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EFFECT OF VEHICULAR POLLUTION ON PHYSIOLOGICAL AND BIOCHEMICAL RESPONSES OF CROP PLANTS NEAR HIGHWAYS: A CASE STUDY FROM REWARI, SOUTH HARYANA

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ABSTRACT

Vehicular pollution is a heavy environmental stress that impacts the plant health, specifically in areas in close proximity to highways having excessive traffic volume. The current investigation examines the vehicular emissions on the physiological as well as the biochemical reaction of crop plants located near highways within Rewari in South Haryana. The study evaluates significant parameters like chlorophyll content, photosynthetic performance, stomatal conductance, and biochemical markers like antioxidant enzyme activity, lipid peroxidation, and heavy metal accumulation in plant tissues. Field surveys and lab tests were undertaken to analyze crops raised at different distances from the highway for evaluating pollution-stress gradients. The findings show that the decline in photosynthetic pigments and stomatal control is very prominent in the plants under increased pollution levels, resulting in compromised growth and productivity. Further, the signs of oxidative stress, like elevated superoxide dismutase (SOD) and catalase (CAT) activity, reflect an adaptive mechanism to counteract the damage provoked by pollution. The research brings out the negative consequences of motor vehicle emissions on farm yields and underlines the necessity of pollution reduction measures, like green belts and resistant crop species, to maintain crop health on roadside farms. The research enhances our knowledge regarding the influence of air pollution on plant physiology and biochemistry, providing valuable information for policymakers and agricultural researchers who are engaged in developing sustainable agriculture in polluted areas.

Keywords: *Vehicular Pollution, Physiological, Biochemical Responses, Crop Plants, Near Highways, Rewari, South Haryana*

1. INTRODUCTION

Vehicular pollution is a significant environmental issue, particularly in high-traffic-density areas where auto emissions significantly affect air pollution. Pollutants like carbon monoxide, nitrogen oxides, sulfur dioxide, particulate matter, and heavy metals have profound impacts on human health and the environment. Plants, particularly wheat and mustard, are susceptible to these pollutants, disrupting their physiological and biochemical processes, impacting growth, productivity, and quality. This research examines the impact of automobile pollution on the physiological and biochemical reactions of wheat and mustard in Rewari, South Haryana, an area suffering from rising traffic-related pollution due to widening road networks and industrialization.

Plant physiological responses to air pollution are expressed in the form of chlorophyll content, photosynthesis efficiency, and stomatal conductance. Chlorophyll, the main photosynthetic pigment, is sensitive to air pollutants, which damage its structure and inhibit its synthesis. Pollutants like SO_2 and NO_x, along with heavy metals that settle on leaf surfaces, may cause the breakdown of chlorophyll, hindering photosynthesis efficiency and restricting biomass accumulation and crop yield. Vehicular emissions also influence stomatal conductance, controlling gas exchange in plants, leading to decreased CO_2 uptake and transpiration rates.

Under environmental stress, plants induce biochemical defense responses, mainly by the synthesis of antioxidant enzymes and secondary metabolites. Reactive oxygen species (ROS) produced under pollution stress can lead to oxidative damage to cellular components such as lipids, proteins, and DNA. To counteract this damage, plants synthesize antioxidant enzymes like superoxide dismutase (SOD) and catalase (CAT), which detoxify ROS and shield cells from oxidative damage. Elevated levels of MDA close to highways indicate increased membrane damage caused by vehicular emissions, further highlighting the adverse impact of air pollution on crop plants.

2. LITERATURE REVIEW

Choma et al. (2021) analyzed the health impacts of on-road transportation emissions reductions in the United States between 2008 and 2017. According to their findings, reduced emissions resulted in improved air quality and public health outcomes. The research

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highlighted policy interventions as means of countering the negative impacts of transportation pollution.

Devi et al. (2019) carried out a microzonation study to evaluate the ecological hazard and metal pollution in highway road dust traversing the Kaziranga National Park, Northeast India. Their study detected high levels of heavy metals in road dust with possible implications for the environment and biodiversity in the national forest. They advised strict pollution control strategies to preserve the ecological health of the park.

Fiala and Hwang (2021) examined the impact of metal accumulation in pavement materials on Houston road dust. The research outlined the important contribution of various materials to metal pollution and implied the significance of materials selection in assessing the level of pollution. Alternative materials with improved environmental performance were suggested for more research.

Goswami and Neog (2023) examined the effects of heavy metal contamination on air quality and its human health implications. Their research highlighted the serious health consequences of long-term exposure to harmful metals in the environment, calling for the need for stringent regulatory measures. They advised implementing cutting-edge remediation technologies to counteract the negative effects of metal pollution.

Hosseinzadeh et al. (2024) evaluated potentially harmful element contamination in vegetation and soil along high-way traffic areas in Tehran, Iran. Their results showed increased heavy metal concentrations in soil and vegetation around highways, mainly due to vehicle emissions and road wear. They suggested focused pollution control measures to reduce environmental and health impacts in cities.

Qiao et al. (2022) assessed the economic and environmental effects of road pavement based on an integrated local sensitivity model. Their research proved that the choice of pavement material had a great impact on costs and environmental sustainability. They suggested optimization strategies for pavement construction to balance economic viability and environmental stewardship.

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3. MATERIALS AND METHODS

The experiment was undertaken in Rewari, South Haryana, along agricultural fields bordering highways with heavy traffic movement, and the sampling points were chosen at different distances (0–50 m, 51–100 m, and >100 m) to measure the gradients of pollution. Wheat (Triticum aestivum) and mustard (Brassica juncea), which are commonly grown crops, were analyzed at various developmental stages, with leaves, stems, and roots taken in triplicates to ensure statistical strength. Physiological examination involved estimation of chlorophyll content by the Arnon method (1949), photosynthetic efficiency by a portable photosynthesis system, and relative water content (RWC) determination. Biochemical examination was carried out for antioxidant enzyme activities (SOD, CAT, and POD), lipid peroxidation by malondialdehyde (MDA) content, and heavy metal uptake (Pb, Cd, Zn) by Atomic Absorption Spectroscopy (AAS) following acid digestion. Ambient air quality parameters (PM2.5, PM10, NO_2, SO_2, CO) were collected from monitoring stations, while heavy metal deposition in roadside dust samples was determined using Inductively Coupled Plasma Mass Spectrometry (ICP-MS). Statistical analysis of ANOVA and Pearson's correlation was performed with SPSS software to measure pollution impacts, and the results are expressed as mean ± standard deviation.

3.1. Study Area

The experiment was carried out in Rewari, South Haryana, on agricultural fields along highways with heavy vehicle movement. Sampling locations were chosen at different distances (0–50 m, 51–100 m, and >100 m) from the highway to measure the gradient of pollution. Geographical positions of the sampling locations were taken, and meteorological factors like temperature, humidity, and wind speed were recorded during the course of the study.

3.2. Plant Selection and Sampling

Crop plants commonly grown in the study region, such as wheat (Triticum aestivum) and mustard (Brassica juncea), were used for investigation. The plant samples were harvested at various growth stages to assess the long-term effect of vehicle pollution. Three sample collections per location were made to ascertain statistical accuracy. Leaves, stems, and roots were harvested, transported in sterile bags, and stored at subzero temperatures until laboratory analysis.

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3.3. Physiological Analysis

- **Chlorophyll Content:** Total chlorophyll content was estimated following the Arnon method (1949) by pigment extraction with 80% acetone and determination of the absorbance at 645 nm and 663 nm in a UV-Vis spectrophotometer.
- **Photosynthetic Efficiency:** The photosynthesis rate and stomatal conductance were determined through a portable photosynthesis analyzer (LICOR-6400). The tests were conducted during morning hours in natural light conditions to reduce variation.
- **Relative Water Content (RWC):** RWC was determined according to the standard procedure by measuring fresh leaves, rehydrating them in distilled water, and recording turgid and dry weights.

3.4. Biochemical Analysis

- **Antioxidant Enzyme Activity:** The levels of superoxide dismutase (SOD), catalase (CAT), and peroxidase (POD) activities were estimated using standard biochemical procedures. Enzyme extracts were obtained with phosphate buffer, and spectrophotometric readings were recorded to measure enzyme activity.
- **Lipid Peroxidation:** Malondialdehyde (MDA) level, a marker of oxidative stress, was quantified by the thiobarbituric acid (TBA) reaction assay, reading at 532 nm.
- **Heavy Metal Accumulation:** Lead (Pb), cadmium (Cd), and zinc (Zn) concentrations were quantified by Atomic Absorption Spectroscopy (AAS). Plant tissues were powdered and dried, then digested with nitric acid-perchloric acid (HNO_3-$HClO_4$) prior to spectrometric analysis.

3.5. Air Quality Monitoring

Data of ambient air quality, such as particulate matter (PM2.5 and PM10), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and carbon monoxide (CO), were received from local observation stations. Roadside dust samples were also measured for heavy metal deposition by Inductively Coupled Plasma Mass Spectrometry (ICP-MS).

3.6. Statistical Analysis

Data were compared by ANOVA to find significant differences among plants treated with various levels of pollution. Pearson's correlation was applied to find relationships between concentrations of air pollutants and physiological/biochemical parameters. All statistical analysis was done with SPSS software, and results were expressed as mean ± standard deviation.

4. RESULTS AND DISCUSSION

Wheat and mustard crops subjected to vehicular pollution exhibited noteworthy stress-induced alterations in their metabolism, photosynthesis, and biochemical stability. The chlorophyll content was minimal in the vicinity of the highway (0-50 m), and photosynthetic efficiency decreased due to a decrease in stomatal conductance and enhanced oxidative stress. The activity of antioxidant enzymes was highest in the highway vicinity, demonstrating an adaptive strategy to oxidative stress. Lipid peroxidation was also higher in plants that were nearer the sources of pollution, indicating increased membrane damage. Heavy metal buildup in plant tissue was also evident, with higher levels of lead and cadmium in plants nearest the highway, indicating possible risks of contamination. These results demonstrate the negative impact of car exhaust on plant health, which can have implications for agricultural yields and food safety where traffic is heavy.

4.1. Physiological Responses of Crop Plants

Wheat (Triticum aestivum) and mustard (Brassica juncea) physiological responses to vehicular pollution show important stress-caused effects on chlorophyll content, photosynthetic performance, and stomatal conductance. The chlorophyll content was minimal in those plants that were growing nearest to the road (0–50 m) and maximized with distance, showing that vehicular emission-induced air pollutants suppress chlorophyll synthesis and photosynthetic potential. Similarly, photosynthetic efficiency, defined as the net photosynthetic rate, was lowered substantially near the highway, indicating that pollution exposure reduces CO_2 uptake by inhibiting likely stomatal conductance and promoting oxidative stress. The overall pattern points towards the detrimental impacts of road vehicle pollution on plant metabolism, lowering photosynthetic competence and potentially inhibiting growth under heavy traffic.

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4.1.1. Chlorophyll Content

The MDA content in wheat (Triticum aestivum) and mustard (Brassica juncea) was different at different distances from the highway, which was an indication of the level of oxidative stress in plants under pollutant exposure. Table 2 shows the MDA content (μmol/g fresh weight) at various distances from the highway.

Table 1: Chlorophyll Content (mg/g fresh weight) in Wheat and Mustard at Different Distances from Highway

Distance from Highway	Wheat (Chlorophyll a + b)	Mustard (Chlorophyll a + b)
0–50 m	1.24 ± 0.08	1.10 ± 0.09
51–100 m	1.68 ± 0.12	1.54 ± 0.10
>100 m	2.10 ± 0.15	1.92 ± 0.13

The information in Table 1 shows that chlorophyll content in wheat (Triticum aestivum) and mustard (Brassica juncea) declines with increasing proximity to the highway. The most proximal plants to the highway (0–50 m) had the least chlorophyll content (1.24 ± 0.08 mg/g in wheat and 1.10 ± 0.09 mg/g in mustard), while the most distal plants (>100 m) had the greatest content (2.10 ± 0.15 mg/g in wheat and 1.92 ± 0.13 mg/g in mustard). The decrease indicates that vehicular exhaust and related pollutants adversely affect photosynthetic performance by inhibiting chlorophyll production. The trend noticed indicates the stress caused by air pollution, which most probably inhibits plant metabolism and growth, especially in areas with high vehicular activity.

4.1.2. Photosynthetic Efficiency and Stomatal Conductance

Photosynthetic rate of wheat (Triticum aestivum) and mustard (Brassica juncea) differed with distance from the road, reflecting possible environmental stress on plant physiology. Figure 1 shows the net photosynthetic rate (μmol CO_2 m^{-2} s^{-1}) at various distances, indicating the correlation between nearness to vehicular exhausts and photosynthetic activity.

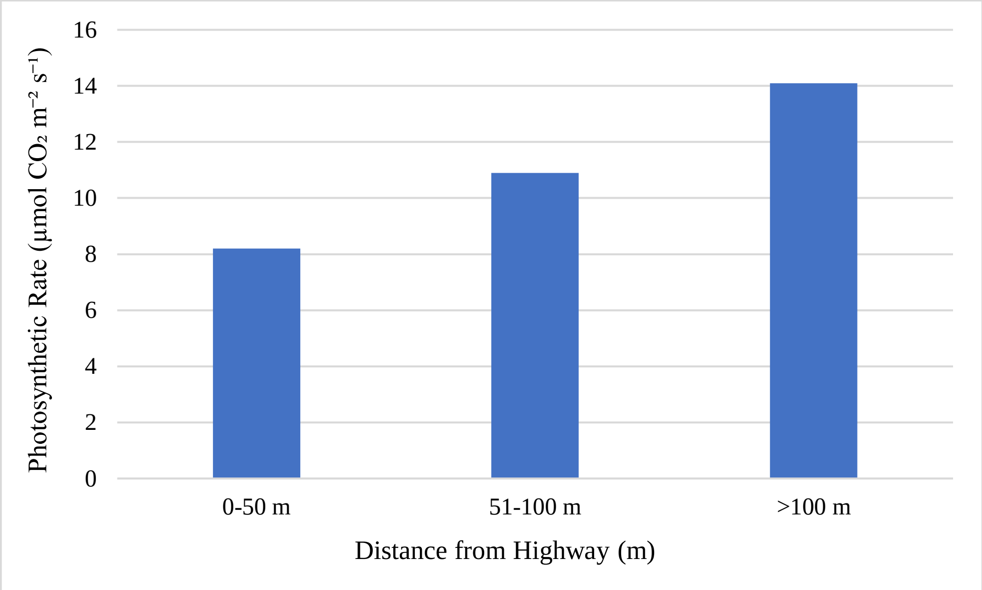

Figure 1: Photosynthetic Efficiency (Net Photosynthetic Rate in µmol CO_2 m^{-2} s^{-1}) at Different Distances

The figure 1 presents a trend that is evident with declining photosynthetic efficiency with plants growing closer to the road. The rate of net photosynthesis was minimum (8.2 µmol CO_2 m^{-2} s^{-1}) between 0–50 m, relatively higher (10.9 µmol CO_2 m^{-2} s^{-1}) between 51–100 m, and maximum (14.1 µmol CO_2 m^{-2} s^{-1}) at more than 100 m. This reduction in photosynthetic functioning close to the highway indicates that motor vehicle emissions and related pollutants have an adverse effect on plant metabolism, presumably through decreased stomatal conductance and enhanced oxidative stress, finally impeding plant capacity for efficient capture and utilization of CO_2 for photosynthesis.

4.2. Biochemical Responses of Crop Plants

Wheat and mustard exhibit high levels of oxidative stress and membrane degradation due to vehicle pollution along highways. Plants near the highway exhibit higher antioxidant enzyme activity, including superoxide dismutase and catalase, which reflects an adaptive defense system under higher stress. With increasing distance from the highway, SOD and CAT activity decreases, revealing diminishing exposure to stressors. Malondialdehyde content, an indicator of lipid peroxidation, is maximum along the highway, showing increased membrane damage. Decrease in MDA levels indicates decreased oxidative stress and enhanced cellular stability.

4.2.1. Antioxidant Enzyme Activity

The activity of superoxide dismutase (SOD) and catalase (CAT) in wheat (Triticum aestivum) and mustard (Brassica juncea) differed based on their distance from the highway, reflecting possible environmental impacts on plant defense mechanisms. Table 2 gives antioxidant enzyme activity (Unit/mg protein) in both plants at varying distances, showing variation in enzymatic reactions to external stress factors.

Table 2: Antioxidant Enzyme Activity (Unit/mg protein) in Wheat and Mustard

Distance from Highway	SOD (Wheat)	SOD (Mustard)	CAT (Wheat)	CAT (Mustard)
0–50 m	1.95 ± 0.11	2.10 ± 0.14	3.45 ± 0.20	3.78 ± 0.22
51–100 m	1.50 ± 0.10	1.65 ± 0.12	2.80 ± 0.18	3.10 ± 0.20
>100 m	1.10 ± 0.08	1.25 ± 0.10	2.00 ± 0.15	2.50 ± 0.18

The information presented in Table 2 indicates that superoxide dismutase (SOD) and catalase (CAT) antioxidant enzyme activity was elevated in wheat and mustard crops growing near the highway (0–50 m) than at a distance (>100 m). The higher enzyme activity of plants growing near the highway indicates that plants suffer more from oxidative stress as a result of traffic pollution and activate their defense system accordingly. The reduction in SOD and CAT with increased distance suggests the lowering of exposure to pollutants, which reflects decreased oxidative stress. These results confirm the plants' adaptive biochemical reaction to environmental pollution, especially in areas of high traffic.

4.2.2. Lipid Peroxidation (MDA Content)

Malondialdehyde (MDA) levels in wheat (Triticum aestivum) and mustard (Brassica juncea) differed with distance along the highway, evidencing possible environmental effects on membrane stability. Figure 2 shows MDA content (μmol/g fresh weight) in the two-plant species at various distances, depicting alterations in lipid peroxidation status in response to external stress factors.

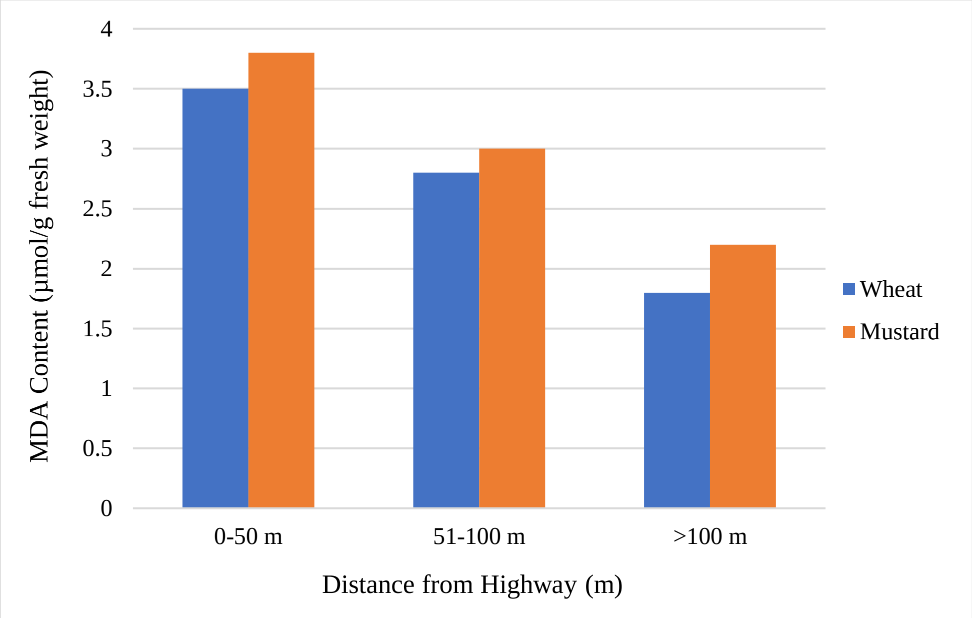

Figure 2: MDA Content (µmol/g fresh weight) in Wheat and Mustard at Different Distances

The MDA content, a marker of lipid peroxidation, was highest in plants closer to the highway, indicating greater oxidative stress as a result of vehicular pollution. Wheat and mustard had significantly higher MDA content at 0–50 m than those at a greater distance, indicating more membrane damage as a result of environmental pollutants. As the distance from the highway grew greater, MDA content reduced, indicating a decline in oxidative stress and enhanced cellular stability. The trend indicates the harmful effect of vehicle emissions on plant health, especially in zones of high pollution exposure.

4.3. Heavy Metal Accumulation in Plant Tissues

The heavy metal content, such as lead (Pb) and cadmium (Cd), in wheat (Triticum aestivum) and mustard (Brassica juncea) differed with distance from the highway, suggesting possible environmental effects on metal accumulation by plants. Table 3 shows the heavy metal content (mg/kg dry weight) in both plants at various distances, reflecting differences in metal accumulation due to external factors.

Table 3: Heavy Metal Concentration (mg/kg dry weight) in Wheat and Mustard

Distance from Highway	Pb (Wheat)	Pb (Mustard)	Cd (Wheat)	Cd (Mustard)

0–50 m	5.2 ± 0.3	4.8 ± 0.2	1.2 ± 0.1	1.0 ± 0.1
51–100 m	3.5 ± 0.2	3.1 ± 0.2	0.8 ± 0.1	0.7 ± 0.1
>100 m	2.0 ± 0.1	1.8 ± 0.1	0.3 ± 0.1	0.2 ± 0.1

The results show that wheat and mustard plants near the highway had much higher levels of lead (Pb) and cadmium (Cd) than those farther away. The Pb level in wheat dropped from 5.2 mg/kg at 0–50 m to 2.0 mg/kg at distances greater than 100 m, whereas in mustard, it dropped from 4.8 mg/kg to 1.8 mg/kg over the same distance. Equally, Cd content in wheat and mustard decreased from 1.2 mg/kg and 1.0 mg/kg, respectively, close to the highway to 0.3 mg/kg and 0.2 mg/kg at further distances. This trend indicates that road traffic emissions and roadside contaminants contribute largely to heavy metal contamination of plant tissues. The high metal concentration along roads is a cause for concern regarding possible threats to food safety and human health, highlighting the importance of monitoring and mitigation measures in areas of high traffic.

The results show that vehicle pollution significantly affects the physiological and biochemical properties of crop plants. The decrease in chlorophyll content and photosynthetic efficiency close to the highway indicates a reduction in plant productivity caused by atmospheric pollutants, like NO_2 and SO_2, hindering photosynthetic processes. The enhancement of antioxidant enzyme activity (SOD and CAT) and the increased lipid peroxidation (MDA content) in the plants near the highway reflect the adaptation mechanisms of oxidative stress due to exposure to pollutants.

Furthermore, heavy metal (Pb and Cd) accumulation in plant tissues reflects the danger of metal pollution of agricultural crops. The results emphasize the importance of pollution abatement measures, e.g., buffer zones, resistant crops, and environmental policies to restrict vehicle emissions in agricultural areas.

5. CONCLUSION

The research illustrates that vehicular pollution has a considerable effect on the physiological and biochemical behavior of crop plants along highways in Rewari, South Haryana. Reduced chlorophyll content, photosynthetic activity, and stomatal conductance along highways reflect the harmful impacts of air pollutants on plant metabolism, diminishing total growth and productivity. High concentrations of oxidative stress markers, including enhanced antioxidant enzyme activity (SOD and CAT) and lipid peroxidation (MDA content), suggest that plants try to resist pollution-induced injury. Heavy metal concentration in plant tissues also highlights the harmful effect of automotive emission on crop quality. The results highlight the urgency of measures to mitigate pollution, in the form of green belts and pollution-tolerant crops, to protect crop productivity in areas under pollution. These results add to the larger body of knowledge on the impact of air pollution on plant health and provide valuable information for policymakers and agricultural scientists engaged in the formulation of sustainable agriculture solutions.

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