Despite their importance, the role of gibberellins in Salviniaceae species has been scarcely investigated. For some Salvinia species, endogenous gibberellins have been implicated in the regulation of sporophyte growth and development [19]. Gaudet and Koh [25] reported that low concentrations of exogenous GA_3 stimulated a 6% increase in fresh weight (FW) and a 6.7% increase in dry weight (DW) in sterile cultures of *Salvinia rotundifolia*. In contrast, higher concentrations had no significant impact on biomass accumulation. Exogenous GA_3 also had minimal effects on morphology, except for a slight reduction in floating frond area.

Heavy metals negatively affect photosynthetic activity by inhibiting pigment biosynthesis, disrupting electron transport, inducing lipid peroxidation, and damaging organelle membranes [26]. Mohan and Hosetti [27] reported a decrease in chlorophyll content in *Salvinia natans* sporophytes exposed to Cd. The initial symptom of Cd toxicity was chlorosis, which progressed to necrosis with increasing Cd concentration and exposure duration. In control plants, total chlorophyll content peaked at 0.425 ng/g FW, whereas it dropped to 0.109 mg/g after 8 days of Cd exposure. Similarly, exposure to Cr and Zn in *S. natans* led to a reduction in photosynthetic pigments and a decline in Rubisco activity [28]. Furthermore, Cd, Pb, Ni, Zn, and mercury (Hg) caused a progressive decrease in photosynthetic pigment and protein content as HM concentration and exposure duration increased [29–32].

This decline may result from HM interference with the sulfhydryl sites of enzymes involved in pigment biosynthesis [26].

Our previous studies showed that abscisic acid (10^{-6} M) inhibited fern biomass accumulation, while kinetin and GA_3 (10^{-6}M) promoted growth. Additionally, zeatin (10^{-6} M) mitigated Zn-induced damage to the pigment complex in young *S. natans* sporophytes [7, 33]. Given the widespread Zn contamination of water bodies near industrial areas, this study aims to investigate the effects of exogenous gibberellic acid on *S. natans* growth, photosynthetic pigment content, and its capacity for Zn ion removal under Zn stress.

Materials and Methods

Plant Material Collection

Sporophytes of the floating aquatic fern *Salvinia natans* (L.) All. were collected in June and August 2023 from the Prorva River near Hnidyn village, Boryspil district, Kyiv region. During these months, the average air temperatures were 26 °C and 28 °C, while water temperatures were 23 °C and 25 °C, respectively.

Effect of Gibberellic Acid and Zinc Sulfate on Salvinia natans Growth

Two developmental stages of *S. natans* sporophytes were studied: 1. Young Sporophytes: Consisting of 3–5 pairs of floating and submerged fronds attached to a horizontal stem. 2. Mature Sporophytes: Undergoing sori formation and spore maturation. Young sporophytes (four individuals per container) and mature sporophytes (one individual per container) were placed in 250 ml glass containers filled with purified tap water supplemented with: 1. Gibberellic acid (GA_3) at a concentration of 10^{-6} M. 2. Zinc sulfate providing 10 $mg \cdot L^{-1}$ of zinc. 3. A combination of GA_3 (10^{-6} M) and zinc sulfate (10 $mg \cdot L^{-1}$ zinc). Control plants were grown in water without additives. All ferns were cultivated for seven days in a VOTSCH GmbH (Germany) vegetation chamber under the following conditions:

- Temperature: 22 °C;
- Illumination: 190 $\mu mol \cdot m^{-2} \cdot s^{-1}$;
- Photoperiod: 16 hours light / 8 hours dark;
- Relative humidity: 65% ± 5%.

Biometric parameters were recorded at the start and after seven days of cultivation.

Photosynthetic Pigment Analysis

On the seventh day, 200 mg of plant material was collected for pigment analysis. Photosynthetic pigments were extracted using 100% acetone and quantified as described by [7]. Absorbance measurements were taken with a Jenway UV-6850 spectrophotometer (UK) at 662 nm, 664 nm, and 440.5 nm, using acetone as the blank.

Zinc Removal Capacity of Salvinia natans Sporophytes

Young *S. natans* sporophytes (4 g) in the intensive growth phase were placed in 1-liter containers. Water samples (5 ml) were collected on days 4, 6, 8, 10, 12, and 14 using a syringe, ensuring no solid residues were included. Samples were filtered through 0.2 µm regenerated cellulose membrane syringe filters. Zinc ion concentrations were determined using a Macherey-Nagel PF-12 Plus portable photometer, employing method 5981 as per the instrument interface. Reagents from Macherey-Nagel test kit No. 5-98 (REF 931098) were added to the samples following the manufacturer's instructions for Zn^{2+} quantification. Initial zinc ion concentrations in reservoir water were below the method's detection limit of 0.1 $mg \cdot L^{-1}$.

Statistical Analysis

Experiments were conducted in triplicate, with three analytical replicates each. Results are presented as mean ± standard error. Differences between means were analyzed using two-way ANOVA, with significance set at $P < 0.05$. Statistical analyses were performed using Statistix v. 10.0 (Analytical Software, Tallahassee, FL, USA). Graphs were generated using Microsoft Excel (Redmond, USA).

Results and Discussion

Effect of Exogenous Gibberellic Acid and Zinc Sulfate on Sporophyte Morphometric Parameters

After seven days of vegetation, no significant changes in FW were observed in control *S. natans* plants, which were in the intensive growth stage. Compared to the control, the addition of exogenous GA_3 to the culture medium increased sporophyte FW by 9.6%, whereas zinc sulfate reduced FW by 9.1%. The combined application of GA_3 and zinc sulfate resulted in a 6.3% decrease in FW (Table 1).

At the stage of sori formation and spore maturation, FW decreased across all experimental variants. Compared to the control, FW declined by 19.5% with zinc sulfate and by 13.4% with the combined GA_3 and zinc treatment. However, GA_3 alone increased FW by 9.5% relative to the control.

GA_3 also stimulated an increase in DW at both growth stages—by 7.5% during intensive growth and by 17.5% during sori formation and spore maturation. Conversely, zinc sulfate significantly reduced DW in young sporophytes by 52.4% and in mature sporophytes by 33.0%. In the GA_3 + Zn treatment, DW decreased by 44.4% in young sporophytes and by 9.3% in mature ones. DW

Table 1

Effect of gibberellic acid and zinc sulfate on fresh weight (FW) and dry weight (DW) accumulation of *Salvinia natans* sporophyte in the stage of intensive growth and stage of sori formation and spore maturation

Experiment option	Fresh weight, g		Gain of fresh weight on the 7th day, %	Dry weight, mg/g
	1st day	7th day		
The stage of intensive growth (five plants)				
Control (water)	1.38±0.07	1.41±0.07	102.2	187.14± 9.35
GA_3 (10^{-6} M)	1.25±0.06	1.40±0.07	112.0	201.03± 10.05
Zn (10 mg/L)	1.27±0.06	1.18±0.06*	92.9	89.21± 4.45*
Zn + GA_3	1.19±0.06	1.14±0.06*	95.8	104.19± 5.20*
The stage of sori formation and spore maturation (one plant)				
Control (water)	2.57±0.3	2.20±0.11	85.6	97.08± 4.85
GA_3 (10^{-6} M)	1.59±0.08	1.49±0.07*	93.7	114.31± 5.70*
Zn (10 mg/L)	2.41±0.12	1.66±0.08*	68.9	65.12±3.25*
Zn + GA_3	2.59±0.13	1.92±0.10	74.1	88.23±4.40

Note: $n = 15$; $x \pm$ standard error (SE), * indicates significant differences between the indicators of the control and experimental groups ($P \leq 0.05$).

reflects a plant's resource allocation strategy, balancing assimilation, growth, and reserve storage [34, 35]. Our findings suggest that under stress conditions, *S. natans* sporophytes prioritize preserving reserve substances. Similar studies by Hołtra & Zamorska-Wojdyła [6] found that DW changes in *S. natans* depended on metal concentrations in the aquatic environment. Exposure to high Cu^{2+} concentrations (15–20 mg Cu/dm^3) led to a DW loss of 2–9%, while lower concentrations (5–10 mg Cu/dm^3) increased DW by 12–20%. Additionally, at a zinc concentration of 228 mg/L in zinc sulfate, *S. natans* growth halted, sporophyte biomass decreased by up to 51%, and toxicity symptoms became severe [33]. Reports indicate that *S. minima* sporophytes can tolerate low heavy metal concentrations (0.03 mg/L Cd, 0.40 mg/L Ni, 1.00 mg/L Pb, and 1.00 mg/L Zn) for 60 days while maintaining pollutant accumulation capacity [4]. In our study, GA_3 (10^{-6} M) promoted FW and DW accumulation in *S. natans* at both growth stages, whereas zinc sulfate had the opposite effect. In the GA_3 + Zn treatment, FW and DW were higher than with zinc sulfate alone but remained lower than in the control and GA_3-only variants (Table 1).

Overall, the changes in morphometric parameters due to gibberellic acid and zinc sulfate were more pronounced in mature sporophytes, with notable phenotypic alterations. In the presence of zinc, floating fronds developed a brownish-red coloration, accompanied by necrotic spots. However, with the addition of GA_3, the adaxial surface of floating fronds in mature sporophytes turned dark green. This suggests that GA_3 mitigated the adverse effects of metal contamination (Fig. 1).

Effect of Exogenous Gibberellic Acid and Zinc Sulfate on Photosynthetic Pigment Content

At the stage of sori formation and spore maturation, total chlorophyll content nearly doubled compared to the intensive growth stage, while carotenoid levels increased by 1.2 times. Our previous research showed that during *S. natans* sporophyte development, photosynthetic pigment content in floating fronds increased, and the chloroplastic photosynthetic electron transport chain functioned efficiently [36].

Exposure to exogenous GA_3 increased total chlorophyll content in floating fronds of young and mature *S. natans* sporophytes by 16% compared to the control. In contrast, zinc reduced total chlorophyll content in young sporophyte fronds by 23%, while the combination of zinc and GA_3 caused no significant differences from the control. In mature sporophytes, zinc decreased total chlorophyll content by 44%, and the combined treatment with GA_3 led to a 38% reduction. The observed decline in total chlorophyll (*a*+b) suggests reduced photochemical activity, likely due to zinc-induced oxidative stress and chlorophyll degradation [37].

The chlorophyll-to-carotenoid ratio ((*a*+*b*)/carotenoids) is a key indicator of photosynthetic apparatus stability, as its reduction signifies chlorophyll degradation or compensatory carotenoid accumulation [38]. In young sporophytes, this ratio remained within the control range under zinc exposure, suggesting photosynthetic apparatus stability. GA_3 treatment increased the ratio by 7%, while the GA_3 + Zn combination reduced it by 15%. At the sori formation and spore maturation stage, the (*a*+*b*)/carotenoids ratio decreased by 29% with zinc alone and by 31% with the GA_3 + Zn treatment (Table 2).

Chlorophyll and carotenoid levels serve as reliable markers of HM pollution [39]. In *Salvinia rotundifolia* and *S. minima*, exposure to 20 mg/L Cr(VI) reduced chlorophyll *b* and carotenoid content [40]. Similarly, mercury contamination (0.30 mg Hg/dm^3) decreased chlorophyll content in *S. natans* fronds by 53% [30]. Dhir et al. [5] reported that HM ions inhibit photosynthesis in *S. natans* by disrupting carbon assimilation, though primary photochemical processes and photophosphorylation remain largely unaffected. Leal-Alvarado et al. [41] found that lead exposure reduced the photosynthesis rate by 44% in *S. minima* due to membrane damage in submerged fronds and stomatal closure in floating fronds, leading to decreased

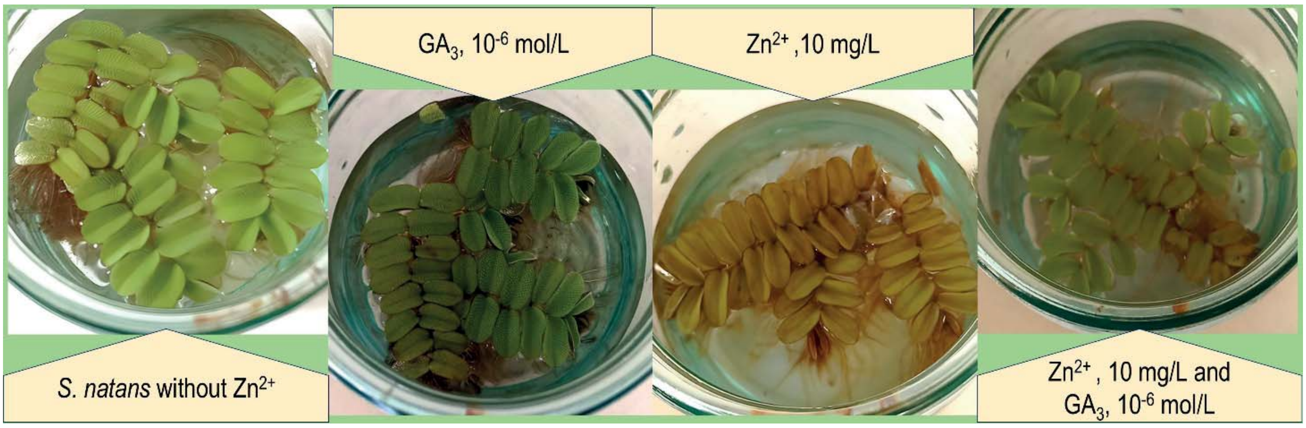

Fig. 1. **Sporophytes of *Salvinia natans* during cultivation on media containing gibberellic acid (10^{-6} M), zinc sulfate (the content of pure zinc per liter of water is indicated), and a mixture of zinc and GA_3 on the seventh day of the experiment at the stage of formation of sori and maturation of spores)**

Table 2

The effect of GA_3, zinc sulfate, and the combination of GA_3 + zinc sulfate on the content of photosynthetic pigments in floating fronds of *Salvinia natans* sporophytes on the 7th day of cultivation, mg/g FW

Option experiment	(*a*+*b*), mg/g FW	(*a*+*b*) / carotenoid
The stage of intensive growth (five plants)		
Control (water)	0.346±0.012	6.7
Zn (10 mg/L)	0.266±0.014*	6.5
GA_3 (10^{-6} M)	0.401±0.010*	7.2
Zn + GA_3	0.322±0.008*	5.9*
The stage of sori formation and spore maturation (one plant)		
Control (water)	0.655±0.006	10.5
Zn (10 mg/L)	0.370±0.008*	7.5*
GA_3 (10^{-6} M)	0.758±0.009*	9.9*
Zn + GA_3	0.408±0.005*	7.3*

Note: * indicates significant differences between the indicators of the control and experimental groups ($P \leq 0.05$).

CO_2 availability. Additionally, at Ni concentrations exceeding 80 μM (1.5 mg/g) in *S. minima* tissues, physiological processes were disrupted, photosystem II efficiency declined, cell membrane integrity was compromised, and photosynthetic pigment content decreased [42]. *S. natans* plants exposed to high lithium levels showed a decrease in potassium and photosynthetic pigment content, while their total antioxidant activity was not significantly changed [43]. However, other studies indicated that there were no adverse effects on photosynthetic pigments under single stress of copper (0.1) mg/L with polybrominated diphenyl ethers [44].

Gibberellins help mitigate heavy metal toxicity by regulating oxidative stress and activating antioxidant defenses. In the unicellular green alga *Chlorella vulgaris*, exogenous GA_3 (10^{-7}–10^{-6} M) under low Pb and Cd contamination preserved developmental processes by increasing photosynthetic pigments, monosaccharides, and protein content [45]. In our study, exogenous GA_3 increased chlorophyll content at both developmental stages of *S. natans*. The GA_3 + Zn treatment alleviated metal stress effects, particularly during intensive growth. Additionally, qualitative changes in fern phenotype confirmed the biotoxicity of excessive zinc concentrations, reinforcing *S. natans* as a promising bioindicator.

Effect of Exogenous Gibberellic Acid on Zinc Ion Extraction from the Aqueous Medium by Salvinia natans Sporophytes

In the control variant (water with 10 mg/L of pure zinc from zinc sulfate, without *S. natans* sporophytes), the zinc ion concentration remained unchanged. However, *S. natans* sporophytes (2 g fixed weight) effectively removed zinc from the aquatic environment, reducing its concentration more than tenfold from 10 mg/L to 0.6 mg/L after 14 days of cultivation. The addition of GA_3 enhanced zinc uptake by 10% by day 6 of the experiment. In both experimental variants, the highest rate of zinc ion adsorption occurred by the sixth day. In the GA_3-treated group, zinc content in water decreased more rapidly than in the untreated variant, indicating a higher adsorption rate at the early stages of the experiment. After day 6, the extraction rate of HM ions slowed significantly, and zinc levels stabilized by day 12 in both conditions. By day 14, zinc concentration in water had decreased to 6% of its initial level in both experimental variants (Fig. 2).

Aquatic macrophytes act as efficient absorbers of pollutants and toxic substances [1]. Phytohormones, including auxins, gibberellins, cytokinins, ethylene, abscisic acid, salicylic acid, and jasmonates, regulate key physiological and biochemical processes involved in HM ion absorption, translocation, and detoxification. These hormones also

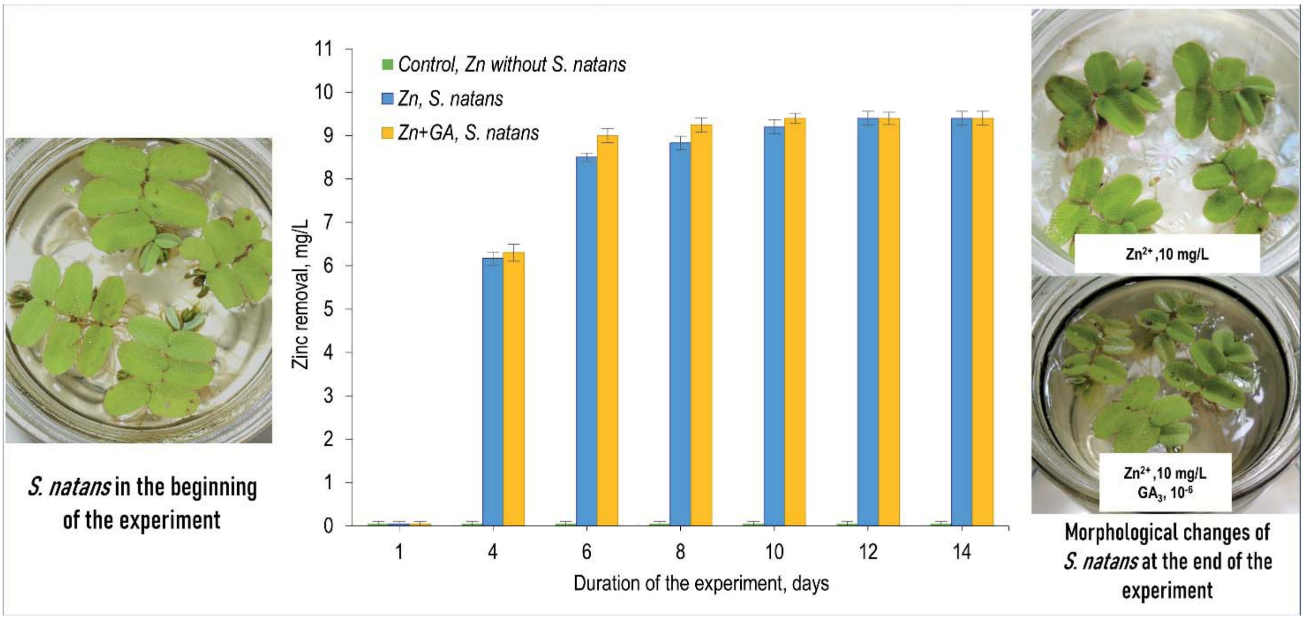

Fig. 2. Dynamics of biological extraction of zinc ions from water by sporophytes of *Salvinia natans* at the stage of intensive growth

enhance plant resistance to environmental stressors [17].

Gibberellins help mitigate HM toxicity by controlling oxidative stress and activating the antioxidant system [46–48]. In *Chlorella vulgaris*, the exogenous application of gibberellins, auxins, cytokinins, and polyamines under Cd, Cu, and Pb intoxication stimulated the biosynthesis of antioxidant enzymes (superoxide dismutase, ascorbate peroxidase, catalase) and the accumulation of ascorbate and glutathione. This reduced oxidative stress, as indicated by decreased lipid peroxidation rates and lower hydrogen peroxide levels [49].

In *Arabidopsis thaliana*, gibberellins alleviated cadmium toxicity by reducing nitric oxide accumulation and downregulating *IRT1*, a gene involved in cadmium uptake [50]. Transcriptomic analysis following exogenous gibberellin application showed upregulation of *GAST1*, a gene regulating ROS accumulation [51]. Additionally, gibberellins enhance the biosynthesis of glutathione (GSH) phytochelatin, a key low-molecular-weight antioxidant, by promoting sulfate assimilation. This mechanism is critical for plant defense against metal stress. In *A. thaliana*, gibberellin signaling increased the expression of adenosine 5′-phosphosulfate reductase, a key enzyme in sulfate assimilation, thereby improving stress tolerance [52].

Our findings demonstrate that GA_3 stimulated zinc ion extraction by *S. natans* sporophytes during the intensive growth stage. We suggest that the enhanced adsorption observed between days 4 and 10 may be due to GA_3-induced sporophyte growth and its ability to mitigate zinc-induced oxidative stress. By the end of the experiment, zinc levels in the water had dropped to 0.6 mg/L, which is below Ukraine's maximum permissible limit for domestic water use (1 mg/L) [53].

Conclusions

This study investigated the effect of exogenous gibberellic acid (GA_3) on growth, photosynthetic pigment content, and zinc ion biosorption in *Salvinia natans* sporophytes. At both the intensive growth stage and the stage of sori formation and spore maturation, GA_3 promoted an increase in fresh and dry weight and alleviated the negative impact of zinc sulfate on these parameters. Morphometric changes induced by GA_3 and zinc sulfate were more pronounced in mature sporophytes.

GA_3 treatment also enhanced chlorophyll content at both developmental stages, mitigating the adverse effects of metal stress on the pigment complex. Zinc exposure caused floating fronds to develop a brownish-red hue and necrotic spots. However, GA_3 treatment restored the adaxial surface of mature fronds to a dark green color. These phenotypic changes highlight the biotoxicity of zinc and support the potential application of *S. natans* as a bioindicator of water pollution.

Additionally, *S. natans* sporophytes effectively biosorbed zinc ions from the aqueous medium. After 14 days of cultivation, zinc concentration decreased more than tenfold, from 10 mg/L to 0.6 mg/L. The presence of GA_3 further enhanced zinc uptake by 10% by day 6 of the experiment.

These findings suggest that GA_3 can enhance both growth and heavy metal tolerance in *S. natans*, reinforcing its potential for use in phytoremediation and environmental monitoring.

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Conflict of Interest

The authors declare that they have no conflict of interest.

Author Contributions

Author Contributions: Conceptualization, I.V. Kosakivska, and V.A. Vasyuk; methodology, V.A. Vasyuk, L.V. Voytenko, M.M. Shcherbatiuk and K.O. Romanenko; investigation, V.A. Vasyuk, M.M. Shcherbatiuk, L.V. Voytenko and K.O. Romanenko; data curation, V.A. Vasyuk, M.M. Shcherbatiuk, L.V. Voytenko and K.O. Romanenko.; writing—original draft preparation, V.A. Vasyuk, M.M. Shcherbatiuk, and K.O. Romanenko; writing—review and editing, I.V. Kosakivska, V.A. Vasyuk, L.V. Voytenko; supervision, V.A. Vasyuk. All authors have read and agreed to the published version of the manuscript.

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ВПЛИВ ГІБЕРЕЛОВОЇ КИСЛОТИ ($ГК_3$) НА РІСТ, ВМІСТ ФОТОСИНТЕТИЧНИХ ПІГМЕНТІВ ТА БІОСОРПЦІЮ МЕТАЛУ СПОРОФІТАМИ ВОДЯНОЇ ПАПОРОТІ *Salvinia natans (* L.) All. ЗА ЦИНКОВОГО СТРЕСУ

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Мета. Дослідити вплив екзогенної гіберелової кислоти ($ГК_3$) на ріст, вміст фотосинтетичних пігментів та біосорбцію іонів цинку із водного середовища спорофітами водяної папороті *Salvinia natans* на початковій і завершуючій стадіях онтогенезу

Методи. Визначення здатності спорофітів *S. natans* вилучати цинк з водного середовища оцінювали за результатами аналізу проб води після вирощування рослин за допомогою портативного фотометра *Macherey-Nagel PF-12 Plus*. Фотосинтетичні пігменти екстрагували 100% ацетоном. Вимірювання проводилися за допомогою спектрофотометру *Jenway UV-6850* (Великобританія) на довжині хвиль 662, 664 та 440,5 нм, ацетон використовували як контроль.

Результати. На стадії інтенсивного росту та стадії формування сорусів і дозрівання спор екзогенна $ГК_3$ індукувала зростання маси сирої і сухої речовини спорофіту *S. natans* , підвищувала вміст хлорофілу та пом'якшувала негативний вплив сульфату цинку на ці показники. Більш виразні зміни морфо-фізіологічних параметрів зафіксовані у зрілих спорофітах. Продемонстровано здатність спорофіта *S. natans* до біосорбції іонів цинку з водного середовища. За додавання$ГК_3$ поглинання цинку молодими спорофітами збільшилось на 10% .

Висновки. Встановлено, що у фазу інтенсивного росту спорофіти *Salvinia natans* ефективно очищують воду від сполук цинку. Виявлено протекторний ефект екзонгеної гіберелової ($ГК_3$, 10^{-6} М) за негативного впливу цинку (10 $мг/л^{-1}$) на ріст та вміст фотосинтетичних пігментів папороті. Якісні зміни у фенотипі папороті, які демонструють біотоксичність цинку, дозволяють використовувати *Salvinia natans* як біоіндикатор забрудненості водойм.

Ключові слова: *Salvinia natans*, цинк, гібереліни, пігменти, ростові показники, біосорбція.