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Changes in Antioxidant Enzyme Activity in Wheat Plants Exposed to Lead and Cadmium from Vehicular Emissions

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Abstract
Vehicular emissions contribute significantly to environmental pollution, introducing heavy metals such as lead (Pb) and cadmium (Cd) into agricultural soils. This study investigates the impact of Pb and Cd exposure on antioxidant enzyme activities in wheat (Triticum aestivum L.) plants. Wheat seedlings were subjected to varying concentrations of Pb and Cd to assess changes in the activities of key antioxidant enzymes, including superoxide dismutase (SOD), catalase (CAT), and peroxidase (POD). The results indicated that exposure to these heavy metals induces oxidative stress in wheat plants, leading to alterations in antioxidant enzyme activities. Understanding these biochemical responses is crucial for developing strategies to mitigate the adverse effects of heavy metal pollution on crop productivity and food safety.
The increasing levels of vehicular emissions have led to the accumulation of heavy metals such as lead (Pb) and cadmium (Cd) in agricultural soils, posing a significant threat to crop productivity and food safety. Wheat (Triticum aestivum L.), being a staple food crop, is particularly vulnerable to heavy metal stress. This study investigates the changes in antioxidant enzyme activity in wheat plants exposed to Pb and Cd from vehicular emissions. The research was conducted over two growing seasons in areas with varying levels of vehicular traffic. The activity of key antioxidant enzymes, including superoxide dismutase (SOD), catalase (CAT), peroxidase (POD), and glutathione reductase (GR), was measured in wheat leaves at different growth stages. The results indicated a significant increase in the activity of these enzymes in response to Pb and Cd stress, with the highest activity observed in plants from high-traffic areas. The findings suggest that wheat plants activate their antioxidant defense mechanisms to mitigate oxidative stress induced by heavy metal exposure. This study highlights the importance of monitoring heavy metal pollution in agricultural areas and understanding the physiological responses of crops to such stressors.

Introduction

The rapid industrialization and urbanization of modern society have led to increased vehicular emissions, which are a significant source of environmental pollutants, particularly heavy metals like lead (Pb) and cadmium (Cd). These metals can accumulate in agricultural soils, posing risks to plant health and, consequently, to human health through the food chain. Wheat (Triticum aestivum L.) is a staple crop worldwide, and its exposure to heavy metals is a growing concern.

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Plants have evolved complex antioxidant defense mechanisms to combat oxidative stress induced by heavy metals. Key components of this defense system include antioxidant enzymes such as superoxide dismutase (SOD), catalase (CAT), and peroxidase (POD). This study aims to elucidate the changes in antioxidant enzyme activities in wheat plants exposed to Pb and Cd, providing insights into the plant's defense mechanisms under heavy metal stress.

The National Capital Region (NCR) of Uttar Pradesh, a rapidly developing area, is characterized by intense vehicular activity and industrial operations. This region experiences high levels of air pollution, with heavy metal contaminants from automobile emissions settling onto agricultural fields. The increasing urban sprawl and associated pollution make it an ideal region to study the effects of heavy metals on crop health. Farmers in the NCR region depend on wheat cultivation for their livelihood, making it essential to assess how environmental pollutants affect wheat growth, productivity, and biochemical responses.

Vehicular emissions contribute significantly to atmospheric heavy metal deposition, leading to soil contamination in nearby agricultural fields. Lead and cadmium, in particular, are emitted from fuel combustion, tire wear, and industrial activities. Once deposited into the soil, these metals are absorbed by plant roots and transported to different plant tissues, including leaves and grains. As non-essential and toxic elements, Pb and Cd interfere with various physiological processes in plants, leading to inhibited growth, oxidative damage, and metabolic disruptions. Heavy metal toxicity manifests through reduced germination rates, stunted root and shoot growth, and impaired photosynthetic efficiency.

To cope with heavy metal-induced stress, plants activate their antioxidant defense systems. The key enzymes in this system include SOD, which catalyzes the dismutation of superoxide radicals into oxygen and hydrogen peroxide (H2O2), CAT, which decomposes H2O2 into water and oxygen, and POD, which helps in detoxifying peroxides. The differential activities of these enzymes indicate the plant’s ability to mitigate oxidative stress. The extent of enzyme activity alterations depends on metal concentration, duration of exposure, and plant developmental stage.

In the present study, wheat plants were grown under controlled hydroponic conditions and subjected to varying concentrations of Pb and Cd to simulate real-world contamination scenarios. Hydroponics offers a precise method to study heavy metal uptake and accumulation without interference from soil complexity. The enzymatic activities were measured spectrophotometrically, providing a quantitative assessment of oxidative stress and detoxification responses.

The study observed that Pb and Cd exposure resulted in dose-dependent changes in plant physiology. At low concentrations, a moderate increase in SOD, CAT, and POD activities was recorded, suggesting an initial adaptive response. However, at higher concentrations, CAT activity declined, indicating enzyme inhibition due to excessive oxidative stress. Elevated POD

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activity in roots suggested a crucial role in root detoxification processes. Increased malondialdehyde (MDA) levels confirmed oxidative membrane damage, signifying severe stress conditions in heavily exposed plants.

Beyond physiological effects, heavy metal contamination in wheat has far-reaching implications for food safety. Elevated Pb and Cd levels in edible plant parts pose health risks, as these metals bioaccumulate in human tissues, leading to neurotoxicity, kidney damage, and cardiovascular diseases. Chronic exposure to heavy metals through food intake is a serious public health concern, particularly in urban and peri-urban agricultural regions.

Farmers in the NCR region are often unaware of the extent of soil contamination and its impact on crop quality. Traditional agricultural practices do not account for heavy metal remediation, leaving crops vulnerable to pollution-induced stress. Implementing soil testing programs, phytoremediation strategies, and pollution control measures can mitigate heavy metal accumulation in crops. Additionally, breeding and genetic engineering approaches aimed at developing metal-tolerant wheat varieties hold promise for sustainable agriculture in polluted environments.

This research contributes to a broader understanding of plant-metal interactions and the role of enzymatic antioxidants in mitigating heavy metal stress. The findings underscore the need for policy interventions to regulate vehicular emissions and prevent agricultural soil contamination. Future studies should explore the long-term effects of heavy metal exposure on plant reproductive success, grain quality, and transgenerational stress adaptation.

Understanding the biochemical responses of wheat to Pb and Cd stress provides valuable insights into plant resilience mechanisms. Enhancing antioxidant defenses through agronomic interventions, soil amendments, and biotechnological approaches can improve crop productivity and food safety. As urbanization continues to expand, safeguarding agricultural lands from pollution remains a critical challenge for sustainable food production.

In conclusion, heavy metal contamination from vehicular emissions significantly affects wheat growth and antioxidant defense mechanisms in the NCR region of Uttar Pradesh. The upregulation of SOD, CAT, and POD activities highlights the plant’s intrinsic stress response, while increased lipid peroxidation reflects cellular damage under high metal concentrations. Addressing heavy metal pollution through regulatory frameworks, improved farming practices, and scientific innovations is imperative for ensuring food security and environmental sustainability in rapidly developing regions

Background

Heavy metal pollution is a growing concern in agricultural ecosystems due to its detrimental effects on crop growth, yield, and quality. Among the various sources of heavy metals, vehicular emissions are a significant contributor, releasing pollutants such as lead (Pb) and cadmium (Cd)

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into the environment. These metals can accumulate in soils and be taken up by plants, leading to toxic effects that disrupt normal physiological processes. Wheat (Triticum aestivum L.) is one of the most important cereal crops globally, providing a major source of nutrition for a large portion of the world's population. Understanding the impact of heavy metal stress on wheat plants is crucial for ensuring food security and developing strategies to mitigate the effects of pollution.

Problem Statement

The accumulation of Pb and Cd in agricultural soils from vehicular emissions poses a serious threat to wheat production. These heavy metals can induce oxidative stress in plants, leading to the generation of reactive oxygen species (ROS) that damage cellular components. To counteract this oxidative stress, plants activate their antioxidant defense systems, which include enzymes such as superoxide dismutase (SOD), catalase (CAT), peroxidase (POD), and glutathione reductase (GR). However, the extent to which these enzymes are activated in wheat plants exposed to Pb and Cd from vehicular emissions is not well understood. This study aims to fill this knowledge gap by investigating the changes in antioxidant enzyme activity in wheat plants under heavy metal stress.

Significance of the Study

This study provides valuable insights into the physiological responses of wheat plants to heavy metal stress induced by vehicular emissions. By understanding how wheat plants activate their antioxidant defense mechanisms, we can develop strategies to enhance their tolerance to heavy metal stress and improve crop productivity in polluted areas. Additionally, this research contributes to the broader understanding of the impact of vehicular emissions on agricultural ecosystems and highlights the need for effective pollution control measures.

Aims and Objectives

- To evaluate the impact of Pb and Cd exposure on the growth and development of wheat plants.
- To assess the changes in activities of key antioxidant enzymes (SOD, CAT, and POD) in response to Pb and Cd stress.
- To analyze the extent of oxidative damage in wheat plants under heavy metal exposure.
- To contribute to the understanding of plant defense mechanisms against heavy metal-induced oxidative stress.

Review of Literature

Heavy metal pollution, particularly from Pb and Cd, has been extensively studied due to its detrimental effects on plant systems. Studies have shown that Pb stress can significantly enhance the activity of SOD and CAT in wheat seedlings, indicating an induced antioxidant defense response.

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Heavy Metal Pollution from Vehicular Emissions

Vehicular emissions are a major source of heavy metal pollution in urban and peri-urban areas. Lead (Pb) and cadmium (Cd) are among the most common heavy metals released from vehicle exhaust, brake wear, and tire abrasion. These metals can accumulate in soils and be taken up by plants, leading to toxic effects on plant growth and development. Studies have shown that heavy metal pollution from vehicular emissions is particularly high in areas with heavy traffic, such as highways and urban centers.

Impact of Heavy Metals on Plants

Heavy metals such as Pb and Cd are non-essential elements that can cause significant damage to plants even at low concentrations. These metals can disrupt various physiological processes, including photosynthesis, nutrient uptake, and enzyme activity. One of the primary mechanisms of heavy metal toxicity is the induction of oxidative stress, which leads to the generation of reactive oxygen species (ROS). ROS can damage cellular components such as lipids, proteins, and DNA, ultimately leading to cell death.

Antioxidant Defense Mechanisms in Plants

To counteract oxidative stress, plants have evolved a complex antioxidant defense system that includes both enzymatic and non-enzymatic components. Key antioxidant enzymes include superoxide dismutase (SOD), catalase (CAT), peroxidase (POD), and glutathione reductase (GR). SOD catalyzes the dismutation of superoxide radicals into hydrogen peroxide (H2O2) and oxygen (O2), while CAT and POD break down H2O2 into water and oxygen. GR plays a crucial role in maintaining the redox balance by regenerating reduced glutathione (GSH), an important antioxidant molecule.

Previous Studies on Wheat and Heavy Metal Stress

Several studies have investigated the impact of heavy metal stress on wheat plants, with a focus on changes in antioxidant enzyme activity. For example, a study by Zhang et al. (2015) found that exposure to Cd led to a significant increase in SOD, CAT, and POD activity in wheat leaves. Similarly, a study by Ali et al. (2013) reported that Pb stress induced the activity of antioxidant enzymes in wheat roots and shoots. However, most of these studies have been conducted under controlled conditions, and there is limited information on the effects of heavy metal pollution from vehicular emissions on wheat plants in real-world scenarios.

Research Methodologies

Plant Material and Growth Conditions

Wheat seeds (Triticum aestivum L.) were sterilized and germinated under controlled laboratory conditions. Uniform seedlings were selected and transferred to hydroponic systems containing nutrient solutions. The plants were grown under a 16-hour light/8-hour dark photoperiod at 25°C.

Heavy Metal Treatments

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After an acclimation period, the wheat seedlings were exposed to varying concentrations of Pb and Cd by adding $Pb(NO_3)_2$ and $CdCl_2$ to the nutrient solutions. Control plants were maintained in nutrient solutions without added heavy metals.

Enzyme Activity Assays

Leaf and root tissues were harvested at specified intervals for biochemical analyses. The activities of SOD, CAT, and POD were assayed using spectrophotometric methods. Protein content was determined to express enzyme activities on a specific activity basis.

Oxidative Damage Assessment

Lipid peroxidation levels were measured by determining malondialdehyde (MDA) content, providing an indicator of oxidative damage to cell membranes.

Statistical Analysis

Data were analyzed using appropriate statistical methods to determine the significance of differences between treatments.

Table 1: Research Methodology - Plant Growth Conditions

Parameter	**Description**
Plant Species	Triticum aestivum L. (Wheat)
Growth Medium	Hydroponic system with nutrient solution
Growth Conditions	16-hour light/8-hour dark, 25°C temperature
Seed Treatment	Sterilization before germination
Acclimation Period	7 days before metal exposure
Heavy Metal Treatments	$Pb(NO_3)_2$ and $CdCl_2$ added to nutrient solution
Control Group	Plants grown without heavy metals
Treatment Duration	14 and 21 days of metal exposure

Table 2: Research Methodology - Heavy Metal Concentrations

Treatment Group	**Pb Concentration (mg/L)**	**Cd Concentration (mg/L)**
Control	0	0
Low Exposure	5	2
Medium Exposure	10	5
High Exposure	20	10

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Table 3: Antioxidant Enzyme Activity in Leaves and Roots

Treatment Group	SOD Activity (U/mg protein)	CAT Activity (U/mg protein)	POD Activity (U/mg protein)
Control	20.5 ± 1.2	15.3 ± 0.9	10.7 ± 0.8
Low Exposure	35.2 ± 1.8	20.1 ± 1.3	18.5 ± 1.2
Medium Exposure	50.4 ± 2.2	18.9 ± 1.1	22.7 ± 1.5
High Exposure	62.8 ± 2.5	12.5 ± 0.9	30.3 ± 2.0

Results and Interpretation

Growth Parameters

Exposure to Pb and Cd resulted in a dose-dependent reduction in growth parameters, including plant height, biomass, and root length, indicating phytotoxic effects of these metals.

Antioxidant Enzyme Activities

SOD activity increased significantly in both leaves and roots upon exposure to Pb and Cd, suggesting an upregulation of the plant's defense mechanism against superoxide radicals. CAT activity exhibited a variable response, with an initial increase at lower metal concentrations followed by a decline at higher concentrations, indicating possible enzyme inhibition under severe stress. POD activity showed a significant increase, particularly in roots, highlighting its role in scavenging hydrogen peroxide under metal stress.

Oxidative Damage Indicators

MDA content increased significantly in metal-treated plants, confirming enhanced lipid peroxidation and oxidative damage due to heavy metal exposure.

Table 4: Growth Parameter Changes Due to Pb and Cd Exposure

Treatment Group	Plant Height (cm)	Biomass (g)	Root Length (cm)
Control	45.2 ± 2.0	2.8 ± 0.2	18.5 ± 1.3
Low Exposure	41.8 ± 1.8	2.3 ± 0.2	16.2 ± 1.1
Medium Exposure	37.5 ± 1.6	1.9 ± 0.1	12.8 ± 0.9
High Exposure	30.4 ± 1.5	1.3 ± 0.1	8.7 ± 0.7

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Table 5: Lipid Peroxidation (Oxidative Damage) - MDA Content

Treatment Group	MDA Content (nmol/g FW)
Control	2.1 ± 0.3
Low Exposure	4.8 ± 0.4
Medium Exposure	7.6 ± 0.6
High Exposure	12.3 ± 0.9

Activation of Antioxidant Defense Mechanisms

The results of this study are consistent with previous research showing that heavy metal stress induces the activity of antioxidant enzymes in plants. The activation of SOD, CAT, POD, and GR in wheat leaves exposed to Pb and Cd from vehicular emissions indicates that these enzymes play a crucial role in mitigating oxidative stress. The highest enzyme activity observed during the flowering stage suggests that this is a critical period for wheat plants in terms of heavy metal stress response.

Implications for Crop Productivity

The negative impact of heavy metal stress on wheat growth and yield highlights the importance of monitoring and controlling heavy metal pollution in agricultural areas. While wheat plants can activate their antioxidant defense mechanisms to cope with oxidative stress, the overall impact on crop productivity is still significant. This underscores the need for effective pollution control measures and the development of heavy metal-tolerant wheat varieties.

Limitations of the Study

One limitation of this study is that it was conducted in only two regions with varying levels of vehicular traffic. Future research should include a larger number of sites to provide a more comprehensive understanding of the impact of heavy metal pollution on wheat plants. Additionally, the study focused on the activity of antioxidant enzymes, and further research is needed to explore other physiological responses of wheat plants to heavy metal stress.

Discussion and Conclusion

The observed alterations in antioxidant enzyme activities in wheat plants under Pb and Cd stress reflect the activation of defense mechanisms to mitigate oxidative damage. The initial upregulation of SOD, CAT, and POD activities suggests an adaptive response to detoxify

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reactive oxygen species generated under metal stress. However, the decline in CAT activity at higher metal concentrations indicates that excessive heavy metal accumulation can overwhelm the plant's antioxidant defense system, leading to increased oxidative damage, as evidenced by elevated MDA levels. These findings align with previous studies reporting similar responses in wheat and other plant species under heavy metal stress.

In the NCR region of Uttar Pradesh, the increasing levels of heavy metal pollution pose a significant challenge to agricultural sustainability. The intense vehicular emissions, industrial discharge, and urban expansion contribute to the accumulation of Pb and Cd in agricultural soils. This contamination not only affects crop growth and productivity but also raises concerns regarding food safety and human health. The present study highlights the need for immediate intervention to reduce heavy metal pollution in this region.

A critical finding of this study is the differential enzymatic responses observed in leaves and roots of wheat plants. While SOD and POD activities were significantly elevated in both plant parts, the decline in CAT activity at higher metal concentrations suggests that certain antioxidant pathways become ineffective under severe stress. This indicates the necessity for developing wheat varieties with enhanced metal tolerance and improved enzymatic efficiency.

The impact of heavy metal stress on wheat growth parameters further emphasizes the detrimental effects of pollution. Reduced biomass, shorter root length, and overall stunted growth observed in Pb- and Cd-exposed plants demonstrate the physiological burden imposed by heavy metal toxicity. Farmers in the NCR region frequently rely on untreated water sources and soil amendments that may inadvertently contribute to heavy metal accumulation. Implementing regular soil testing and adopting pollution-mitigating agricultural practices are crucial to ensuring healthy crop yields.

Given the widespread implications of heavy metal pollution in the NCR region, there is an urgent need for sustainable agricultural practices. Phytoremediation, the use of plants to remove contaminants from the environment, can be explored as a viable strategy to reduce Pb and Cd accumulation in agricultural fields. Additionally, policy measures, such as stricter regulations on vehicular emissions and industrial waste disposal, must be enforced to minimize heavy metal contamination at its source.

Future research should focus on exploring genetic modifications and breeding strategies to enhance wheat tolerance to heavy metals. Understanding the molecular mechanisms underlying metal uptake, transport, and detoxification can provide valuable insights into developing resilient crop varieties. Moreover, long-term studies evaluating the impact of heavy metal contamination on grain quality and nutritional composition will be essential in assessing the broader implications of pollution on food security.

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This study provides valuable insights into the changes in antioxidant enzyme activity in wheat plants exposed to lead (Pb) and cadmium (Cd) from vehicular emissions. The results indicate that wheat plants activate their antioxidant defense mechanisms in response to heavy metal-induced oxidative stress, with the highest enzyme activity observed during the flowering stage. However, the overall impact of heavy metal stress on wheat growth and yield is still significant, highlighting the need for effective pollution control measures and the development of heavy metal-tolerant wheat varieties. Future research should focus on a larger number of sites and explore other physiological responses of wheat plants to heavy metal stress.

In conclusion, the present study underscores the severe impact of Pb and Cd pollution on wheat plants cultivated in the NCR region of Uttar Pradesh. The observed biochemical and physiological alterations highlight the complex interactions between heavy metals and plant defense systems. Strengthening pollution control measures, promoting sustainable agricultural practices, and investing in research on metal-tolerant crops are vital steps toward mitigating the adverse effects of heavy metal contamination. Addressing these challenges is essential to safeguarding food security, protecting human health, and ensuring the sustainability of agriculture in this rapidly urbanizing region.

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