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Keywords: Plastics; Phytoremediation; Aquatic plants



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Article

Removing Microplastics from Aquatic Environments with *Iris pseudacorus* and *Lythrum anceps*

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Abstract: (1) Background: Since microplastics in the aquatic environment are difficult to prevent and can cause adverse physiological and biochemical reactions to various organisms, we aimed to analyze the effectiveness of an eco-friendly removal method using aquatic plants with high ornamental value and excellent water purification ability. (2) Methods: *Iris pseudacorus* and *Lythrum anceps* were planted in tap water contaminated with microplastics to analyze the removal rate and root adsorption of microplastics. (3) Results: The amount of microplastics in the planting boxes of *Iris pseudacorus* and *Lythrum anceps* was significantly reduced, and the adsorption of microplastics on the roots was confirmed. (4) Conclusions: It was found that the removal of microplastics in water by aquatic plants is effective and that microplastic pollution does not significantly affect plant growth. However, the removal of microplastics by adsorption on plant roots may be affected by various environmental factors. Therefore, it is necessary to consider various limitations.

Keywords: plastics; phytoremediation; aquatic plants

1. Introduction

Plastics are lightweight, durable, versatile, low-corrosive, and inexpensive, making them widely used in many applications and the worldwide plastic manufacturing volume is increasing [1,2]. The annual production of plastics has increased 200-fold from 1950 to 381 Mt in 2015, resulting in a significant amount of landfilled and dumped plastics [3], and the accumulation of plastics is expected to continue to increase due to their slow degradation rate compared to the rate at which we consume them [4].

In general, plastics such as polyethylene (PE) or polystyrene (PS) do not completely decompose when exposed to the natural environment but can be broken into small pieces by a variety of factors, resulting in numerous microplastics [5,6]. Microplastics generally refer to plastic particles smaller than 5 mm [7], and the occurrence of microplastics in surface waters was first reported in the early 1970s by Carpenter and Smit (1972) [8]. UNEP (United Nations Environment Programme) defined solid plastic particles of 5 mm or less that cannot be decomposed in water as microplastics [9], and the International Organization for Standardization Environmental Aspects (ISO/TC 61/SC14) defines any solid plastic particle insoluble in water with any dimension between 1 μm and 1000 μm . Plastics are widely used in everyday life, and their high production, rapid consumption, and resistance to complete decomposition have led to large-scale release into and long-term persistence in aquatic and terrestrial environments [4,10,11]. Rivers carry 70–80% of plastics, resulting in extensive sedimentation in aquatic environments such as rivers and oceans [12].

Microplastics from consumer products such as plastic bags and food wrappers, personal care products, polyester, nylon and other fibers, materials and textile industry raw materials, etc. [13] as well as from bath products, cosmetics, facial cleansers, etc. microplastics [14,15] are attracting global

attention because they are very difficult to prevent because they flow into rivers and oceans through sewage pipes [16] and can cause adverse physiological and biochemical reactions in various organisms [17,18]. Particularly in the aquatic environment, they are present in high concentrations [19], and when persistent organic pollutants are adsorbed on the surface of microplastics and ingested, they are likely to have adverse effects on organisms [20]. Increasing societal interest in the effects of these microplastics on human health and ecosystems has raised concerns about their formation, chemical interactions, and potential impacts on the environment [20,21], and research on their investigation and analysis has been actively conducted [22].

Methods for removing microplastics in the aquatic environment include physical methods involving filtration and sedimentation, chemical methods to decompose and convert them, and biological methods to decompose them using microorganisms or plants [23–30]. Among these, the physical method is economical and has a high removal rate, but it is difficult to reuse the adsorbent, resulting in waste; in cases such as coagulation [31,32] and decomposition methods, operating costs may increase owing to the continuous injection of chemicals [31–33].

In various aquatic environments other than sewage treatment plants, microplastics remain suspended in water bodies, while some float to the surface and denser microplastics sink to the bottom [22,34]. Therefore, as a sustainable maintenance plan that is suitable for application to a variety of aquatic environments, has low operating costs, is adaptable for large-scale treatment, and can treat various pollutants together, biological treatment can be considered effective. Previous research on biological methods has focused on the removal of microplastics by microorganisms or sea creatures [25,35–37] and considered only the environment or the interrelationship between plants and microplastics [25,35,38–40]. Research on the removal of microplastics by plants is lacking. Plants alleviate pollutants by absorbing and adsorbing pollutants through their roots [41–46] or by slowing down wetland runoff to prevent MPs from settling in sediments [47]. Plants are used to restore polluted environments because they can be stabilized and decomposed [48]. In addition, aquatic plants have both direct and indirect effects on the aquatic environment. They can absorb many organic substances and increase the water purification ability of aquatic microorganisms [49], which has a positive effect on the removal of MP from the aquatic environment.

Accordingly, this study investigated whether the amount of microplastics in the aquatic environment can be reduced using yellow irises and Buddha's flowers, which are aquatic water-purifying plants with high ornamental value, and investigated various parameters (time, microplastic size, and plant type), focusing on their effect on the amount of microplastics in the aquatic environment.

2. Materials and Methods

2.1. Microplastics

The microplastics used in this study were white polyethylene (PE) powder, which is used in industrial and research applications, purchased from ThyssenKrupp. White PE is widely used in paints and coatings, cosmetics, and personal care applications and has high electrical conductivity and oil resistance that have ensured its use in a variety of fields, such as transparent agricultural films, disposable products, toys, and plant containers. It is a mass-produced plastic found not only in the soil but also in the aquatic environment.

There were two types of PE particle sizes in this study: 46 μm and 140 μm . As plastic waste accumulates in the environment and decomposes into smaller particles over time [50,51], we aimed to determine the removal range of various particle sizes.

2.2. Plant Materials and Planting

Two aquatic plants were selected to investigate their adaptability and growth in microplastics pollution sources and their ability to remove microplastics (Table 1). *Iris pseudacorus* and *Lythrum anceps* (Figure 1), which have a long flowering period and are used near watersides and in gardens, are perennial water plants that grow naturally throughout Korea's watersides.

Table 1. The two kinds of hydrophyte were used for this experiment.

Family	Scientific name	Plant height (cm)	Flowering Period (Month)
Iridaceae	<i>Iris pseudacorus</i>	50~120	May
Lythrostroemia	<i>Lythrum anceps</i>	100	May~August

**Figure 1.** The two kinds of hydrophyte were used this experiment: *Iris pseudacorus* (left) and *Lythrum anceps* (right).

These two plants were selected because they have high ornamental value and are excellent at adapting to environmental stress conditions [52–54]. These two plants could be used in future experiments to investigate their ability to remove microplastics from waterfronts and general soils.

This study was conducted for four months in a greenhouse-type growing room of a plant factory called Samyuk Eco-Farm Center at Samyuk University, located at Hwarang University in Nowongu, Seoul. The experimental environment was a combined solar and convection plant factory with natural light, and three 24W LED plant lamps (Designer Sunbell) were used as supplemental light in case of light shortage. To simulate the circadian cycle, lights were turned on for 10 h per day (8 a.m. to 6 p.m.). The air temperature and humidity were 25.8°C and 97.7% on average, and the water temperature was 26.3°C on average (Table 2). The water temperature in the cultivation zone where *Iris pseudacorus* and *Lythrum anceps* were planted is shown in Table 1 and had an average value of 26.3°C. The temperature and humidity meter was a greenhouse complex ventilation system 'MAGMA-1000' (MAGMA-1000') installed in the growing room, and the water temperature measurement system was a Caple temperature recorder (CP22-WA15).

In April 2023, 60 unblooming *Iris pseudacorus* and *Lythrum anceps* in 2-inch plastic pots were purchased from a cultivation farm. The first acclimatization process was conducted in a greenhouse cultivation room for 14 days to reduce growth disorders due to environmental changes. After the first purification process, the soil attached to the roots was lightly shaken off and completely removed by rinsing with tap water, and the plants were then immersed in tap water for 14 days to perform the second purification in a hydroponic form.

Table 2. Greenhouse-type cultivation room environment on the 2nd floor in the Sahmyook Eco-Farm Center plant factory.

	Temperature (°C)	Humidity (%)	Water temperature (°C)
May	24.3	98	26.2
Jun.	29.0	97.7	29.5
Jul.	29.7	97.9	29.7
Aug.	20.2	97.5	19.8
Mean±SD	25.8±4.4	97.7±0.2	26.3±4.6

The containers for the experiments were made of stainless steel to minimize the impact of plastic, and the dimensions were 1.2m×0.2m×0.3m for width, length, and height, respectively). To float the plants in the container, a lid was made of 0.28×1.15 m. Five holes with a diameter of 5 cm were drilled at 15 cm intervals, taking into account the plant spacing (Figure 2). To confirm the effectiveness of removing floating microplastics using plant roots, each plant was floated in a cultivation box and fixed with a sponge inserted into the cover hole of the cultivation box (Figure 3).

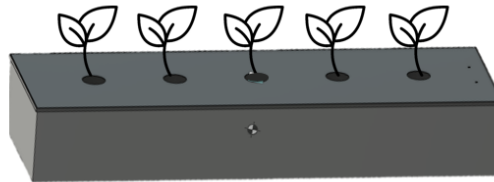


Figure 2. Schematic diagram of experimental plantings.



Figure 3. Plant roots fixed using a sponge.

The planting beds were 1.5 m x 0.9 m x 3.0 m (W*D*H) and were set up in two tiers, with *Iris pseudacorus* on the right and *Lythrum anceps* on the left (Figure 4). Three boxes of plants were used as a treatment (15 weeks) and one box as a control (5 weeks) for each plant.



Figure 4. Experimental cultivation stand (2nd floor greenhouse-type cultivation room in the Sahmyook Eco Farm Center plant factory).

2.3. Exposure Experimental Set-Up

The grow boxes were filled with 70 L of tap water and treated with two types of PE powder (46 μm and 140 μm) at a concentration of 1 mg/L. The bubble generator (Resun Air-4000) was set to allow the water to flow through the planting bed, considering that the microplastics would not float or sink and be adsorbed by the plant roots, and the effect of flow rate in the natural environment.

2.4. Analyzing the Adsorption of Microplastics by Plants and the Concentration of Microplastics in Aquatic Environments

To analyze the microplastic removal content in the aquatic environment, pre- and post-treatment water quality was analyzed using FT-IR with a microscope (NicoletTM iN10MX FT-IR microscope, Thermo Fisher Scientific, Waltham, MA, USA).

Samples were placed in 500 mL beakers and filtered under reduced pressure through a metal mesh filter (20 μm , 25 diameter). The filter was divided into four compartments across the front of the filter using the Omnic Picta Program (Thermo Fisher Scientific Inc., Waltham, MA, USA) to obtain IR spectra of all areas by ultra-fast mapping. The IR spectra obtained from each compartment were library-matched with the plastic IR spectra and considered as plastic when the matching rate was more than 70%, and quantitative data were collected by counting (Figure 5).

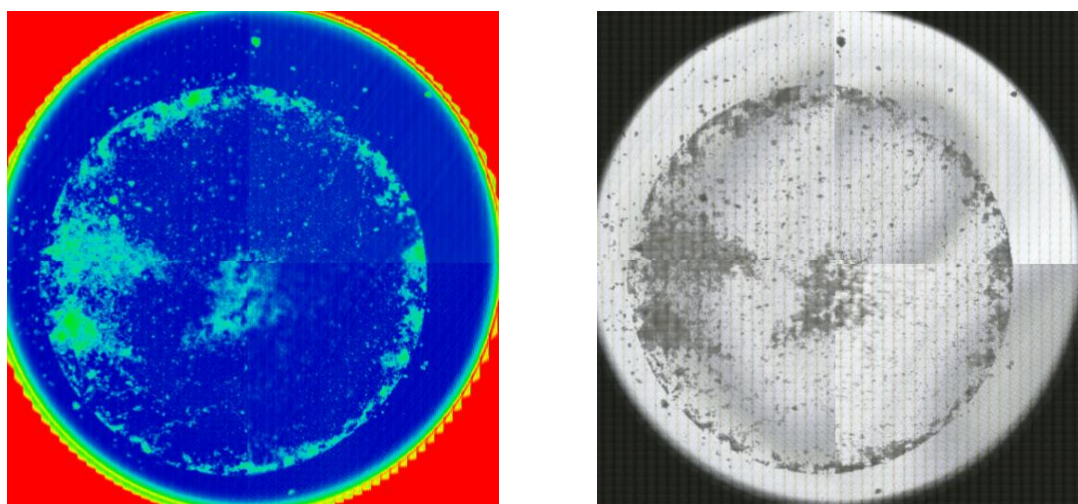


Figure 5. Microplastics analysis using FT-IR (*Lythrum* 140 μm).

To identify the adsorbed microplastic particles from the plant roots, some roots of *Iris pseudacorus* and *Lythrum anceps* were removed and analyzed using a JEOL Scanning Electron Microscope JSM-6510. The adsorption analysis was performed once post-mortem (90 days).

2.4. Grow Survey

Pre- and post-planting growth surveys were conducted during May through August to examine water quality adaptation of aquatic plants. Height was measured from the base to the tip of the longest leaf, and Width was measured at a point 15 cm above the base in the planted state. Leaf number was measured for *Iris pseudacorus* and branch number for *Lythrum anceps*.

2.5. Statistical Analysis

Statistical analysis was performed using the SPSS 26.0 (IBM Co., Armonk, NY, USA) program. Normality and homogeneity of variance were tested by Shapiro-Wilk and Levene tests, respectively. As a result, parametric statistical methods were used. Paired sample t-tests were performed to determine the significant difference between pre- and post-microplastic removal for each plant species and microplastic particle size. One-way ANOVA was performed to test the significant effect of microplastic concentration level according to microplastic particle size, and Duncan's test was

applied. Descriptive statistical analysis was conducted to determine the changes in plant growth following microplastic removal.

3. Results

3.1. Plants Remove Microplastics from Aquatic Environment

We measured the removal rate of microplastics in water and found that different plant species had a positive effect on microplastic removal depending on the size of the microplastic particles. The removal rate of *Iris pseudacorus* decreased by 72.1% from 252.9 to 70.4, and the removal rate of *Lythrum anceps* decreased by 70.2% from 203.5 to 60.5. When measuring removal by microplastic size, 46 μm decreased from 222.6 to 78.0, a 64.9% reduction, and 140 μm decreased from 233.7 to 52.9, a 77.3% reduction. The correlation between microplastic removal rate by plant type and microplastic removal rate by microplastic particle size showed a significant difference between *Iris pseudacorus* ($t=11.068$, $p<.001$), *Lythrum anceps* ($t=13.113$, $p<.001$), and 46 μm ($t=10.773$, $p<.001$) and 140 μm ($t=12.344$, $p<.001$) by microplastic particle size (Table 3).

Table 3. Pre-post comparative test of microplastics removal average.

Type	Variable	Pre-test(May) ^z	Post-test(Aug.) ^z	t	p
Plant	<i>Iris pseudacorus</i>	252.9±82.5	70.4±78.6	11.068***	<.001
	<i>Lythrum anceps</i>	203.5±±67.9	60.5±35.2	13.113***	<.001
Microplastic Size	46 μm	222.6±68.3	78.0±49.9	10.773***	<.001
	140 μm	233.7±84.4	52.9±28.8	12.344***	<.001

^z Mean±SD(n=30) *** $p<.001$.

Pre- and post-measurements of the effectiveness of *Iris pseudacorus* and *Lythrum anceps* in removing microplastics from the water showed that *Iris pseudacorus* and *Lythrum anceps* had a positive impact on reducing microplastics in the water.

The microplastic removal rate for the plots planted with *Iris pseudacorus* decreased by 79.7% from 240.99 to 92.20 for the 46 μm microplastic size, and by 81.5% from 264.82 to 48.76 for the 140 μm microplastic size (Figure 6). The microplastic removal rate of the *Lythrum anceps* planted plots decreased by 68.7% from 204.3 to 63.92 for the microplastic size of 46 μm , and by 68.7% from 182.76 to 57.16 for the microplastic size of 140 μm (Figure 6).

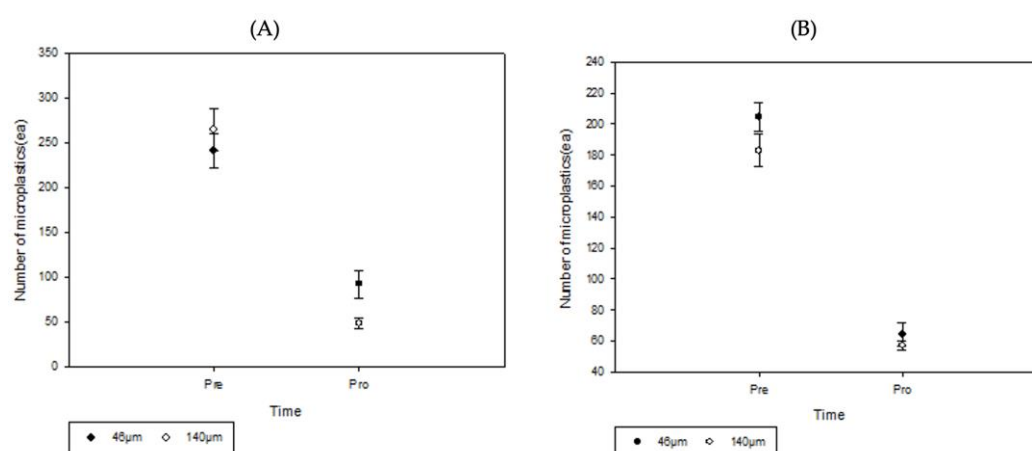


Figure 6. Analysis of microplastics concentration in the water: Number of microplastics in cultivation boxes planted with (A) *Iris pseudacorus*, (B) *Lythrum anceps*.

The correlation of microplastic removal rate with microplastic particle size by plant showed a significant difference between *Iris pseudacorus* ($F=39.014$, $p<.001$) and *Lythrum anceps* ($F=33.801$, $p<.001$) depending on the microplastic particle size (Table 4).

Table 4. Microplastic removal effect depending on microplastic size.

Plant	PE Size (μm)	Pre-test(M0) ^z	Post-test(M2) ^z	F	p
<i>Iris pseudacorus</i>	46	240.9 \pm 73.7	92.2 \pm 57.5	39.014	<.001
	140	264.8 \pm 91.4	48.7 \pm 23.7		
<i>Lythrum anceps</i>	46	204.3 \pm 72.1	63.9 \pm 37.7	33.801	<.001
	140	182.7 \pm 66.0	57.1 \pm 33.4		

^z Mean \pm SD(n=15).

Scanning electron microscopy (SEM) was used to identify adsorbed particles on the roots of *Iris pseudacorus* and *Lythrum anceps* (Figures 7–9). This confirmed that the microplastic particles were removed by adsorption on the plant roots.

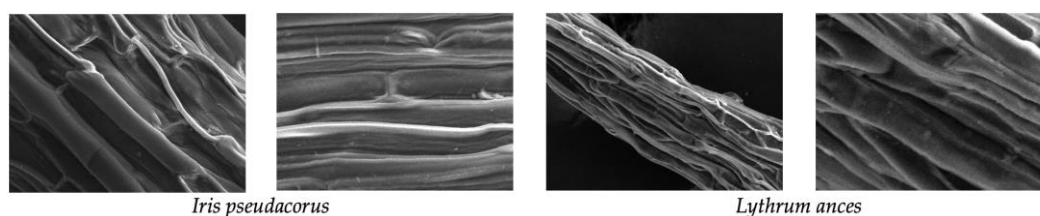


Figure 7. SEM images treated of control(L:x55, R:x650).

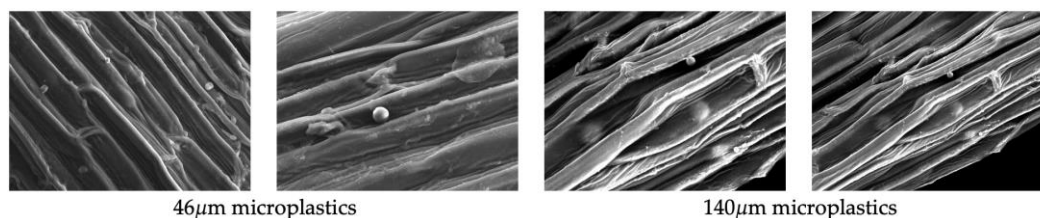


Figure 8. SEM images of *Iris pseudacorus* (L:x55, R:x650).

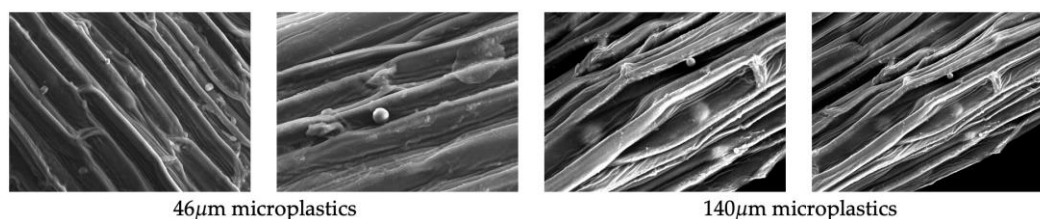


Figure 9. SEM images of *Lythrum anceps* (L:x55, R:x650).

3.2. Plant Growth as a Function of Microplastic Concentration

When *Iris pseudacorus* and *Lythrum anceps* were grown in microplasticized tap water for 4 months from May to August, both the Height, width, and number of leaves of *Iris pseudacorus* increased over time (Figure 10). At a microplastic particle size of 140 μm , the initial width of the *Lythrum anceps* decreased from 8.3 cm to 5.1 cm. In addition, both the height and leaf number of the *Lythrum anceps* increased over time (Figure 11). The correlation of plant growth changes (height, width, branch number, and leaf number) with microplastic concentration was not statistically significant.

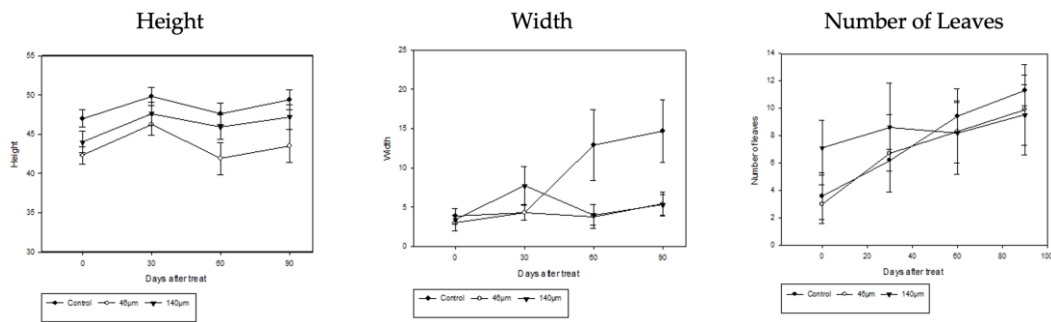


Figure 10. *Iris pseudacorus* growth changes in aquatic environments polluted with microplastics.

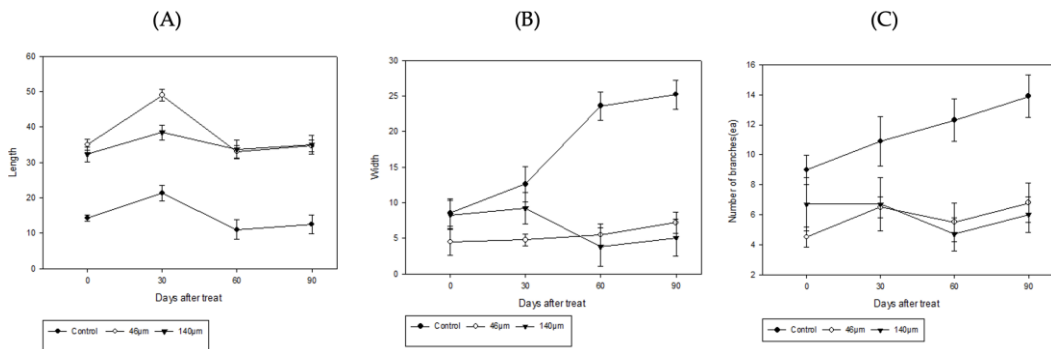


Figure 11. *Lythrum anceps* growth changes in aquatic environments polluted with microplastics: (A)Length (B)Width (C)Number of branches.

4. Discussion

This study was conducted to verify the effectiveness of microplastic remediation in the aquatic environment using aquatic plants. Currently, microplastics are classified as contaminants of emerging concern, and most microplastics generated in our daily lives flow into various aquatic environments, such as sewage treatment plants and rivers, through sewage. Microplastics in sewage treatment plants are treated using sedimentation or filtration, microbial treatment, and reverse osmosis; however, these are generally not effective or highly efficient [55–57]. In addition, research is needed on economical and efficient methods that can be applied not only to sewage treatment plants but also to various aquatic environments such as rivers, soil, and coastal waters.

Phytoremediation is the most environmentally efficient method for removal of pollutants from water bodies such as rivers and streams, with the expectation of aesthetic effects [25,58]. Therefore, research is needed on methods to reduce microplastic pollution in the aquatic environment using plants that can adsorb microplastics through their roots or leaves [54,59,60].

In this study, we found that the concentration of microplastics in the water was reduced in the planter boxes planted with *Iris pseudacorus* and *Lythrum anceps*. The removal of microplastics was confirmed by their adsorption by *Iris pseudacorus* and *Lythrum anceps* roots. Plants absorb nutrients through their roots and adsorb suspended solids [61,62], which can promote the purification process of pollutants in the aquatic environment. This is consistent with the results of previous studies [63–66]. Waterside plants, such as yellow irises and Buddha's flowers, are rooted at the bottom of the aquatic environment, and parts of their leaves and stems are within the aquatic environment, making them effective at removing microplastics floating in the aquatic environment or settling on the bottom.

We measured the change in microplastic concentration as a function of microplastic size, and found that larger microplastic particle size had a significant effect on reducing microplastic concentration in both *Iris pseudacorus* and *Lythrum anceps*. This suggests that larger particles of floating microplastics are better adsorbed by dense plant roots exposed to water. However, in the actual environment, yellow irises and Buddha's flowers are often rooted in the soil rather than

underwater; therefore, additional research is needed on the adsorption of microplastics in the aquatic environment that has settled in the soil.

As a result of measuring plant growth changes to check the growth status of plants in an aquatic environment polluted with microplastics, it was confirmed that the height, width, and number of branches (leaf number for *Iris pseudacorus*) of *Iris pseudacorus* and *Lythrum anceps* all increased. The size of the microplastic particles did not negatively impact plant growth, which is consistent with previous studies [46,49,67,68]. As a result, it appears that microplastics in the aquatic environment did not have a significant negative impact on the growth of the roots of yellow irises and Buddha's flowers in the water; therefore, aboveground growth was also smooth. However, microplastics can affect plant biomass and seed germination [11], and it is necessary to consider their impact on plants continuously exposed to the toxicity of microplastics. In particular, *Iris pseudacorus* and *Lythrum anceps* are highly ornamental plants with prolonged flowering, so it is worth investigating the effects of long-term exposure to microplastics on flowering, coloration, and fragrance.

The microplastics used in this study were larger than the pore size of plant root cell walls, 4 nm [69], and were, therefore, unlikely to be absorbed into the root cell walls during the study period. Therefore, removal through absorption was not confirmed. However, there have been cases where microplastics have been broken down into nanoparticles and absorbed into cell walls [70]; therefore, it is necessary to confirm their absorption through plant roots. In addition, when applied to the actual environment, microplastics remain attached to the plant surface in water. Therefore, there is a need to further evaluate the stability of microplastics in the aquatic environment when plants are removed from the aquatic environment or when they age.

5. Conclusions

While research on aquatic microplastic removal by plants is still in its infancy, the results of this study confirm that removing microplastics from the water through aquatic plants is effective and does not significantly affect plant growth. However, the potential loss of microplastics through adsorption by plants should also be considered during plant removal in extreme weather conditions or after plant restoration. Future experiments will need to test the method in real-world conditions and consider possible limitations, such as the adsorption of microplastics by plant roots over time, removal of microplastics through plant uptake, and sensitivity to other contaminants.

In conclusion, we believe that the method proposed in this study will be useful for removing microplastics using aquatic plants near waterfronts.

Author Contributions: Conceptualization, Y.K. and S.C.; methodology, Y.K. and K.P.; software, S.C.; validation, K.P. and J.B.; formal analysis, J.B.; investigation, S.C. and J.B.; resources, Y.K. and K.P.; data curation, S.C.; writing—original draft preparation, Y.K.; writing—review and editing, S.C. and K.P.; visualization, S.C.; supervision, Y.K. and K.P.; project administration, Y.K.; funding acquisition, Y.K. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement: The data that support the findings of this study are available from the corresponding author, Sueran Choi, upon reasonable request.

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Conflicts of Interest: The authors declare no conflicts of interest.

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