

PHYSIOLOGICAL AND BIOCHEMICAL RESPONSES OF MEDICINAL PLANTS TO URBAN POLLUTION IN SARGODHA REGION.

Komal Rasheed^{*1}, Asma Ibrahim², Rameez Hussain³

^{*1,2} Department of Botany, Superior University, Lahore, Pakistan

³ Department of Botany, University of Sargodha, Sargodha

DOI: <https://doi.org/10.5281/zenodo.17240441>

Keywords

Stress, Work-Life Balance, Emotional Intelligence, Ambulance personnel, Paramedics

Article History

Received: 08 July 2025

Accepted: 18 September 2025

Published: 30 September 2025

Copyright @Author

Corresponding Author: *

Komal Rasheed

Abstract

The study was conducted in three different sites i.e. Bhatti chowk, vicinity of University of Sargodha and Bhagatwala to evaluate the effect of urban pollution on three plant species i.e. *Azadirachta indica* (Neem), *Aloe barbadensis miller* (Aloe vera) and *Vachellia nilotica* (Kikar). Biochemical parameters e.g. proline contents, lipid peroxidation and Anti-oxidants such as CAT, SOD and POD along with physiological attributes e.g. chlorophyll contents and relative water contents (RWC) of plant species were studied and compared with each other and also with control site to analyze the impact of pollution. The variations in the properties of selected plants were also compared to find the impact of pollution. Three replicates were selected from each site and were statistically analyzed by one-way ANOVA. Analyses such as Correlation and regression were also performed to assess the relationship between pollution level and plant responses. It was concluded that all plant species showed negative correlation between pollution level and chlorophyll contents/RWC while showed positive correlation between pollution level and Proline, MDA, SOD, CAT and POD. *Vachellia nilotica* was found to be the most sensitive to pollution and showed elevated levels of Proline and MDA. *Azadirachta indica* was resilient plant specie as it maintained comparative amount of chlorophyll and water contents. *Aloe barbadensis miller* was having good water retention ability suggesting it moderate tolerant plant species.

1. Introduction

An environment is a naturally occurring geographical region which supports all life forms because it provides clean air, rich soil and fresh water to all kinds of creatures (Emina KA, 2021). The industries and urban developments have made the environment unsustainable. The disposal of trash polluted with metals, gasoline, mining operations and fertilizer applications are some of the factors which are responsible for the accumulation of toxic metals in the environment (Mishra & De, 2024). Plants are adversely affected by the deterioration of the chemical composition of soil and water which might cause

stress in plants (Msimbira LA & Smith DL, 2020).

Although some metals are very essential such as copper, iron and Zinc for physiological functions but their excess concentrations can be toxic and thus harmful. The toxic nature of heavy metals can limit the metabolism and also causes oxidative stress and nutrition stress in plants (Shah MP, Bharadvaja N & Kumar L 2024). Plants have defense mechanisms against these stresses such as vacuole sequestration, metal chelation, transporter-regulated metal intake, and improved antioxidant systems (Khatiwada B *et al.*, 2020). Enzymatic anti-oxidants such as catalase, superoxide dismutase and ascorbate are produced

by plant cells (AL-Aloosy YA *et al.*, 2019). The ROS species produced under stress are scavenged and neutralized by these anti-oxidants (Ozougwu, 2016).

There are also some other adaptive mechanisms in plants to endure the environmental challenges (Raza A *et al.*, 2020). Absciscic acid is a non-enzymatic anti-oxidant produced under stress condition and is significant in managing plant's stress reactions. The elevated levels of stress increase the absciscic acid contents which bring changes in the morphology of plants (Singh A & Roychoudhury A, 2023). The morphological changes include growing smaller sized leaves which limit the metabolic expenditure and reduced water loss under stress condition in polluted areas (Carlson JE *et al.*, 2016).

Plants also show some anatomical responses which indicate cytological changes in the tissues under unfavorable conditions. The organization of xylem and phloem rings is declined under chemical stress as compared to control (Jyske T & Hölttä T, 2015). The decline in the tissue size is the result of the pollutants which limit the cell growth and also decreases the size of stomata in epidermal cells (Chen Z *et al.*, 2023).

The photosynthetic pigments such as chlorophyll and carotenoids are decreased by the impact of pollutants. The capacity of plants to absorb sunlight is also diminished after the breakdown of photosynthetic pigments (Simkin AJ *et al.*, 2022). Nitrogen oxides (NO_x), ozone (O₃), and sulphur dioxide (SO₂) are some of the pollutants which damage the chlorophyll molecules by causing oxidative stress which ultimately reduce photosynthetic rates (Awaad HA, 2021).

2. Material and Method

2.1 Study Area

The research study was conducted in the urban and semi-urban regions of Sargodha. Sargodha has a semi-arid climate and it is also subjected to increasing levels of air and soil pollution due to high traffic density, construction work and industrial activity. Three different sites were selected based upon pollution intensity: Bhatti Chowk (**Site A**) which is a high pollution zone due to high traffic density, University of

Sargodha vicinity (**Site B**) which is moderate pollution zone due to residential area with moderate human activity and Bhagatwala (**Site C**) which is a control site having rural areas away from major roads.

2.2 Plant Species Selection

Three medicinal plants i.e. Aloe Vera (*Aloe barbadensis miller*), Kikar (*Vachellia nilotica*) and Neem (*Azadirachta indica*) were selected from each site for the study.

2.3 Experimental Design

The experiment was plotted by using **Completely Randomized Design (CRD)** with three treatments (pollution levels: high, moderate, low) and three replications per species per location. A total 90 plant samples were collected. Fresh fully expanded healthy plant leaves were collected in the morning for analysis.

2.4 Physiological Parameters

2.4.1 Chlorophyll Contents

Arnon's method (1949) was used to estimate the chlorophyll contents in the leaves. Fresh leaf sample was ground with 80% acetone and then centrifuged for 10 minutes at 10,000 revolution per minute. The supernatant layer was discarded and used to check the absorbance at different wavelengths (663nm, 645nm, and 480nm) by using spectrophotometer.

The below mentioned formulae were used for measuring the chlorophyll contents:

$$Chl\ a = [12.7(OD_{663}) - 2.69(OD_{645})] \times V / 1000 \times W$$

$$Chl\ b = [22.9(OD_{645}) - 4.68(OD_{663})] \times V / 1000 \times W$$

2.4.2 Leaf Relative Water Content (RWC)

Mullan D & Pietragalla JJ (2012) approach was used to measure the RWC.

$$RWC\ (\%) = [(FW - DW) / (TW - DW)] \times 100$$

Whereas FW is a fresh weight, TW is a turgid weight measured after soaking in distilled water

for 04 hours and DW is a dry weight measured after drying at 70°C for 48 hours

2.5 Biochemical Parameters

2.5.1 Proline Content

Bates et al. (1973) method was used to estimate the proline contents. Leaf samples were homogenized in 3% sulfosalicylic acid, filtered, and reacted with acid ninhydrin. The absorbance was read at 520 nm using a spectrophotometer.

Proline concentration ($\mu\text{mol/g FW}$) = $\frac{[\mu\text{g proline/ml}] \times [\text{ml toluene}] / [115.5 \mu\text{g}/\mu\text{mole}]}{[(\text{g sample})/5]} = \mu\text{moles proline/g of fresh weight material}$

2.5.2 Lipid Peroxidation (MDA Content)

Malondialdehyde (MDA) contents were determined by using the method of Ghani MA *et al.*, (2017). Leaf samples were homogenized in trichloroacetic acid (TCA) and then heated with TBA reagent. The absorbance was read at wavelengths of 532 nm and 600 nm to correct for turbidity. MDA content was calculated using the extinction coefficient of $155 \text{ mM}^{-1}\text{cm}^{-1}$.

MDA concentration (mM) = $(A_{532} - A_{600}) / 155$
Whereas A_{532} is the absorbance at 532 nm, A_{600} is the absorbance at 600 nm and 155 is the molar extinction coefficient of the MDA-TBA adduct at 532 nm.

2.5.3 Antioxidant Enzyme Activity Superoxide Dismutase (SOD)

Activity was determined based on its ability to inhibit the photochemical reduction of nitroblue tetrazolium (NBT). Absorbance was recorded at 560 nm.

Catalase (CAT)

CAT activity was measured by monitoring the decomposition of hydrogen peroxide (H_2O_2) at 240 nm.

Peroxidase (POD)

POD activity was assessed using guaiacol as a substrate. Absorbance was recorded at 470 nm. Enzyme activities were expressed as units per mg of protein, with protein concentrations

determined using the Bradford method (Bradford, 1976).

2.5.4 Pollution Monitoring

To correlate plant responses with pollution levels, basic environmental parameters such as air quality and soil analysis were monitored. Data on $\text{PM}_{2.5}$, SO_2 and NO_x was obtained using portable air quality monitoring devices while soil samples were collected from site to estimate the EC, pH and heavy metals concentrations by atomic absorption spectroscopy (AAS).

2.6 Statistical Analysis

All data were subjected to **Analysis of Variance (ANOVA)** using SPSS. Significant differences among treatments were determined using **Duncan's Multiple Range Test (DMRT)** at $p \leq 0.05$. Correlation and regression analyses were performed to assess relationships between pollution levels and plant responses.

3. Results and Discussions

3.1. Chlorophyll contents

Figure 3.1 shows the values of chlorophyll 'a', 'b' and total chlorophyll contents in Aloe Vera (*Aloe barbadensis miller*), Kikar (*Vachellia nilotica*) and Neem (*Azadirachta indica*) collected from three different sites.

Neem leaves had highest value of chlorophyll contents from Site A which indicated a healthy photosynthetic capacity despite of urban pollution (Gyang, 2020). Chlorophyll 'a' was more abundant (0.95 mg/g) as compared to chlorophyll 'b' (0.56 mg/g). The total chlorophyll contents were about 1.42 mg/g which suggested that Neem was constructively retaining its photosynthetic functions and demonstrating resilience to adverse environmental conditions in the urban setting (Chauhan A & Singh H, 2024). At Site B, Neem had lower levels of chlorophyll, with chlorophyll 'a' (0.65 mg/g) and chlorophyll 'b' (0.435 mg/g) which resulted a total chlorophyll content of about 1.085 mg/g. The decline in the values of photosynthetic pigments points towards a reduced plant's photosynthetic potential (Nouck AE, 2024). Compared to Site A, the reduced chlorophyll contents at Site B

infers that Neem experienced high environmental stress potentially due to elevated level of pollution (Prasad R & Prasad S, 2018).

The lowest levels of chlorophyll were found in the Neem leaves from Site C, with chlorophyll 'a', 'b' and total chlorophyll contents about 0.635 mg/g, 0.3175 mg/g and 0.9 mg/g respectively. This decline suggested that Neem plants at Site C were under higher levels of environmental stress as compared to plants at Site A and B. The decrease in the pigment levels indicated that Site C was most polluted and unfavorable environment for Neem (Bessonova VP, Chongova AS & Sklyarenko AV, 2020).

At Site A, Kikar had a high value of chlorophyll contents, with chlorophyll 'a' and chlorophyll 'b' about 0.94 mg/g and 0.49 mg/g respectively. The high ratio of chlorophyll 'a' to 'b' indicated a healthy photosynthetic activity. The Kikar at Site A was non-significantly affected by environmental pollution and site provided favorable conditions for the physiological functioning of plants (Rehman G *et al.*, 2024).

At Site B, Kikar exhibited more chlorophyll 'a' (0.615 mg/g) than chlorophyll 'b' (0.285 mg/g) with total chlorophyll contents (0.9 mg/g) while at Site C, Kikar had total chlorophyll contents about 0.86 mg/g, with chlorophyll 'a' and chlorophyll 'b' at 0.555 mg/g and 0.305 mg/g respectively. The level of photosynthetic pigment

was found to be lower as compared to other sites. The decline in the pigments might be due to some factors such as nutrient availability, temperature and pollution causing damaging effects on chloroplast due to effects of SO₂ and NO_x (Dhir B, 2016).

At Site A, Aloe vera had chlorophyll 'a', 'b' and total chlorophyll contents about 0.93 mg/g, 0.47 mg/g and 1.316 mg/g respectively. These values are considered to be reasonable while the declined value might be the results of chlorophyll degradation by some air pollutants such as SO₂ and NO_x, which suggested that plants were facing environmental stress (Hariram M *et al.*, 2018).

At Site B, Aloe vera exhibited chlorophyll 'a' of 0.59 mg/g and chlorophyll 'b' of 0.26 mg/g, which resulted the total chlorophyll about 0.84 mg/g. It was found that chlorophyll 'a' was a dominant pigment as compared to chlorophyll 'b' while the overall value of chlorophyll indicated moderate photosynthetic capacity (Gu J *et al.*, 2017).

At Site C, the chlorophyll 'a', 'b' and total chlorophyll were found to be approximately 0.555 mg/g, 0.285 mg/g and 0.845 mg/g. These values suggested that Aloe vera had moderate photosynthetic capacity at Site C (Khajeeyan R *et al.*, 2019).

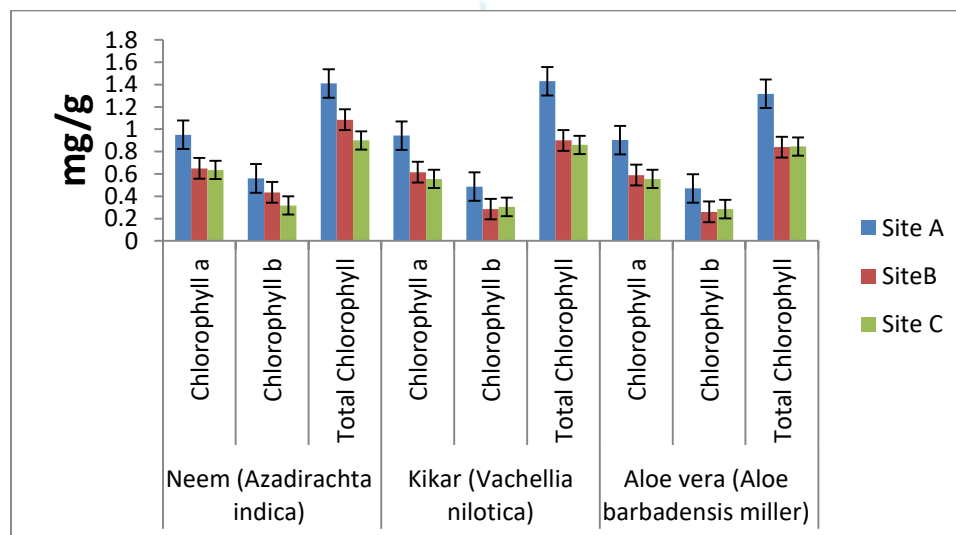


Figure 3.1 Chlorophyll contents

3.2. Relative Water Content (RWC %)

Figure 3.2 shows the values of relative water contents (RWC) in Aloe Vera (*Aloe barbadensis miller*), Kikar (*Vachellia nilotica*) and Neem (*Azadirachta indica*) collected from three different sites.

Neem from Site C exhibited the highest value of RWC (81.17%), followed by Site B (70.73%) and Site A (61.13%). As Relative water contents refer to the status of water in plant tissues, it suggests that Neem was fully hydrated under least water stress while plants of Site A were found to be

under high level of water stress among the three sites (Khajeeyan R *et al.*, 2019).

Aloe vera plants of Site C had highest RWC (89.5%), followed by Site B (79.5%) and Site A (69.5%). It suggested that Aloe vera at Site C was the best hydrated and experienced least water stress while Site A plants were facing higher water stress (Delatorre-Castillo *et al.*, 2022).

In case of Kikar, the trend of RWC increased from Site A (60.5%) to Site B (70.5%) and was highest at Site C (80.5%). This pattern indicated that Kikar from Site C was best hydrated while Kikar at Site A, experienced the highest level of water stress (Kisambo BK *et al.*, 2024).

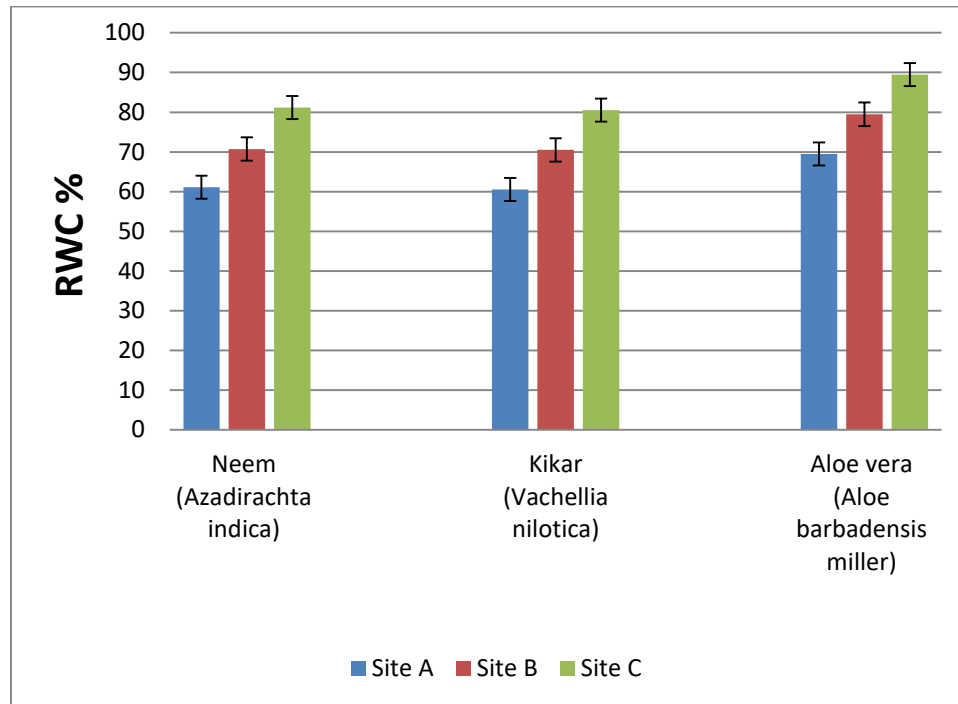


Figure 3.2 Relative water contents (RWC)

3.3 Proline Content ($\mu\text{mol/g FW}$)

Figure 3.3 shows the values of proline contents in Aloe Vera (*Aloe barbadensis miller*), Kikar (*Vachellia nilotica*) and Neem (*Azadirachta indica*) collected from three different sites.

Proline contents in Neem followed a decreasing pattern from Site A to Site C. Highest proline contents were observed in the plant from Site A ($3.06 \mu\text{mol/g}$), followed by Site B ($2.275 \mu\text{mol/g}$) and Site C with the lowest ($1.5 \mu\text{mol/g}$). Since the proline accumulation is a response of plant

against stress such as drought or pollution, so the highest proline values at Site A suggested that Neem plants experienced highest level of environmental stress as compared to the other sites (Al Shaheen MA, Al-Shaheen MR & Mahmood SA, 2021).

Kikar also exhibited the same trend like Neem and had highest proline contents at Site A ($3.725 \mu\text{mol/g}$), followed by Site B ($2.635 \mu\text{mol/g}$), and the lowest was recorded at Site C ($1.81 \mu\text{mol/g}$). The highest value of proline at Site A, suggested

that plants were experiencing greater environmental stress since proline accumulation always increases under stress such as drought or pollution (Spormann S *et al.*, 2023).

Aloe vera also followed the same trend like Neem and Kikar and had highest level of proline at Site

A (3.16 $\mu\text{mol/g}$), followed by Site B (2.605 $\mu\text{mol/g}$) and Site C (1.54 $\mu\text{mol/g}$). It suggested that Aloe vera at Site A was found under highest environmental stress due to high proline accumulation, while the plants at Site C were least affected (Spormann S *et al.*, 2023).

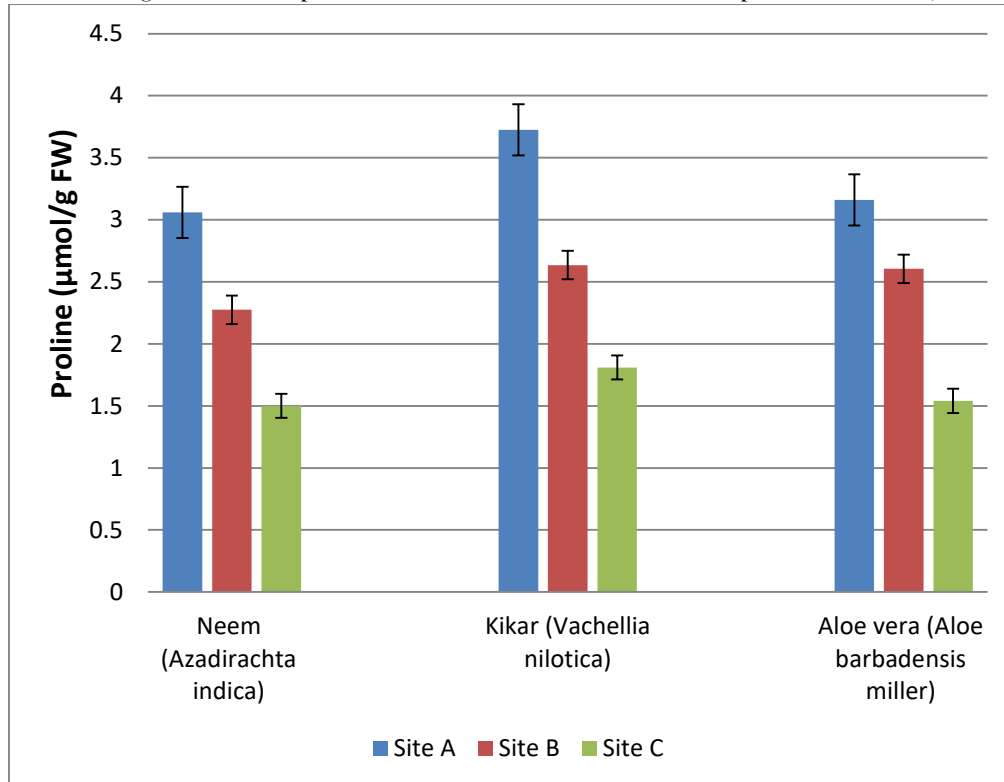


Figure 3.3 Proline contents

3.4 Lipid Peroxidation (MDA, nmol/g FW)

Figure 3.4 shows the values of Lipid Peroxidation (MDA) in Aloe Vera (*Aloe barbadensis miller*), Kikar (*Vachellia nilotica*) and Neem (*Azadirachta indica*) collected from three different sites.

Neem exhibited highest levels of lipid peroxidation at Site A (3.06 nmol/g), followed by Site B (2.275 nmol/g) and Site C (1.5 nmol/g). The increased values of lipid peroxidation indicate oxidative stress and cellular damage which suggested that Neem tress experienced the highest level of environmental stress at Site A, due to higher levels of pollution, while plants at Site C facing least stress (Abu-Elala NM *et al.*, 2023).

Kikar also followed the same trend like Neem since it also had highest lipid peroxidation values at Site A (4.68 nmol/g), followed by Site B (3.315 nmol/g) and Site C (1.82 nmol/g). Since lipid peroxidation is the reflection of oxidative stress induced by environmental stresses like pollution, the higher values at Site A suggested that Kikar were facing adverse conditions at Site A as compared to the plants at Site C, which were under least stress (Demidchik V, 2015).

Aloe vera also exhibited the same trend like Neem and Kikar and showed the highest values of lipid peroxidation at Site A (4.58 nmol/g), followed by Site B (3.315 nmol/g), and Site C (1.82 nmol/g). It indicated that Aloe vera plants

at Site A, were under highest oxidative stress, most probably because of polluted environment,

while plants at Site C experienced the least stress (Kumar J *et al.*, 2017).

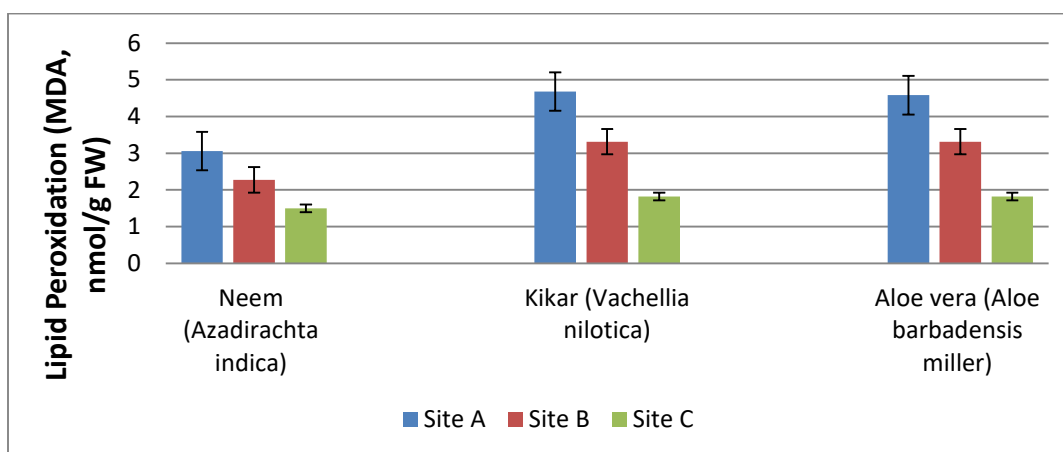


Figure 3.4 Lipid Peroxidation

3.5 Superoxide dismutase (SOD)

Figure 3.5 shows the values of Superoxide dismutase (SOD) in Aloe Vera (*Aloe barbadensis miller*), Kikar (*Vachellia nilotica*) and Neem (*Azadirachta indica*) collected from three different sites.

Neem had highest values of SOD at Site A (30.15 U/mg protein), followed by Site B (25.85 U/mg protein) and Site C (19.95 U/mg protein). The increased SOD activity suggests a stronger antioxidant response to oxidative stress, suggesting that Neem at Site A, experienced an intense unfavorable stress as compared to plants at Site B, and Site C (Akram M *et al.*, 2024).

Kikar also followed the same trend and showed the highest activity of SOD at Site A (31.7 U/mg

protein), moderate by Site B (26.85 U/mg protein) and lowest by Site C (21.4 U/mg protein). The decreasing trend suggested that Kikar at Site A, was experiencing highest level of oxidative stress induced by elevated environmental stress as compared to other Kikar plants at Site B, and Site C (Sarma B *et al.*, 2023). Aloe vera also exhibited the highest SOD activity at Site A (30.45 U/mg protein), moderate at Site B (26 U/mg protein) and lowest at Site C (20.5 U/mg protein). This trend suggested that Aloe vera at Site A was under highest oxidative stress which triggered greater enzyme activity as compared to plants at Site B, and Site C (Kavian S *et al.*, 2022).

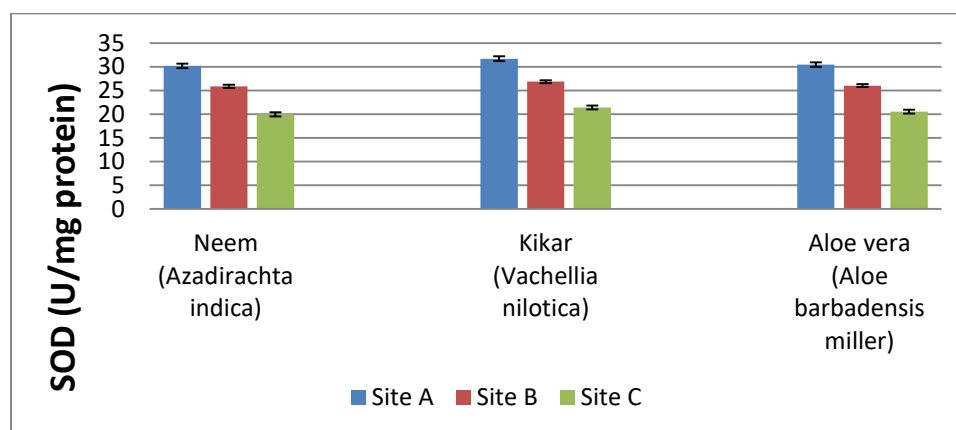


Figure 3.5 Superoxide dismutase (SOD)

3.6 Catalase (CAT)

Figure 3.6 shows the values of Catalase (CAT) in Aloe Vera (*Aloe barbadensis miller*), Kikar (*Vachellia nilotica*) and Neem (*Azadirachta indica*) collected from three different sites.

Neem exhibited the highest value of CAT at Site A (5.045 U/mg protein), followed by Site B (4.35 U/mg protein) and Site C (3.625 U/mg protein). Highest CAT values at Site A suggested that Neem trees were exposed to elevated levels of oxidative stress most probably due to unfavorable polluted environment which triggered

antioxidant defense to breakdown the hydrogen peroxide (Hossain MA *et al.*, 2015).

The average values of CAT in Aloe vera at Sites A, B and C exhibiting the highest level at Site A (4.625 U/mg protein), Site B (4.205 U/mg protein) and Site C (3.03 U/mg protein). It suggested that Aloe vera at Site A was experiencing highest environmental stress which triggered elevated physiological responses as compared to plants at other sites (Delatorre-Castillo JP *et al.*, 2022).

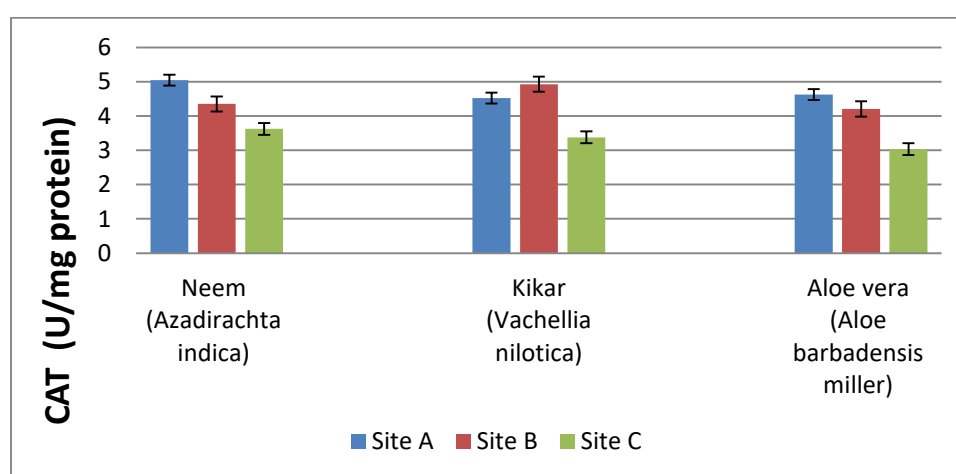


Figure 3.6 Catalase (CAT)

5.7. Peroxidase (POD)

Figure 3.7 shows the values of Peroxidase (POD) in Aloe Vera (*Aloe barbadensis miller*), Kikar (*Vachellia nilotica*) and Neem (*Azadirachta indica*) collected from three different sites.

Neem exhibited a decreasing trend in POD activity with highest value recorded at Site A (0.795 U/mg protein), moderate at Site B (0.525 U/mg protein), and lowest at Site C (0.395 U/mg protein). The highest level of POD at Site A suggested a strong anti-oxidant response of plant towards oxidative stress, most probably due to greater environmental stress such as pollution while, plants at Site C, showed lower activity of POD indicating least stress exposure (García-Caparrós P *et al.*, 2021).

Kikar also followed the same decreasing trend of POD activity with highest value at Site A (0.815

U/mg protein), moderate at Site B (0.67 U/mg protein) and lowest at Site C (0.43 U/mg protein). It indicated that Site A, was imposing highest oxidative stress to plants which resulted into elevated level of POD as a physiological response. Plants at Site C, experienced a least environmental stress (Zulfiqar F & Ashraf M, 2021).

Aloe vera exhibited the highest POD activity with Site A (0.73 U/mg protein), followed by Site B (0.63 U/mg protein) and Site C (0.415 U/mg protein). It suggested that Site A, was imposing highest environmental pressure on the plants and therefore they were experiencing highest oxidative stress as compared to plants at Site B, and Site C. Plants at Site C, were found to be under least environmental stress (Qamer Z *et al.*, 2021).

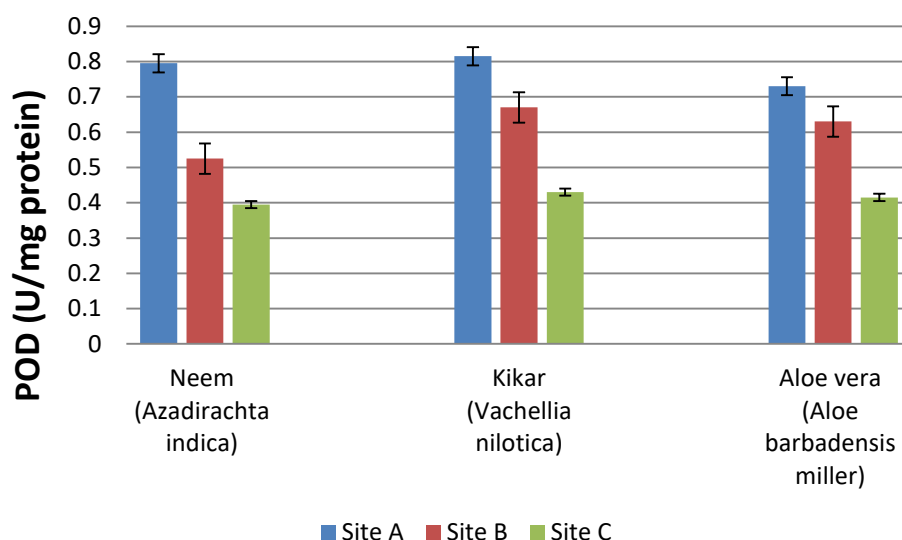


Figure 3.7 Peroxidase (POD)

Conclusion

A distinct pattern of plant response to differing degrees of urban environmental stress is shown by comparing physiological and biochemical characteristics across the three sites. At Site A, neem, kikar, and aloe vera showed greater amounts of proline, antioxidant enzyme activity (SOD, CAT, and POD), and chlorophyll content, suggesting that this site imposed the most environmental stress, most likely as a result of higher pollution levels. At Site C, these stress markers were continuously lower, indicating better circumstances and less oxidative stress. The stress gradient between the sites was further supported by the matching lipid peroxidation levels (MDA), which likewise followed this pattern, with Site A exhibiting the most oxidative damage and Site C the lowest.

Together with biochemical markers like proline accumulation and antioxidant enzyme activity, the physiological reactions of the plants—particularly the variations in chlorophyll concentration and relative water content—highlight the adaptive strategies used by these species when they are under stress from pollution. The results indicate that aloe vera, kikar, and neem can tolerate different levels of environmental stress, with Site C providing relatively ideal growth conditions. Given that

these species not only survive urban pollution but also exhibit quantifiable physiological changes, these findings highlight their potential for application in urban greening and phytoremediation.

References

- Abu-Elala NM, Khattab MS, AbuBakr HO, Helmy S, Hesham A, Younis NA, Dawood MA, El Basuini MF. Neem leaf powder (*Azadirachta indica*) mitigates oxidative stress and pathological alterations triggered by lead toxicity in Nile tilapia (*Oreochromis niloticus*). *Scientific Reports*. 2023 Jun 6;13(1):9170.
- Akram M, Sajid Z, Farooq AB, Ahmad I, Jamal A, Rizwana H, Almunqedhi BM, Ronga D. Characterization of Physiological and Biochemical Attributes of Neem (*Azadirachta indica* A. Juss) under Salinity Stress. *Horticulturae*. 2024 Jul 3;10(7):702.

- Al Shaheen MA, Al-Shaheen MR, Mahmood SA. Evaluation of The Biological Response of Neem (*Azadirachta Indica*) Spraying With Proline, and Addition of Mycorrhizal Fungi. In IOP Conference Series: Earth and Environmental Science 2021 May 1 (Vol. 761, No. 1, p. 012040). IOP Publishing.
- AL-Aloosy YA, AL-Tameemi AJ, Jumaa SS. The role of enzymatic and non-enzymatic antioxidants in facing the environmental stresses on plant: a review. *Plant Archives*. 2019 Jun;19(1):1057-60.
- Awaad HA. Environmental Pollution Tolerance in Crop Plants. Mitigating Environmental Stresses for Agricultural Sustainability in Egypt. 2021:141-73.
- Bessonova VP, Chongova AS, Sklyarenko AV. Influence of multicomponent contamination on the content of photosynthetic pigments in the leaves of woody plants commonly planted for greening of cities. *Biosystems Diversity*. 2020;28(2):203-8.
- Carlson JE, Adams CA, Holsinger KE. Intraspecific variation in stomatal traits, leaf traits and physiology reflects adaptation along aridity gradients in a South African shrub. *Annals of botany*. 2016 Jan 1;117(1):195-207.
- Chen Z, Zhu LT, Luo ZH. Characterizing flow and transport in biological vascular systems: A review from physiological and chemical engineering perspectives. *Industrial & Engineering Chemistry Research*. 2023 Dec 21;63(1):4-36.
- Chauhan A, Singh H. Biological Insights into the Adaptive Responses of Medicinal Plants to Changing Urban Environments. In *Urban Forests, Climate Change and Environmental Pollution 2024* (pp. 73-92). Springer, Cham.
- Delatorre-Castillo JP, Delatorre-Herrera J, Lay KS, Arenas-Charlín J, Sepúlveda-Soto I, Cardemil L, Ostria-Gallardo E. Preconditioning to water deficit helps aloe vera to overcome long-term drought during the driest season of Atacama Desert. *Plants*. 2022 Jun 6;11(11):1523.
- Demidchik V. Mechanisms of oxidative stress in plants: from classical chemistry to cell biology. *Environmental and experimental botany*. 2015 Jan 1;109:212-28.
- Dhir B. Air pollutants and photosynthetic efficiency of plants. In *Plant responses to air pollution 2016* Aug 3 (pp. 71-84). Singapore: Springer Singapore.
- Emina KA. Sustainable development and the future generations. *Social Sciences, Humanities and Education Journal (SHE Journal)*. 2021 Jan 30;2(1):57-71.
- García-Caparrós P, De Filippis L, Gul A, Hasanuzzaman M, Ozturk M, Altay V, Lao MT. Oxidative stress and antioxidant metabolism under adverse environmental conditions: a review. *The Botanical Review*. 2021 Dec;87:421-66.
- Ghani MA, Barril C, Bedgood Jr DR, Prenzler PD. Measurement of antioxidant activity with the thiobarbituric acid reactive substances assay. *Food chemistry*. 2017 Sep 1;230:195-207.
- Gu J, Zhou Z, Li Z, Chen Y, Wang Z, Zhang H. Rice (*Oryza sativa* L.) with reduced chlorophyll content exhibit higher photosynthetic rate and efficiency, improved canopy light distribution, and greater yields than normally pigmented plants. *Field Crops Research*. 2017 Jan 1;200:58-70.
- Gyang PJ. Molecular characterization of Kenyan common bean germplasm using SSR and peroxidase gene markers 2021. Nairobi: University of Nairobi

- Hariram M, Sahu R, Elumalai SP. Impact assessment of atmospheric dust on foliage pigments and pollution resistances of plants grown nearby coal based thermal power plants. Archives of environmental contamination and toxicology. 2018 Jan;74:56-70.
- Hossain MA, Bhattacharjee S, Armin SM, Qian P, Xin W, Li HY, Burritt DJ, Fujita M, Tran LS. Hydrogen peroxide priming modulates abiotic oxidative stress tolerance: insights from ROS detoxification and scavenging. Frontiers in plant science. 2015 Jun 16;6:420.
- Jyske T, Hölttä T. Comparison of phloem and xylem hydraulic architecture in *Picea abies* stems. New phytologist. 2015 Jan;205(1):102-15.
- Kavian S, Safarzadeh S, Yasrebi J. Zinc improves growth and antioxidant enzyme activity in *Aloe vera* plant under salt stress. South African Journal of Botany. 2022 Jul 1;147:1221-9.
- Khajeeyan R, Salehi A, Dehnavi MM, Farajee H, Kohanmoo MA. Physiological and yield responses of *Aloe vera* plant to biofertilizers under different irrigation regimes. Agricultural Water Management. 2019 Nov 20;225:105768.
- Khatiwada B, Hasan MT, Sun A, Kamath KS, Mirzaei M, Sunna A, Nevalainen H. Proteomic response of *Euglena gracilis* to heavy metal exposure-identification of key proteins involved in heavy metal tolerance and accumulation. Algal Research. 2020 Jan 1;45:101764.
- Kisambo BK, Wasonga OV, Kipchirchir OK, Karuku GN. Effects of Soil Type and Watering Regime on Performance of C4 Grass Ecotypes in A Simulated Semi-Arid Environment in Kenya. East African Journal of Agriculture and Biotechnology. 2024 Aug 22;7(1):399-415.
- Kumar S, Yadav M, Yadav A, Yadav JP. Impact of spatial and climatic conditions on phytochemical diversity and in vitro antioxidant activity of Indian *Aloe vera* (L.) Burm. f. South African journal of botany. 2017 Jul 1;111:50-9.
- Mishra S, De A. Various Sources of Heavy Metals Contamination, Including Industrial Activities, Mining, Agriculture, and Urbanization. In Heavy Metal Contamination in the Environment 2024 Dec 30 (pp. 71-94). CRC Press.
- Msimbira LA, Smith DL. The roles of plant growth promoting microbes in enhancing plant tolerance to acidity and alkalinity stresses. Frontiers in Sustainable Food Systems. 2020 Jul 10;4:106.
- Mullan D, Pietragalla JJ. Leaf relative water content. Physiological breeding II: A field guide to wheat phenotyping. 2012;25:25-35.
- Nouck AE. Salinity-induced changes on growth, chlorophyll, metabolites, mineral distribution and productivity of three varieties of eggplant (*Solanum melongena* L.).
- Ozougwu JC. The role of reactive oxygen species and antioxidants in oxidative stress. International Journal of Research. 2016 Jun 6;1(8):1-8.
- Prasad R, Prasad S. Neem and the Environment. International Journal of Plant and Environment. 2018 Jan 31;4(01):01-9.
- Qamer Z, Chaudhary MT, Du X, Hinze L, Azhar MT. Review of oxidative stress and antioxidative defense mechanisms in *Gossypium hirsutum* L. in response to extreme abiotic conditions. Journal of Cotton Research. 2021 Apr 9;4(1):9.

- Raza A, Ashraf F, Zou X, Zhang X, Tosif H. Plant adaptation and tolerance to environmental stresses: mechanisms and perspectives. Plant ecophysiology and adaptation under climate change: Mechanisms and perspectives I: General consequences and plant responses. 2020:117-45.
- Rehman G, Muhammad J, Ilyas M, Subhanullah M, Ullah K, Massimzhan M, Toktar M, Bektay Y, Kalybekov M, Ydyrys A, Zhakypbek Y. Phytoremediation of heavy metals from soil and their effects on plant physiology-A review. ES Materials & Manufacturing. 2024 Nov 6;26:1298.
- Sarma B, Kashtoh H, Lama Tamang T, Bhattacharyya PN, Mohanta YK, Baek KH. Abiotic stress in rice: Visiting the physiological response and its tolerance mechanisms. Plants. 2023 Nov 23;12(23):3948.
- Shah MP, Bharadvaja N, Kumar L, editors. Biogenic nanomaterials for environmental sustainability: principles, practices, and opportunities. Springer Nature; 2024 Jan 3.
- Simkin AJ, Kapoor L, Doss CG, Hofmann TA, Lawson T, Ramamoorthy S. The role of photosynthesis related pigments in light harvesting, photoprotection and enhancement of photosynthetic yield in planta. Photosynthesis Research. 2022 Apr;152(1):23-42.
- Singh A, Roychoudhury A. Absciscic acid in plants under abiotic stress: Crosstalk with major phytohormones. Plant cell reports. 2023 Jun;42(6):961-74.
- Spormann S, Nadais P, Sousa F, Pinto M, Martins M, Sousa B, Fidalgo F, Soares C. Accumulation of proline in plants under contaminated soils—are we on the same page?. Antioxidants. 2023 Mar 8;12(3):666.
- Zulfiqar F, Ashraf M. Bioregulators: unlocking their potential role in regulation of the plant oxidative defense system. Plant Molecular Biology. 2021 Jan;105:11-41.