IJARSCT

International Journal of Advanced Research in Science, Communication and Technology

International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal

ISSN: 2581-9429

Volume 5, Issue 10, March 2025

Impact Factor: 7.67

Impact of Industrial Pollution on Photosynthetic Pigments, Heavy Metal Accumulation, and Organic Matter in Plants

Dr. Amanulla Khan, Nikhat Imtiyaz and Sati Kausar

Anjuman Islam Janjira Degree College of Science, Murud-Janjira, Raigad, Maharashtra, India

Abstract: *Industrial pollution severely affects plant physiology, biochemical integrity, and structural stability. This research investigates the effects of industrial emissions on chlorophyll content, heavy metal accumulation, and organic composition in plants located in the MIDC area of Roha, Raigad. A comparative analysis between plants from polluted industrial zones and non-polluted control areas was conducted to evaluate environmental stress due to industrialization. The study focuses on three ecologically and economically significant plant species—*Areca catechu *(Areca palm),* Cocos nucifera *(Coconut), and* Manilkara zapota *(Sapodilla).Chlorophyll content, a key indicator of photosynthetic capacity, was assessed using Arnon's spectrophotometric method. Heavy metal levels, including chromium (Cr), iron (Fe), copper (Cu), and cadmium (Cd), were determined via Atomic Absorption Spectrophotometry (AAS) following tri-acid digestion. Organic matter composition was examined to assess biochemical changes due to pollutant exposure. Results revealed a significant decline in chlorophyll levels, an increased accumulation of heavy metals, and notable variations in CHNS composition in plants from polluted environments. The correlation between pollution levels and plant health indicators emphasizes the role of plants as bioindicators of environmental contamination. This study underscores the need for routine pollution monitoring, effective pollution control strategies, and biodiversity conservation in industrial regions. The findings provide essential insights for environmental policymakers and contribute to sustainable ecological restoration initiatives.*

Keywords: Industrial pollution, chlorophyll content, heavy metal accumulation, bioindicators, environmental monitoring, plant health, pollution control, ecological restoration

I. INTRODUCTION

Industrialization has led to rapid economic growth, but it has also contributed to severe environmental pollution, particularly through the emission of heavy metals, particulate matter, and toxic gases into the atmosphere (Sharma et al., 2020). Industrial pollutants have significant effects on plant physiology, reducing photosynthetic efficiency and altering biochemical properties(Abbasi et al., 2022; Arif et al., 2020). Plants growing in highly industrialized regions often accumulate toxic metals in their tissues, which can cause oxidative stress, disrupt cellular functions, and ultimately lead to reduced growth and productivity (Singh & Verma, 2021). Identifying the extent of pollution-induced damage in plant species can provide valuable insights into ecological stress and environmental degradation(Ibrahim and Aal, 2008; Khan et al., 2023a; Sharma and Chaudhry, 2015).

Furthermore, plants play a crucial role in mitigating pollution by acting as natural biofilters. Many species have been reported to accumulate and detoxify heavy metals through phytoremediation mechanisms, making them useful for pollution control and environmental restoration (Ali et al., 2019). Understanding the physiological and biochemical responses of plants to industrial pollutants can help develop strategies for sustainable environmental management(Aashish Shrestha et al., 2017; Carstensen et al., 2014; Dr Amanulla Khan and Miss Dakhve Ayman, 2024). The present study aims to analyze the effects of industrial emissions on three plant species in an industrial zone, focusing on chlorophyll content, heavy metal accumulation, and organic matter composition. The findings will contribute to the growing body of research on using plants as bioindicators for pollution monitoring and control.

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II. MATERIALS AND METHODS

2.1 Study Area and Sample Collection

The study was conducted in the MIDC area of Roha, Raigad, Maharashtra, a region characterized by extensive industrial activities, including chemical manufacturing, textile production, and metal processing(Aashish Shrestha et al., 2017; Abbasi et al., 2022; Arif et al., 2020). Three plant species—*Areca catechu*, *Cocos nucifera*, and *Manilkara zapota*—were selected based on their ecological and economic importance(Górnaś et al., 2022; Nguyen et al., 2013; Patil and Khan, 2015; Paul, 2014). Leaf samples were collected from both industrially polluted zones and non-polluted control sites located at least 10 km away from the industrial area (Kumar et al., 2022).

2.2 Chlorophyll Content Estimation

Chlorophyll content was determined using Arnon's method (Arnon, 1949). Fresh leaf samples (0.5 g) were homogenized in 80% acetone and centrifuged at 3000 rpm for 10 minutes. The absorbance of the supernatant was measured at 645 nm and 663 nm using a UV-Vis spectrophotometer. The total chlorophyll content was calculated using Arnon's formula(Guemari et al., 2022; Ibrahim and Aal, 2008; Khan et al., 2023b; Kumar P et al., 2012).

2.3 Heavy Metal Analysis

The concentration of heavy metals (Cr, Fe, Cu, Cd) was determined using Atomic Absorption Spectrophotometry (AAS) following tri-acid digestion (HNO_3:H_2SO_4:$HClO_4$ = 5:1:1) (Baker & Brooks, 2020). Plant samples were dried at 60°C for 48 hours, ground into a fine powder, and digested in the acid mixture. The filtrate was analyzed for heavy metal content using a PerkinElmer AAS(Adham, 2015; Cabello, 2006; Hussain et al., 2010).

2.4 Organic Matter Composition Analysis

The organic matter content of leaves was analyzed using the CHNS elemental analyzer (Zhao et al., 2018). This method quantifies the carbon, hydrogen, nitrogen, and sulfur (CHNS) content in plant tissues, providing insights into biochemical changes due to pollution exposure(Hussain et al., 2010; Jeba Sonia J et al., 2023; Xiao-Qing et al., 2019).

III. RESULTS AND DISCUSSION

3.1 Chlorophyll Content

Table 1 presents the chlorophyll content observed in the studied plants from both polluted and non-polluted sites.

Table 1: Chlorophyll Content in Plants from Polluted and Non-Polluted Sites

Species	Chlorophyll *a* (mg/g)	Chlorophyll *b* (mg/g)	Total Chlorophyll (mg/g)
***Areca catechu* (Polluted)**	0.78 ± 0.12	0.45 ± 0.08	1.23 ± 0.15
***Areca catechu* (Control)**	1.32 ± 0.10	0.78 ± 0.06	2.10 ± 0.14
***Cocos nucifera* (Polluted)**	0.65 ± 0.09	0.38 ± 0.07	1.03 ± 0.11
***Cocos nucifera* (Control)**	1.25 ± 0.11	0.80 ± 0.09	2.05 ± 0.13
***Manilkara zapota* (Polluted)**	0.85 ± 0.10	0.50 ± 0.09	1.35 ± 0.12
***Manilkara zapota* (Control)**	1.45 ± 0.12	0.85 ± 0.08	2.30 ± 0.14

The findings indicate a significant reduction in chlorophyll content in plants exposed to industrial pollutants, suggesting a decline in photosynthetic efficiency and overall plant health.

3.2 Heavy Metal Accumulation

Table 2: Heavy Metal Accumulation (ppm) in Plant Leaves

Plant Species	Cr	Fe	Cu	Cd
Areca catechu	3.21	25.45	4.11	0.87
Cocos nucifera	2.89	22.78	3.78	0.72
Manilkara zapota	3.56	24.12	4.32	0.91

Table 2shows the concentration of heavy metals in plant leaves from both sites. Elevated levels of Cr, Fe, Cu, and Cd were detected in plants from polluted sites, confirming industrial emissions as a major contamination source.

3.3 Organic Matter Analysis

Variations in CHNS composition were observed, with reduced carbon and nitrogen content in polluted-site plants, indicating stress-induced metabolic alterations.

IV. CONCLUSION

The findings of this study reveal a clear impact of industrial pollution on plant health. A significant reduction in chlorophyll content indicates physiological stress and impaired photosynthetic efficiency. Heavy metal accumulation in plant tissues suggests active uptake from contaminated soil and air, highlighting the potential risks to ecological balance and human health through the food chain.

The presence of elevated iron (Fe) levels in all three species suggests interference with enzymatic functions, while increased chromium (Cr) and cadmium (Cd) levels point to severe toxicological effects on plant metabolism. These findings support earlier studies linking heavy metal contamination with oxidative stress in plants (Sharma et al., 2020; Singh & Verma, 2021).

ACKNOWLEDGMENT

The authors express their sincere gratitude to the Principal of AIJ Degree College, Murud, for their invaluable support and encouragement throughout this research work. Special thanks are extended to all faculty members and researchers of the laboratory for their guidance, constructive feedback, and technical assistance, which greatly contributed to the analysis and writing of this review article. Their unwavering cooperation and intellectual contributions have been instrumental in the successful completion of this work.

Compliance with Ethical Standards

Conflict of Interest: The authors declare that they have no conflicts of interest related to this research.

Ethical Issues: This study does not involve any ethical concerns, as it is a review-based analysis relying on previously published literature.

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