

## Effect of Roadside Dust Induced Heavy Metal Stress on Growth, Yield and Physiological Attributes of Soybean (*Glycine max* L.)

Sajid Usman<sup>1</sup>, Muhammad Anwar-ul-Haq<sup>1</sup>, Imran Khan<sup>2</sup>, Muhammad Umer Chattha<sup>2</sup>,  
Muhammad Talha Aslam<sup>3\*</sup>, Ahmed Mahmoud Ismail<sup>4\*</sup>, Ramy S. Yehia<sup>5</sup>,  
Basem M. Abdallah<sup>5</sup>, Enas M. Ali<sup>5</sup>, Abdelrahman R. Ahmed<sup>6</sup>

<sup>1</sup>Institute of Soil and Environmental Science, University of Agriculture Faisalabad 38040, Pakistan

<sup>2</sup>Department of Agronomy, Faculty of Agriculture, University of Agriculture Faisalabad 38040, Pakistan

<sup>3</sup>Key Laboratory of Crop Physiology, Ecology, and Genetic Breeding, Ministry of Education/College of Agronomy, 1101 Fang Zhimin Avenue, Economic and Technological Development Zone, Nanchang 330045, China

<sup>4</sup>Pests and Plant Diseases Unit, College of Agricultural and Food Sciences, King Faisal University, Al-Ahsa-31982, Saudi Arabia

<sup>5</sup>Department of Biological Sciences, College of Science, King Faisal University, Al-Ahsa 31982, Saudi Arabia

<sup>6</sup>Food and Nutrition Science Department, College of Agricultural and Food Sciences, King Faisal University, Al Ahsa, Saudi Arabia

\*Corresponding authors. E-mail: taslamuaf@gmail.com; amismail@kfu.edu.sa

### ABSTRACT

Dust is a serious atmospheric pollution and it is becoming a major pollutant owing to automobile pollution. Dust particles impose negative effects on humans, animals and plants. Therefore, this study was executed to determine the impact of foliar applied dust particles on growth, morho-physiological and biochemical traits of soybean crop. In the present study soybean plants were subjected to different treatments; control (no dust spray), 3 g/L dust spray, 6 g/L dust spray and 10 g/L dust spray. The results indicate that maximum soybean root and shoot growth, seed weight and grain yield was observed in control linked with better relative water contents (RWC), photosynthetic pigments and synthesis of osmolyte (TSP and FAA) and reduction oxidative stress markers. All levels of dust particle treatment particularly, 10 g/L dust spray significantly reduced the growth and yield traits of soybean by reducing photosynthetic pigments, TSP, FAA and membrane stability.

**Keywords:** antioxidant, biomass, dust particles, membrane stability, soybean.

### INTRODUCTION

The elevated air pollution due to rapid industrialization and heavy vehicles is a serious concern across the globe. Air pollution affects human health; environment quality, and plant growth and development (Mukherjee et al., 2019). Vehicle traffic is a significant source of greenhouse gases (GHGs) emissions and they also release significant amounts of particulate matter and lethal heavy metals into the environment (Bell et al., 2011). These pollutants either stay in the atmosphere, deposit on the soil surface or reach underground water (Gunawardena et al., 2013). Thus, it is the primary course of low air quality index, and roadside soil (dust) acts as a sink for heavy metal deposition (Khalid et al., 2019).

Approximately 60-70% of air pollution is caused by these components released into environment through vehicle-based traffic (Uka et al., 2019). Moreover, wind increases the roadside dust deposition on the leaves of roadside crop plants (Zhang et al., 2016), which adversely affects the stomatal opening, plant anatomy, as well as morphological and biochemical processes (Swami, 2018).

Dust contains a solid matter in fine state which is easily carried through the wide. Other activities includes coal power plants, transportation, crushing of stones, cement industries and thermal power plants are a major source for the entry of dust particles into the atmosphere (Shukla et al., 2019). Dust particles also lifted up from natural sources such as volcanic eruptions and they also contain a small quantity of grains, papers

fibers and humans and animal hairs (Anjum et al., 2021).

The enhanced level of dust particles is a major threat to plants and they also slow down the leaf gas exchange, water uptake and resulting in reduction in photosynthesis (Shah et al., 2017; Shahid et al., 2017). It is also reported that absorbance of infrared radiations is higher in dusted leaves as compared to dust free leaves (Nawaz et al., 2022). Further, dust particles also cause iron deficiency in plants which negatively affect chlorophyll synthesis (Nawaz et al., 2021). Besides this dust particles develop visible symptoms in plants, for example dust deposition changed the structure of plant (Nawaz et al., 2022).

Roadside dust particles contain vehicle based heavy metals that decreased the interception of photosynthetic active radiation (PAR), photosynthesis rate, water transpiration, and chlorophyll synthesis resulting in stunted growth and low yield (Khalid et al., 2018).

Plant species especially, tree and shrubs are an important source to trap and absorb the pollutants, particulates and aerosols (Anjum et al., 2021). Plants play an important role to maintain the environmental balance through contributing in nutrient cycling and atmospheric gases (Mustafa et al., 2025). They further explained that the plants are mostly affected by airborne pollutants and plants provide a significant leaf area to absorb and accumulate pollutants.

Soybean (*Glycine max* L.) is an imperative crop with high protein, oil, and vitamins and it also has many implications in daily food products and the animal feed industry (Gnoinsky et al., 2019). The growing global population demands increased soybean production (Lokuruka, 2011), whereas various abiotic factors, e.g., roadside dust particles, are substantially decreasing crop production (Glatter and Elliott, 2016; Khalid et al., 2018, 2019). However, no study reported the adverse effect of dust on soybean crop. Therefore, this experiment was planned to assess the impact of roadside dust particles on soybean growth and physiological attributes.

## MATERIAL AND METHODS

### Experimental details

A pot experiment was executed in at University of Agriculture Faisalabad Pakistan. This site has semi-arid climate with rainy monsoon climate and dry winter. The soil used in study was collected from student research station and it was air dried, ground and sieved (2 mm) to fill 8 kg soil in the pots having the dimension of 28 cm wide and 33 cm long. The experimental soil had sandy clay loam texture with silt (2:1) having 7.85 pH, 6.70 dSm<sup>-1</sup> EC, and 35.98 TSS mmol<sub>c</sub> L<sup>-1</sup>.

### Collection of dust samples

There are three most busy traffic roads in Faisalabad; Jhang Road (JR), Sargodha Road (SrR), and Sumandri Road (SR). The dust particles were collected from these roads all these roads have different surroundings. For example, SR passes through the urban areas and agricultural cropping lands, and SrR has a distinct industrial side while, JR comprises wild fields, agricultural supermarkets, and urban areas. Furthermore, dust sampling was complete two times at 10 km apart from each roadside. These samples were mixed in a plastic jar to make a composite sample. Further, dust samples were analyzed following the standard guidelines of AOAC (1990) using Atomic absorption spectrophotometer (Hitachi Polarized Zeeman AAS, Z-8200, Japan) (Elik, 2003). Later, these dust particles were used for the experiment. The experiment site has semi-arid climate with sandy loam soil and pH of pH 7.72, EC 1.10 dSm<sup>-1</sup>, organic matter 0.79%, available N 0.041%, available P 14 mg kg<sup>-1</sup> and available K 168 mg kg<sup>-1</sup>, respectively.

### Chemical composition of dust samples

Heavy metals in dust particles were evaluated following the protocol of Qadeer et al. (2020). The collected dust samples were subjected to over-drying, grounded and sieved through 100 µm sized nylon mesh sieve. Later, working sample (1 g) was placed into Erlenmeyer flask for digestion using nitric, sulfuric and hydrochloric acids up to volume at 5:1:1 at 180-350°C in electrothermal plate. The digested solution

was filtered into volumetric flask (50 ml) and dH<sub>2</sub>O was added for dilution. Finally, the amount of heavy metals in dust samples were determined through atomic absorption spectrophotometer (Hitachi Polarized Zeeman AAS, Z-8200, Japan). Further, the level of heavy metal contamination in composite dust samples were about Cd (2.53 mg/kg), Cu (21.3 mg/kg), Ni (9.75 mg/kg), Pb (34.75 mg/kg), and Zn (60.5 mg/kg).

### Experimental treatments

The experiment was comprised of dust spray on plant surface with the following treatments: control (no dust spray), 3 g/L (dust spray), 6 g/L (dust spray), and 10 g/L (dust spray). The experiment was performed in completely randomized design (CRD) with three replications. Six seeds of soybean variety (Faisal soybean) was sown in each pot and recommended dose of NPK was given @ 0.26 g/pot, 1.78 g/pot, and 0.576 g/pot, respectively.

### Determination of growth and yield traits

Plant growth parameters, i.e., plant height (cm), root length (cm), number of leaves/plant, fresh and dry weight (g) of both root and shoot, along with yield attributes and thousand-grain weight (g) were determined after harvesting. The plants were carefully harvested and root was separated from shoots to their fresh weights were taken as well their length of the longest root was measured. For separation of roots, the whole pot was well watered and maintained the same situation for 12 hours for the safely removal of plant roots. Later, root and shoot was oven dried to determine their dry weights. Besides this, the number of pods per plant and grains per pot were counted manually.

### Leaf water status, membrane stability and photosynthetic pigment determination

Fresh leaves were taken from plants and they were weighed to record fresh weight (FW). After this, the leaves were placed in water for 24 h weighed to measure turgid weight (TW). Afterward, the same leaf samples were oven-dried at 70°C till the

constant weight to determine the dry weight (DW) and relative water contents was determined with following equation.

$$RWC (\%) = \frac{FW-DR}{TW-DR} \times 100 \quad (\text{Eq. 1})$$

The leaf sample (0.5 g) was added with 10 ml of deionized water in a test tube and placed in a water bath at 40°C for 30 minutes and EC was measured (EC<sub>1</sub>). Then, test tubes were placed in a water bath at 100°C for 30 minutes and the EC was again (EC<sub>2</sub>) and MSI was measured with following equation.

$$MSI = 1 - \left(\frac{EC_1}{EC_2}\right) \times 100 \quad (\text{Eq. 2})$$

The photosynthetic pigments and carotenoid contents were determined using the prescribed method of Arnon (1949). For this, fresh leaves were taken and ground in 80% acetone to collect the extract, then this extract was centrifuged at 10000 rpm for 5 minutes. Later, the supernatant was collected to determine the chlorophyll (chl) a, b, total chl, and carotenoids using the reading spectrophotometer (IRMECO U2020, Germany).

### Antioxidants and potential osmolytes determination

**For antioxidant activity, 0.5 g fresh leaf samples (top, middle and base part of plant) was ground by using 5 mL of potassium buffer.** Then, mixture was centrifuged at 10,000 rpm for 15 min to record the absorbance at 240, 190, and 470 nm to determine the CAT, POD, and APX activities, respectively (Aebi, 1984; Gutteridge and Halliwell, 1990; Guan et al., 2009). While, H<sub>2</sub>O<sub>2</sub> activity was determined by following the method described by Velikova et al. (2000), and SOD contents were determined using the method of Beauchamp and Fridovich (1971). For determination H<sub>2</sub>O<sub>2</sub>, 0.5 g fresh leaves were ground by using trichloroacetic acid (TCA: 0.5 mL) to obtain the extract and then it was added with 1 mL of each potassium iodide (KI) and potassium buffer (PPB) and then allowed for half hour and then reading was observed at 390 nm for determination H<sub>2</sub>O<sub>2</sub>

concentration. To determine MDA contents, 0.5 g fresh leaves was taken and homogenized by using 5 mL of TCA and then centrifuged for 15 minutes at 12000 rpm. Thereafter, the extract was added with 5 mL thiobarbituric acid and placed for 30 minutes in water bath (100°C), then, this mixed was cooled quickly and absorbance was noted at 532 nm. Additionally, total free amino acid was determined by following the prescribed method of Hamilton and Van-Slyke (1943).

### Statistical Analysis

Analysis of variance (ANOVA) was used to analyze the recorded data through Statistix 8.1 statistical software, whereas treatment means were compared at a 5% probability level by using LSD test (Steel et al., 1980).

## RESULTS AND DISCUSSION

### Growth and yield attributes

The growth attributes of soybean were significantly ( $p < 0.05$ ) affected by exogenous application of dust particles (Figure 1). Plant height decreased with increasing dust particles and maximum reduction (14.66%) was recorded with 10 g/L spray of dust particles as compared to control (Figure 1).

Further, different levels of dust particle also gave least difference in root length and maximum reduction of 18.92% in root length of soybean was observed 10 g/L spray of dust particles (Figure 1). On the other hand maximum fresh biomass of shoot (43.5 g) and root (11.78 g) was recorded in control followed by T<sub>2</sub> treatment and lowest root and shoot biomass was observed with 10 g/L spray of dust particles (Figure 1).

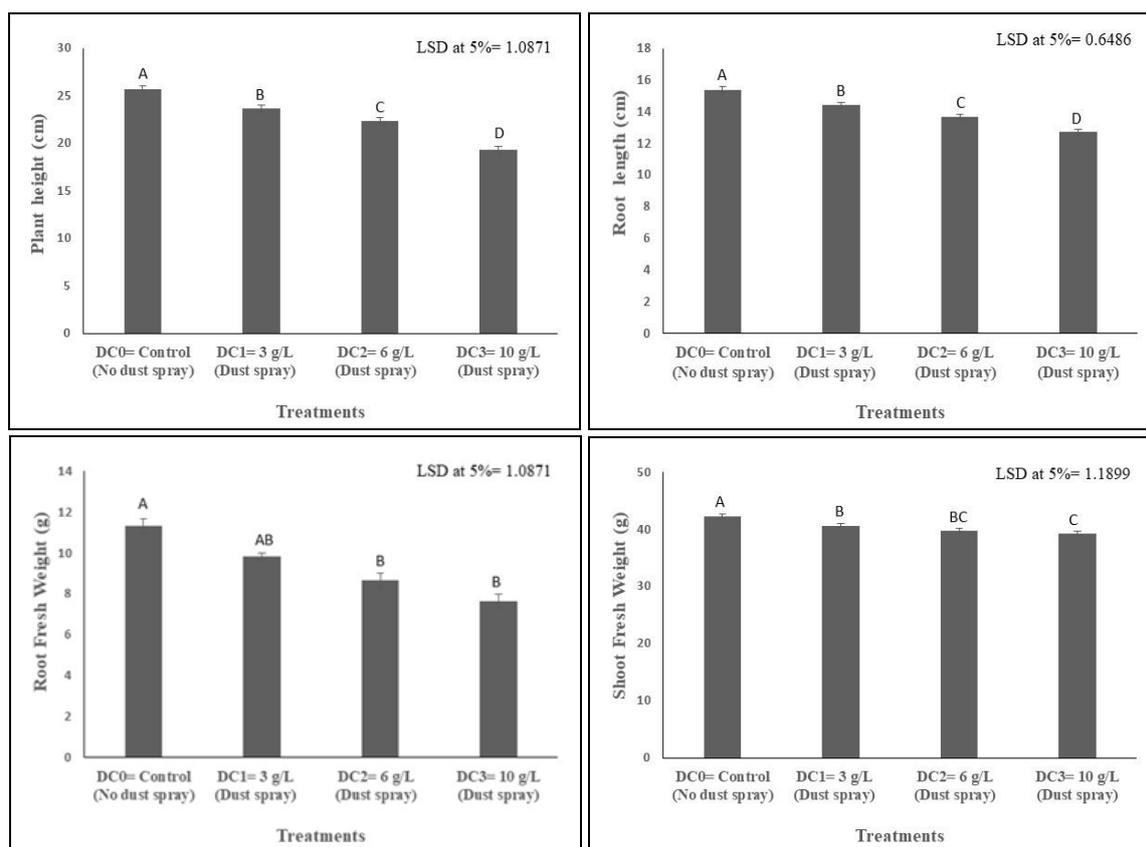


Figure 1. Effect of different concentrations of foliar applied road side dust on growth traits of soybean crop. The data is mean of three replications with  $\pm$  SE.

The increasing concentration of roadside dust particle spray decreased the dry weight of both root and shoot (Figure 2). The maximum shoot dry weight (10.23 g) was

recorded where no dust particle was sprayed (control) that was at par with 3 g/L dust spray (T<sub>2</sub>) followed by T<sub>3</sub>, while minimum shoot dry weight was observed when 10g/L

roadside dust particle was sprayed (Figure 2). Also, roadside dust particle spray significantly affected the number of leaves/plants ( $p < 0.05$ ). The maximum

number of leaves/plant (20) counted from control treatment followed by T<sub>2</sub> that was at par with T<sub>3</sub>, and minimum LPP was recorded with 10 g/L spray of dust particles (Figure 2).

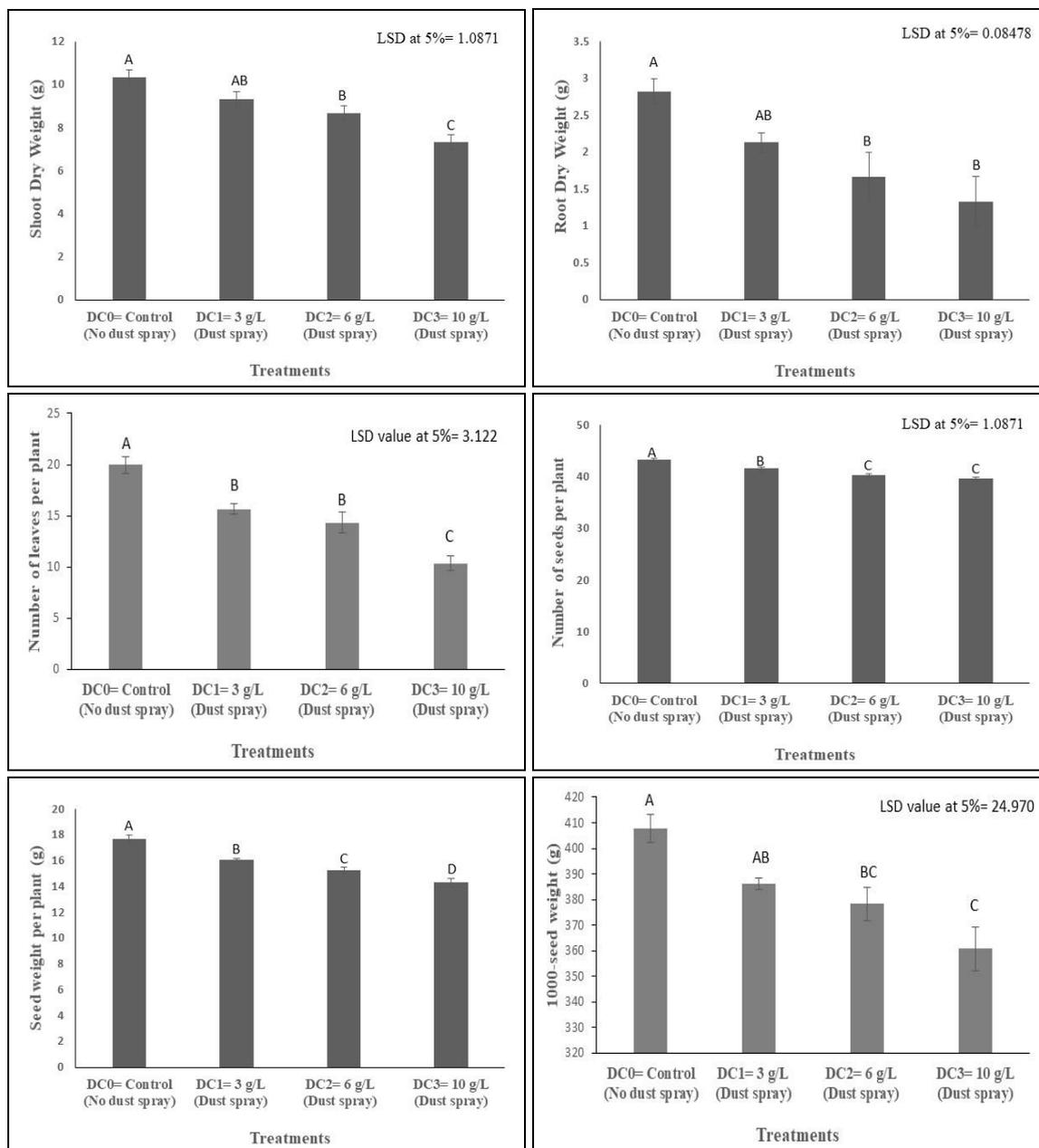


Figure 2. Effect of different concentrations of foliar applied road side dust on biomass production and yield related traits of soybean crop. The data is mean of three replications with  $\pm$  SE.

The maximum seed per plant was recorded in control followed by T<sub>2</sub> and lowest seed weight was recorded with 10 g/L spray of dust particle (Figure 2). Furthermore, the highest value of seed weight/plant (17.66 g) and thousand seed weight (407.68 g) was recorded with control and lowest seed weight/plant (14.3 g) and

1000-seed weight of soybean (360.68 g) was recorded where roadside dust particle was sprayed at 10 g/L.

#### Photosynthetic pigments

Chlorophyll contents also significantly decreased with foliar spray of dust particles (Figure 3). The highest value of Chl a (8.27 mg

$\text{g}^{-1}$  F. Wt.), b ( $6.96 \text{ mg g}^{-1}$  F. Wt.) and carotenoid ( $0.0446 \text{ mg g}^{-1}$  F. Wt.) were recorded in control that similar to 6 g/L dust application ( $T_3$ ). In contrast, the maximum reduction of 61.26%,

48.35%, and 77.57% in Chl a, b and carotenoids, respectively was recorded with 10 g/L spray of dust particle (Figure 3).

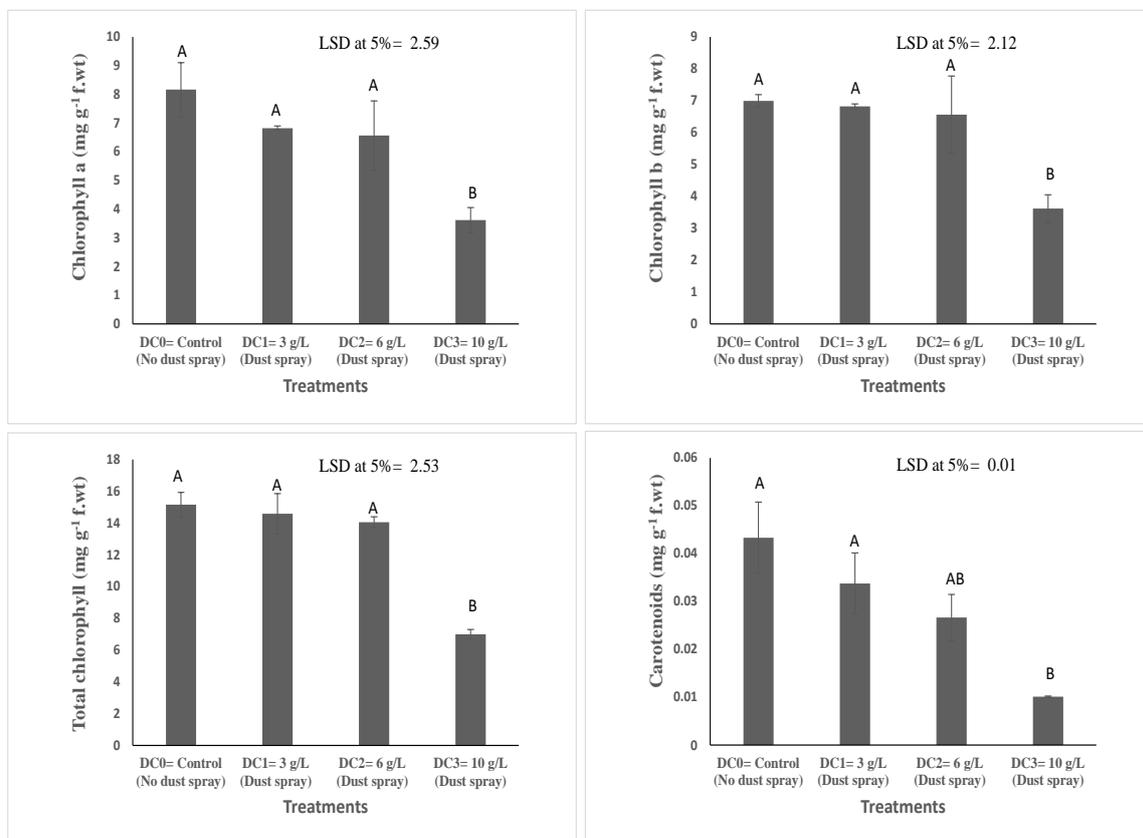


Figure 3. Effect of different concentrations of foliar applied road side dust on chlorophyll contents and carotenoids of soybean leaf. The data is mean of three replications with  $\pm$  SE.

### Leaf relative water contents and membrane stability

The roadside dust particles significantly ( $p < 0.05$ ) affected the physiological parameters of soybean. The control treatment (no dust spray) gave the highest value of relative water contents (51.63%) followed by  $T_2$  and

$T_3$  treatments and 10 g/L spray of roadside dust particles resulted in lowest RWC. The maximum membrane stability index was recorded in control and lowest MSI (16.26%) was recorded with 10 g/L spray of dust particle (Figure 4).

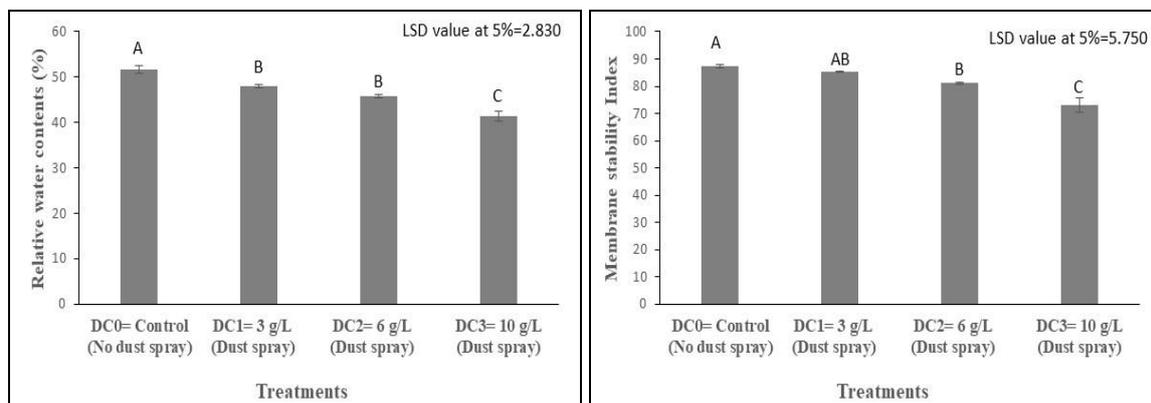


Figure 4. Effect of different concentrations of foliar applied road side dust on relative water content (%) and membrane stability index of soybean crop. The data is mean of three replications with  $\pm$  SE.

### Oxidative stress markers and osmolyte

The results indicate the foliar spray dust significantly increased the production of both MDA and H<sub>2</sub>O<sub>2</sub> (Figure 5).

The concentration of H<sub>2</sub>O<sub>2</sub> was significantly increased by 7.74%, 26.02% and 44.35% with 3, 6 and 10 g/L spray of dust particles as compared to control. Moreover, concentration of MDA also showed an increase of 10.48%, 17.37% and 29.93% was

recorded at 3, 6 and 10 g/L spray of dust particles (Figure 5).

On the other hand concentration of both TSP and FAA showed a significant decrease with increase in concentration of dust particles. The maximum concentration of both TSP and FAA was recorded in control, while lowest concentration of TSP and FAA was observed with foliar spray 10 g/L dust spray particles (Figure 5).

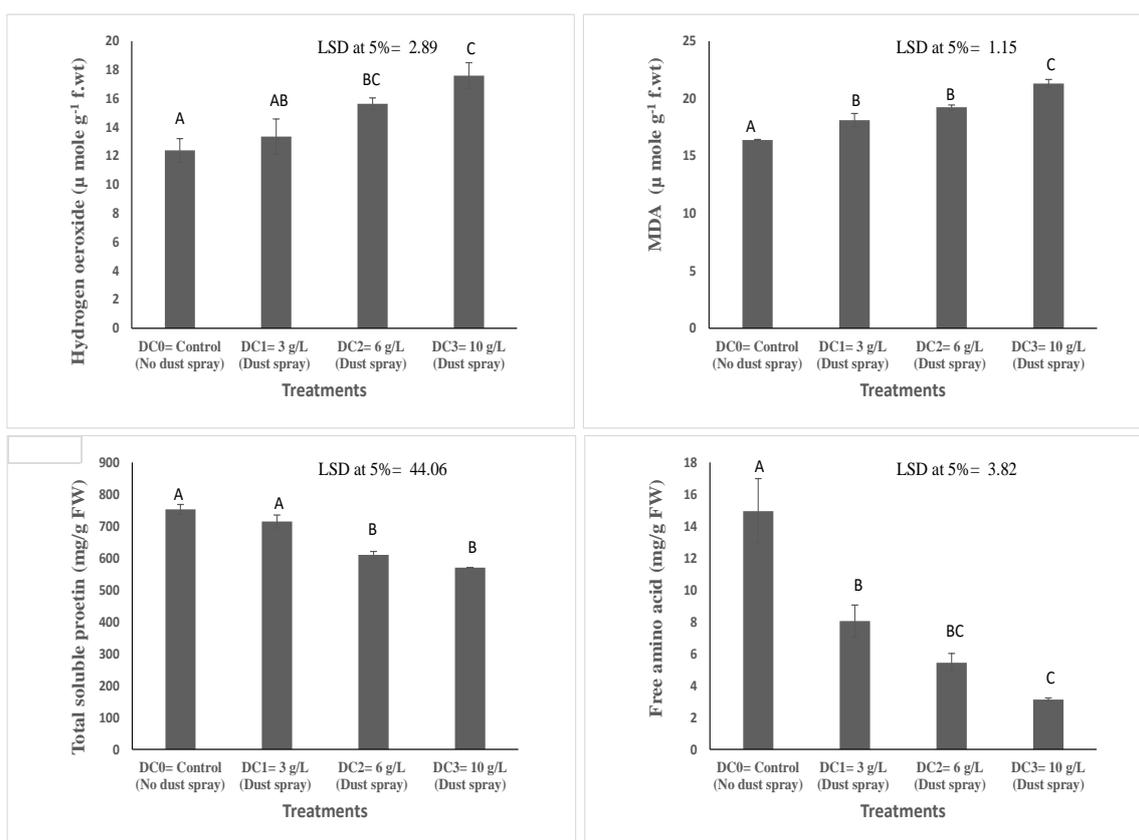


Figure 5. Effect of different concentrations of foliar applied road side dust on H<sub>2</sub>O<sub>2</sub>, MDA, total soluble protein and free amino acid concentration of soybean crop. The data is mean of three replications with  $\pm$  SE.

### Antioxidant activities

The activities of all the antioxidants were significantly increased with increasing concentration of dust particles. The maximum increase in the activities of both APX and POD was recorded with foliar spray of 10 g/L dust spray particles followed by foliar spray of 6 and 3 g/L dust spray particles (Figure 6). In comparison with control, the activities of APX was increased by 10.86%, 33.42% and 53.40% was

recorded at 3, 6 and 10 g/L spray of dust particles. On the other hand an increase 18.26%, 20% and 42.11% in POD activity was observed at 6 and 10 g/L spray of dust particles (Figure 6). The activities of CAT and SOD also significantly increased under foliar spray of dust particles. The maximum CAT and SOD activities was observed with 10 g/L dust spray and lowest was observed in control.

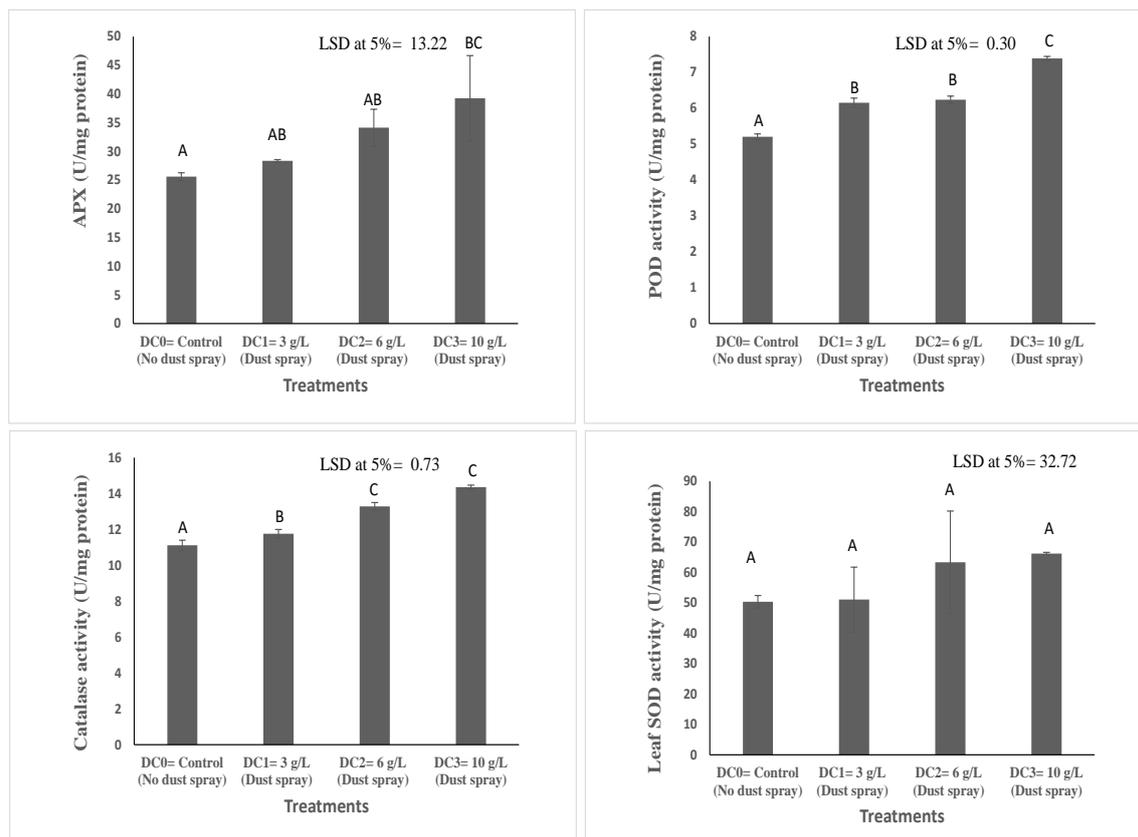


Table 6. Effect of different concentrations of foliar applied road side dust on APX, POD, CAT and SOD activity in soybean leaves. The data is mean of three replications with  $\pm$  SE.

The rapid urbanization and industrialization resulted in a significant increase in roadside traffic and air pollution. Polluted air negatively affects human health, wildlife and crop performance (Manisalidis et al., 2020; Verma et al., 2023). High automobile vehicles exhausted a bulk of polluted gases comprised of toxic heavy metals (HMs), including Cr, Hg, Ni, Cd, and Pb. These toxic metals are widely present in the air and deposit in roadside dust particles (Rai et al., 2019; Nawaz et al., 2022) which cause a reduction in plant growth and development (Ghosh et al., 2020). In the present study, foliar spray of dust particles significantly reduced the growth and biomass production of soybean. The decrease growth and biomass could be due to the HMs toxicity that reduced the photosynthetic efficiency of the plants by lowering the chlorophyll synthesis under stress (Hussaini et al., 2022). Besides this heavy metals also disrupted nucleic acid and caused denaturation of DNA structure, protein, and lipid oxidation and leading to

reduction in plant growth and biomass production (ur Rehman et al., 2021).

The foliar application of roadside dust particles significantly decreased the yield components. Dust particles convert the alkaline nature of acidic stigma, which badly affects the germination of pollen grains; subsequently, poor fertilization results in decreased seeds/plant and seeds per pod (Sett, 2017). Furthermore, dusty leaves experienced less light interception under shading effect due to the suspended particles deposition on the leaf surface, which reduced the photosynthetic ability of plants. Furthermore, clogging the stomatal opening through the heavy metal in roadside dust particles inhibits the gas exchange which reduced the plant performance by affecting photosynthesis (FeleKari et al., 2017; Gnoinsky et al., 2019). Photosynthesis is a crucial process for plants, however, dusty air impedes the photosynthetic rate of plants (Sabir et al., 2023). HMs from vehicle exhaust settle on leaves and obstruct the

stomatal functions by reducing the chlorophyll contents (Guo et al., 2023).

We observed photosynthetic a reduction in photosynthetic pigments with increasing the dust spray concentration. These results are similar to the observations of Hadayat et al. (2019), who stated that chlorophyll contents are inversely related to the concentration of dust particles. Therefore, plants growing along roadsides have less chlorophyll because automobile heavy metals boost chlorophyllase enzyme activity and substitute the magnesium atom in chlorophyll molecules (Anjum et al., 2021). Increased SO<sub>2</sub> also modifies the structure of chlorophyll by generating pheophytin by substituting H atoms for Mg<sup>2+</sup> (Geeta and Namrata, 2014). Since carotenoids are sensitive to SO<sub>2</sub>, it decreased the leaf carotenoid contents of roadside-grown plants (Singh et al., 2023).

The findings demonstrated that the roadside dust particles stimulated the functioning of the antioxidant enzymes. The antioxidant enzyme activity in plants significantly increased under stress conditions. Moreover, a strong positive correlation exists between the increasing dust particle concentrations and the augmentation of antioxidant enzyme activity (Zhang et al., 2014). The high concentrations of HMs inactivate the enzymatic actions, lower the membrane porosity and mineral ions uptake, and cause oxidative damage to plants (Afaj et al., 2017). Several researchers reported that dust deposition in plants leads to an increase in SOD activity (Siqueira-Silva et al., 2017), which is consistent with our findings. On the other hand, the POD enzyme collaborates with the SOD enzyme and is responsible for safeguarding proteins and lipids from oxidative injury due to ROS (Aslam et al., 2023).

The study findings demonstrated a considerable rise in peroxidase (POD) activity. Previous studies reported POD activation in various tree and plant species in response to dust pollution (Karami et al., 2017). Soluble protein levels were lower in dust spray treatments than in control plants. This drop in protein concentration could be

due to atmospheric pollutants, including SO<sub>2</sub>, NO<sub>2</sub>, and other harmful HMs (Rai and Panda, 2015). These pollutants trigger the unnecessary breakdown of proteins into amino acids (Mulenga et al., 2020). Moreover, the oxidative stress caused by the deposition of HMs on plant leaf surfaces also reduces the soluble protein concentration (Tang et al., 2023). Further, our results indicated that FAA concentration was higher in the leaves collected from high doses of foliar-applied dust particles. These results correspond with the previous studies suggesting that free amino acid rises with an increase in dust pollution (Mulenga et al., 2020). Other studies reported FAA acts as a buffer for plant defense against dust pollution (Ghori et al., 2019; Aslam et al., 2026).

## CONCLUSIONS

Dust particles significantly affected the growth, yield and physio-biochemical traits of soybean. Foliar exposure to dust particles (10 g/L) significantly reduced the growth and yield of soybean primarily due to increased malondialdehyde (MDA) and reactive oxygen species (ROS) production, along with decreased photosynthetic pigments, membrane stability, total soluble proteins (TSP) and free amino acids (FAA). Shortly, dust particles can significant reduce the growth and yield of soybean, thus proper measures must be taken to control the air pollution in order to ensure global food security, sustainable and safer crop production.

## FUNDING

This work was funded by the Deanship of Scientific Research, Vice Presidency for Graduate Studies and Scientific Research, King Faisal University, Saudi Arabia, through grant number KFU254334.

## REFERENCES

- Aebi, H., 1984. *Catalase in vitro*. In: Colowick, S.P., Kaplan, N.O. (eds.), *Methods in Enzymology*. Academic Press, New York: 121-126.

- Afaj, A.H., Jassim, A.J., Noori, M.M., Schüth, C., 2017. *Effects of lead toxicity on the total chlorophyll content and growth changes of the aquatic plant Ceratophyllum demersum L.* International Journal of Environmental Studies, 74: 119-128.
- Anjum, S., Hussain, M., Hameed, M., Ahmad, R., 2021. *Physiological, biochemical and defense system responses of roadside vegetation to auto-exhaust pollution.* Bulletin of Environmental Contamination and Toxicology, 107: 946-954.
- Aslam, M.T., Imran, K., Chattha, M.U., Maqbool, R., Ziaulhaq, M., Lihong, W., Arshad, M., 2023. *The critical role of nitrogen in plants facing the salinity stress: Review and future prospective.* Notulae Botanicae Horti Agrobotanici Cluj-Napoca, 51: 13347-13347.
- Aslam, M.T., Khan, I., Chattha, M.U., Murtaza, G., 2026. *Coated Urea Improves Productivity and Nitrogen Use Efficiency in Wheat.* Journal of Soil Science and Plant Nutrition, 3: 1-23.
- Beauchamp, C., and Fridovich, I., 1971. *Superoxide dismutase: improved assays and an assay applicable to acrylamide gels.* Analytical Biochemistry, 44: 276-287.
- Bell, J.N.B., Honour, S.L., Power, S.A., 2011. *Effects of vehicle exhaust emissions on urban wild plant species.* Environmental Pollution, 159: 1984-1990.
- Elik, A., 2003. *Heavy metal accumulation in street dust samples in Sivas.* Communications in Soil Science and Plant Analysis, 34: 145-156.
- FeleKari, H., Ghobadi, M.E., Ghobadi, M., Jalali-Honarmand, S., Saeidi, M., 2017. *Effect of dust deposition on yield and yield components of chickpea (Cicer arietinum L.) under rain fed and supplemental irrigation conditions in Kermanshah.* Journal of Agroecology, 9: 535-544.
- Geeta, C., and Namrata, C., 2014. *Effect of air pollution on the photosynthetic pigments of selected plant species along roadsides in Jamshedpur, Jharkhand.* Research in Plant Biology, 4(5).
- Ghori, N.H., Ghori, T., Hayat, M.Q., Imadi, S.R., Gul, A., Altay, V., Ozturk, M., 2019. *Heavy metal stress and responses in plants.* International Journal of Environmental Science and Technology, 16: 1807-1828.
- Ghosh, S.P., Raj, D., Maiti, S.K., 2020. *Risks assessment of heavy metal pollution in roadside soil and vegetation of national highway crossing through industrial area.* Environmental Processes, 7: 1197-1220.
- Glatter, M., and Elliott, J., 2016. *Simulating US agriculture in a modern dust bowl drought.* Nature Plants, 3: 16193.
- Gnoinsky, A., Hargiss, C.L., Prischmann-Voldseth, D., DeSutter, T., 2019. *Road dust fails to impact soybean physiology and production.* Agronomy Journal, 111: 1760-1769.
- Guan, Y.J., Hu, J., Wang, X.J., Shao, C.X., 2009. *Seed priming with chitosan improves maize germination and seedling growth in relation to physiological changes under low temperature stress.* Journal of Zhejiang University Science B, 10: 427-433.
- Gunawardena, J., Egodawatta, P., Ayoko, G.A., Goonetilleke, A., 2013. *Atmospheric deposition as a source of heavy metals in urban stormwater.* Atmospheric Environment, 68: 235-242.
- Guo, K., Yan, L., He, Y., Li, H., Lam, S.S., Peng, W., Sonne, C., 2023. *Phytoremediation as a potential technique for vehicle hazardous pollutants around highways.* Environmental Pollution, 121130.
- Gutteridge, J.M., and Halliwell, B., 1990. *The measurement and mechanism of lipid peroxidation in biological systems.* Trends in Biochemical Sciences, 15: 129-135.
- Hadayat, N., Hussain, M., Shahbaz, M., Ahmad, R., 2019. *Physio-biochemical responses of apple-of-sodom [calotropis procera (aiton) wt aiton] to vehicular pollution.* Pakistan Journal of Botany, 51: 609-616.
- Hamilton, P.B., and Van-Slyke, D.D., 1943. *Amino acid determination with ninhydrin.* Journal of Biological Chemistry, 150: 231-233.
- Hussaini, K.M., Akhtar, J., Anwar-ul-Haq, M., Maann, A.A., 2022. *Impact of heavy metals-enriched dust particles on the growth, metal accumulation and gas exchange attributes of various plant species in urban areas of Faisalabad, Pakistan.* Pakistan Journal of Agricultural Sciences, 59: 122-136.
- Karami, L., Ghaderi, N., Javadi, T., 2017. *Morphological and physiological responses of grapevine (Vitis vinifera L.) to drought stress and dust pollution.* Folia Horticulturae, 29: 231.
- Khalid, N., Noman, A., Sanaullah, T., Akram, M.A., Aqeel, M., 2018. *Vehicle pollution toxicity induced changes in physiology, defence system and biochemical characteristics of Calotropis procera L.* Chemistry and Ecology, 34: 565-581.
- Khalid, N., Masood, A., Noman, A., Aqeel, M., Qasim, M., 2019. *Study of the responses of two biomonitor plant species (Datura alba & Ricinus communis) to roadside air pollution.* Chemosphere, 235: 832-841.
- Lokuruka, M.N., 2011. *Effects of processing on soybean nutrients and potential impact on consumer health: an overview.* African Journal of Food, Agriculture, Nutrition and Development, 11: 5000-5017.
- Manisalidis, I., Stavropoulou, E., Stavropoulos, A., Bezirtzoglou, E., 2020. *Environmental and health impacts of air pollution: a review.* Frontiers in Public Health, 8: 14-23.
- Mukherjee, S., Chakraborty, A., Mondal, S., Saha, S., Haque, A., Paul, S., 2019. *Assessment of common plant parameters as biomarkers of air pollution.* Environmental Monitoring and Assessment, 191: 1-8.
- Mulenga, C., Clarke, C., Meincken, M., 2020. *Physiological and growth responses to pollutant-induced biochemical changes in plants: A review.* Pollution, 6: 827-848.

- Mustafa, A., Khan, I., Chattha, M.U., Wahab, H.A., Nadeem, F., Awan, R., Hassan, M.U., 2025. *Mitigating the greenhouse gases intensity and improving fine rice productivity with coated urea fertilizers in semi-arid conditions*. Journal of Soil Science and Plant Nutrition, 25: 2709-2725.
- Nawaz, M.F., Rashid, M.H.U., Arif, M.Z., Sabir, M.A., Farooq, T.H., Gul, S., Gautam, N.P., 2021. *Ecophysiological response of Eucalyptus camaldulensis to dust and lead pollution*. New Zealand Journal of Forestry Science, 51: 13-22
- Nawaz, M.F., Rashid, M.H.U., Saeed-Ur-Rehman, M., Gul, S., Farooq, T.H., Sabir, M.A., Iftikhar, J., Abdelsalam, N.R., Dessoky, E.S., Alotaibi, S.S., 2022. *Effect of Dust Types on the Eco-Physiological Response of Three Tree Species Seedlings: Eucalyptus camaldulensis, Conocarpus erectus and Bombax ceiba*. Atmosphere, 13: 1010.
- Qadeer, A., Saqib, Z.A., Ajmal, Z., Xing, C., Khalil, S.K., Usman, M., Liu, M., 2020. *Concentrations, pollution indices and health risk assessment of heavy metals in road dust from two urbanized cities of Pakistan: Comparing two sampling methods for heavy metals concentration*. Sustainable Cities and Society, 53: 101959.
- Rai, P.K., and Panda, L.S., 2015. *Assessment of air pollution tolerance index (APTI) with road side plants in East and North East India: an eco-sustainable approach*. Journal of Pollution Effects and Control, 3: 26-38.
- Rai, P.K., Lee, S.S., Zhang, M., Tsang, Y.F., Kim, K.H., 2019. *Heavy metals in food crops: Health risks, fate, mechanisms, and management*. Environment International, 125: 365-385.
- Sabir, M.A., Nawaz, M.F., Khan, T.H., Zulfiqar, U., Naseer, J., Hussain, S., Roy, R., 2023. *Impact of dust load and lead (Pb) stress on leaf functioning of urban vegetation*. Turkish Journal of Agriculture and Forestry, 47: 713-726.
- Sett, R., 2017. *Responses in plants exposed to dust pollution*. Horticulture International Journal, 1: 22-37.
- Shah, K., Amin, N.U., Ahmad, I., Shah, S., Hussain, K., 2017. *Dust particles induce stress, reduce various photosynthetic pigments and their derivatives in Ficus benjamina: a landscape plant*. International Journal of Agriculture and Biology, 19: 1469-1474.
- Shahid, M., Dumat, C., Khalid, S., Schreck, E., Xiong, T., Niazi, N.K., 2017. *Foliar heavy metal uptake, toxicity and detoxification in plants: A comparison of foliar and root metal uptake*. Journal of Hazardous Materials, 325: 36-58.
- Shukla, S., Sharma, R., Sahu, M., 2019. *Research article dust pollution affect morphophysiological traits of plant Mangifera indica L*. International Journal of Botany, 15: 1-4.
- Singh, H., Singh, P., Agrawal, S.B., Agrawal, M., 2023. *Assessment of the reverberations caused by predominant air pollutants on urban vegetation: a multi-site study in Varanasi Located in Indo-Gangetic Plains*. Gases, 3: 57-76.
- Siqueira-Silva, A.I., Pereira, E.G., de Lemos-Filho, J.P., Modolo, L.V., Paiva, E.A.S., 2017. *Physiological traits and antioxidant metabolism of leaves of tropical woody species challenged with cement dust*. Ecotoxicology and Environmental Safety, 144: 307-314.
- Steel, R.G.D., Torrie, J.H., Dickey, D.A., 1980. *Principles and Procedures of Statistics: A Biometrical Approach*. McGraw-Hill, New York.
- Swami, A., 2018. *Impact of automobile induced air pollution on road side vegetation: A review*. ESSENCE International Journal for Environmental Rehabilitation and Conservation, 9: 101-116.
- Tang, H., Hassan, M.U., Nawaz, M., Yang, W., Liu, Y., Yang, B., 2023. *A review on sources of soil antimony pollution and recent progress on remediation of antimony polluted soils*. Ecotoxicology and Environmental Safety, 266: 115583.
- Uka, U.N., Belford, E.J., Hogarth, J.N., 2019. *Roadside air pollution in a tropical city: physiological and biochemical response from trees*. Bulletin of the National Research Centre, 43: 1-12.
- ur Rehman, M.Z., Waqar, M., Bashir, S., Rizwan, M., Ali, S., El Baroudy, A.A.E.F., Khalid, H., Ayub, M.A., Usman, M., Jahan, S., 2021. *Effect of biochar and compost on cadmium bioavailability and its uptake by wheat-rice cropping system irrigated with untreated sewage water: a field study*. Arabian Journal of Geosciences, 14: 1-12.
- Velikova, V., Yordanov, I., Edreva, A.J.P.S., 2000. *Oxidative stress and some antioxidant systems in acid rain-treated bean plants: protective role of exogenous polyamines*. Plant Science, 151: 59-66.
- Verma, N., Rachamalla, M., Kumar, P.S., Dua, K., 2023. *Assessment and impact of metal toxicity on wildlife and human health*. In: Kumar, P.S., Prasad, R. (eds.), Metals in Water. Elsevier, Amsterdam: 93-110.
- Zhang, H., Zhang, Y., Wang, Z., Ding, M., Jiang, Y., Xie, Z., 2016. *Traffic-related metal (loid) status and uptake by dominant plants growing naturally in roadside soils in the Tibetan plateau, China*. Science of the Total Environment, 573: 915-923.
- Zhang, X., Yin, H., Chen, S., He, J., Guo, S., 2014. *Changes in antioxidant enzyme activity and transcript levels of related genes in Limonium sinense Kuntze seedlings under NaCl stress*. Journal of Chemistry, 749047.