water

Article

Control of Aquatic Weed *Eichhornia crassipes* Using Florpyrauxifen-benzyl Herbicide—Case Study in Cangkuang Lake (Indonesia)

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Abstract: Water hyacinth (*Eichhornia crassipes* (Mart). Solms) is a rapidly growing plant that can easily invade water bodies and negatively impact aquatic ecosystems. Cangkuang Lake is currently facing a major issue due to the increased proliferation of this plant species. Although herbicide can be used to manage weeds in aquatic ecosystems to save labor and time, their impact and toxicity on the environment must be considered. Therefore, this study aims to determine the effectiveness of the Florpyrauxifen-benzyl herbicide in controlling water hyacinth in Cangkuang Lake, Garut Regency, West Java, and its impact on water quality. A randomized block design (RBD) was used with eight treatments, and each treatment was replicated four times to obtain a total of 32 experimental plots with a size of 1 m × 1 m. Each plot contained water hyacinth weeds, with a range of 8–10 leaves and a weight range of 250–300 g. The treatment consisted of herbicide with active ingredients Florpyrauxifen-benzyl (5, 15, 25, 35, and 45 g a.i./ha), 2,4-D Dimethyl Amine (DMA) (1200 g a.i./ha), Penoxsulam (25 g a.i./ha), and the control. The study also measured several water quality parameters, including dissolved oxygen (DO), pH, total dissolved solids (TDS), and ammonia levels. The results showed that Florpyrauxifen-benzyl, starting at a dose of 15 g a.i./ha, was effective in controlling *E.crassipes* weeds with a growth reduction percentage of up to 100% and no weed regrowth at 42 DAA (day after application). However, all water quality parameters were within the standard threshold for the Government Regulation of the Republic of Indonesia No. 22/2021. This study suggests that Florpyrauxifen-benzyl can be an effective herbicide for controlling water hyacinth in Cangkuang Lake, and that its use did not have a negative impact on water quality. However, this study also highlights the importance of considering the potential environmental impact and toxicity of herbicides before their use in aquatic ecosystems.

Keywords: aquatic weeds control; *Eichhornia crassipes* (Mart). Solms; Florpyrauxifen-benzyl herbicide; water quality

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1. Introduction

Water hyacinth is a highly invasive aquatic vegetation that poses a serious threat to the environment, society, and economy due to its rapid growth, ecological resilience, and global distribution [1]. Previous reports showed that the plant has invaded several continents, including Asia, Europe, Africa, and America [2]. Furthermore, it has various effects such as reducing the amount of dissolved oxygen (DO), increasing water loss in lakes and rivers, inhibiting sunlight from reaching water's surface, and clogging waterways [3–5]. In Indonesia, the uncontrolled growth of water hyacinth has caused problems in various places, including Cangkuang Lake (West Java), Lake of Rawapening (Central Java), and the Jatiluhur Reservoir (West Java) [6–8]. Water hyacinth is a major issue affecting the ecological balance of Cangkuang Lake, which is a popular tourist destination in the Garut Regency, West Java Province, with a total area of 340775 ha [9]. The blooming rate of water hyacinth weeds in this lake has reduced the space available for bamboo rafting, has limited transportation activities, and has diminished the aesthetic value.

Controlling water hyacinth weeds is crucial to maintaining the health of ecosystems, and various methods can be used for this purpose, including physical, mechanical, biological, and chemical techniques [10]. Although chemical control with herbicide is less costly compared to mechanical methods, it is important to consider the impact on human health and the environment during selection [11]. Herbicides have been reported to experience degradation over time, leading to the loss of their biological activity [12]. Furthermore, some of these chemicals have been widely utilized in the Americas and Australia for aquatic weeds control [13–15], including Glyphosate, 2,4-D, Diquat, Endothal, Fluridone, Penoxsulam, Florpyrauxifen-benzene, Imazamox, Imazapyr, and Flumioxazin [16–18]. Florpyrauxifen-benzyl (FPB) is a new synthetic auxin herbicide from the arylicolinate family with a post-emergence systemic mechanism of action [19,20]. It also has broad-spectrum effects with rapid absorption and is often used to control weeds among crops and in aquatic ecosystems [21]. Synthetic auxin herbicide imitates the natural hormone auxin, leading to the bending of stems and petioles, suppression of growth, chlorosis at growing points, necrosis, and death of sensitive plants [22,23]. Florpyrauxifen-benzyl is suitable and non-toxic to birds, mammals, reptiles, and bees, with a half-life of 4–6 days and two days in aerobic and anaerobic environments, respectively [24]. It is also not acutely hazardous to fish, as evidenced by a carp (*Cyprinus carpio*) acute toxicity test with an LC50-96-h value of >120 mg/L [25].

Water hyacinth is known for its ability to rapidly spread on the surface of water bodies, where it alters physical, biological, and chemical processes, leading to a decrease in quality [26]. The decomposition of weeds after herbicide treatment can reduce DO needed by aquatic organisms [4]. A low DO is closely associated with the presence of dense submerged aquatic vegetation and the breakdown of aquatic weeds [27,28]. The physical and chemical parameters that influence the survival of aquatic species, such as pH, DO, temperature, CO_2, ammonia, nitrite, alkalinity, total dissolved solids (TDS), salinity, and nutrients, can directly or indirectly affect water quality [29–31]. Plant decomposition and degradation or decay can increase the demand for biochemical oxygen in significant quantities [32,33]. Increased ammonia levels caused by the decomposition of organic materials by microorganisms and the products of animal metabolism [29,34] must be maintained to ensure the continued existence of aquatic biota.

In Indonesia, there are limited studies on the adverse effects of the application of herbicide to control aquatic weeds. Therefore, this study aims to determine the effectiveness of Florpyrauxifen-benzyl herbicide in controlling water hyacinth in Cangkuang Lake, Garut Regency, West Java, and its impact on water quality. The results are expected to identify the most effective type and dosage for controlling the invasive species *E. crassipes* and minimizing their influence.

2. Materials and Methods

2.1. Study Location

This study was carried out in Cangkuang Lake Tourism Village, Leles District, Garut Regency, West Java, Indonesia from November to December 2022 at the coordinates of 7°6′24″ S 107°55′16″ E, as shown in Figure 1. Based on the Kopen climate classification, the climatic condition at the experimental site was generally described as a humid tropical environment [35]. Furthermore, the average temperature ranged from 25.7 to 30 °C, which was perfect for the growth of aquatic weeds, such as water hyacinth. Observations showed that the area had an average relative humidity of 89 to 90%.

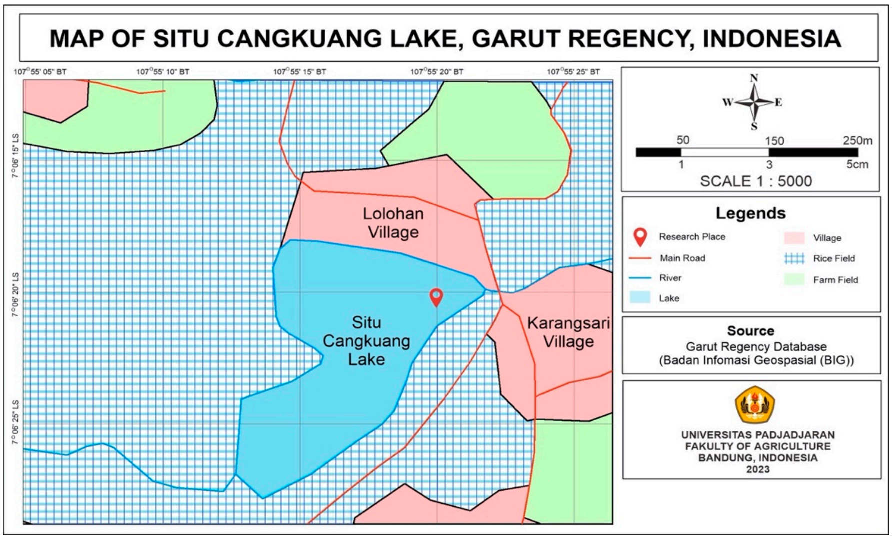

Figure 1. Map of the study location at Cangkuang Lake, Indonesia.

Observations started in early November 2022, which was the beginning of the rainy season, based on statistics from the Garut Space and Atmospheric Technology Test and Observation Center from November 2022 to December 2022 [36]. The collection of data on precipitation and temperature are as shown in Figures 2 and 3.

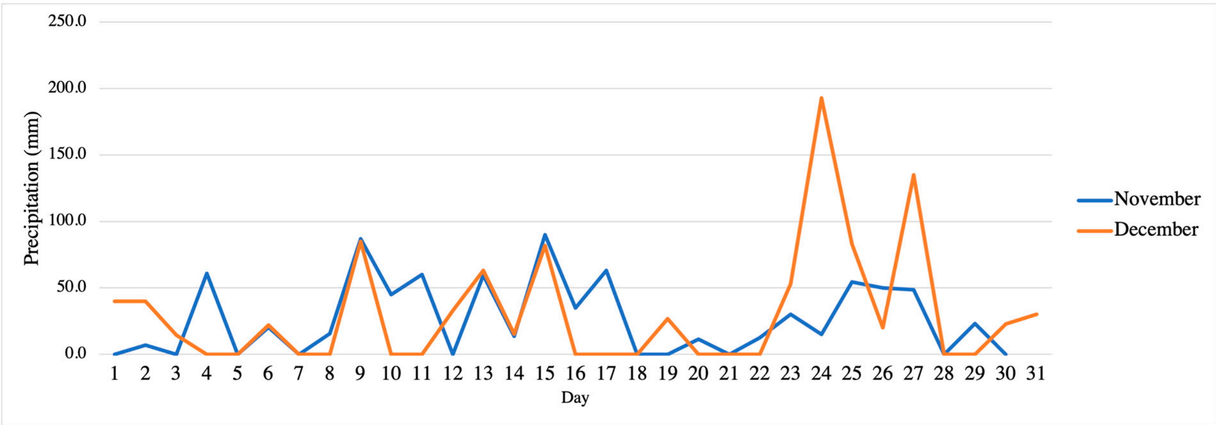

Figure 2. Daily precipitation from November to December 2022.

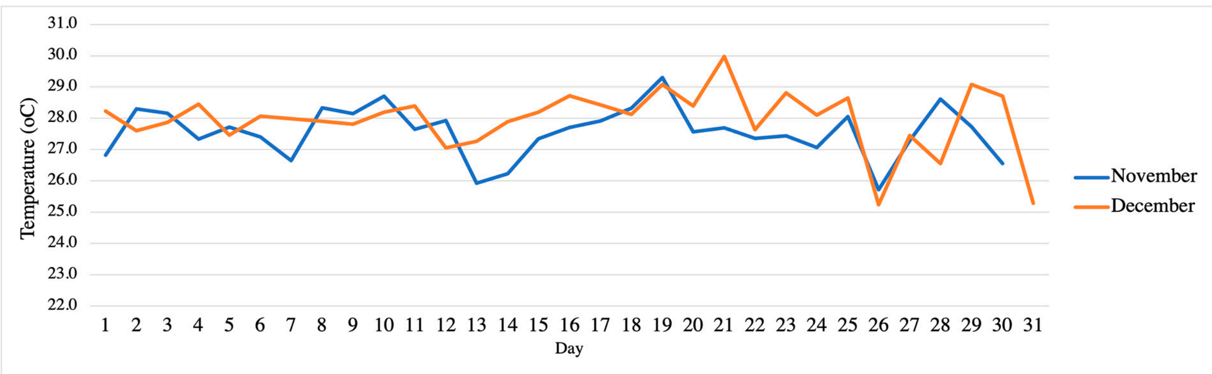

Figure 3. Daily temperature from November to December 2022.

2.2. Plant Materials

Water hyacinth weeds used in this study were obtained from the water's surface and were lifted carefully to prevent the dripping of water. Furthermore, the samples had a homogenous size, with a fresh weight ranging from 250 to 300 g and contained eight to ten leaves. To plant the weeds into the lake, 40 were placed in square pipes measuring 1 m × 1 m. The treatment boxes were then kept at the eastern end, at the coordinates of 7°06′18.2″ S 107°55′21.8″ E. To facilitate the adaptation process, weeds were sown on the test plot three weeks before herbicide treatment. A total of 1280 weed propagules were used in lake trials.

2.3. Experimental Design and Herbicide Application

This study was carried out in a lake using an RBD with eight treatments and four replications to obtain a total of 32 experimental unit plots. A total of 40 of the lake's water hyacinth weed propagules were kept in a pipe box measuring 1 m × 1 m. Furthermore, this study used eight treatments and each treatment was replicated four times, indicating that 1280 propagules were utilized. The distance between the treatments was 0.5 m, while between replication was 2 m. The evaluated treatments included Florpyrauxifen-benzyl doses of (5, 15, 25, 35, and 45 g a.i./ha; Loyant 25 EC, Corteva Agriscience Manufacturing, Indonesia), 1200 g a.i./ha (2,4-D DMA; DMA-6 825 SL, Corteva Agriscience Manufacturing, Indonesia), 12.5 g a.i./ha (penoxsulam; Clipper 25 OD, Corteva Agriscience Manufacturing, Indonesia) and the control. Herbicide was sprayed into the lake once in the morning after the water hyacinth had acclimated and became homogenous. The application of the treatments was facilitated by bamboo rafting water transportation in the surrounding area. A semi-automatic knapsack sprayer with a flat fan nozzle was used to spray herbicide on water hyacinth weeds above water in the 1 m × 1 m square pipes. The volume of water used was 400 L per acre at a pressure of 1 kg per square centimeter (15–20 p.s.i). Based on the treatment plan, weeds were placed in square pipes, and observations were carried out up to 42 DAA (day after application).

2.4. Water Quality Measurement

The observation of water quality was carried out from 0 DAA to 42 DAA using in situ and ex situ methods. In situ measurements in Cangkuang Lake were performed on the parameters of DO, power of hydrogen (pH), TDS, and temperature. Meanwhile, ex situ assessments were carried out on ammonia parameters at the Unpad Faculty of Fisheries and Marine Sciences at Aquatic Resources Laboratory. A DO meter Lutron DO-5509 (Lutron Electronic Co., Ltd, Taipei, Taiwan) was used to detect DO, while water pH was measured using pH meter (HI98107, Hanna Instruments Indotama, Jakarta, Indonesia). In this study, TDS and temperature was measured with HI8731(Hanna Instruments Indotama, Jakarta, Indonesia), and a Genesys 20 VIS spectrophotometer (ThermoFisher Scientific, Waltham, MA, USA) was utilized to quantify ammonia. The technique for measuring DO, pH, temperature, and TDS values consisted of preparing a tool, followed by its insertion into a water body at the tip for 3 min. Readings were then taken on the scale and the results were recorded in an observation table. The instruments were calibrated, and their probes were inserted into the water, followed by a reading on the monitor until constant values were obtained, which were recorded in the observation table.

The ammonia concentration was determined using a spectrophotometer and the Nessler method [37]. A water sample totaling 50 mL was collected, and 25 mL was filtered and placed in a test tube. Furthermore, 1 mL of Signett solution and 0.5 mL of Nessler solution (Aquatic Resources Laboratory Universitas Padjadjaran, Sumedang, Indonesia), were added and the mixture was allowed to stand for 10 min. The concentrations were then determined using a spectrophotometer at a wavelength of 425 nm. The results were calculated using the formula: 100/25 × Absorbance of samples/Absorbance of standards × 5 μg [38].

Based on the Government Regulation of Republic Indonesia No. 22/2021 [39], concerning the implementation of environmental protection and management, water can be categorized into four classes: (1) Class I: intended for drinking and/or other uses. (2) Class II: intended for use at recreation infrastructure/facilities, freshwater fish cultivation, animal husbandry, irrigating plants, and other uses. (3) Class III: intended for freshwater fish cultivation, animal husbandry, irrigating plants, and other uses. (4) Class IV: intended for irrigating crops, and other uses.

2.5. Morphological Structure and Topography of Water Hyacinth Petioles

Observation of the morphological structure and topography of water hyacinth petioles was carried out using scanning electron microscope (SEM) JEOL JSM 6510LA (Jeol Ltd., Akishima, Tokyo, Japan). Observations were carried out at the SEM Laboratory at Faculty of Mathematics and Natural Sciences ITB, Indonesia, at magnifications of 40× and 4000×.

2.6. Statistical Analyses for Dose–Response Experiments

The weed samples were evaluated by measuring their dry weight, which was obtained through the process of destruction and drying in an oven at 80 °C for 48 h until the values were constant at 14, 28, and 42 DAA. The dry weight can be used to calculate the percentage of growth reduction by comparing values obtained from samples treated with herbicide to those in the control. The calculation of growth reduction percentage was carried out [40] using the formula: $\%GR = 1 - (T/C) \times 100\%$; where %GR = percentage inhibition of treatment, T = dry weight value of weeds treated with herbicide, C = dry weight value of control weeds. Furthermore, field water quality measurement data, such as DO, TDS, pH, and ammonia, were analyzed using a statistical test kit. Data processing was carried out using the ANOVA test with the SASM Agri 8.1 software. If the treatment showed a significant effect, a further test was carried out on the difference in mean values between the treatments using the Scottt-Knott advanced test at $\alpha = 5\%$.

3. Results

3.1. Effect of Herbicide on the Weeds E. crassipes

3.1.1. Dry Weight of the Weeds *E. crassipes*

The results indicated that Florpyrauxifen-benzyl herbicide treatment at dose levels of 5 to 45 g a.i./ha was significantly different from the control (Table 1).

Table 1. Effect of herbicide on the dry weight of the weeds *E. crassipes* at 14 DAA to 42 DAA.

Treatment (Herbicide)	Rate (g a.i./ha)	Dry Weight (g)		
		14 DAA	28 DAA	42 DAA
Florpyrauxifen-benzyl	5	20.05 ^{c} ± 0.48	16.67 ^{c} ± 0.36	13.48 ^{b} ± 0.59
Florpyrauxifen-benzyl	15	15.75 ^{d} ± 0.33	7.04 ^{d} ± 0.35	0.00 ^{e} ± 0.00
Florpyrauxifen-benzyl	25	15.67 ^{d} ± 0.51	0.00 ^{e} ± 0.00	0.00 ^{e} ± 0.00
Florpyrauxifen-benzyl	35	12.24 ^{e} ± 0.89	0.00 ^{e} ± 0.00	0.00 ^{e} ± 0.00
Florpyrauxifen-benzyl	45	10.83 ^{e} ± 2.17	0.00 ^{e} ± 0.00	0.00 ^{e} ± 0.00
2,4-D DMA	1200	15.71 ^{d} ± 1.67	7.43 ^{d} ± 1.10	5.12 ^{d} ± 0.13
Penoxsulam	25	23.28 ^{b} ± 1.24	18.49 ^{b} ± 0.92	12.30 ^{c} ± 0.09
Control	-	39.07 ^{a} ± 1.51	42.42 ^{a} ± 1.09	50.28 ^{a} ± 1.07

Note: The average value followed by the same letter is not significantly different ($p < 0.05$) based on the Scott-Knott test. DAA = day after application.

The results indicated that all Florpyrauxifen-benzyl herbicide treatments were significantly different from the control. At 14 DAA to 28 DAA, Florpyrauxifen-benzyl at a dose level of 15 g a.i./ha showed no significant difference from the synthetic auxin 2,4-D Dimethyl Amine with a dosage of 1200 g a.i./ha. Furthermore, there was a significant difference between 2,4-D Dimethyl Amine and Florpyrauxifen-benzyl at a dosage of 5 to 45 g a.i./ha during observation at 42 DAA. Florpyrauxifen-benzyl treatment at a dosage range of 15 g a.i./ha–45 g a.i./ha showed a lower average dry weight compared to 2,4-D Dimethyl Amine. Florpyrauxifen-benzyl treatment at a dose range of 15–45 g a.i./ha can control *E.crassipes* in aquatic habitats up to 42 DAA. This was indicated by a reduction in the weed's biomass to a value below that of the control, as well as another herbicide, such as 1200 g a.i./ha 2,4-D Dimethyl Amine and penoxsulam 25 g a.i./ha. Furthermore, the application of 5 g a.i./ha Florpyrauxifen-benzyl and 12.5 g a.i./ha penoxsulam were less successful at controlling weeds up to 42 DAA.

The rapid absorption and transport of systemic herbicide by the leaf of *E.crassipes* caused visible signs of petiole bending/epinastication at 3 DAA. These findings are in line with the SEM images of the petiole's morphological structure, as shown in Figure 4. The petiole used in the control treatment was the upper portion of the petiole closest to the control leaf (without herbicide) (Figure 4e). The twisting of the petiole indicated that herbicide molecules had been translocated from the strands. Furthermore, the 4000 × 500 m SEM test results showed that herbicide molecules were linked to the vascular tissue in each treatment compared to the control, as shown in Figure 4a–d. The higher the concentration of herbicide used, the higher the death rate of the weeds. The maximum dose of Florpyrauxifen-benzyl was 45 g base area per hectare, as shown in Figure 4b. Compared to the dosage of 5 g a.i./ha (Figure 4a), there was a considerable buildup of herbicide molecules surrounding the vascular tissue. The results showed that Florpyrauxifen-benzyl, 2,4-D Dimethyl Amine, and Penoxsulam were all effectively absorbed by plants even during the rainy season.

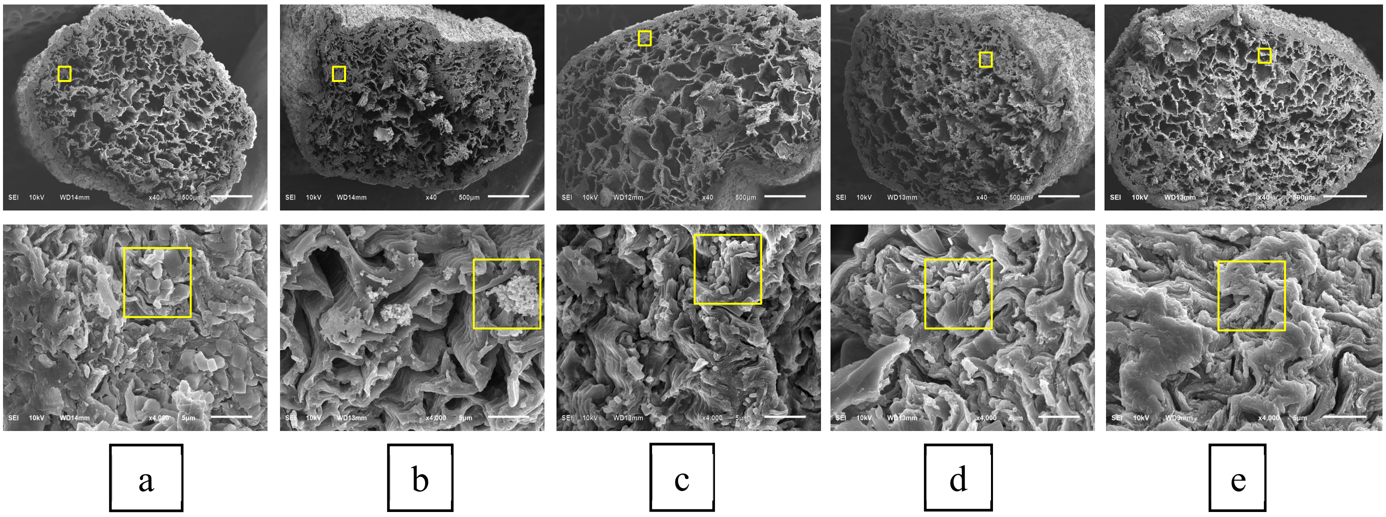

Figure 4. Internal cross-section structure of petiole *E. crassipes* (SEM Test Results) at 3 DAA (day after application). SEM test results at magnifications 40× and 4000× (**a**) Florpyrauxifen-benzyl herbicide dose 5 g a.i./ha, (**b**) Florpyrauxifen-benzyl herbicide dose 45 g a.i./ha, (**c**) herbicide 2,4-D Dimethyl Amine dose 1200 g a.i./ha, (**d**) Penoxsulam herbicide dose 25 g a.i./ha, (**e**) control (without herbicide).

3.1.2. Growth Reduction of the Weeds *E. crassipes*

The result showed that the type and dosage of herbicide had a significant effect on the growth reduction of *E. crassipes*. From a dose of 15 g a.i./ha, Florpyrauxifen-benzyl was successful in controlling weeds at 42 DAA (day after application) with a growth reduction percentage value of >75%, which was insignificantly different from other doses. At 42 DAA, 5 g a.i./ha Florpyrauxifen-benzyl, 1200 g a.i./ha 2,4-D doses, and 25 g a.i./ha Penoxsulam were significantly different compared to 15–45 g a.i./ha Florpyrauxifen-benzyl and the control treatment, as shown in Figure 5.

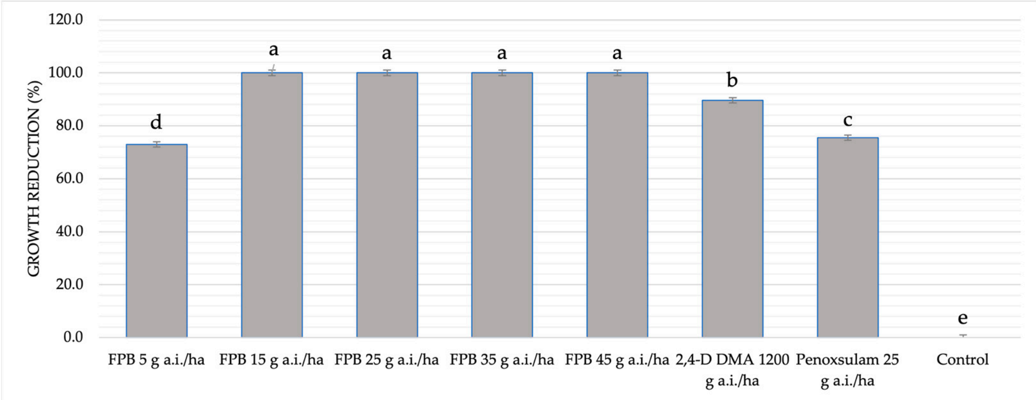

Figure 5. The effect of application of Florpyrauxifen-benzyl (FPB), 2,4-D DMA, and Penoxsulam herbicides on growth reduction percentage in the weeds *E. crassipes* at 42 DAA (day after application). The average value of the treatments on the graph followed by the same letter is not significantly different ($p < 0.05$) based on the Scott-Knott test.

The growth reduction in weeds was found to be more significant with doses of 1200 g a.i./ha 2,4-D Dimethyl Amine (89.81%) and 25 g a.i./ha Penoxsulam (75.53%). Furthermore, at Cangkuang Lake, 5 g a.i./ha Florpyrauxifen-benzyl was less successful in controlling *E.crassipes* with a growth reduction of 72.97%, which was below 75%.

3.2. Effect of Herbicides on Water Quality

3.2.1. Dissolved Oxygen (DO)

Based on the results obtained at 0 DAA to 42 DAA, Figure 6 shows that the application of the three types of herbicides, namely 5 g a.i./ha to 45 g a.i./ha Florpyrauxifen-benzyl, 1200 g a.i./ha 2,4-D Dimethyl Amine, and Penoxsulam, was not significantly different from the control treatment during any week of the observation period.

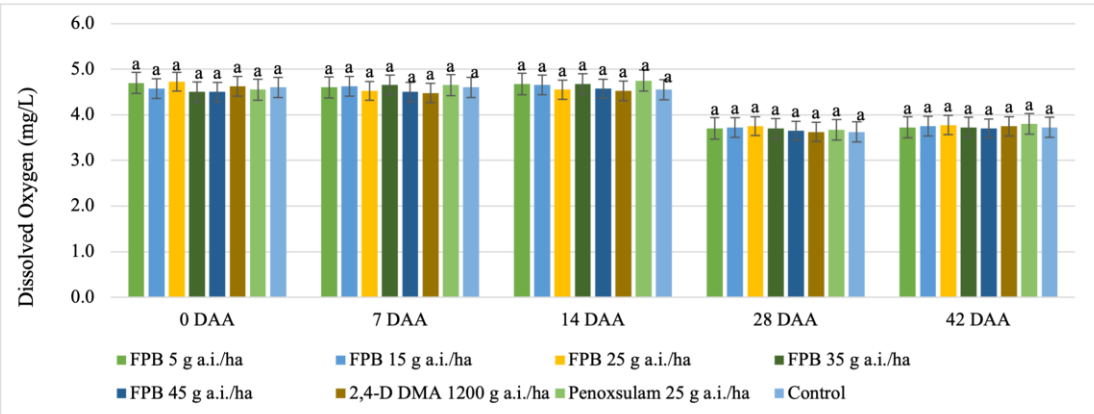

Figure 6. The effect of application of Florpyrauxifen-benzyl (FPB), 2,4-D DMA, and Penoxsulam herbicides on dissolved oxygen (DO) at 0 DAA to 42 DAA (day after application). The average value of the treatments on the graph followed by the same letter is not significantly different ($p < 0.05$) based on the Scott-Knott test.

DO parameters observed in Cangkuang Lake varied from 3.70 to 4.75 at 42 DAA. The measurement of the average DO in each treatment revealed that the concentration at the study site was <5 mg/L. During the trial, the highest concentration was 4.75 mg/L, which was obtained with 25 g a.i./ha Penoxsulam at 14 DAA. Meanwhile, the lowest was 3.63 mg/L at 28 DAA and was found in the control treatment and 2,4-D Dimethyl Amine herbicide dosage 1200 g a.i./ha, as shown in Figure 6. Although DO parameters showed a decline from 28 DAA to 42 DAA, the type and dose of herbicide used had no effect.

3.2.2. Power of Hydrogen (pH)

Observations showed that there were changes in the water's pH value until the end of the experiment, as shown in Figure 7.

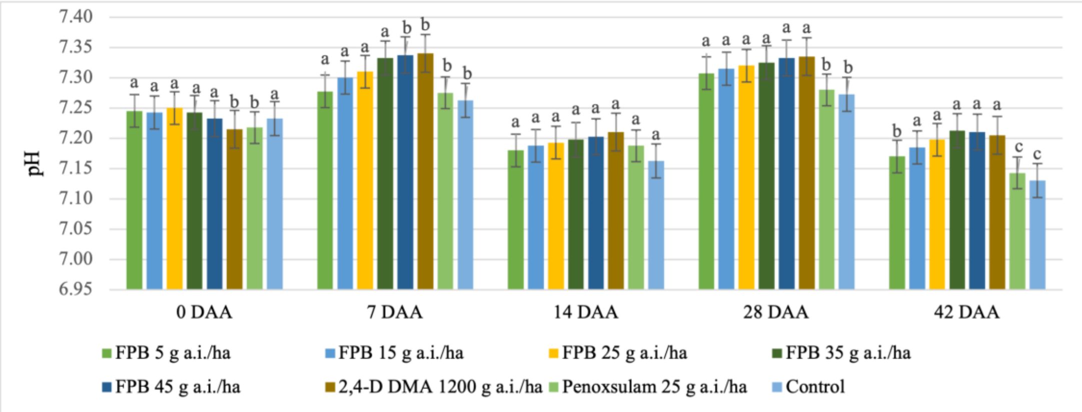

Figure 7. The effect of application of Florpyrauxifen-benzyl (FPB), 2,4-D DMA, and Penoxsulam herbicides on pH at 0 DAA to 42 DAA (day after application). The average value of the treatments on the graph followed by the same letter is not significantly different ($p < 0.05$) based on the Scott-Knott test.

The measurement of the average pH value of each treatment revealed that at 0 DAA, Florpyrauxifen-benzyl herbicide treatment was not significantly different from the control, with a range of 7.22 and 7.28. At 7 DAA to 42 DAA, the value obtained began to fluctuate, with an average range of 7.13 to 7.34. Furthermore, during the trial, the maximum pH was 7.34, which was obtained from 5–15 g a.i./ha Florpyrauxifen-benzyl at 7 DAA. The lowest was found at 42 DAA in the control treatment with a value of 7.13. Observations at 42 DAA revealed that the application of 5 g a.i./ha to 45 g a.i./ha Florpyrauxifen-benzyl yielded significantly different results compared to the control. The results showed that the effect of the three types of herbicides, namely Florpyrauxifen-benzyl, 2,4-D Dimethyl Amine, and Penoxsulam, fluctuated weekly and had no influence on the pH level of the water in Cangkuang Lake.

3.2.3. Water Temperature

Observations of water temperature in all treatments of Florpyrauxifen-benzyl, 2,4-D Dimethyl Amine, Penoxsulam, and the control showed changes up to 42 DAA, as shown in Figure 8.

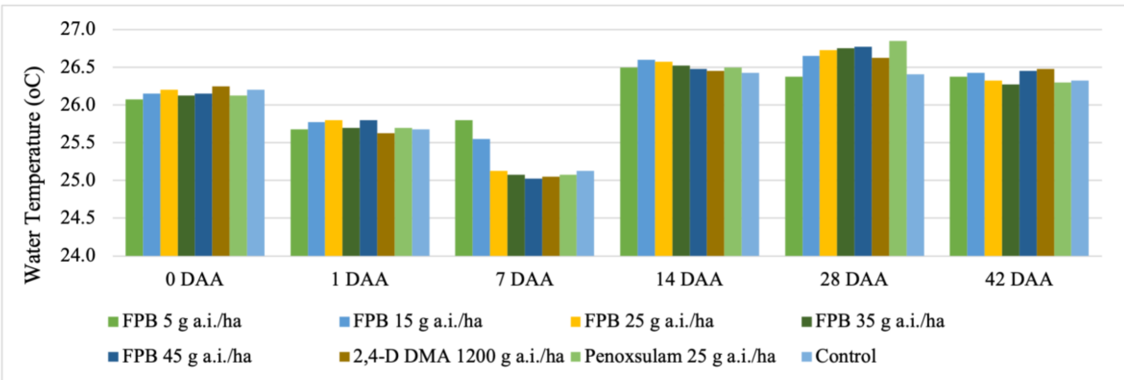

Figure 8. The effect of application of Florpyrauxifen-benzyl (FPB), 2,4-D DMA, and Penoxsulam herbicides on water temperature at 0 DAA to 42 DAA (day after application).

During the measurements at Cangkuang Lake, the temperature ranged from 25.3 to 27.1 °C, which was typical and posed little threat to aquatic life. At 7 DAA, the lowest average value of 25.2 °C was obtained with a range of 25.0–26.0 °C, while the highest range of 26.2–27.0 °C occurred at 14 DAA. The temperature variation was caused by differences in environmental conditions and measurement times in each repetition. Furthermore, the average values obtained in this study ranged from 25.3 to 27.1 °C, which was below the standard for water hyacinth survival, namely 28.0–30.0 °C [41].

3.2.4. Total Dissolved Solids (TDS)

Based on the experiment at Cangkuang Lake, TDS values increased at 7 DAA and 28 DAA, and then fluctuated up to 42 DAA, as shown in Figure 9.

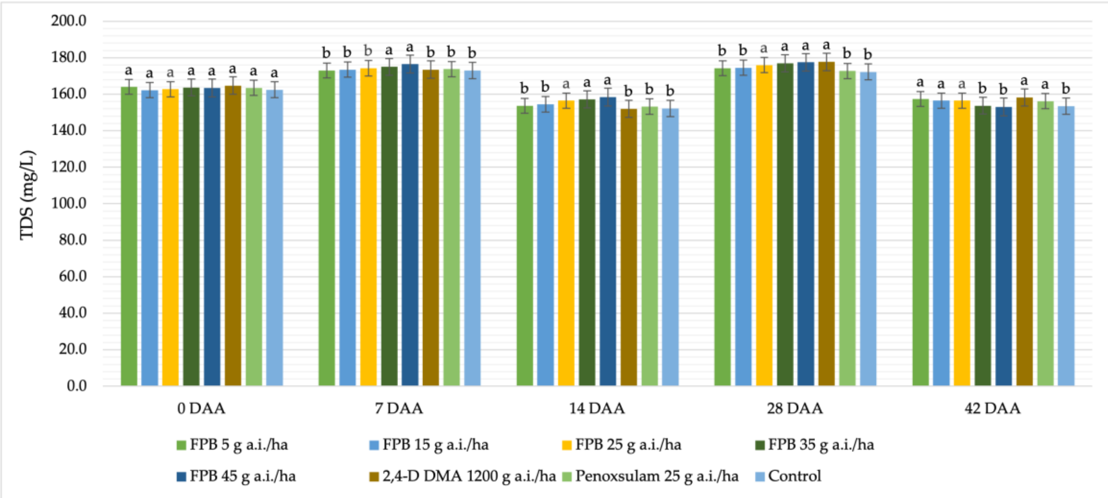

Figure 9. The effect of application of Florpyrauxifen-benzyl (FPB), 2,4-D DMA, and Penoxsulam herbicides on TDS at 0 DAA to 42 DAA (day after application). The average value of the treatments on the graph followed by the same letter is not significantly different ($p < 0.05$) based on the Scott-Knott test.

The measurement of each treatment revealed that none of the herbicide treatments differed significantly from the control treatments at 0 DAA, whose levels varied from 162.75 to 165.25 mg/L. Observations showed that TDS values at 7 DAA to 42 DAA began to fluctuate, ranging from 153.00–177.50 mg/L. Furthermore, at 7 to 28 DAA, the application of 5 to 25 g a.i./ha Florpyrauxifen-benzyl did not significantly differ from the control. The results showed that the application of the three types of herbicides, namely Florpyrauxifen-benzyl, 2,4-D Dimethyl Amine, and Penoxsulam, at all dose levels did not have a significant influence on TDS up to 42 DAA.

3.2.5. Ammonia (NH3-N)

A free non-ionized type of ammonia (NH_3-N) was observed during the study period. Observations of ammonia concentrations in Cangkuang Lake up to 42 DAA revealed low amounts. At 21 DAA, the value obtained ranged from 0.0041 mg/L to 0.0089 mg/L, while a range of 0.0050 mg/L–0.0066 mg/L was found at 42 DAA.

Based on the observations of ammonia levels at 21 DAA, the application of the three herbicides, namely 5 g a.i./ha–45 g a.i./ha Florpyrauxifen-benzyl, 1200 g a.i/ha 2,4-D Dimethyl Amine, and 25 g a.i./ha Penoxsulam, yielded significantly different values compared to the control. The weekly measurements showed that the values obtained tended to fluctuate. At 21 DAA, the highest average ammonia of 0.0089 mg/L was found in the 1200 g a.i./ha 2,4-D Dimethyl Amine herbicide treatment. Meanwhile, the lowest of 0.0041 mg/L was obtained in the control treatment, which involved the absence of herbicide, as shown in Table 2.

Table 2. The effect of application of Florpyrauxifen-benzyl (FPB), 2,4-D DMA, and Penoxsulam herbicides on Ammonia (NH3-N).

Treatment (Herbicide)	Rate (g a.i./ha)	Ammonia (NH_3-N) (mg/L)	
		21 DAA	42 DAA
Florpyrauxifen-benzyl	5	0.0083 ± 0.0027 [a]	0.0051 ± 0.0022 [a]
Florpyrauxifen-benzyl	15	0.0086 ± 0.0038 [a]	0.0055 ± 0.0023 [a]
Florpyrauxifen-benzyl	25	0.0086 ± 0.0033 [a]	0.0057 ± 0.0022 [a]
Florpyrauxifen-benzyl	35	0.0086 ± 0.0038 [a]	0.0060 ± 0.0026 [a]
Florpyrauxifen-benzyl	45	0.0087 ± 0.0038 [a]	0.0059 ± 0.0024 [a]
2,4-D DMA	1200	0.0089 ± 0.0039 [a]	0.0066 ± 0.0035 [a]
Penoxsulam	25	0.0078 ± 0.0036 [a]	0.0055 ± 0.0010 [a]
Control	-	0.0041 ± 0.0009 [b]	0.0050 ± 0.0014 [a]

Notes: The average value followed by the same letter is not significantly different ($p < 0.05$) based on the Scott-Knott test. DAA = day after application.

The application of the three herbicides, namely Florpyrauxifen-benzyl, 2,4-D Dimethyl Amine, and Penoxsulam, at all dose levels had no significant influence on the ammonia concentration in Cangkuang Lake. This was likely due to environmental variables, such as water runoff from agricultural areas and settlements surrounding the lake, which can affect the rise and fall of the parameter. All water quality parameters observed in this study were at the threshold according to the Government Regulation of the Republic of Indonesia No. 22 of 2021 which regulates DO, pH, TDS, and ammonia levels used for infrastructure or facilities for water recreation, freshwater fish farming, animal husbandry, and agriculture, as shown in Table 3.

Table 3. Water quality measurement and river, lake water quality standards based on Government Regulation of the Republic of Indonesia No. 22/2021 [39].

Water Quality Parameter	Class II	Class III	Results
DO	4 mg/L	3 mg/L	3.70–4.75
Temperature	Dev 3	Dev 3	25.3–27.1 °C
pH	6–9	6–9	7.13–7.34
TDS	1.000 mg/L	1.000 mg/L	153.00–177.50 mg/L
Ammonia	0.2 mg/L	0.5 mg/L	0.0050–0.0066 mg/L

4. Discussion

4.1. Efficacy of Florpyrauxifen-benzyl on Eichhornia crassipes

Florpyrauxifen-benzyl, a novel synthetic auxin herbicide, has recently been registered as a low-risk herbicide for the control of invasive weeds species [42]. Furthermore, it can boost aquatic plant selectivity, lower application rates, and mitigate the danger of resistance development [43,44]. In an indoor and outdoor mesocosm study, the formulations suspension concentrate (SC) and emulsifiable concentrate (EC) of Florpyrauxifen-benzyl auxin reduced water hyacinth weed biomass by 90–100% within 5 weeks of application [45]. In this study, the Florpyrauxifen-benzyl herbicide, starting at a dose of 15 g a.i./ha, successfully reduced weed biomass with a percentage growth reduction of >75% with a value of 100% at 42 DAA (day after application). Comparatively, 5 g a.i./ha Florpyrauxifen-benzyl was less successful in controlling *E. crassipes,* with a growth reduction of 72.97%, which was below 75%. Florpyrauxifen-benzyl can be effective in controlling weeds compared to the control treatment and two other herbicides, 2,4-D DMA and Penoxsulam, with percentage growth reduction rates of 89.81% and 75.53%, respectively. Florpyrauxifen-benzyl and penoxsulam herbicides had no weed regrowth, in contrast to 2,4-D DMA herbicide. High doses of herbicide caused the leaf stem to become brittle, the petiole to decay, and the weed's body to separate. This loss of weed body equilibrium was caused by uneven growth and decreased biomass due to variations in turgidity, unregulated cell division, and growth [46].

The decrease in average dry weight of *E. crassipes* was caused by Florpyrauxifen-benzyl's capabilities as a fast-acting IAA hormone imitator as well as its capability to increase weeds metabolism. Herbicide affected the proteins involved in plant regulation and this caused unrestrained gene expression [47,48], leading to increased accumulation of abscisic acid, hydrogen peroxide, and ethylene. Increased ABA concentrations have been reported to cause stomatal closure, which delays CO2 absorption and leads to the production of reactive oxygen species (ROS). These changes in the plants led to rapid leaf aging, cell death, and turgor loss [23]. The success of an herbicide in the field can be affected by environmental conditions, such as sunlight, carbon dioxide, temperature, relative humidity, rainfall, soil moisture, and wind [49]. This study was carried out during the rainy season when weeds can rapidly absorb herbicide molecules, such as Florpyrauxifen-benzyl, 2,4-D DMA, Penoxsulam, and transport them to all regions of their bodies, as indicated by the SEM test results in Figure 4. Florpyrauxifen-benzyl had unique features in terms of its selectivity for dicot plants, absorption rate, and mobility through the phloem of sensitive plants [19,20].

4.2. Herbicide Effect on Water Quality

Water hyacinth can rapidly spread on the surface of water bodies, where it alters physical, biological, and chemical processes, as well as reduces water quality [26]. Based on observations of water quality in Cangkuang Lake, it was observed that the dose of herbicide used in the experiment did not have a significant effect on the control treatment, but a decrease in DO levels from 14 DAA to 42 DAA was thought to be related to the start of the decomposition of water hyacinth weeds with the loss of leaf and root organs which increased weakening in the experimental plot. The decrease in DO around the experimental plots can also be influenced by external factors such as the presence of submerged weeds such as *Hydrilla verticillata,* which died and were pulled over and around the experimental plots and are thought to be related to the decomposition process of organic matter due to the death of aquatic weeds. Variables that affect changes in DO concentration are wind speed and water temperature. Wind speed can reduce the potential for heat flow to the river; thus, the water temperature tends to be lower. This causes the solubility of oxygen to increase so that the increase in DO concentration tends to be greater [50]. Biochemical oxygen depletion in this study was caused by plant mortality, decomposition, or decay [51]. Aquatic species, including fish, invertebrates, and plants, require DO in water. Depletion in this can lead to a lack of nutrients and hypoxia, leading to death and a decline in lake fish populations [52,53]. Although the amount of DO in water fluctuated during the experiment at Cangkuang Lake, there were no fish deaths in the vicinity of the experimental plots until 42 DAA. During the trial, DO value ranged between 3.70 and 4.75 mg/L, above the minimum threshold for water quality regulations (DO > 3 mg/L) in classes II and III based on the Government Regulation of the Republic of Indonesia No. 22/2021.

The pH value of aquatic biota was regulated by temperature and DO levels, with variations being confined within a specific range of values [51]. Various biochemical activities in water, such as enzyme function, solubilization, and ion absorption, such as ammonium, are influenced by pH [54], which limited the distribution of aquatic species. Furthermore, the results showed that the application of Florpyrauxifen-benzyl herbicide had no significant effect on the acidity level of Cangkuang Lake's water up to 42 DAA. This was likely due to the influence of water movement, various home and agricultural activities, the presence of rivers near the study site, and daily rainfall. Water quality can be altered by various climatic elements including precipitation, river flow, and human activities, such as rural or urban land use [55–57]. Based on the Government Regulation of Republic Indonesia No. 22/2021, the pH value at Cangkuang Lake during the study was within the maximum threshold for water quality standards with a range of 6–9 (classes II and III). Temperature can influence the growth and development of *E.crassipes* in aquatic environments with an optimum range of 25 °C to 30 °C [41]. It can also affect the physical, chemical, and biological aspects of water, including DO concentration, animal metabolism, and the photosynthesis of plants [58]. Variations at each observation period were caused by changes in the climatic condition of the study area. A previous study reported that changes in water temperature can be influenced by environmental factors such as solar radiation, air temperature, weather, and climate [30].

TDS are naturally present in water and can be produced by industrial water treatment. TDS often consist of minerals and organic molecules, as either nutrients or hazardous pollutants [59]. The measurement results showed a weekly increase in the parameter but later reduced until the end of the observation period at 42 DAA. The application of Florpyrauxifen-benzyl herbicide at all dose levels had no significant influence on TDS levels in Cangkuang Lake. This was due to the influence of fluctuating daily water flow rates and precipitation conditions. Human activities, such as runoff from the soil, anthropogenic effect (home and industrial waste), and rock weathering, can raise TDS concentrations in water bodies [60–62]. Based on the Government Regulation of the Republic of Indonesia No. 22/2021, the value obtained at Cangkuang Lake remained below the threshold for class II and III quality standards requiring a TDS of 1.000 mg/L for use in water recreation infrastructure or facilities, freshwater fish farming, animal husbandry, and agriculture.

Natural sources of ammonia include the breakdown of organic matter from plants and animals, nitrogen fixation, the addition of fertilizers, and human waste, such as industrial and agricultural runoff [63–65]. Furthermore, excessive levels can impair fish immunity, leading to mortality and economic losses in aquaculture [66,67]. The treatment of Florpyrauxifen-benzyl herbicide at all dose levels led to fluctuations in the levels of ammonia in Cangkuang Lake at 42 DAA but had no significant effect. This was likely due to environmental issues such as agricultural runoff and human settlements around the lake. During this study, the continuous flow of water and rising water levels due to precipitation were believed to have influenced the fluctuation of ammonia levels. At low concentrations, ammonia can have chronic and acute hazardous effects, and its presence was affected by environmental parameters, including temperature, pH, salinity, and DO [68–71]. Ionized NH_3 was more hazardous and became significantly more toxic with elevated pH and temperature [72]. During the experiment at Cangkuang Lake, ammonia levels remained below the maximum threshold for water quality standards with an ammonia value of 0.2 and 0.5 mg/L (class II and III, respectively) based on the Government Regulation of the Republic of Indonesia No. 22/2021.

Florpyrauxifen-benzyl herbicide was able to completely kill water hyacinth weeds until 42 DAA and no regrowth was found in the experiment. It is necessary to pay attention to the accuracy in determining the amount of herbicide doses given to minimize the potential for aquatic weed resistance, and the long-term negative impacts that can be caused. In addition, it is important to consider the potential impacts on the aquatic environment that arise after the death of weeds due to the use of herbicides such as a decrease in dissolved oxygen content in the water due to weed decomposition and the presence of ammonia toxicity which can affect the survival of aquatic biota. Herbicide application needs to be executed systematically and gradually on some weed cover, so that aquatic biota such as fish can escape from areas that have been sprayed with herbicides and can prevent a significant decrease in water quality. However, in this study all observed water quality parameters such as DO, pH, TDS, water temperature, and ammonia did not have a significant effect because it was heavily influenced by external factors such as the environment and were still within the safe limits of standard regulations water quality in Indonesia.

5. Conclusions

Florpyrauxifen-benzyl can be an effective herbicide for controlling water hyacinth in Cangkuang Lake, beginning at a dose of 15 g a.i./ha with a 100% growth reduction and no weed regrowth up to 42 DAA (day after application). Florpyrauxifen-benzyl did not have a negative impact on water quality parameters such as dissolved oxygen (DO), pH, total dissolved solids (TDS), and ammonia levels. All water quality parameters were within the standard threshold for Government Regulation of the Republic of Indonesia No. 22/2021.

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