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Growth Response, Enrichment Effect, and Physiological Response of Different Garden Plants under Combined Stress of Polycyclic Aromatic Hydrocarbons and Heavy Metals

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Abstract: The combined pollution of heavy metals and polycyclic aromatic hydrocarbons is very common in China and needs urgent addressal. The use of resistant garden plants for phytoremediation accounts for both ecological restoration and ornamental value and has great application potential. In this study, cadmium (Cd) and pyrene (Pyr) were used as contaminants, and the growth responses, enrichment characteristics, and physiological responses of common garden plants were studied using greenhouse pot experiments. The Cd-Pyr compound stress affected the growth responses of plants. Chinese *Pennisetum* and *lotus* exhibited the best Cd-Pyr removal effect: the removal rates of Cd were 68.91% and 60.25%, respectively, and those of Pyr were 77.52% and 63.74%, respectively. Compound stress promoted the protective enzymes of *ryegrass*, *lotus*, and Chinese *Pennisetum*. Malondialdehyde (MDA) content in the leaves of the five plants was higher than that in the control group, whereas the chlorophyll and carotenoid content were lower. Overall, the order of resistance of the five garden plants tested under Cd-Pyr compound stress was: Chinese *Pennisetum*, *lotus* > *ryegrass* > *Hemerocallis*, *Purple Coneflower*.

Keywords: garden plants; soil; compound pollution of cadmium-pyrene (Cd-Pyr); enrichment characteristics; resistance mechanism

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1. Introduction

With the rapid development of urbanization and industrialization in China in the past 40 years, a large number of pollutants, such as heavy metals and organic polycyclic aromatic hydrocarbons (PAHs), have been discharged, causing serious soil pollution, which has had a significant impact on human health, food security, and the ecological environment [1]. According to the data of a national census of pollution, China has more than 1.5 million sites of heavy-metal exposure [2,3]. In addition, relevant research shows that PAH emissions from 2013 to 2017 reached 100–113 Gg, ranking first in the world [4]. Remediation of soil pollution in China is urgently needed.

At present, most research on soil pollution remediation focuses on soil contaminated with a single pollutant, rather than heavy-metal–organic compound pollution [5]. The current physical and chemical soil remediation methods are expensive and prone to secondary pollution. Physical methods, such as electrokinetic remediation technology, are at a disadvantage because they are more suitable for granular soil and require high energy [6]. Chemical methods, such as soil-leaching remediation technology, are disadvantageous because they have a poor remediation effect on soils with heavy viscosity and poor permeability, and the typically injected leaching agent is resistant to biodegradation and hence easily remains in the soil [7]. Phytoremediation technology is an emerging bioremediation technology that has incomparable advantages over the aforementioned methods and is an effective strategy to remediate polluted soil [8].

Current research on phytoremediation is mostly focused on hyperaccumulators, e.g., *Arabidopsis arenosa* is a novel zinc (Zn) and cadmium (Cd) hyperaccumulator [9], and mosses and a few vegetable crops can be considered effective PAH accumulators [10]. However, hyperaccumulators generally have low ornamental value and exhibit shortcomings such as small individuals, slow growth, shallow root extension, and difficult aftercare treatment, which seriously restrict their application in the field of phytoremediation [11]. In comparison, resistant garden plants are more ornamental and have strong environmental adaptability; hence, they can provide economic and environmental benefits to human beings, as well as contribute to creating a more livable and beautiful environment [12–16]. However, few related studies have systematically screened ornamental garden plants for phytoremediation and even less have screened for plant resistance to heavy-metal–organic compound pollution.

There have been a few reports on the resistance of garden plants to heavy metals and PAHs, but most of them are limited to single pollutants. For heavy-metal pollution remediation, Liu et al. studied the growth response, Cd accumulation, and absorption capacity of six Compositae plants under Cd stress and found that *Tagetes erecta* L. and *Tagetes patula* L. exhibited strong tolerance and accumulation capacity for even high concentrations of Cd (100 mg/kg) [17]. Jeelani et al. studied the independent and interactive effects of *Acorus calamus* and found that the combined treatment of low amounts of Cd and PAHs increased plant biomass and Cd accumulation in the plant tissues [18]. Guo et al. found that *Miscanthus* spp. shows high Cd resistance and good growth [19]. Jiang et al. found that the antioxidant enzyme system and key resistant substances of *ryegrass* have important and antagonistic effects on Cd and arsenic (As) stresses [20]. Luo et al. found that the activity of peroxidase (POD) and catalase (CAT) in *ryegrass* increased with the supply of Cd [21]. For PAH pollution remediation, Wei's study showed that under the single planting mode, alfalfa had the highest phytoremediation ability for phenanthrene (Phe), and that white clover had the most effective phytoremediation ability for pyrene (Pyr) [22]. *Festuca arundinacea* and *Panicum virgatum* had a strong ability to remove Pyr in soil [23]. Alfalfa, *Brassica napus*, and *Lolium perenne* had some remediation effects on Pyr pollution [24]. Li et al. found that Pyr can promote the growth of *ryegrass* and then improve the removal of co-pollutants, whereas excessive Cd exerts toxicity and an inhibitory effect on the removal of co-pollutants by *ryegrass* [25].

There are also many cases of ecological restoration using plants in China. A common approach is to adapt to local conditions, such as selecting native plants from wasteland surrounding a Zn smelter in Feng County for phytoremediation [26]. Some other studies used native plants to transform the landscape of old industrial sites, such as the Qijiang Park in Zhongshan city, Guangdong Province [27,28]. However, this phytoremediation method might not be effective, and the plants used may not have an exact scientific basis and may be relatively blind.

In view of this, Cd and Pyr were selected as the representative pollutant species of heavy metals and PAHs, respectively, based on screening a variety of ornamental resistant garden plants using the literature, and a pot experiment was conducted in a greenhouse. In a pre-experiment, the plants were observed separately under Cd and Pyr stress for further screening. Then, under the combined pollution effect of Cd (20 mg/kg) + Pyr (30 mg/kg), the plants with good growth were screened by apparent observation. The change in concentration of pollutants in the plants was detected to identify the enrichment effect, and the physiological response was determined using a number of physiological indicators, such as chlorophyll and superoxide dismutase (SOD) levels, to provide a scientific basis for the application of the screened plants to compound pollution remediation. In addition, our findings are widely applicable, and can be used as the theoretical basis for the design of plant community levels and plant group configuration in the restoration of abandoned brownfields and serve to improve the ornamental nature and experience of landscape green space.

2. Materials and Methods

2.1. Materials

A total of 10 species of garden plants were screened by reading the literature, which are common ornamental herbs widely planted. The specific background of each plant is shown in Table 1.

Table 1. Background introduction of the 10 tested plants.

Latin Name	Family	Lifecycles	Planting Ranges	Flowering Plants (Yes/No)	Main Ornamental Parts	Purchase Source
Lolium perenne L.	Poaceae	Perennials	Widely planted in the north and south	Yes	Used as forage grass or cool-season lawn grass, etc.	Shandong Huazhu Agriculture Co., Ltd., Shandong, China
Muhlenbergia capillaris (Lam.) Trin.	Poaceae	Perennials	Shanghai, Hangzhou, and other places in China	Yes	Flowers	Shandong Huazhu Agriculture Co., Ltd., Shandong, China
Pennisetum alopecuroides (L.) Spreng.	Poaceae	Perennials	From Northeast and North China to East China, Central South, and Southwest China	Yes	Inflorescences	Shandong Huazhu Agriculture Co., Ltd., Shandong, China
Tagetes erecta L.	Asteraceae	Annuals	All over China	Yes	Flowers	Shandong Huazhu Agriculture Co., Ltd., Shandong, China
Echinacea purpurea	Asteraceae	Perennials	Many places in China	Yes	Flowers	Shandong Huazhu Agriculture Co., Ltd., Shandong, China
Hemerocallis hybrida Bergmans	Liliaceae	Perennials	Many places such as Beijing, Shanghai, Heilongjiang, and Jiangsu	Yes	Flowers	Shandong Huazhu Agriculture Co., Ltd., Shandong, China
Iris sibirica L.	Iridaceae	Perennials	Many places in China	Yes	Flowers	Shandong Huazhu Agriculture Co., Ltd., Shandong, China
Viola tricolor L.	Violaceae	Bienni or perennials	Widely planted in the north and south	Yes	Flowers	Shandong Huazhu Agriculture Co., Ltd., Shandong, China
Leucanthemum maximum (Ramood) DC.	Asteraceae	Bienni or perennials	Many places in China	Yes	Flowers	Shandong Huazhu Agriculture Co., Ltd., Shandong, China
Nelumbo nucifera 'Fenguiren'	Nelumbonaceae	Perennials	In most parts of China	Yes	Flowers and leaves	Nanjing Yilianyuan Flower Co., Ltd., Nanjing, China

The experiment sites were the Baima Base of Nanjing Agricultural University and the laboratory of the National Experimental Teaching Center for Plant Production of Nanjing Agricultural University. The test soil was collected from the Baima Base of Nanjing Agricultural University. The basic physical and chemical properties of the test soil are shown in Table 2. The measured data were found to be reliable by standard deviation.

2.2. Methods

2.2.1. Stress Treatment in Pot Experiment

The seeds of the 10 plants mentioned above were disinfected with 5% ethanol and planted in pots; after each plant germinated, the seedlings were fixed when *E. purpurea*, *I. sibirica L.*, *H. hybrida* Bergmans, and *lotus* had three leaves and *ryegrass* and Chinese *Pennisetum* were 5 cm.

Table 2. The basic physicochemical properties of the test soil.

Soil Type	**pH**	**Organic Matter/g·kg^{-1}**	**Nitrogen (N)/mg·kg^{-1}**	**Phosphorus (P)/mg·kg^{-1}**	**Cd/mg·kg^{-1}**	**Pyr/mg·kg^{-1}**	**Cation Exchangeable Capacity (CEC)/cmol·kg^{-1}**
Yellow brown soil	6.93 ± 1.32 [a]	22.45 ± 4.37	180.2 ± 17.4	71.4 ± 14.3	0.09 ± 0.02	0.04 ± 0.01	24.22 ± 3.43

[a] Mean ± standard deviation.

Considering that the toxicity of direct combined stress could be too high, a pre-test was carried out in the greenhouse of Baima Base of Nanjing Agricultural University. Each plant was exposed to different concentration gradients of single Cd and Pyr pollution stress (0, 10, 20, 30, 40, and 50 mg/kg) and three groups of repetitions. Naturally air-dried soil (1.5 kg) passed through a 1 mm sieve was taken, and Pyr was added in the form of acetone solution and then evenly mixed to prepare Pyr-contaminated soil samples with similar concentration levels. Similarly, Cd was added in the form of water-soluble $CdCl_2$, and soil samples contaminated by this heavy metal at similar concentration levels were prepared. Treated soils were potted and maintained at 60% soil WHC in the greenhouse. On 1 March 2021, the seedlings of the 10 plants to be screened were planted in each treated soil, keeping the WHC of the soil at 60% and the experiment period as 30 days.

Five plants, namely, *lotus*, *ryegrass*, Chinese *Pennisetum*, *E. purpurea,* and *H. hybrida* Bergmans, were screened out by pre-experimental apparent observation, and pansy, iris, hairawn muhly, marigold, and *L. maximum* (Ramood) DC., which exhibited obvious adverse reactions, were discarded. At the same time, it was found that plants exposed to only 20 mg/kg of Cd pollution and only 30 mg/kg of Pyr pollution exhibited a certain resistance reaction; hence, the compound stress for the five plants was applied at these concentrations.

The pot experiment began on 1 April 2021. The pots used were all 22 cm in diameter, with three plants in each pot of *E. purpurea*, *H. hybrida* Bergmans, and *lotus*, and about 150 plants in each pot of *ryegrass* and Chinese *Pennisetum*. The plants were grown in a greenhouse, and daily weighing and water replenishment were carried out to maintain the WHC of the soil at about 60% for 30 days. The concentrations of Cd-Pyr compound-polluted soil samples were set at 20 mg/kg of Cd and 30 mg/kg of Pyr at the beginning of May 2021, and the prepared solution was added to the soil samples for the compound stress test. Furthermore, a pot with no soil pollutants was set as control 1 (CK1), and a pot with only soil pollutants but no plants was set as control 2 (CK2). Each tested plant was set with triplicate treatments, triplicate CK1, and triplicate CK2, totaling 45 pots. After 60 days, the experiment was concluded and the resistant plants were further screened out by apparent comparison with CK1, and their physiological characteristics were determined using physiological indexes; finally, the most suitable resistant plants were screened out.

2.2.2. Determination of Contents

Photos of all potted plants were taken every 7 days from 15:00 to 16:00 in the afternoon. The test plants and soil materials were sampled every 20 days, and the samples were frozen with liquid nitrogen and stored in a −30 °C refrigerator.

(1) Plant morphological index

① Leaf area, number of leaves, number of flowers, and flower diameter

The leaf area of plants was measured with a photoplanimeter every 20 days [29]. The number of leaves and the flowering number of flowering plants were recorded every 20 days (*ryegrass* and Chinese *Pennisetum* were not counted because of the small and numerous leaves). The flower diameter of each flower (including bud) of flowering plants was measured with a steel ruler every 20 days.

② Plant height

The plant height of all plants was measured every 20 days. Based on the edge of the pot, the vertical height from the top of all plants to the edge of the pot was measured with a tape measure.

③ Biomass (dry weight)

On the 60th day, the whole plant was taken out of the soil, and the aboveground and belowground biomass were measured. The whole plant was rinsed with deionized water and the surface water was absorbed. Each plant sample was placed in an envelope, dried at 80 °C for 48 h, cooled to room temperature in a dryer, and weighed for the dry weight of the above- and below-ground parts with a balance [30]. The dried plant samples were ground with an agate mortar, screened with a 60-mesh nylon sieve, and placed in a −30 °C refrigerator for later use.

(2) Contents of Cd and Pyr in plants and soil

Every 20 days, the iCAP 7400 inductively coupled plasma emission spectrometer (Thermo Fisher Company, Waltham, MA, USA) of the Department of Environmental Science and Engineering, Nanjing Agricultural University, was used to measure the Cd content in plant and soil samples. The freshly sampled materials were placed in an oven at 105 °C for 30 min, dried at 80 °C to a constant weight, ground in a mortar, passed through a 60-mesh screen, accurately weighed to 0.2 g, and placed in a digestion tube. After filtering, 1 mL of water sample was measured with a pipette and placed into the digestion tube, 5 mL of HNO_3 (analytical purity) was added, and the sample was placed in a microwave digestion instrument (CEM MARS6). The procedure lasted for 20 min at 180 °C. After digestion, the sample was taken out, the digestion tube was rinsed with ddH_2O, and the sample was diluted to a constant volume of 50 mL. A Cd standard solution was prepared along with the solution to be tested, it was measured by ICP-AES, a standard curve was drawn, and then the Cd content in each sample was measured [31,32].

Every 20 days, the Pyr content in plant and soil samples was determined using ACQUITY UPLC (Waters Company, Milford, MA, USA) in the central laboratory of the College of Horticulture, Nanjing Agricultural University: 2.0 g samples were placed in a centrifuge tube, 2 g of anhydrous sodium sulfate was added, and the mixture was evenly mixed. Dichloromethane (10 mL) was added, and ultrasonic extraction was performed at 40 °C for 1 h, followed by centrifugation at 4000 r/min. The supernatant (3 mL) was passed through a Fisher Pasteur glass tube silica gel column, eluted with 1:1 dichloromethane and *n*-hexane solution, concentrated by drying at 40 °C, made up to 2 mL with methanol, passed through a 0.22 μm pore filter membrane, and analyzed by HPLC. The aforementioned indices were measured thrice [33,34].

(3) Plant physiological indicators

The related contents and methods are shown in Table 3. SOD, POD, and CAT are important components of the antioxidant system in plant cells, which can inhibit the production of reactive oxygen species, scavenge superoxide anion free radicals, control lipid peroxidation, and reduce damage to the plasma membrane system. Malondialdehyde (MDA) is the product of membrane lipid peroxidation in plants under stress, and its accumulation in plant tissues can reflect the degree of membrane lipid peroxidation. Chlorophyll is an important substance involved in plant photosynthesis, and its content in plants can reflect the metabolism and stress resistance to a certain extent. Carotenoids exist in the protein complexes of chloroplast photosynthetic systems i and ii, and their role is to quench excess light energy.

Table 3. Determination of contents and methods used.

Physiologic Indexes of Plant	Determination Method	Interval Days
SOD activity	Nitrogen blue tetrazole method [35,36]	20 days
POD activity	Guaiacol method [37,38]	20 days
CAT activity	Ultraviolet absorption method [39]	20 days
MDA content	Thiobarbituric acid method [40]	20 days
The content of chlorophyll and carotenoids	Ethanol extraction method [41,42]	20 days

2.3. Statistical Analysis of Data

The relative increment in plant height was calculated using Formula (1):

$$\Delta a = a_n - a_{n-1} \tag{1}$$

In this formula, Δa is the relative increase in plant height, a_n is the plant height at the current measurement, and a_{n-1} is the plant height at the last measurement.

The aboveground enrichment coefficient reflects the ability of plants to absorb pollutants from the soil, and it was calculated using Formula (2):

$$EF = \frac{C_p}{C_s} \tag{2}$$

In this formula, EF is the enrichment coefficient of heavy metals or PAHs in the aboveground parts of plants, C_P is the content of heavy metals or PAHs in the aboveground parts of plants, and C_S is the content of heavy metals or PAHs in the soil.

All experimental groups and control groups were analyzed in parallel, in triplicates. EXCEL 2019 software was used to process experimental data, GraphPad Prism 8.0.2 was used to draw graphs, and SPSS 26 statistical analysis software was used to perform variance analysis on experimental data, for which the significance level was $p < 0.05$.

3. Results

3.1. Growth Response of Different Ornamental Plants under Compound Stress

3.1.1. Analysis of Changes in Main Apparent Ornamental Characteristics of Plants

Changes in plant growth are the most intuitive manifestations of plants under stress. During the combined stress test, by comparing with the growth of the control group (Figure 1), it was found that *Hemerocallis fulva* and *Pennisetum* grew well, and their growth was basically similar to that of the control group. The plants were green, and their stems and leaves developed well. Compared with the growth of the control group, *E. purpurea* and *lotus* grew slightly slower. Compared with the growth of the control group, *ryegrass* was partially withered and yellow at 60 days, but its overall growth in the compound-polluted soil was acceptable, and its growth was basically similar to that of the control group at 20 and 40 days. Therefore, based on the pre-experiment, the apparent ornamental characteristics were further observed through the compound stress test, and it was found that the five plants basically had no obvious adverse reactions.

3.1.2. Effect of Cd-Pyr Compound Treatment on Plant Height

The incremental changes in plant height of the five garden plants after 20, 40, and 60 days of culture under Cd-Pyr compound treatment are shown in Figure 2. At 20 days, the increment in plant height in the treated groups of *ryegrass*, Echinacea, *lotus*, and *Pennisetum* was positive and not significantly affected by combined stress, whereas that in the treated group of *Hemerocallis* was negative, which was significantly different from that in the control group ($p < 0.05$) (Figure 2A). At 40 days, the plant height increments of the five treated groups were all positive, and that of the treated *Hemerocallis* group increased from negative to positive, but it was still significantly lower than that of the control group. The stress resistance of *Hemerocallis* was stimulated, and the plant height partially recovered. However, the height increment of *lotus* in the control and treated groups decreased: the decrease in the treated group was extremely significant (only 7.06% of that in the control group and 3.01% of that in the treated group at 20 days), indicating that with an increase in stress time, the height increment of *lotus* changed from the initial promotion to inhibition. The plant height increment of the treated and control *Pennisetum* groups increased, but the increment in the treated group was significantly lower than that in the control group (only 29.41%) (Figure 2B). At 60 days, the plant height increment of the treated and control *Hemerocallis* and *Pennisetum* groups decreased, and the difference was no longer significant. The height increment of *lotus* in the control and treated groups was negative, and there was no significant difference between the two groups. Combined with the flowering time, it was speculated that the height of *lotus* in the control group decreased because the flowers withered at 60 days, whereas that in the treated group decreased because the stress time was long. Additionally, this shows that the inhibition degree of *lotus* height growth increased more than that of other plants with an increase in stress time (Figure 2C). Overall, after 20, 40, and 60 days, although there were some negative effects on plant height, it was still within the tolerance range.

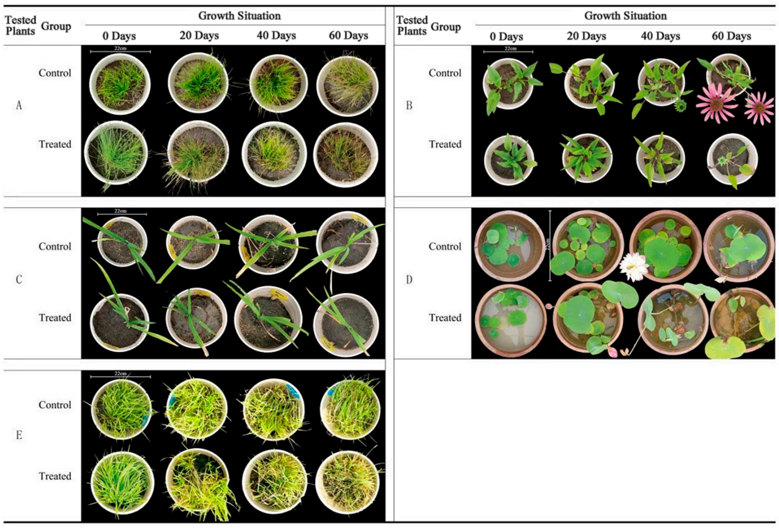

Figure 1. Growth situation of five plants tested under Cd-Pyr compound stress. (**A**) *Lolium perenne* L., (**B**) *Echinacea purpurea*, (**C**) *Hemerocallis hybrida* Bergmans, (**D**) *Nelumbo nucifera* Gaertn., (**E**) *Pennisetum alopecuroides* (L.) Spreng.

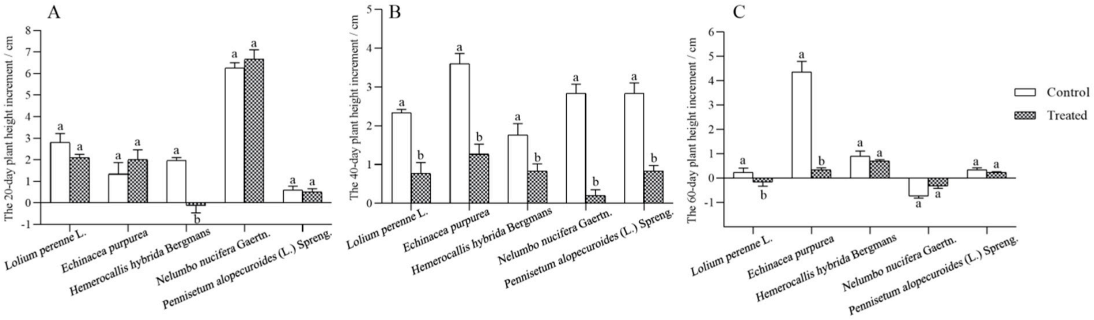

Figure 2. Plant height increments of five garden plants under Cd-Pyr compound stress at 20, 40, and 60 days. Note: Different lowercase letters indicate significant differences among different treated groups ($p < 0.05$). (**A**) 20 days, (**B**) 40 days, and (**C**) 60 days.

3.1.3. Effects of Cd-Pyr Compound Treatment on Related Indices of Leaves and Flowers

The morphological indices of five resistant garden plants, namely, the leaf area, leaf number, flowering number, and flower diameter, are shown in Table 4. After combined stress, the leaf area of the 'Fenguiren' *lotus* in the control and treated groups increased first and then decreased. The leaf area of the treated group was lower than that of the control group at 20 and 40 days. The leaf area of the treated group at 40 days decreased by about 42.34%, which was 1.39 times the decrease rate of the control group. The leaf area of the treated group was higher than that of the control group at 60 days, but there was no significant difference. The leaf number was significantly lower than that of the control group at 20 days, and it was lower than that of the control group at 40 and 60 days, with no significant difference. From the point of view of flower number and diameter, the flower bud formed in the treated group at 20 days, which was earlier than that in the control group. There was no significant difference in flower number between the treated and control groups at 40 days, but the flower diameter of the control group was significantly larger than that of the treated group. It was speculated that Cd-Pyr compound stress had little effect on the physiological activities of normal budding in the early stage, but with the prolongation of stress time, it could affect the normal opening of *lotus*. After *ryegrass* and Echinacea were treated with Cd-Pyr, the leaf area of the control and treated groups increased first and then decreased. After Cd-Pyr combined stress treatment, the leaf area of *Pennisetum* was significantly lower than that of the control at 20, 40, and 60 days, indicating that this stress significantly inhibited the expansion of the leaf area. The leaf area of *Hemerocallis* after Cd-Pyr combined stress treatment at 20, 40, and 60 days was significantly lower than that of the control (82.21%, 82.42%, and 75.13%, respectively). The number of leaves of *Hemerocallis* was higher than that of the control, but there was no significant difference, indicating that the compound stress treatment inhibited the expansion of the leaf area of this plant.

3.1.4. Effect of Cd-Pyr Compound Treatment on Biomass

The dry weights of the above- and below-ground parts of five resistant garden plants at 60 days are shown in Figure 3. Under the combined stress of Cd-Pyr, the above- and below-ground biomass of Echinacea and *lotus* decreased significantly compared with that in the control group. The above- and below-ground biomass of *lotus* in the treated group were 73.77% and 64.59% of that of the control group, respectively. The belowground part of the *lotus* was more inhibited. Compared with that of the control group, the aboveground biomass of *ryegrass* decreased significantly (about 52.35%) and the aboveground biomass was greatly inhibited (Figure 3A). The belowground part was less affected, and there was no significant difference between the treated and control groups (Figure 3B). Compared with that of the control group, the aboveground biomass of *Pennisetum* decreased, but the difference was not significant, and the aboveground part was less affected (Figure 3B). The belowground biomass was significantly lower than that of the control group (about 53.59%) (Figure 3B). Compared with that of the control group, the above- and below-ground biomass of the treated *Hemerocallis* group were not significantly different, and the aboveground biomass was slightly higher (accounting for 104.58%) (Figure 3A), which had little impact overall. Therefore, from the biomass point of view, the inhibitory effect of compound stress on the growth of the belowground parts of *Hemerocallis*, *lotus*, and *Pennisetum* was slightly greater than that on the aboveground parts, while the effect of *ryegrass* was the opposite.

Table 4. Effects of Cd-Pyr combined stress on morphological indexes of the five tested plants ($\bar{X}$ ± SE).

Tested Plant	**Group**	**Leaf Area/cm^2**				**Leaf Number**				**Flowering Number**				**Diameter/cm**			
		0 Days	**20 Days**	**40 Days**	**60 Days**	**0 Days**	**20 Days**	**40 Days**	**60 Days**	**0 Days**	**20 Days**	**40 Days**	**60 Days**	**0 Days**	**20 Days**	**40 Days**	**60 Days**
Lolium perenne L.	Control	166.98 ± 7.40 a	198.04 ± 6.42 a	178.17 ± 7.38 a	157.87 ± 4.01 a	/	/	/	/	/	/	/	/	/	/	/	/
	Treated	169.35 ± 5.39 a	189.49 ± 6.37 a	157.82 ± 5.93 b	139.45 ± 6.45 b	/	/	/	/	/	/	/	/	/	/	/	/
Echinacea purpurea	Control	271.05 ± 9.81 a	321.99 ± 11.23 a	232.29 ± 16.36 a	185.99 ± 6.04 a	23.7 ± 0.3 a	23.7 ± 0.9 a	19.3 ± 0.9 a	15.0 ± 0.6 a	0	0	1.7 ± 0.3 a	2.0 ± 0.1 a	0	0	9.63 ± 0.44 a	20.20 ± 1.17 a
	Treated	252.95 ± 16.39 a	341.74 ± 4.54 a	198.43 ± 6.58 a	113.08 ± 7.39 b	18.3 ± 0.9 b	20.0 ± 0.6 b	15.7 ± 0.3 b	6.3 ± 0.9 b	0	0	0.3 ± 0.3 b	0.7 ± 0.3 a	0	0	2.21 ± 2.21 a	6.59 ± 3.30 b
Hemerocallis hybrida Bergmans	Control	226.23 ± 12.18 a	224.49 ± 4.14 a	221.66 ± 5.66 a	225.04 ± 4.94 a	7.7 ± 0.7 a	6.7 ± 0.7 a	7.3 ± 0.3 a	6.7 ± 0.3 a	/	/	/	/	/	/	/	/
	Treated	201.32 ± 9.02 a	184.55 ± 6.76 b	182.69 ± 10.67 b	169.08 ± 9.64 b	7.7 ± 0.3 a	7.3 ± 0.7 a	8.3 ± 0.3 a	7.0 ± 0.6 a	/	/	/	/	/	/	/	/
Nelumbo nucifera Gaertn.	Control	149.57 ± 10.39 a	469.07 ± 5.58 a	326.30 ± 8.43 a	224.72 ± 13.30 a	11.0 ± 0.6 a	16.7 ± 0.9 a	10.3 ± 0.7 a	7.3 ± 0.3 a	0	0 b	1.3 ± 0.3 a	0	0	0 b	10.43 ± 0.23 a	0
	Treated	165.61 ± 8.85 a	466.56 ± 9.12 a	269.00 ± 12.78 b	249.56 ± 17.16 a	10.0 ± 0.6 a	13.0 ± 0.6 b	9.3 ± 0.3 a	6.0 ± 0.6 a	0	1.7 ± 0.3 a	0.3 ± 0.3 a	0	0	3.88 ± 0.15 a	1.61 ± 1.61 b	0
Pennisetum alopecuroides (L.) Spreng.	Control	336.30 ± 7.71 a	374.22 ± 7.10 a	367.09 ± 6.64 a	385.28 ± 6.66 a	/	/	/	/	/	/	/	/	/	/	/	/
	Treated	333.38 ± 10.78 a	334.39 ± 3.90 b	340.29 ± 2.58 b	326.26 ± 5.24 b	/	/	/	/	/	/	/	/	/	/	/	/

Different lowercase letters in the same column indicate the significant ($p < 0.05$) difference.

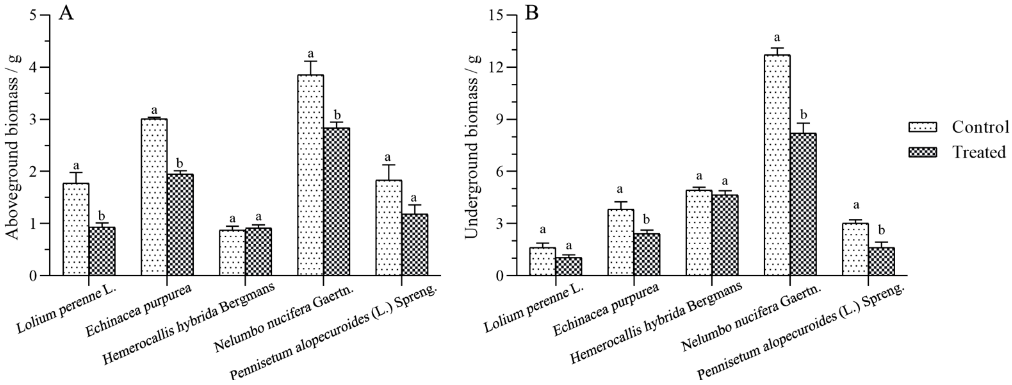

Figure 3. Biomass of the five garden plants under Cd-Pyr combined stress for 60 days. Note: Different lowercase letters indicate significant differences among different treated groups ($p < 0.05$). (**A**) Aboveground biomass, (**B**) Underground biomass.

3.2. *Enrichment Characteristics of Cd and Pyr in Different Ornamental Plants*

3.2.1. Absorption of Pollutants by Aboveground Parts of Five Plants

The changes in Cd and Pyr contents in the aboveground parts of five garden plants with time are shown in Figure 4. The order of Cd content in the aboveground part at 60 days is: 'Fenguiren' *lotus* (9.39 mg/kg) > *Pennisetum* (9.34 mg/kg) > *Echinacea* (6.85 mg/kg) > *ryegrass* (6.48 mg/kg) > *Hemerocallis fulva* (3.85 mg/kg). The order of Pyr content in aboveground parts is: *Pennisetum* (12.81 mg/kg) > 'Fenguiren' *lotus* (10.61 mg/kg) > Echinacea (5.88 mg/kg) > *Hemerocallis fulva* (4.06 mg/kg) > *ryegrass* (3.17 mg/kg). With an increase in stress time, the contents of Cd and Pyr in the aboveground parts of the five plants increased continuously, but the enrichment of pollutants at each time period showed different characteristics.

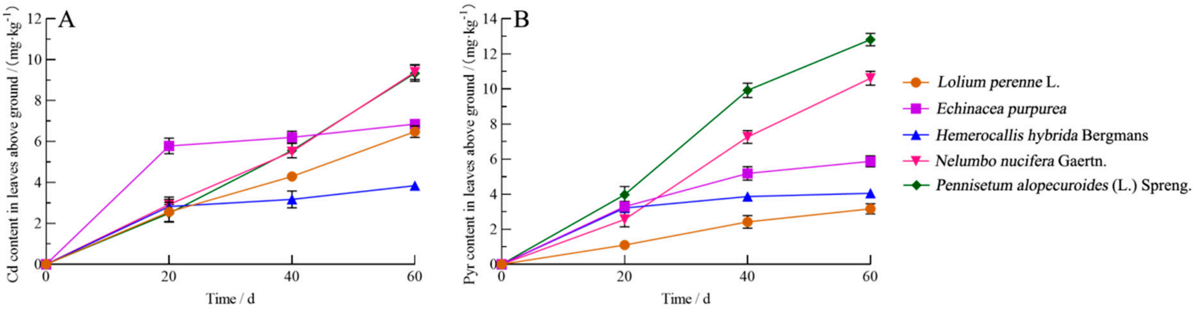

Figure 4. Absorption of pollutants by the five resistant garden plants over time. (**A**) Cd content, (**B**) Pyr content.

Figure 4A shows that for Cd enrichment, the average growth rate of Cd content in Echinacea is about 0.289 mg/kg·d after planting for 0–20 days, which is about twice that in the other 4 plants. Considering that the stress time was short, it had little effect on Echinacea. Moreover, the plants may have been in the germination growth stage, and their biomass was still low; hence, the Cd enrichment was not high. From 20 to 40 days, the average Cd content growth rate of Echinacea and *H. fulva* decreased obviously and tended to be flat at 0.021 and 0.018 mg/kg·d, respectively. It was considered that with the extension of stress time, Echinacea and *H. fulva* had a slow Cd transportation rate to protect their own aboveground parts, but still had a certain enrichment effect. The rate for *Pennisetum* was slightly higher at 0.154 mg/kg·d, whereas that for *lotus* and *ryegrass* slightly decreased. From 40 to 60 days, the average growth rate for *lotus*, *Pennisetum*, and *ryegrass* increased slightly compared with that in the previous stage, indicating that they still had a strong enrichment trend at the end of the experiment, whereas the average Cd content growth rate of Echinacea and *Hemerocallis* tended to be moderate, and the enrichment was inhibited. At 60 days, the absorbed Cd content of the aboveground part of 'Fenguiren' *lotus* was the highest, and the content in *Pennisetum* was similar to that in *lotus*, about 99.47%.

Figure 4B shows that the average growth rate of Pyr content in *ryegrass* tends to be moderate at each time stage. It was considered that *ryegrass* had a slow Pyr transportation rate to protect its aboveground parts, but still had a certain enrichment effect. The trend of Pyr enrichment in *Pennisetum* and 'Fenguiren' *lotus* was similar, but the Pyr content of *Pennisetum* aboveground was always higher than that of 'Fenguiren' *lotus* at each stage. There was a big difference in the average growth rate between the two plants from 0 to 20 days. The average growth rate for *Pennisetum* was the highest among those for the five plants, and the rate for *lotus* was only 64.51% of that for *Pennisetum*. The average growth rate for both was highest from 20 to 40 days, with *Pennisetum* (0.298 mg/kg·d) > 'Fenguiren' *lotus* (0.235 mg/kg·d). From 40 to 60 days, the average growth rate for *lotus* was higher than that for *Pennisetum*, at 0.168 and 0.144 mg/kg·d, respectively, and both still had a strong enrichment trend. At 60 days, the Pyr absorption in the aboveground part of *Pennisetum* was the highest, followed by that in *lotus*, which accounted for 82.85% of that in *Pennisetum*. The Pyr enrichment of *ryegrass*, *Hemerocallis*, and Echinacea was not optimal (only 24.75%, 31.69%, and 45.90% of that in *Pennisetum*, respectively).

3.2.2. Changes in Pollutant Levels in Potted Soil of the Five Plants

The changes in Cd and Pyr levels in soil with time are shown in Figure 5. The pollutant levels in potted soil of the five plants decreased with time. The soil removal rates of *ryegrass*, Echinacea, *Hemerocallis*, 'Fenguiren' *lotus*, and *Pennisetum* were 68.35%, 57.81%, 54.40%, 60.25%, and 68.91% for Cd at 60 days, and 59.51%, 48.91%, 47.31%, 63.74%, and 77.52% for Pyr at 60 days, respectively. The order of the Cd removal rate was *Pennisetum* > *ryegrass* > *Lotus* > *Echinacea* > *Hemerocallis fulva*, and the order of the Pyr removal rate was *Pennisetum* > 'Fenguiren' *lotus* > *ryegrass* > *Echinacea* > *Hemerocallis fulva*.

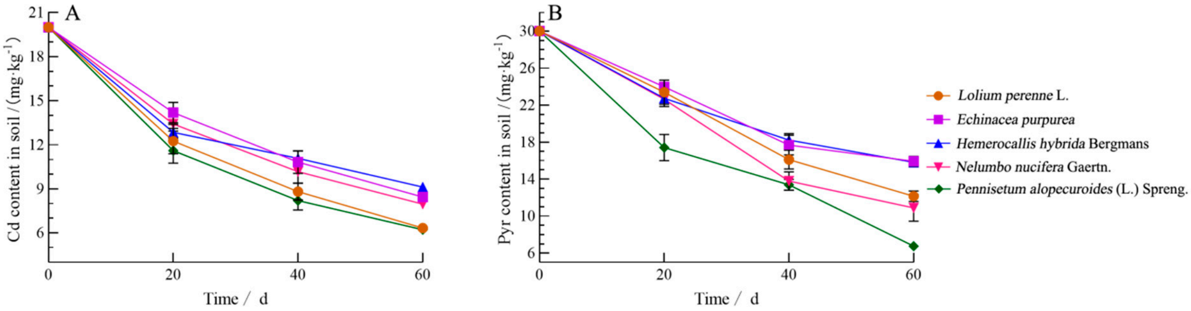

Figure 5. Changes in pollutant levels in soil with time. (**A**) Cd content, (**B**) Pyr content.

Except for that of *H. fulva*, the average removal rates of the plants tended to be flat with time (Figure 5A). From 0 to 20 days, the removal rate of *H. fulva* was 85.24% of that of *Pennisetum*. From 20 to 40 days, the average removal rates were in the order of *ryegrass*, Echinacea, *Pennisetum*, *lotus*, and *H. fulva*. At this stage, the rate for *H. fulva* quickly decreased to the minimum, only 24.86% of the rate at 0 to 20 days, and there was little difference among the other 4 plants. From 40 to 60 days, the average removal rates were 0.124 mg/kg·d (*ryegrass*), 0.119 mg/kg·d (Echinacea), 0.111 mg/kg·d (*lotus*), 0.099 mg/kg·d (*Pennisetum*), and 0.098 mg/kg·d (*H. fulva*). At 60 days, the lowest Cd content was in *Pennisetum* soil, and the soil Cd content for *ryegrass* was about 101.77% of that for *Pennisetum*, whereas the contents for *H. fulva*, Echinacea, and *lotus* were 146.55%, 135.73%, and 127.80% of that for *Pennisetum*, respectively.

Figure 5B shows that the Pyr levels in the soils of the five plants decreased with time, the average removal rate of *Pennisetum* decreased first and then increased with time, whereas that of Echinacea, *ryegrass*, and 'Fenguiren' *lotus* increased first and then decreased. The average removal rate of *Hemerocallis* gradually decreased and tended to be flat with time. From 0 to 20 days, the average removal rates were 0.630 mg/kg·d (*Pennisetum*), 0.368 mg/kg·d (*lotus*), 0.363 mg/kg·d (*Hemerocallis*), and 0.331 mg/kg·d (*ryegrass*). At this stage, *Pennisetum* had a significant ability to remove Pyr. From 20 to 40 days, the average removal rate of *Pennisetum* quickly decreased to the bottom of those for the 5 plants and was only 32.06% of that in the previous stage, whereas the average removal rates of Echinacea, *ryegrass*, and *lotus* increased, and were 104.65%, 109.97%, and 120.38% of those in the previous stage, respectively. From 40 to 60 days, the average removal rates were 0.331 mg/kg·d (*Pennisetum*), 0.198 mg/kg·d (*ryegrass*), 0.145 mg/kg·d (*lotus*), and 0.121 mg/kg·d (*Hemerocallis fulva*). The average removal rate of Pyr in soil by *Pennisetum* at this stage was significantly different from those of the other plants. It was 163.86% of the rate in the previous stage.

Overall, *Pennisetum* and 'Fenguiren' *lotus* exhibited the most advantages in the removal of Cd-Pyr soil pollutant under combined stress, followed by *ryegrass*, whereas the removal rates of Echinacea and *Hemerocallis* were lower.

3.2.3. Enrichment Coefficient of Pollutants in Aboveground Parts of the Five Plants

The enrichment coefficients of the aboveground parts of *ryegrass*, *lotus*, and *Pennisetum* were all greater than 1, showing their enrichment effect on Cd in soil (Figure 6). The enrichment coefficient of *Pennisetum* was the highest, and the coefficients of *ryegrass* and *lotus* were 70.84% and 81.62% of that of *Pennisetum.* Combined with the comparison of Cd content in leaves of various plants at 60 days (Figure 4A), this shows that 'Fenguiren' *lotus* and *Pennisetum* mainly transport Cd to aboveground leaves. However, the Cd content in *ryegrass* leaves was significantly different from that in the other two, only about 69.01% of that of *lotus* (Figure 4A), presumably because some Cd is fixed by the roots of *ryegrass*, and the roots have some tolerance to Cd. It was also noted that the Cd content of Echinacea was slightly higher than that of *ryegrass* at 60 days (105.66%), whereas the enrichment coefficient of Echinacea was less than 1, which indicated that Echinacea had a weak ability to accumulate Cd, and that its root tolerance to Cd was less than that of *ryegrass*. The enrichment coefficient of Cd in the aboveground part of *Hemerocallis fulva* was less than 1, and only 29.16% of that of *Pennisetum*, indicating that *H. fulva* is not suitable for Cd enrichment and remediation.

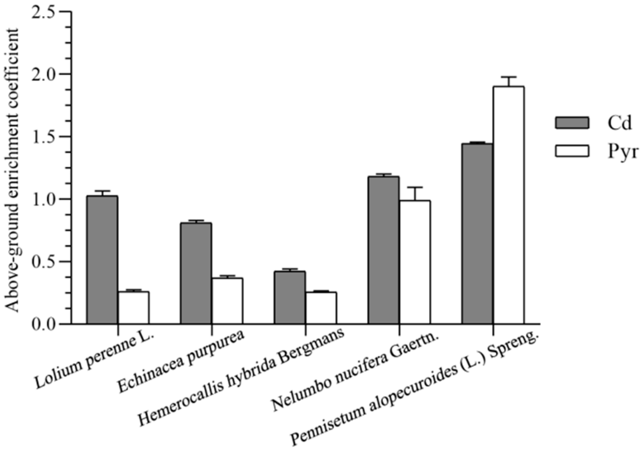

Figure 6. Enrichment coefficients of aboveground parts of the five garden plants.

The enrichment coefficient of Pyr in the aboveground part of *Pennisetum* was greater than 1 (Figure 6), and those of the other plants were only 13.72%, 19.39%, 13.45%, and 52.08% of that of *Pennisetum*, which showed that it has a far greater potential for soil Pyr enrichment than other plants. The aboveground part of 'Fenguiren' *lotus* had an enrichment coefficient of less than 1 for Pyr, but the soil removal rate was more than 50% (Figure 5B); therefore, it still had a certain enrichment effect on Pyr. Although the enrichment coefficient of Pyr in the aboveground part of *ryegrass* was only 0.261 (Figure 6), and the Pyr content in the aboveground leaves was the lowest among the five plants at 60 days (Figure 4B), the soil removal rate was still more than 50% (Figure 5B). It is speculated that most Pyr is fixed by the roots of *ryegrass*, and this is the main way to remediate Pyr using this plant. The enrichment coefficient of Pyr in the aboveground parts of *H. fulva* and Echinacea was less than 1, and the soil removal rate was not high at 47.3% and 48.91%, respectively (Figure 5B), indicating that they are not suitable for the enrichment and remediation of Pyr.

In summary, *Pennisetum* is a hyperaccumulator of Cd and Pyr, *ryegrass* and *lotus* are hyperaccumulators of Cd, and the removal effect of Pyr is acceptable. *Hemerocallis* and Echinacea have poor ability to remove the two pollutants.

3.3. Trends of Different Physiological Indices with Time

3.3.1. Effects of Cd-Pyr Compound Treatment on SOD, POD, and CAT Activities and MDA Content

The SOD, POD, and CAT activities and the MDA content of the control and treated groups of the five garden plants after 20, 40, and 60 days of culture under Cd-Pyr compound treatment are shown in Table 5. The SOD activity of *lotus* in the treated group gradually increased and was significantly higher than that in the control group: the increases in rates were 33.42% and 5.67% at 40 and 60 days, respectively. The growth rates of *Pennisetum* were 40.31% and 0.23%, which showed that the protective effect of *lotus* and *Pennisetum* gradually increased with the stress time and that the change in SOD activity of *lotus* was higher than that of *Pennisetum*. The SOD activity of the treated and control *Hemerocallis* groups increased first and then decreased with time and was significantly lower than that of the control group at 60 days, indicating that the protective enzyme action of *Hemerocallis* was stimulated after a period of stress but that the SOD activity was also inhibited upon an extension in stress time. The POD activity of the treated *ryegrass*, *Hemerocallis*, and *Pennisetum* groups increased first and then decreased with time, and the POD activity of *ryegrass* at different time periods was significantly higher than that of the control group. The activity of *Hemerocallis* was significantly higher than that of the control group at 20 and 40 days and decreased to no significant difference compared to that of the control group at 60 days. The activity of *Pennisetum* at each time period was higher than that of the control group, but the difference was significant only at 40 days. The POD activity of the treated *lotus* group increased continuously with time, and the activity at each time period was significantly higher than that of the control group (129.74%, 143.50%, and 179.44%, respectively). CAT activity in the treated *ryegrass* and *Pennisetum* groups increased first and then decreased with time, and both were significantly higher than that in the control group, indicating that CAT activity in these two plants was stimulated and played a role in protecting enzymes. The CAT activity of the treated *lotus* group increased continuously with time and was significantly higher than that of the control group at 40 and 60 days (132.62% and 134.95%, respectively). The CAT activity in *lotus* was, hence, stimulated under complex stress. The CAT activity of the treated Echinacea and *Hemerocallis* groups decreased continuously with time, indicating that compound stress inhibited CAT activity in these plants.

At 20, 40, and 60 days, the MDA content in the leaves of the 5 plants after stress treatment was higher than that of the control group, and there was a significant difference, which indicated that membrane lipid peroxidation of plant leaves was intensified under stress conditions and that the combined stress caused some damage to cell membranes. The MDA content in *ryegrass* increased first and then decreased with time and was 224.15% of that in the control at 60 days, indicating that *ryegrass* was still poisoned to some extent despite its stress resistance. The MDA contents in Echinacea, *Hemerocallis*, and *lotus* increased continuously with time, and at 60 days were 532.90%, 302.42%, and 300.62% of that in the control group, respectively. The MDA content in *Pennisetum* decreased first and then increased with time and was 300.20% of that in the control group at 60 days. Therefore, after 60 days, the order of cell membrane damage was Echinacea > *Hemerocallis* > *lotus* > *Pennisetum* > *ryegrass*.

Table 5. Effects of Cd-Pyr stress in soil on activities of SOD, POD, and CAT and MDA content in leaves of the five selected plants ($\bar{X}$ ± SD).

Tested Plant	**Group**	**SOD Activity/(U·g^{-1})**			**POD Activity/(U·g^{-1})**			**CAT Activity/(U·g^{-1})**			**MDA Content/(nmol·g^{-1})**		
		20 Days	**40 Days**	**60 Days**	**20 Days**	**40 Days**	**60 Days**	**20 Days**	**40 Days**	**60 Days**	**20 Days**	**40 Days**	**60 Days**
Lolium perenne L.	Control	187.16 ± 8.32 b	301.60 ± 54.78 b	366.08 ± 21.47 b	362.32 ± 17.54 b	381.28 ± 30.78 b	364.40 ± 29.99 b	137.77 ± 19.24 b	175.70 ± 27.08 b	170.85 ± 14.48 b	4.47 ± 0.32 b	4.02 ± 0.32 b	4.14 ± 0.33 b
	Treated	316.17 ± 38.46 a	766.17 ± 32.90 a	665.15 ± 39.80 a	579.94 ± 12.13 a	688.24 ± 30.62 a	590.83 ± 9.11 a	244.17 ± 32.73 a	285.31 ± 26.19 a	268.15 ± 21.93 a	6.50 ± 0.37 a	13.74 ± 0.41 a	9.28 ± 0.51 a
Echinacea purpurea	Control	279.60 ± 21.43 b	419.83 ± 36.68 b	427.83 ± 13.18 b	353.01 ± 13.75 b	405.73 ± 18.19 b	403.44 ± 28.63 a	200.17 ± 36.48 b	213.61 ± 26.44 a	215.79 ± 13.73 a	1.56 ± 0.36 b	1.56 ± 0.32 b	2.31 ± 0.20 b
	Treated	440.05 ± 52.74 a	590.02 ± 19.03 a	587.00 ± 18.87 a	553.96 ± 16.26 a	625.21 ± 41.55 a	275.62 ± 40.14 b	347.16 ± 38.46 a	162.98 ± 21.71 a	111.34 ± 13.78 b	4.22 ± 0.36 a	6.70 ± 0.32 a	12.31 ± 0.58 a
Hemerocallis hybrida Bergmans	Control	575.13 ± 16.10 a	597.42 ± 10.47 b	581.71 ± 19.68 a	385.10 ± 12.76 b	464.56 ± 27.63 b	456.73 ± 38.77 a	222.62 ± 32.58 a	285.57 ± 16.48 a	289.81 ± 21.15 a	3.64 ± 0.31 b	5.28 ± 0.41 b	4.96 ± 0.35 b
	Treated	541.09 ± 42.34 a	818.22 ± 60.31 a	508.25 ± 13.35 b	550.05 ± 38.10 a	708.02 ± 16.53 a	482.62 ± 29.87 a	294.28 ± 39.70 a	244.49 ± 14.58 b	176.61 ± 22.94 b	10.03 ± 0.29 a	14.97 ± 0.52 a	15.00 ± 0.50 a
Nelumbo nucifera Gaertn.	Control	484.45 ± 23.92 b	680.02 ± 21.97 b	572.74 ± 21.69 b	567.49 ± 40.94 b	616.63 ± 30.45 b	536.53 ± 14.34 b	356.37 ± 38.80 a	379.35 ± 51.18 b	385.71 ± 64.57 b	3.32 ± 0.31 b	3.27 ± 0.45 b	4.83 ± 0.35 b
	Treated	673.96 ± 33.63 a	899.17 ± 37.96 a	950.14 ± 32.90 a	736.24 ± 75.06 a	884.88 ± 14.58 a	962.77 ± 45.13 a	413.88 ± 41.54 a	503.08 ± 39.17 a	520.51 ± 35.08 a	8.64 ± 0.23 a	12.42 ± 0.35 a	14.52 ± 0.90 a
Pennisetum alopecuroides (L.) Spreng.	Control	400.05 ± 33.13 b	551.27 ± 38.19 b	535.72 ± 26.69 b	433.60 ± 46.48 a	482.50 ± 32.99 b	588.23 ± 18.52 a	178.63 ± 21.30 b	231.12 ± 33.20 b	244.72 ± 40.30 b	2.86 ± 0.31 b	5.13 ± 0.27 b	5.10 ± 0.33 b
	Treated	569.88 ± 25.97 a	799.61 ± 47.96 a	801.45 ± 46.85 a	474.42 ± 25.55 a	686.95 ± 27.29 a	645.97 ± 45.60 a	300.68 ± 40.80 a	378.55 ± 23.41 a	359.69 ± 10.30 a	12.86 ± 0.38 a	12.54 ± 0.45 a	15.31 ± 0.67 a

Different lowercase letters in the same column indicate the significant (p < 0.05) difference.

The analysis showed that at 60 days, the activities of the 3 antioxidant enzymes of *ryegrass*, *lotus*, and *Pennisetum* were higher in the treated group than in the control group, indicating that the resistance was stronger under stress. However, the activity of only one enzyme in the treated groups of Echinacea and *Hemerocallis* was significantly higher than that in the control group, respectively. Judging from the content of MDA, *ryegrass*, *lotus*, and *Pennisetum* suffered less damage.

3.3.2. Effect of Cd-Pyr Compound Treatment on Chlorophyll and Carotenoid Contents

The chlorophyll and carotenoid contents of the 5 garden plants after 20, 40, and 60 days of culture under Cd-Pyr treatment are shown in Figure 7. In general, the chlorophyll contents of the five plants decreased under stress. The chlorophyll contents of *ryegrass* and *Pennisetum* were significantly lower than that of the control group in each time period. The contents in *ryegrass* in each time period were 57.61%, 46.50%, and 32.94% of that in the control group, and those in *Pennisetum* were 55.84%, 62.49%, and 54.30% of that in the control. Although chlorophyll synthesis was affected by stress, *Pennisetum* was slightly better than *ryegrass*. The chlorophyll contents of Echinacea, *Hemerocallis fulva*, and 'Fenguiren' *lotus* were lower than that of the control group at 20 days, but there was no significant difference (Figure 7A), whereas the contents were significantly lower than that of the control group at 40 days (Figure 7B). The chlorophyll contents of Echinacea and 'Fenguiren' *lotus* were still significantly lower than that of the control group at 60 days (24.05% and 57.53%, respectively), but there was no significant difference between *H. fulva* and the control group (Figure 7C). The carotenoid contents of the five plants decreased under compound stress. The carotenoid contents of *ryegrass*, *H. fulva*, and *Pennisetum* were significantly lower than those of the control group at 20, 40, and 60 days. For example, the carotenoid contents of *Pennisetum* were 57.88%, 58.44%, and 63.79% of those of the control group at each time period. The carotenoid contents of Echinacea and 'Fenguiren' *lotus* were lower than that of the control group at 20 days, but there was no significant difference (Figure 7D), whereas it decreased significantly at 40 days. The carotenoid contents of Echinacea and 'Fenguiren' *lotus* were significantly lower than that of the control group at 60 days (35.82% and 52.56%, respectively) (Figure 7F). Overall, due to stress, the contents of chlorophyll and carotenoids in the treated groups of the five plants were inhibited and decreased, and the photosynthetic system was destroyed. It can be found that *lotus* and *Pennisetum* were the best according to the total content.

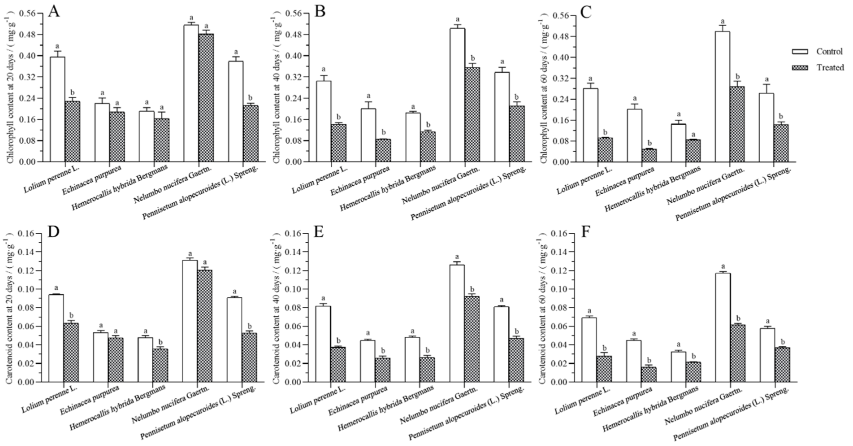

Figure 7. Effects of Cd-Pyr combined stress on chlorophyll and carotenoid contents of the five garden plants. Note: Different lowercase letters indicate significant differences among different treated groups ($p < 0.05$). (**A**) Chlorophyll content at 20 days, (**B**) Chlorophyll content at 40 days, (**C**) Chlorophyll content at 60 days, (**D**) Carotenoid content at 20 days, (**E**) Carotenoid content at 40 days, and (**F**) Carotenoid content at 60 days.

4. Conclusions and Discussion

In view of the increasingly serious soil pollution situation in China, ornamental resistant garden plants were used to carry out systematic screening experiments under compound stress. *Pennisetum* and 'Fenguiren' *lotus* met the screening requirements best, followed by *ryegrass*. Combined stress had no drastic effect on these three plants, which could achieve good pollutant removal rates.

Firstly, this study focused on the growth of different plants under stress. At 20 days, the plant height of 4 plants was not affected much, but that of *Hemerocallis* was inhibited due to the initial stress. The plant height was inhibited at 40 days and greatly inhibited at the later stage, but it was still within the tolerance range overall. The leaf area of the five plant treatment groups was significantly lower than that of the control group at different time periods, and the compound stress inhibited the expansion of the plant leaf area to some extent. Additionally, the stress conditions had some influence on the flowering time of Echinacea and 'Fenguiren' *lotus*. Compound stress treatment had a slightly more inhibitory effect on the growth of the belowground part of *Hemerocallis*, *lotus*, and *Pennisetum* than the aboveground part, whereas the aboveground part of *ryegrass* was slightly more inhibited than the belowground part.

The order of the Cd removal rate was *P. alopecuroides* (L.) Spreng. > *L. perenne* L. > *N. nucifera* > *E. purpurea* > *H. hybrida* Bergmans, and the order of the Pyr removal rate was *P. alopecuroides* (L.) Spreng. > *N. nucifera* > *L. perenne* L. > *E. purpurea* > *H. hybrida* Bergmans. Based on a comprehensive analysis of the pollutant contents and enrichment coefficients of the aboveground parts of the plants, it is speculated that 'Fenguiren' *lotus* and *Pennisetum* mainly transport Cd to the aboveground leaves, which is consistent with the results of Wang's study [43]. The enrichment coefficient of Pyr in the aerial parts of *Pennisetum* was 1.903, and its Pyr removal ability was strong. The Pyr enrichment coefficient of *lotus* was close to 1 and its soil removal rate was more than 50%, indicating that its Pyr removal ability is acceptable. The enrichment coefficients of Echinacea and *Hemerocallis* were both less than 1, and the soil removal rate of Cd was higher than 50% and that of Pyr was close to 50%, indicating that these plants have a certain tolerance to combined stress, but the effect is poor. The specific enrichment sites of the pollutants in these plants are yet to be confirmed, and further experiments will be carried out in the follow-up.

Regarding physiological responses, the SOD, POD, and CAT activities of *Pennisetum*, *ryegrass*, and 'Fenguiren' *lotus* were higher than those of the control group at 20, 40, and 60 days, and there were significant differences, indicating that they play a very good protective role. The MDA content in the leaves of the five plants after stress treatment was higher than that in the control, and there was a significant difference, which indicated that the plants had a stress reaction and were sensitive to the combined stress and that the inhibitory effect of compound stress on the plants resulted in some damage to cell membranes. In general, the chlorophyll and carotenoid contents of the five plants decreased under stress and were lower than those of the control group, indicating that the photosynthetic function of chloroplasts of the five plants was inhibited to different degrees owing to the combined stress, and the photosynthetic system was destroyed. However, at 60 days, the total content in *lotus* and *Pennisetum* was higher, whereas that in Echinacea and *Hemerocallis* was lower, indicating that the photosynthesis of *lotus* and *Pennisetum* was probably the strongest among the five plants.

In summary, considering their growth, enrichment characteristics, and physiological indicators, *Pennisetum* and *lotus* exhibited the best comprehensive performance based on all indicators, followed by *ryegrass*, whereas *Hemerocallis* and Echinacea exhibited poor performance. *Pennisetum*, *ryegrass*, and 'Fenguiren' *lotus* may hence be used as remediation plants for Cd-Pyr compound pollution. These three plants can be widely planted in China and even across the world and have great application potential in the ecological restoration. In the actual remediation of Cd-Pyr brownfield, such as abandoned chemical plants, landfills, and abandoned gas stations, physical remediation methods can be used for proper pre-pollution treatment, and then plants screened out in our study can be used for plant group configuration. Cooperating with the inoculation of microorganisms could further promote pollutant degradation. The above method can also be seen as a new solution to land resources' waste and environmental problems. It should be noted that our experiments were conducted in the greenhouse, so there might be some differences with the actual situation. Studies have shown that phytotechnologies are more advantageous economically than other in situ and ex situ remedial approaches (estimated to be at least 40% less costly) [44]. While reducing the cost of restoration, it also creates more ornamental landscape, and finally achieves the sustainable and stable state of self-circulation of the ecosystem.

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