International Journal of Innovative Research and Scientific Studies, 8(6) 2025, pages: 800-812

ISSN: 2617-6548

URL: www.ijirss.com

Toxicity effect of alpha-cypermethrin on morphological of paddy seedling

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Abstract

Alpha-cypermethrin can impact the biotic and abiotic environment beyond the target. Therefore, efforts are needed to assess the impact on non-target organisms. The research aimed to investigate the toxicity effects of alpha-cypermethrin on the morphological development of paddy seedlings. The experiment was conducted at Pati, Central Java, from August to September 2024, using a water exposure (plant dipping) method, where plastic bottles filled with water contaminated by alpha-cypermethrin were used. The experiments involved two stages, each employing a randomized complete block design with five treatments and three replications. The first stage concentrations were 0, 1111, 2222, 3333, and 4444 ppm, while the second stage concentrations were 0, 138, 277, 555, and 1111 ppm. Each treatment was replicated three times and labeled as P1, P2, P3, P4, and P5, respectively. Observation periods were four days for the first stage and seven days for the second stage. The results indicated that alpha-cypermethrin caused significant growth inhibition in paddy seedlings, including reduced plant height, leaf deformation, and overall biomass. The effects were dose-dependent, with all treatments inhibiting plant height in the range of 0.3-1.7 cm, leaf deformation in the range of 10-100%, leaf area loss between 16-89%, and greenness loss from 3.6-100%.

Keywords: Alpha cypermethrin, Paddy, Seedling, Toxicity.

DOI: 10.53894/ijirss.v8i6.9730
Funding: This study received no specific financial support.
History: Received: 8 July 2025 / **Revised:** 4 August 2025 / **Accepted:** 11 August 2025 / **Published:** 8 September 2025

Competing Interests: The authors declare that they have no competing interests.
Authors' Contributions: All authors contributed equally to the conception and design of the study. All authors have read and agreed to the published version of the manuscript.
Transparency: The authors confirm that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.
Publisher: Innovative Research Publishing

1. Introduction

Alpha-cypermethrin is a synthetic pyrethroid insecticide belonging to a group that mimics natural pyrethrins derived from chrysanthemum flowers [1, 2]. It is widely used to protect crops from many kinds of insect pests, including aphids, beetles, caterpillars, and moth larvae. Its high potency is due to its broad range of insect pests, relatively low toxicity to humans and animals, and stability in the environment [3, 4]. Alpha-cypermethrin with molecular formula $C_{22}H_{19}Cl_2NO_3$ is a stereoisomer of cypermethrin, characterized by its two cyano ($^-$CN) and dichlorovinyl groups attached to a cyclopropane carboxylate structure. This configuration enhances its insecticidal activity. Alpha-cypermethrin has specific stereoisomers that give it a higher insecticidal potency than its parent compound, cypermethrin. It is a crystalline, off-white solid with limited solubility in water but high solubility in organic solvents like acetone and xylene. Its high lipophilicity allows it to easily penetrate the waxy cuticles of insects [5].

Alpha-cypermethrin primarily targets the sodium channels in the nerve cells of insects. Once applied, alpha-cypermethrin interacts with the voltage-gated sodium channels in the axonal membranes of insect nerve cells. It binds to these channels and prevents their normal closing, causing continuous sodium ion influx into the neuron. This prolonged opening of sodium channels leads to uncontrolled repetitive firing of nerve impulses, resulting in hyperactivity, paralysis, and eventually the death of the insect. Alpha-cypermethrin is more toxic to insects than to mammals because it selectively affects the sodium channels in insect nerve cells. Mammalian sodium channels are less sensitive to pyrethroids, which explains the compound's lower toxicity to humans and animals when used appropriately [6].

Alpha-cypermethrin is particularly effective against pests that cause significant damage to crops such as paddy, cotton, corn, and vegetables [7, 8]. It is typically applied as a foliar spray or soil treatment. The insecticide is absorbed by plants and can also act as a contact and stomach poison for pests. In paddy fields, alpha-cypermethrin is used to control paddy stem borers, planthoppers, and leafhoppers [9]. The recommended application rate varies depending on the crop, pest type, and environmental conditions. For paddy, application rates typically range from 20 to 40 grams of active ingredient per hectare. Alpha-cypermethrin is often formulated in emulsifiable concentrates, wettable powders, or granules, with concentrations ranging from 5% to 10% [10]. The frequency of application is typically limited to two or three times during a growing season to minimize environmental impact and reduce the risk of pest resistance development. Apart from agriculture, alpha-cypermethrin is also used in household insect control products and public health programs to control mosquitoes, ticks, and other disease vectors [11].

Paddy seedlings are the initial stage of paddy cultivation, crucial for the development of healthy and productive paddy plants [12]. However, various environmental and chemical factors can pose significant threats to these delicate seedlings [13]. One such chemical agent that has been identified to have destructive effects on crop seedlings is alpha-cypermethrin, a synthetic pyrethroid insecticide commonly used in agricultural practices to control pests. Despite its efficacy in managing pest populations, alpha-cypermethrin has been observed to have adverse impacts on non-target organisms, including crop seedlings [3].

Damage to rice plants often results from abiotic influences, which can occasionally be exceedingly challenging to distinguish from biotic factors such as plant disease, deficiencies in specific nutrients, or substance poisoning [14, 15]. When pesticides are applied excessively or incorrectly, they can damage plants, either directly or indirectly, purposefully or inadvertently. In Indonesia, rice is typically seeded directly from the open rice fields, leaving open the possibility of external contamination, including by pesticides [16]. Recently, it was found that the application of mancozeb, imidacloprid, and sulfentrazone on the model plant Allium cepa showed cytotoxic and genotoxic effects by inducing different types of chromosomal abnormalities, likely sticky, disoriented, and fragmented chromosomes, abnormal DNA condensation, and chromosome coiling due to spindle inactivation, thereby reducing the mitotic index [17]. By examining these aspects, insights into the potential risks associated with the use of alpha-cypermethrin can be gained, along with strategies for mitigating these risks to ensure the health and productivity of paddy crops. The research aimed to investigate the toxic effects of alpha-cypermethrin on the morphology of paddy seedlings at the early stage.

2. Material and Method

2.1. Plant Material and Chemicals

Uniform-sized plants (n=30) of a commercial variety of paddy (Oryza sativa var. Inpari 32) were used as the test plants. Alpha-cypermethrin was obtained from a pesticide store with the trademark Termikon 15 EC.

2.2. Germination Process

Seeds of paddy were germinated in watery and isolated soil in a plastic pot and looked after until the age of 21 days. The soil water was controlled throughout 21 days so that the soil maintained suitable humidity for growth.

2.3. Morphological Response Experiment

The experiment is designed to compare the effects of alpha-cypermethrin on paddy seedlings at different concentrations with a control group that is not exposed to the insecticide. The experiment was carried out at Pati, Central Java, from August to September 2024, using a water exposure (plant dipping) method in which plastic bottles (volume 220 ml) filled with water contaminated by alpha-cypermethrin. The experiments involved two stages, each utilizing a randomized complete block design with five treatments and three replications. The first stage involved concentrations of 0, 1111, 2222, 3333, and 4444 ppm, while the second stage involved concentrations of 0, 138, 277, 555, and 1111 ppm, labeled as P1, P2, P3, P4, and P5, respectively. The paddy variety used in the experiment was Inpari 32. The first stage was conducted at 14 days after seedling (DAS), and the second stage at 21 DAS. Observation periods were 4 days for the first stage and 7 days for the second stage. Water volumes were 150 ml at the first stage and 50 ml at the second stage, to observe the effect of water level or volume on toxicity. The alpha-cypermethrin used was a formulation insecticide with a suggested concentration of 2.5–5 ml/L, equivalent to 2500–5000 ppm.

Observation was included in

1. Growth Measurements. Plant Height: The height of the paddy seedlings is measured from the root level to the tip of the tallest leaf.
2. Visual assessments. Seedlings are visually inspected for signs of leaf deformation, including curling, twisting, or discoloration. The percentage of affected leaves per plant is recorded.
3. Water measurement: Total Dissolved Solids (TDS)
4. Leaf area and greenness. A portable meter was used to measure the relative leaf area and greenness, providing a non-destructive method for assessing the impact of alpha-cypermethrin.

2.4. Data Processing

Collected data were analyzed using statistical description methods to compare the effects of different treatment levels.

3. Results and Discussion

3.1. Results Stage 1

3.1.1. Effect of alpha-cypermethrin on the growth of paddy seedlings

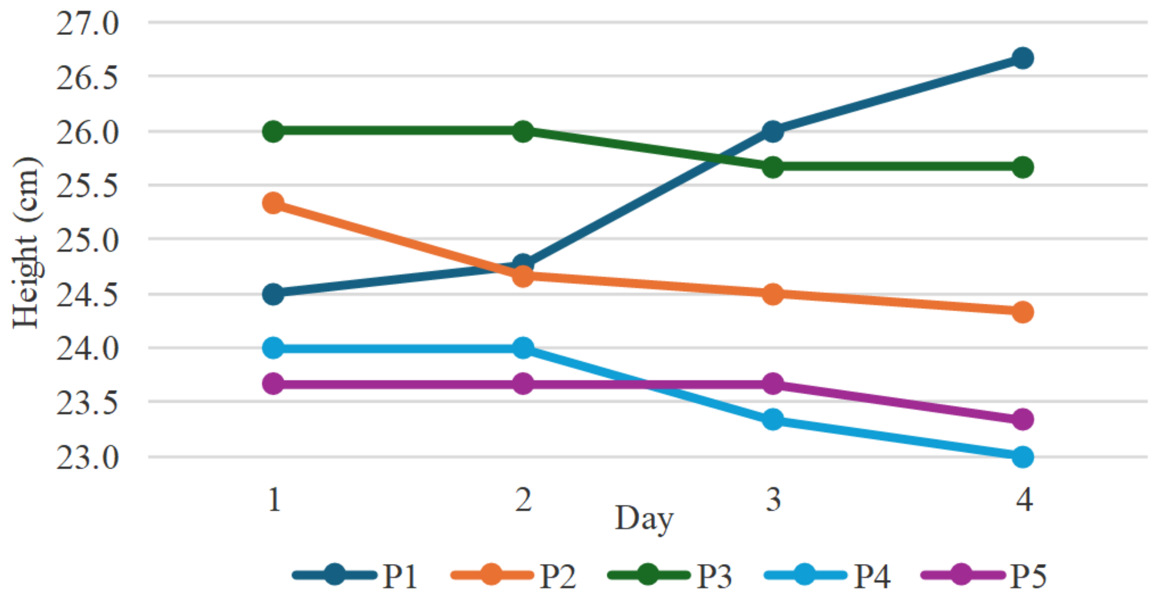

Figure 1.
Graph of plant height.
Note: Remarks: P1: 0 ppm, P2: 1111 ppm, P3: 2222 ppm, P4: 3333 ppm, P5: 4444 ppm.

Figure 1 describes measurements of height (in centimeters) of five different entities, namely P1, P2, P3, P4, and P5, over a period of four days. The trends for each entity's height can be explained as follows: P1 (dark blue line) showed a consistent increase in height, starting from about 24.5 cm on day 1 and reaching approximately 26.7 cm by day 4. On the other hand, P2 (orange line) started with a height of 25.5 cm on day one, then experienced a slight decrease, stabilizing around 24.5 cm by day 4. Another treatment, P3 (green line), remained almost steady across day 1 to day 2, decreasing slightly between day 3 and day 4. P4 (the light blue line) began at around 24 cm on day 1 and showed a steady decline to about 23 cm by day 4. Finally, P5 (the purple line) remained fairly constant, oscillating between 23.2 cm and 24 cm, and decreased on day four.

The data reveals different trends for each entity over the observed period: P1 shows consistent growth, suggesting a steady increase in height, which could be due to favorable conditions or factors affecting its growth. This could be indicative of a positive response to an external stimulus or optimal environmental conditions. P2 and P3, on the other hand, demonstrate a gradual decrease in height, which might be due to toxic effect impacting their growth negatively. The decline stabilizes over time, suggesting the effect is not drastic but steady. P4 shows a clear decline in height over time, which could be an indication of adverse conditions affecting its growth, potentially signaling stress or deterioration in its health caused by the toxic effect of alpha-cypermethrin. P5 exhibits minimal decrease, with slight changes in height. The differences in trends between the entities could be due to the toxic effect of alpha-cypermethrin.

3.1.2. Visual Assessment on Leaf Deformation of Paddy Seedling by Alpha-Cypermethrin Treatment

The bar chart displays the percentage of destruction across five different treatments (T1 to T5) over four days (Day 1 to Day 4). The percentage of destruction increases for all treatments as the days progress. Key observations for each treatment are as follows: T1 (Treatment 1): There was no destruction from Day 1 until Day 4. T2 (Treatment 2), T3

(Treatment 3), T4 (Treatment 4), T5 (Treatment 5): Destruction was high from the beginning, starting at around 50% on Day 1, 60% on Day 2, 70% on Day 3, and increasing sharply to 100% by Day 4. The data reveal clear trends of increasing destruction over time across all treatments, with some key patterns emerging: T2, T3, T4, and T5 all reach 100% destruction by Day 4, indicating that alpha-cypermethrin treatments are particularly aggressive or effective in causing destruction. This suggests that the factors involved in these treatments are highly potent over time, leading to total destruction by the end of the observation period, while T1 showed no destruction at all during the observation period.

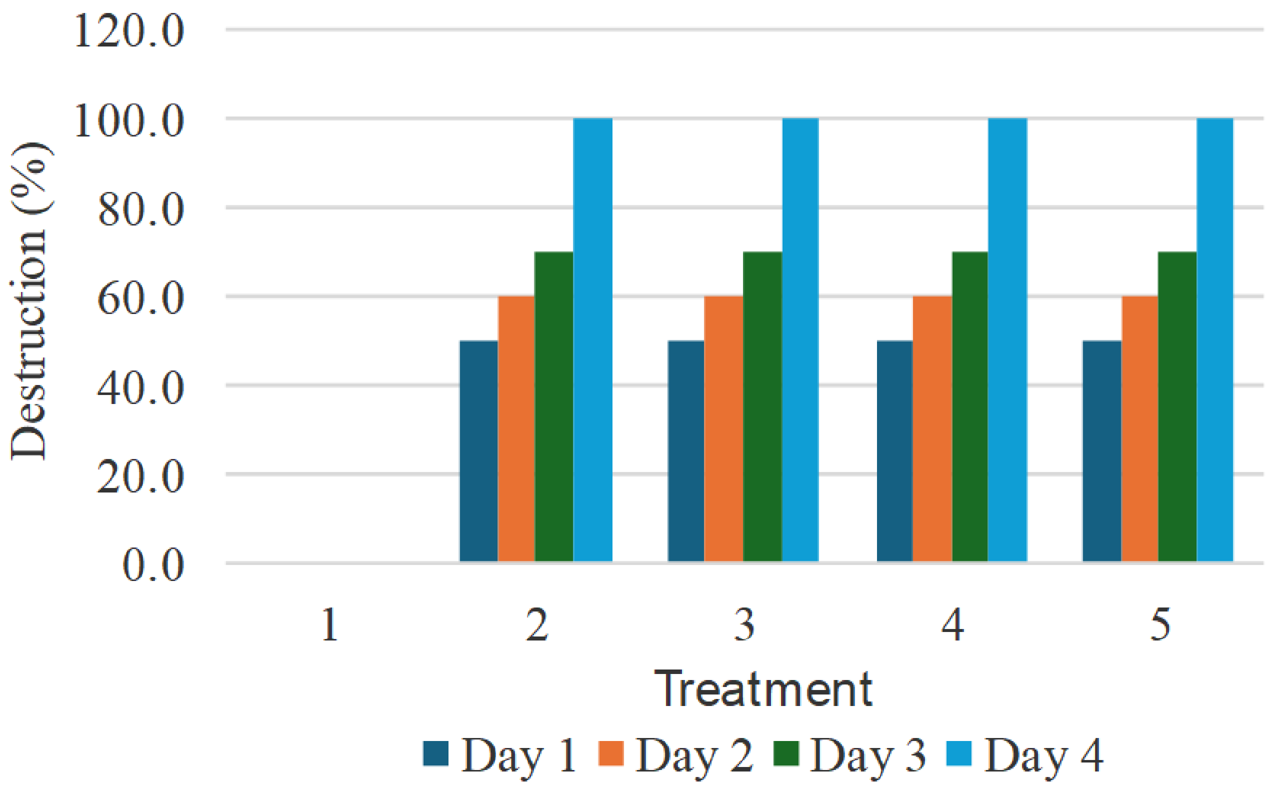

Figure 2.
Graph of leaf deformation.
Note: Remarks: Treatment 1 (T1) : 0 ppm, Treatment 2 (T2) : 1111 ppm, Treatment 3 (T3) : 2222 ppm, Treatment 4 (T4) : 3333 ppm, Treatment 5 (T5) : 4444 ppm.

3.1.3. Relationship of Total Dissolved Solids (TDS) and alpha-cypermethrin concentration

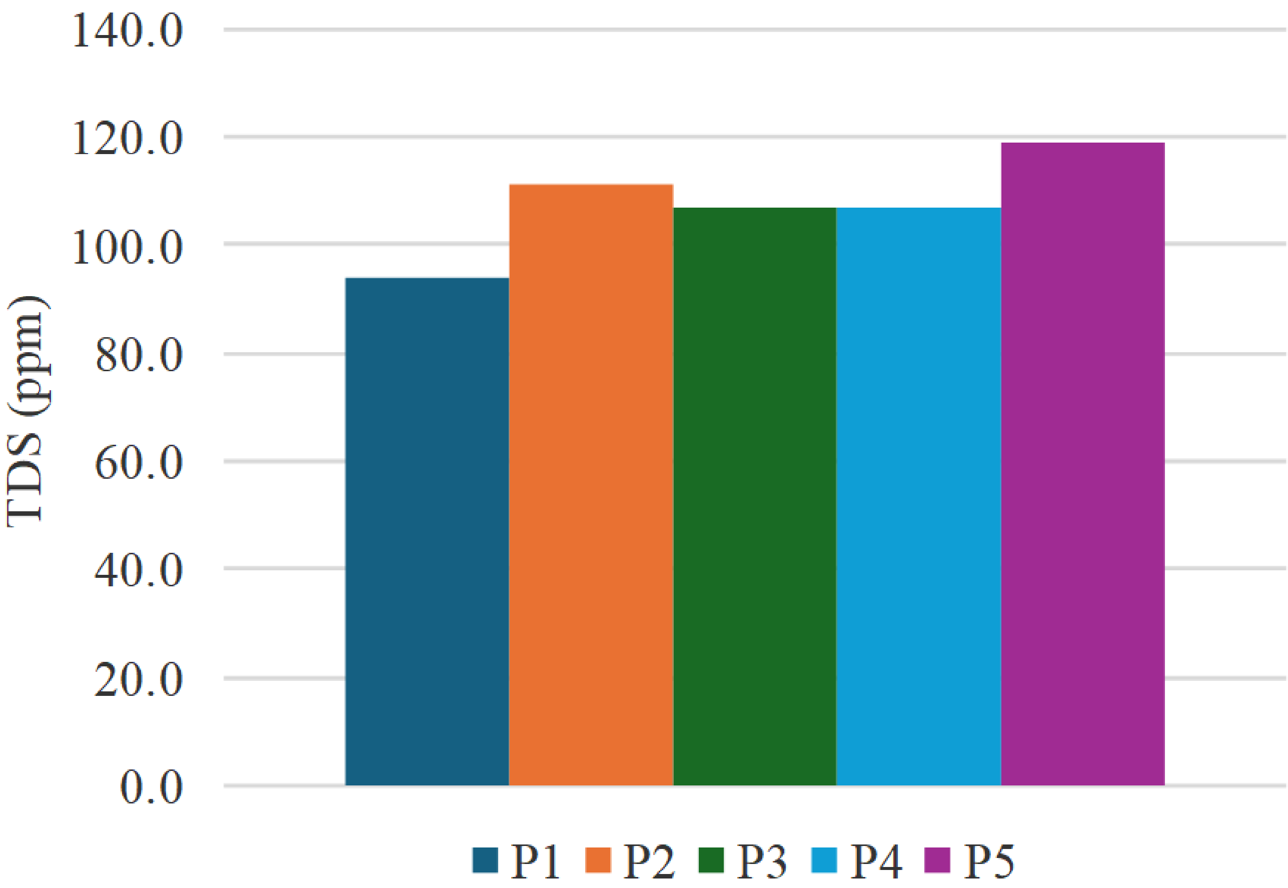

Figure 3.
Graph of TDS.
Note: Remarks: P1 : 0 ppm, P2 : 1111 ppm, P3 : 2222 ppm, P4 : 3333 ppm, P5 : 4444 ppm.

The total dissolved solids (TDS) levels for the five samples (P1, P2, P3, P4, and P5) were recorded and compared. The TDS values for the samples are as follows: P1: approximately 94 ppm, P2: around 117 ppm, P3: close to 107 ppm, P4: similar to P3 at 107 ppm, P5: the highest at approximately 119 ppm. P5 exhibited the highest TDS concentration, while P1 showed the lowest concentration. Samples P3 and P4 had nearly identical TDS values. The results suggest notable variation in TDS levels among the different samples. TDS Overview: TDS is a measure of the combined content of all inorganic and organic substances in water. Higher TDS levels can indicate a greater presence of dissolved minerals and salts, which may affect water quality. Comparison of Results**:** P5 had the highest TDS value at 125 ppm, potentially indicating higher concentrations of minerals or contaminants. This could suggest that P5's water source may be more prone to dissolved substances, perhaps due to environmental factors like water treatment processes. P1 exhibited the lowest TDS level (95 ppm), which suggests that its water source might be less mineralized or has undergone different treatment processes to remove dissolved solids. P2, P3, and P4 are relatively similar in their TDS concentrations, falling within the range of 107–111 ppm. However, the relatively higher TDS in P5 suggests it just contains more alpha-cypermethrin compared to the other samples.

3.1.4. Effect of Alpha-Cypermethrin on Leaf Area of Paddy Seedling

The bar chart provided represents the leaf area in pixels (Px) for five samples labeled P1 through P5. The leaf areas for each sample are approximately: P1: 250,000 Px, P2: 150,000 Px, P3: 75,000 Px, P4: 25,000 Px, P5: 20,000 Px. Among the samples, P1 has the largest leaf area, while P5 has the smallest. The range of leaf areas varies significantly across the samples. Variation in leaf area: P1 displays the largest leaf area at 250,000 pixels, which suggests that this plant has undergone the most substantial leaf growth compared to the others. This could be due to more favorable environmental conditions, such as better nutrient availability, sufficient sunlight, or optimal water supply. The larger leaf area could also imply greater photosynthetic capacity, enabling the plant to produce more energy for growth. P4 and P5 show the small leaf area at 25,000 and 20,000 pixels, indicating limited leaf growth compared to the other samples. Factors such as nutrient deficiency, suboptimal light exposure, or stress conditions could have contributed to the reduced leaf size in this sample. P2 and P3 fall between the extremes, with leaf areas of 150,000 and 75,000 pixels, respectively. These values suggest moderate growth, possibly reflecting intermediate environmental conditions or other physiological factors influencing their leaf development. They might suggest less access to light. Adequate water is essential for plant growth, and stress factors such as excessive water can significantly influence leaf development. P1's larger leaf area may indicate ideal water conditions, whereas smaller leaf areas like P5's might reflect water stress or alpha-cypermethrin toxicity. The leaf area data indicate significant variation among the samples, with P1 demonstrating the largest leaf area and P5 the smallest. The differences in leaf size likely reflect variations in environmental factors such as alpha-cypermethrin toxicity.

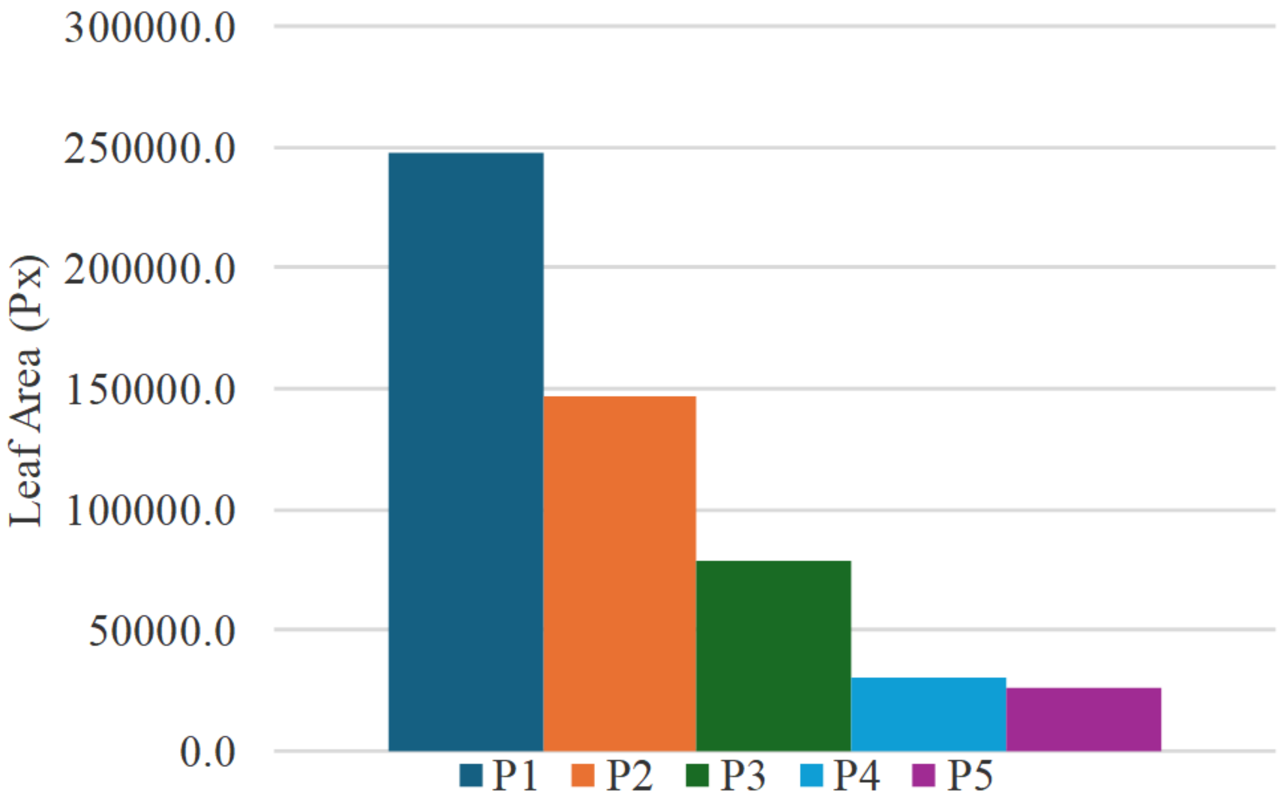

Figure 4.
Graph of leaf area.
Note: Remarks: P1: 0 ppm, P2: 1111 ppm, P3: 2222 ppm, P4: 3333 ppm, P5 : 4444 ppm.

3.1.5. Effect of Alpha-Cypermethrin on Greenness of Paddy Seedling

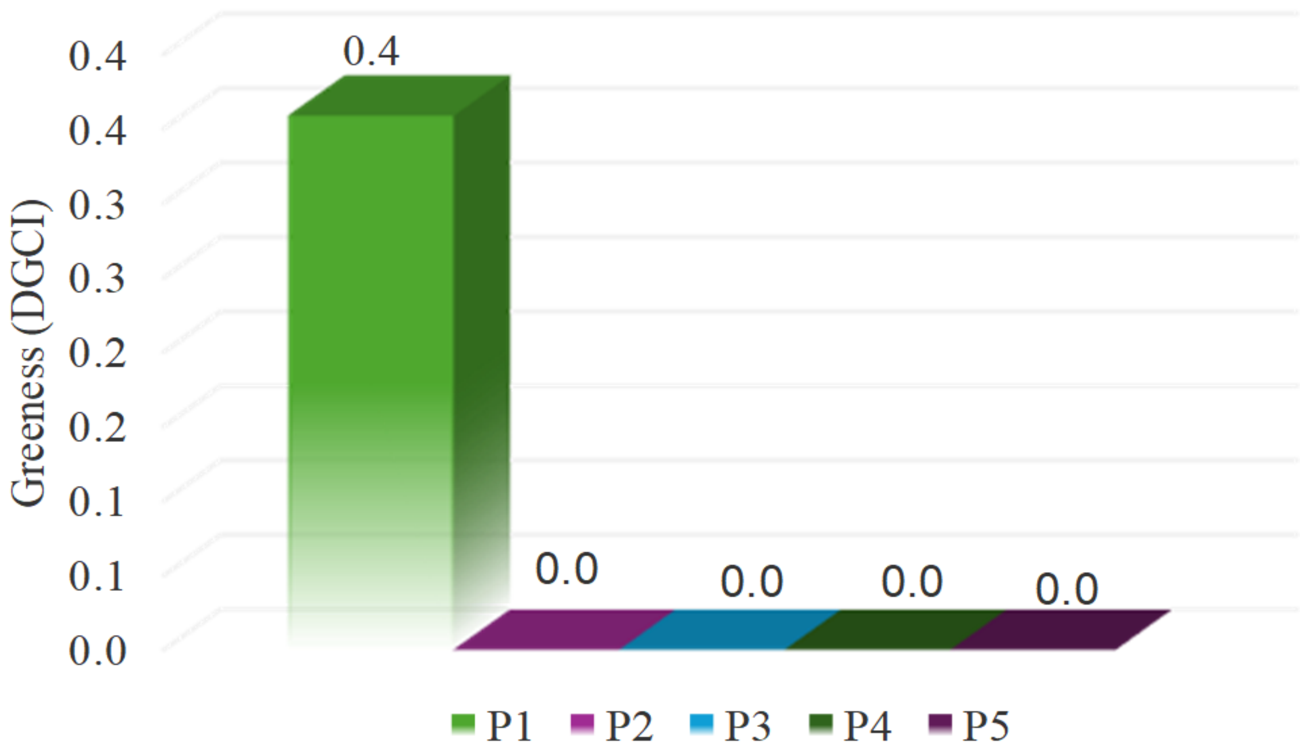

Figure 5.
Graph of leaf greenness.
Note: Remarks: P1: 0 ppm, P2: 1111 ppm, P3: 2222 ppm, P4: 3333 ppm, P5: 4444 ppm.

The bar graph above presents the "Greenness" index (DGCI) for five samples labeled P1, P2, P3, P4, and P5. The greenness index measures the relative green color intensity, indicating plant health or vegetation quality. P1 exhibits the highest greenness with a DGCI value of 0.4. P2, P3, P4, and P5 show a greenness value of 0.0, implying no green color intensity or negligible vegetation health. The greenness index indicates the variation in vegetation or plant health among the samples. P1 demonstrates significantly higher greenness compared to the others, which could indicate healthier or more vibrant plant life in P1. On the other hand, P2, P3, P4, and P5 have no recorded greenness, suggesting either poor plant health, lack of vegetation, or other factors affecting their green color intensity. This stark contrast was due to alpha-cypermethrin toxicity.

3.2. Results Stage 2

3.2.1. Effect of Alpha-Cypermethrin on Growth of Paddy Seedling

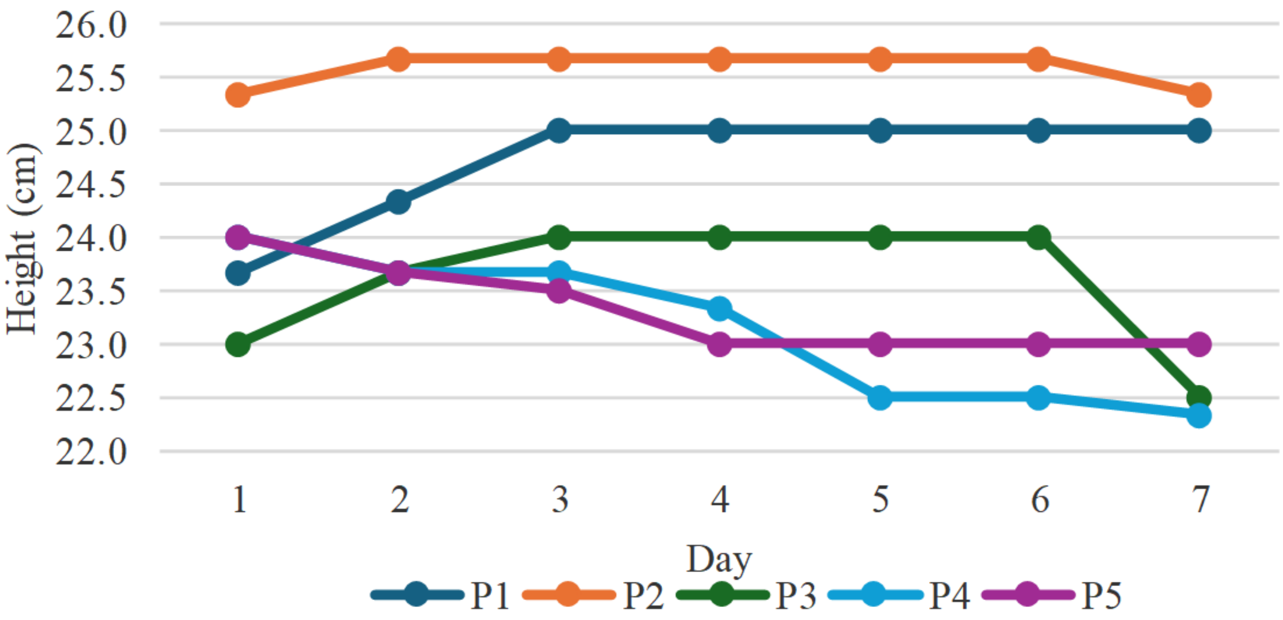

Figure 6.
Graph of plant height.
Note: Remarks: P1: 0 ppm, P2: 138,88 ppm, P3: 277,77 ppm, P4: 555,55 ppm, P5 : 1111,11 ppm.

The graph presents (Figure 6) the height measurements (in centimeters) of five different entities labeled P1, P2, P3, P4, and P5 over a period of seven days are as follows: P1 (dark blue line): There was a consistent increase in height from day 1 until day 3, and the height remained constant from day 3 until day 7. P2 (orange line): P2 increased from day 1 until day 2, then remained constant until day 6, and decreased on day 7. P3 (green line): P3 increased from day 1 until day 3, then remained constant until day 6, and decreased sharply by day 7. P4 (light blue line): P4 began at around 24 cm on day 1 and decreased sharply to about 22.3 cm by day 7. P5 (purple line): The height of P5 decreased sharply until day 4 and remained constant from day 4 until day 7.

The data reveals different trends for each entity over the observed period: P1 shows consistent growth, suggesting a steady increase in height, which could be due to favorable conditions or factors affecting its growth. This could be indicative of a positive response to an external stimulus or optimal environmental conditions. P2 and P3 also demonstrate a gradual increase in height but a decrease at day 7, which might be due to slight toxic effects impacting their growth. P4 shows a clear decline in height over time, which could indicate adverse conditions affecting its growth, potentially signaling stress or deterioration in its health caused by the toxic effect of alpha-cypermethrin. P5 exhibits a significant decrease, with high changes in height. The differences in trends between the entities could be due to the toxic effect of alpha-cypermethrin.

3.2.2. Visual Assessment on Leaf Deformation of Paddy Seedling by Alpha a-Cypermethrin Treatment

The bar chart displays the percentage of destruction across five different treatments (Treatment 1 to Treatment 5) over four days (Day 1 to Day 7). The percentage of destruction increases for all treatments as the days progress. Key observations for each treatment are as follows: T1 (Treatment 1): There was no destruction from Day 1 until Day 7. T2 (Treatment 2) and T3 (Treatment 3): Destruction was low from the beginning, starting at around 0.7% and 1.7% on Day 1, and steadily increasing to 10% and 18.3% by Day 7. T4 (Treatment 4) and T5 (Treatment 5): Destruction was low from the beginning, starting at around 1.7% and 8.3% on Day 1, and increasing sharply to 93.3% and 100% by Day 7.

The data reveal clear trends of increasing destruction over time across all treatments, with some key patterns emerging: T2 and T3 reached low destruction by day 7, indicating that alpha-cypermethrin treatments were particularly less toxic in causing destruction. T4 and T5 reached high destruction by day 7, indicating that alpha-cypermethrin treatments are particularly aggressive or effective in causing destruction. This suggests that the factors involved in these treatments are highly potent over time, leading to destruction by the end of the observation period, while T1 showed no destruction at all during the observation period.

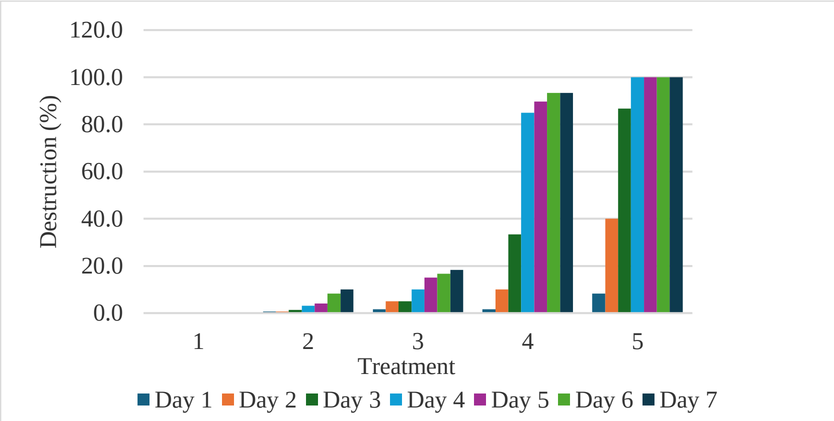

Figure 7.
Graph of leaf deformation.
Note: Remarks: Treatment 1 (T1) : 0 ppm, Treatment 2 (T2) : 138,88 ppm, Treatment 3 (T3) : 277,77 ppm, Treatment 4 (T4) : 555,55 ppm, Treatment 5 (T5) : 1111,11 ppm.

3.2.3. Relationship of Total Dissolved Solids (TDS) And Alpha-Cypermethrin Concentration

The total dissolved solids (TDS) levels for the five samples (P1, P2, P3, P4, and P5) were recorded and compared. The TDS values for the samples are as follows: P1: approximately 76.7 ppm, P2: approximately 66.3 ppm, P3: approximately 101.7 ppm, P4: approximately 102.3 ppm, and P5: approximately 100 ppm. P1 and P2 exhibited lower concentrations than samples P3, P4, and P5, which had nearly identical TDS values.

The results indicate significant variation in TDS levels among the different samples. **TDS Overview:** TDS measures the total concentration of inorganic and organic substances dissolved in water. Elevated TDS levels can suggest a higher presence of dissolved minerals and salts, which may impact water quality. **Comparison of Results:** P1 and P2 exhibited low TDS levels (76.7, 66.3 ppm), indicating that their water sources might be less mineralized or contain fewer contaminants in solid form. Conversely, P3, P4, and P5 showed relatively similar TDS concentrations, ranging from 100 to 102 ppm. The higher TDS in these samples may be associated with increased levels of alpha-cypermethrin compared to the other samples, which could influence water quality and safety.

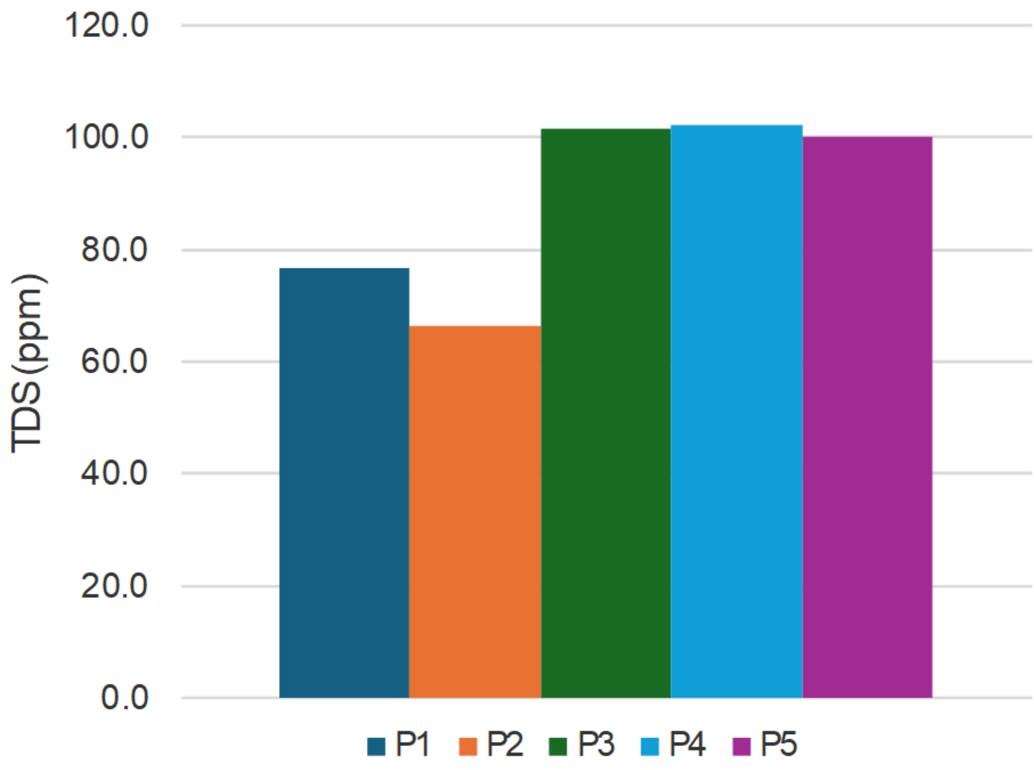

Figure 8.
Graph of TDS.
Note:: *Remarks: P1 : 0 ppm, P2 : 138,88 ppm, P3 : 277,77 ppm, P4 : 555,55 ppm, P5 : 1111,11 ppm.*

3.2.4. Effect of Alpha-Cypermethrin on Leaf Area of Paddy Seedling

The bar chart provided represents the leaf area in pixels (Px) for five samples labeled P1 through P5. The leaf areas for each sample are approximately: P1: 505,122 Px, P2: 419,311 Px, P3: 270,661 Px, P4: 121,177 Px, P5: 81,294 Px. Among the samples, P1 has the largest leaf area, while P5 has the smallest. The range of leaf areas varies significantly across the samples. Variation in leaf area: P1 displays the largest leaf area at 505,122 pixels, which suggests that this plant has undergone the most substantial leaf growth compared to the others. This could be due to more favorable environmental conditions, such as better nutrient availability, sufficient sunlight, or optimal water supply. The larger leaf area could also imply greater photosynthetic capacity, enabling the plant to produce more energy for growth. P4 and P5 show small leaf areas at 121,177 and 81,294 pixels, indicating limited leaf growth compared to the other samples. Factors such as nutrient deficiency, suboptimal light exposure, or stress conditions could have contributed to the reduced leaf size in these samples. P2 and P3 fall between the extremes, with leaf areas of 419,311 and 270,661 pixels, respectively. These values suggest moderate growth, possibly reflecting intermediate environmental conditions or other physiological factors influencing their leaf development. The data might suggest less access to light. Adequate water is essential for plant growth, and stress factors such as excessive water can significantly influence leaf development. P1's larger leaf area may indicate ideal water conditions, whereas smaller leaf areas like P5's might reflect water stress or alpha-cypermethrin toxicity. The leaf area data indicate significant variation among the samples, with P1 demonstrating the largest leaf area and P5 the smallest. The differences in leaf size likely reflect variations in environmental factors such as alpha-cypermethrin toxicity.

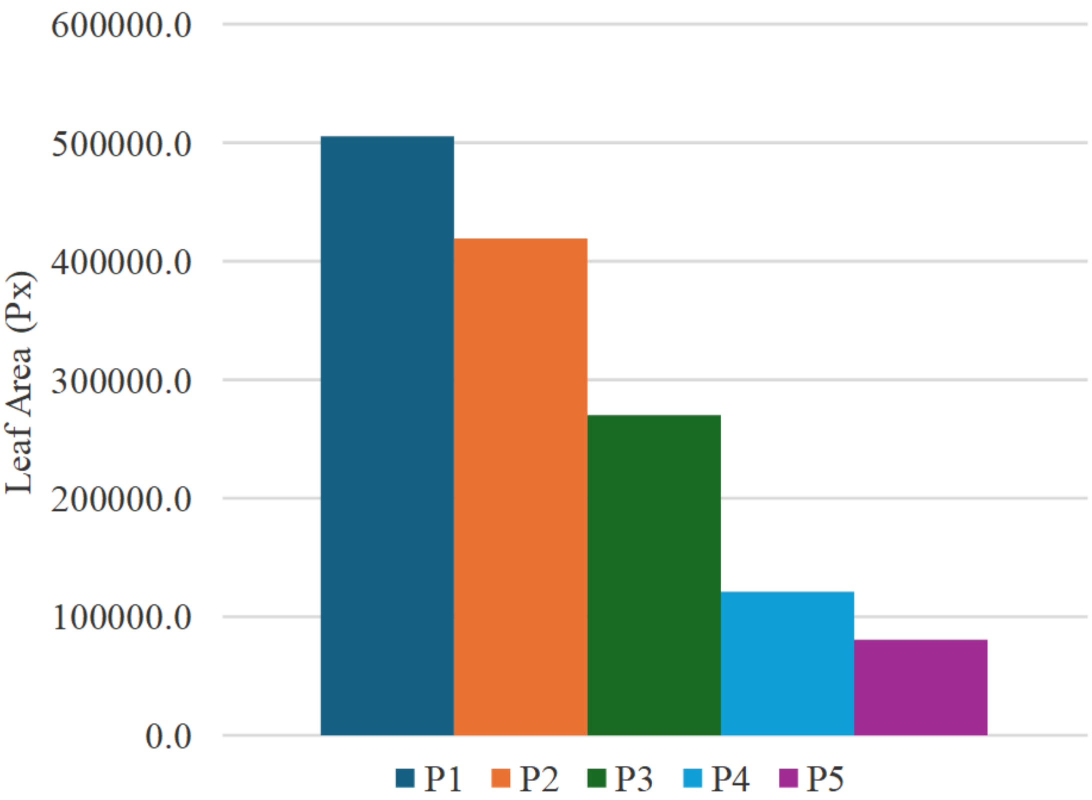

Figure 9.
Graph of leaf area.
Source: Remarks: P1: 0 ppm, P2: 138,88 ppm, P3: 277,77 ppm, P4: 555,55 ppm, P5: 1111,11 ppm.

3.2.5. Effect of Alpha-Cypermethrin on Greenness of Paddy Seedling

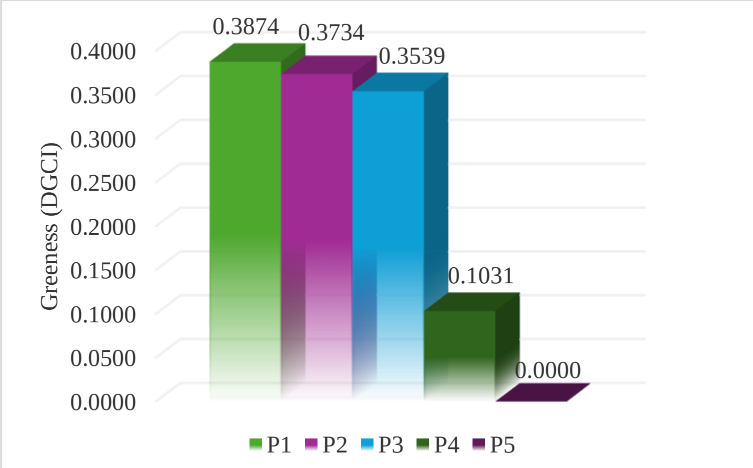

Figure 10.
Graph of leaf greenness.
Note: Remarks: P1: 0 ppm, P2: 138,88 ppm, P3: 277,77 ppm, P4: 555,55 ppm, P5: 1111,11 ppm.

The bar graph above presents the "Greenness" index (DGCI) for five samples labeled P1, P2, P3, P4, and P5. The greenness index measures the relative green color intensity, indicating plant health or vegetation quality. P1 has a DGCI value of 0.3874, P2 has 0.3734, P3 has 0.3539, P4 has 0.1031, and P5 shows a greenness value of 0.0, implying no green color intensity or negligible vegetation health. The greenness index indicates the variation in vegetation or plant health among the samples. P1, P2, and P3 demonstrate significantly higher greenness compared to P4 and P5, which could indicate healthier or more vibrant plant life. This stark contrast is attributed to alpha-cypermethrin toxicity.

3.3. Discussion

Table 1.
Toxicity effect of alpha-cypermethrin on the growth of paddy seedlings at 4 days after application in the first stage of the experiment.

No.	Treatment	Plant Height	Leaf Deformation	Leaf Area Losses	Greenness Losses
		cm	%		
1	P1	2.2	0	0	0
2	P2	-1.0	100	40.6	100
3	P3	-0.3	100	68.4	100
4	P4	-1.0	100	87.7	100
5	P5	-0.3	100	89.3	100

Note: *Remarks: P1: 0 ppm, P2: 1111 ppm, P3: 2222 ppm, P4: 3333 ppm, P5 : 4444 ppm Negative value (-) means decreasing.*

The paddy seedlings exposed to alpha-cypermethrin at the first stage of the experiment showed significant growth inhibition compared to the control (P1-0 ppm). All treatment groups exhibited reduced plant height of paddy seedlings, leaf deformation, decreased leaf area, and reduced greenness. After four days, seedlings in the control (P1-0 ppm) reached an average height increase of 2.2 cm by the end of the experiment, while those in the 1111-4444 ppm group had a decrease in average height of 0.3-1 cm, demonstrating a clear effect of alpha-cypermethrin. Seedlings in the control group showed no leaf deformation by the end of the experiment, while those in the 1111-4444 ppm group exhibited 100% leaf deformation, demonstrating a clear effect of alpha-cypermethrin. Alpha-cypermethrin had a toxic effect, causing a decrease in leaf area of paddy seedlings by 40.6-89.3%, and a decrease in greenness of 100% for treatment concentrations of 1111-4444 ppm.

Table 2.
Toxicity effect of alpha-cypermethrin on the growth of paddy seedlings at 7 days after application during the second stage of the experiment.

No.	Treatment	Plant Height	Leaf Deformation	Leaf Area Losses	Greenness Losses
		cm	%		
1	P1	1.3	0.0	0.0	0.0
2	P2	0.0	10.0	17.0	3.6
3	P3	-0.5	18.3	46.4	8.7
4	P4	-1.7	93.3	76.0	73.4
5	P5	-1.0	100.0	83.9	100.0

Note: Remarks: P1 : 0 ppm, P2 : 138 ppm, P3 : 277 ppm, P4 : 555 ppm, P5 : 1111 ppm Negative value (-) means decreasing.

The paddy seedlings exposed to alpha-cypermethrin at the second stage of the experiment showed significant growth inhibition compared to the control (P1-0 ppm). All treatment groups exhibited reduced plant height of paddy seedlings, leaf deformation, decreased leaf area, and reduced greenness. After seven days, seedlings in the control (P1-0 ppm) reached an average height increase of 1.3 cm by the end of the experiment, while those in the 277–1111 ppm group experienced a decrease in average height of 0.5–1.7 cm, demonstrating a clear effect of alpha-cypermethrin. Seedlings in the control group showed no leaf deformation by the end of the experiment, whereas those in the 138–4444 ppm group exhibited leaf deformation ranging from 10% to 100%, indicating a significant toxic effect of alpha-cypermethrin. The pesticide caused a reduction in leaf area of paddy seedlings, with decreases ranging from 17.6% to 83.9%, and a decrease in greenness of 3.6% to 100% for treatment concentrations of 138–277 ppm. After 7 days of observation, alpha-cypermethrin at 138 ppm still exhibited toxicity effects on paddy seedlings. This finding aligns with another experiment involving cucumber, where cypermethrin concentrations of 50–500 ppm affected three endpoints of seed development, while deltamethrin primarily impacted root length [18].

The observed growth inhibition is likely due to the interference of alpha-cypermethrin with cell division and elongation. Previous studies suggest that pyrethroids can disrupt hormone balance, particularly auxins, which are crucial for plant growth [19]. The control, which did not receive any alpha-cypermethrin, exhibited healthy growth with no visible signs of stress. The average decrease rate in the control was 0%, compared to the highly destructive rates in the treated groups. The stark contrast between the control and treated groups underscores the destructive impact of alpha-cypermethrin on paddy seedlings. The control seedlings' healthy growth demonstrates that the observed effects in treated groups were indeed due to insecticide toxicity rather than environmental factors. Exposure to alpha-cypermethrin can lead to stunted growth in plants [20]. This inhibition of growth may manifest as reduced height and biomass accumulation, ultimately affecting the plants' ability to compete for resources and achieve optimal maturity. The application of alpha-cypermethrin can disrupt essential physiological processes such as photosynthesis and respiration in plants [21]. This disruption can lead to reduced energy production, affecting growth and development negatively. This occurs because the insecticide interferes with metabolic functions essential for cellular division and elongation, leading to reduced plant height, smaller leaves, and lower biomass.

Alpha-cypermethrin, a synthetic pyrethroid insecticide, has been observed to have several destructive effects on paddy seedlings, impacting their growth and overall health. Alpha-cypermethrin can induce visible phytotoxic symptoms in paddy seedlings, such as chlorosis (yellowing of leaves), necrosis (death of tissue), and wilting. These symptoms indicate that the seedlings are experiencing stress due to chemical exposure, which can hinder their development and reduce crop yields [19, 22]. Alpha-cypermethrin exhibits significant phytotoxic effects on paddy seedlings, leading to symptoms such as chlorosis, stunted growth, and root damage. Studies indicate that it can be more toxic than some other commonly used pesticides, such as organophosphates and carbamates, which may have different modes of action and toxicity profiles. For instance, while organophosphates can also be harmful, their effects may vary depending on the specific formulation and environmental conditions [19]. Exposure to alpha-cypermethrin can lead to stunted growth in paddy seedlings.

The insecticide may also have interfered with key metabolic pathways, reducing the production of energy needed for growth and development. Although alpha-cypermethrin primarily targets sodium channels in insects, it can also affect plant cells, particularly those involved in ion transport and signal transduction. Disruption of ion homeostasis can impair cellular function, leading to growth inhibition and increased susceptibility to environmental stressors. This mechanism explains the rapid onset of symptoms such as wilting and necrosis in treated seedlings [7, 8]. Research indicates that alpha-cypermethrin has a higher affinity for plant DNA compared to some alternatives, suggesting that it may pose a greater risk of genetic and physiological damage to paddy seedlings. For example, studies have shown that alpha-cypermethrin (a related compound) is associated with significant DNA damage potential in plants, which could lead to long-term detrimental effects on seedling health and viability [19]. Hormonal imbalance, the inhibition of root and shoot growth, suggests that alpha-cypermethrin may interfere with plant hormones like auxins, which regulate cell division and elongation. Reduced auxin activity can lead to stunted growth, poor root development, and abnormal leaf morphology. Additionally, cytokinin levels, which promote chloroplast development, may have been suppressed, contributing to the observed chlorophyll degradation. Toxicological thresholds [23]. Alpha-cypermethrin has a destructive effect on paddy seedlings, significantly when compared to other pesticides. It exhibits high phytotoxicity, a persistent nature, and a potential for genetic damage, highlighting the need for careful consideration and management practices when using this insecticide [24]. Alpha-cypermethrin, while highly effective as an insecticide, can have detrimental effects on paddy seedlings if misused or overapplied. These effects can manifest through physiological and morphological changes that hinder the growth and development of paddy plants, impacting both their survival and productivity in the long term.

The end product or pesticide residuals are incorporated into the host plant and consequently damage important biomolecules in the plant when they enter the metabolic pathway, thus leading to ROS production. Sufficient literature is available revealing the negative effects at cellular/genetic levels, including cytotoxicity, genotoxicity, chromosomal abnormalities, DNA damage, and increased rates of mutation induction associated with pesticide usage [17]. Pesticides, above permissible doses, severely affect cell development, photosynthesis, biosynthesis, and molecular responses at various stages of plant life [25]. Excessive and repeated application of these chemical pesticides exhibits reduced germination, retarded growth of vegetative and reproductive organs, and severely affects various morphological and physiological efficiencies in several important crops [26].

Highly regulated mechanisms are involved in maintaining the equilibrium between ROS formation and their detoxification during normal growth and metabolism. However, unfavorable conditions such as water scarcity, higher accumulation of salts, ions, and toxic metals, coupled with climatic changes, are responsible for excessive ROS production that disturbs the equilibrium and causes oxidative stress [27]. Although ROS are short-lived, toxic molecules, they degrade important biomolecules such as lipids and proline, and increase content of MDA level [28]. Besides this, the toxicity of mancozeb and chlorpyrifos, in a dose-dependent manner, enhanced the antioxidant system (CAT, POD, and SOD) in Allium to tolerate the morphotoxicity of the pesticides but failed beyond the precise limit [17].

4. Conclusion

Alpha-cypermethrin caused significant growth inhibition in paddy seedlings, with reduced plant height, leaf deformation, and overall biomass. The effect was dose-dependent, in which all treatments inhibited plant height in the range of 0.3-1.7 cm, leaf deformation in the range of 10-100%, leaf area losses of 16-89%, and greenness losses of 3.6-100%.

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