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ESTIMATION OF AIR POLLUTION TOLERANCE INDEX OF CERTAIN PLANT SPECIES FOUND IN THE VICINITY OF BRICK KILN INDUSTRIES IN UDAIPUR, RAJASTHAN

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The brick kiln industry is a small-scale unsystematic industry that is a leadingcause of air pollution. Air pollutants released from the brick kiln industry directly affect the plants foundin the locality of brick kilns. The sensitivity and tolerance of plant species can be accustomed by calculating theair pollution tolerance index (APTI).The purpose of this study was to calculate APTI by using leaf parameters like pH, relative water content (RWC), chlorophyll, and ascorbic acid for plants foundin the vicinity of brick industries of Udaipur District, Rajasthan, India.Three major brick kiln sites of Udaipur, like Debari,Matoon and Sukhanaka were chosen for this study. Leaf samples of five plant species such as *Azadirachta indica*, *Calotropis procera, Holoptelea integrifolia, Lantana camara,* and *Ricinus communis* were collected from the sites mentioned above. The trend of APTI recorded was *C. procera* (12.95) >*L. camara* (12.88)>*H. integrifolia* (12.75)>*R. communis* (12.68) >*A. indica* (11.71) for Polluted Sample and *A. indica* (6.41) >*H. integrifolia* (6.39) >*L. camara* (6.32)>*R. communis* (6.24)>*C. procera* (6.18) for Control Sample. The APTI value of all the plants was found to be much higherinPollutedSample in comparisontothe Control Sample, which indicatedtheair pollution tolerance level of these plants.

Keywords: APTI,Ascorbic acid,Chlorophyll, pH, Relative water content.

Introduction

Atmosphere plays a pivotal role in balancing the earth's climate. It is anenvelopeof air made up of nitrogen, oxygen, argon, carbon dioxide, trace gases and aerosols. Air pollution is a matter of concern because it can cause acute and chronic effects in humans and plants. It is a combination of various toxic substances like PM_{10}, $PM_{2.5}$, polluted gases like carbon monoxide (CO), oxides of sulphur (SO_x), oxides of nitrogen (NO_x), ozone (O_3), methane (CH_4), etc. and soot particles, as well as trace amounts of hazardous metals, organic compounds, and radioactive isotopes in lower quantities that emits majorly from the combustion of various types of fuels in industries and vehicles[1-2].

Among the polluted gases, mostSO_xthat discharged into the atmosphere originates from electric utilities, particularly those which burn coal and petroleum refineries, paper pulp production, cement manufacturing, brick manufacturing, and metal smelting. Similarly,most NO_x introduced by burning fuels at extremely high temperatures. The prime emitters of NO_x are automobiles, industrial boilers, cement kilns, brick kilns, etc.[3]. The burning of coal in powerplants, vehicle exhausts, road dust, industrial processing, and the production of cement, bricks, and fertilizers are the main sources of particulate matter. Particulate matter, including mineral materials, typically dust, is released during the production of bricks[4].

In India, the production of bricks occurs traditionally and in an unsystematic manner that exhausts high energy resources and pollutes the atmosphere to a great extent[5-6]. Mainly substandard coal and other solid waste material like husk, straw, and other waste materials are utilized in the brick kilns, which leads to the production of particulate matter and gaseous pollutants like carbon dioxide (CO_2), carbon monoxide (CO), sulphur dioxide (SO_2), oxides of nitrogen (NO_x), etc.[7]. The brick kiln uses ahuge amount of rubber to begin the flaring process and ignites low-quality coal and used-vehicle oil, thusreleasingCO and other harmful pollutants[8]. The air pollutant released by the brick kiln industry negatively impacts the occupational health of workers, humans, animals, and plants that reside in the vicinity of brick kilns.Air pollutants hamper animal and human health by amplifying the occurrence of diseases like asthma, bronchitis, emphysema, lung cancer, heart ailments, shortness of breath, and other respiratory diseases.Plants develop morphological injury symptoms when they encounter an immense quantity of pollutants for a brief period and develop chronic symptoms when exposed for a prolonged time[9].The physiology of the plant, growth and biomass are affected, and symptoms like chlorosis and necrosisare seen in plants in polluted areas. The pollutants degrade the total chlorophyll content, epidermal thickness, stomatal length, and breadth of leaves.

The leaves have the most pronounced sensitivity of air pollutants because they are the most plentiful and primary recipient of a large variety of air pollutants, acting as a useful indication of pollution[10-11]. The sensitivity and susceptibility of plant species to air pollutants are measured by an index known as the air pollution tolerance index (APTI)[12]. It is calculated using physicochemical (relative water content and pH) and biochemical (ascorbic acid and chlorophyll content) parameters. APTI value indicated plants behaviour to air pollutants where the higher value of APTI represents tolerance, and lower represents sensitivity[13].

From this point of view, this study was executedon the plants foundin the vicinity of the brick industries of Udaipur District, Rajasthan, India. Leaf physicochemical parameters like relative water content and pH and biochemical parameters like ascorbic acid and chlorophyll content were studied,and the air pollution tolerance index (APTI) were calculated.

Material and methods

Selection of sampling sites:

Udaipur district is positioned overtheAravalli hills inthe Southeastern part of Rajasthan, India. Udaipur is positioned amid the latitudes of 24.35°N and 24.58°N, and the longitudes of 73.41°E and 73.68°E. Udaipur has a semi-arid climate that lasts for most of the year. The study was conducted by collecting leaf samples of selected plants found in the vicinity of thebrick kiln industries oftheUdaipur district. Three major sites of brick kiln industry likeDebari, Matoon and Sukhanaka were chosen for this study based on brick kiln availability and their predominance in brick making.No other major industry is prevalent on these sites. All brick kiln siteslie at a distance of 10-15kms from the Udaipur district. The leafsample of selected plants found in the vicinity of the brick kiln industries was taken and considered as a Polluted Sample (PS). The leaf sample of the same plant species was taken from the forest area for reference and considered aControlSample (CS).

Species of Plant:

The locally foundplant species like *Azadirachta indica, Calotropis procera, Holoptelea integrifolia, Lantana camara*and *Ricinus communis*in the vicinity of brick kiln industrieswerechosen for this investigation.To cover the surroundings of brick kiln industries, the leaf sample of selected plants werecollected in triplicates from all directions and averaged data.

Biochemical Parameters

Total Chlorophyll Estimation:

Total Chlorophyll was evaluated by the spectrophotometric method. 1g of the leaf sample was extracted with 20ml of 80% acetone and centrifuged after 15 minutes at 5000 RPM for 5minutes. After filtration, the supernatant was collected, and its absorbance was observed at 645nm and 663nm, using a spectrophotometer. The same amount of leaf sample was kept in an oven for dry weight determination. The amount of chlorophyll was calculated using the formula[14]:

$$\text{Chlorophyll a} = \frac{12.3\ D663 - 0.86\ D645}{1000} \times \frac{V}{W}$$

$$\text{Chlorophyll b} = \frac{19.3\ D645 - 3.6\ D663}{1000} \times \frac{V}{W}$$

Total Chlorophyll (mg/g dry weight) = Chlorophyll a + Chlorophyll b

Ascorbic Acid Estimation:

The titrimetric method was used for the evaluation of Ascorbic acid[15]. A known volume of the working standard was used with oxalic acid and titrated against the dye 2,6-dichloro phenol indophenol for blank reading (V_1 ml). Similarly, the sample was extracted with oxalic acid and then titrated for sample reading (V_2 ml) with the dye solution. An amount of ascorbic acid in the sample was calculated as:

$$AscorbicAcid\ (mg/g) = \frac{0.5mg}{V1ml} \times \frac{V2ml}{5ml} \times \frac{100ml}{Weightofsam} \times 100$$

Estimation of leaf pH:

For pH determination, 2g of leaf sample was homogenized with 20ml deionized water, and the pH of the suspension was measured using a pH meter. The pH meter was pre-calibrated before its usage, with pH 4 and 9 buffer solution. The exercise was triplicated, and the averages of the three readings were used.

Relative Water Content (RWC) Estimation:

For relative water content (RWC), the fresh weight of leaf sampleswas taken. The leaves were allowed to get fully saturated with distilled water overnight and then weighed to obtain the saturated weight and kept in an oven at 70°C for the dry weight and determined the RWC as follows:

$$RWC\ (\%) = \frac{FreshWeight - DryWeight}{SaturatedWeight - DryWeigh} \times 100$$

Air Pollution Tolerance Index (APTI):

Further, by using the values of the above parameters, Air Pollution Tolerance Index (APTI) was calculated by the formula as follows[16]:

$$APTI = \frac{A(T+P)+R}{10}$$

A = Ascorbic Acid (mg/gm)
T = Total Chlorophyll (mg/gm)
P = pH
R = Relative Water Content (RWC) (%)

Results and discussion

All biochemical parameters like total chlorophyll, ascorbic acid, pH, the relative water content (RWC) of leaf extract, and air pollution tolerance index (APTI) are depicted in Table 1.

The total chlorophyll content was ranged from 0.56 ± 0.04mg/g (*R. communis*) to 0.42 ± 0.06mg/g (*C. procera*) for Polluted Sample (PS) while it ranged from 1.83 ± 0.54mg/g (*A. indica*) to 1.13 ± 0.11mg/g (*R. communis*) for Control Sample (CS) (Table 1). The total chlorophyll content was higher in *R. communis* (0.56 ± 0.04mg/g) followed by *L. camara* (0.53 ± 0.09mg/g), *A. indica* (0.49 ± 0.09mg/g), *H. integrifolia* (0.48 ± 0.11mg/g) and *C. procera* (0.42 ± 0.06mg/g) for PS while it was maximum for *A. indica* (1.83 ± 0.54mg/g) followed by *C. procera* (1.48 ± 0.55mg/g), *H. integrifolia*(1.28 ± 0.36mg/g), *L. camara* (1.15 ± 0.20mg/g) and *R. communis* (1.13 ± 0.11mg/g) for CS (Fig1).

The chlorophyll content is very essential for plants, and a reduction in it implies air pollution. The lessening in chlorophyll content was observed in all the samples of

Table 1: Biochemical parameters of Control Sample (CS) and Polluted Sample (PS)

S. no.	Parameter	Plant Species Name	Control Sample (CS)	Polluted Sample (PS)			
			Mean±SD	Debari Brick Kiln Site	Matoon Brick Kiln Site	Sukhanaka Brick Kiln Site	Mean±SD
1	Ascorbic acid (mg/g)	*A. indica*	0.73 ± 0.18	8.72	9.91	9.9	9.51±0.68
		C. procera	0.61±0.21	8.6	9.62	9.49	9.24±0.56
		H. integrifolia	0.61±0.38	10.2	9.65	10.55	10.13±0.45
		L. camara	0.64±0.14	10.17	8.61	10.47	9.75±1.00
		R. communis	0.60±0.25	9.81	9.16	10.54	9.84±0.69
2	Total chlorophyll (mg/g)	*A. indica*	1.83±0.54	0.51	0.57	0.39	0.49±0.09
		C. procera	1.48±0.55	0.41	0.49	0.38	0.42±0.06
		H. integrifolia	1.28±0.36	0.51	0.57	0.35	0.48±0.11
		L. camara	1.15±0.20	0.52	0.62	0.45	0.53±0.09
		R. communis	1.13±0.11	0.54	0.54	0.61	0.56±0.04
3	pH	*A. indica*	6.75±0.07	6.41	6.33	6.29	6.34±0.06
		C. procera	6.83±0.09	6.33	6.27	6.33	6.31±0.03
		H. integrifolia	6.81±0.07	6.35	6.29	6.31	6.32±0.03
		L. camara	6.84±0.05	6.28	6.29	6.23	6.27±0.03
		R. communis	6.83±0.07	6.28	6.23	6.23	6.25±0.02
4	Relative water content (%)	*A. indica*	58.90 ± 4.57	68.99	63.71	63.46	65.39 ± 3.12
		C. procera	57.11 ± 1.72	68.21	67.85	68.66	68.24 ±0.41
		H. integrifolia	58.17 ± 1.52	63.14	60.58	60.80	61.51 ± 1.42
		L. camara	57.70 ± 2.01	65.08	63.79	62.29	63.72 ± 1.40
		R. communis	57.81 ± 2.48	63.83	63.91	64.11	63.95 ± 0.14
5	Air Pollution Tolerance Index (APTI)	*A. indica*	6.41±0.47	11.17	11.67	12.29	11.71±0.56
		C. procera	6.18±0.19	11.83	13.82	13.19	12.95±1.02
		H. integrifolia	6.39±0.20	12.42	12.35	13.49	12.75±0.64
		L. camara	6.32±0.23	12.9	12.49	13.25	12.88±0.38
		R. communis	6.24±0.21	12.92	11.81	13.32	12.68±0.78

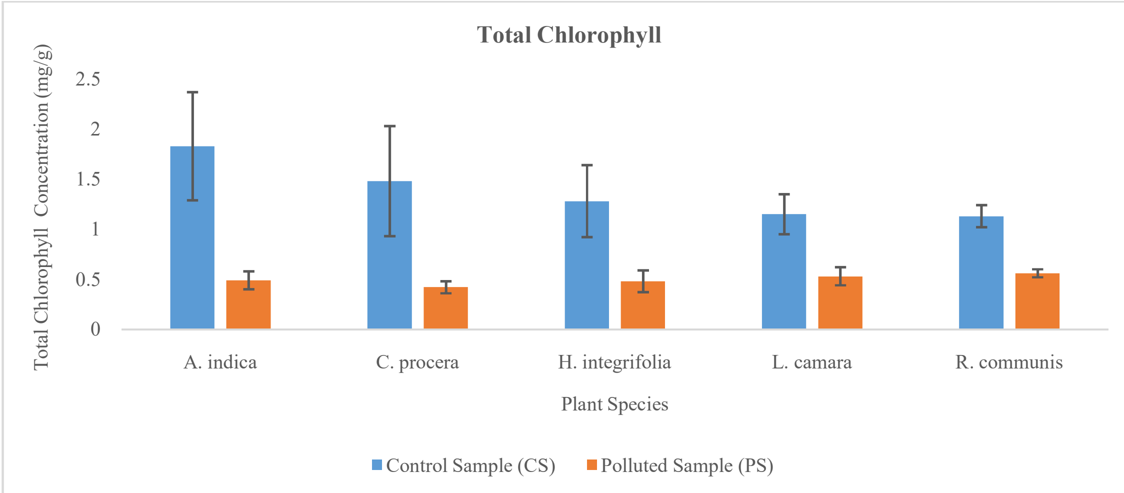

Fig 1: Total Chlorophyll content atControl Sample (CS) and Polluted Sample (PS)

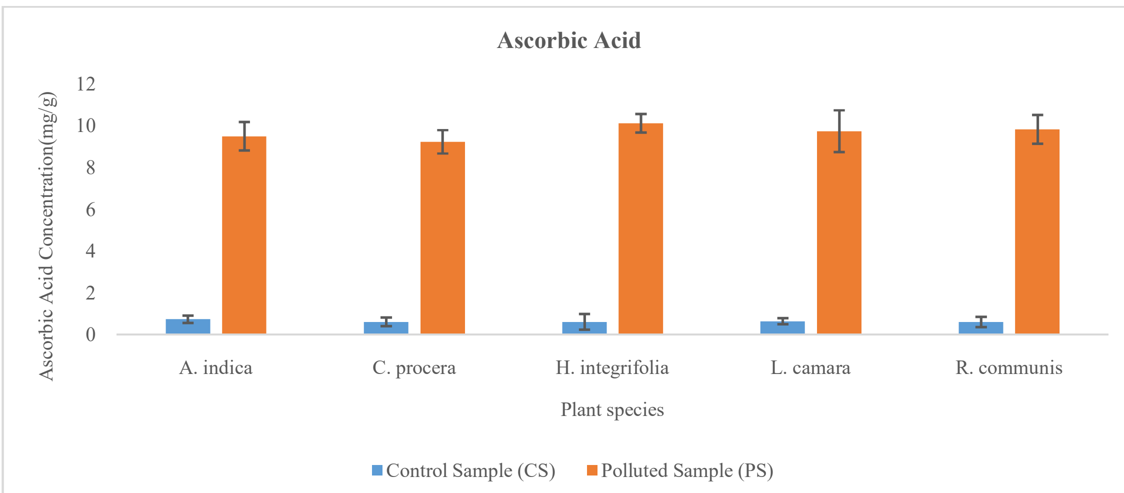

Fig 2: Ascorbic Acid Concentration at Control Sample (CS) and Polluted Sample (PS)

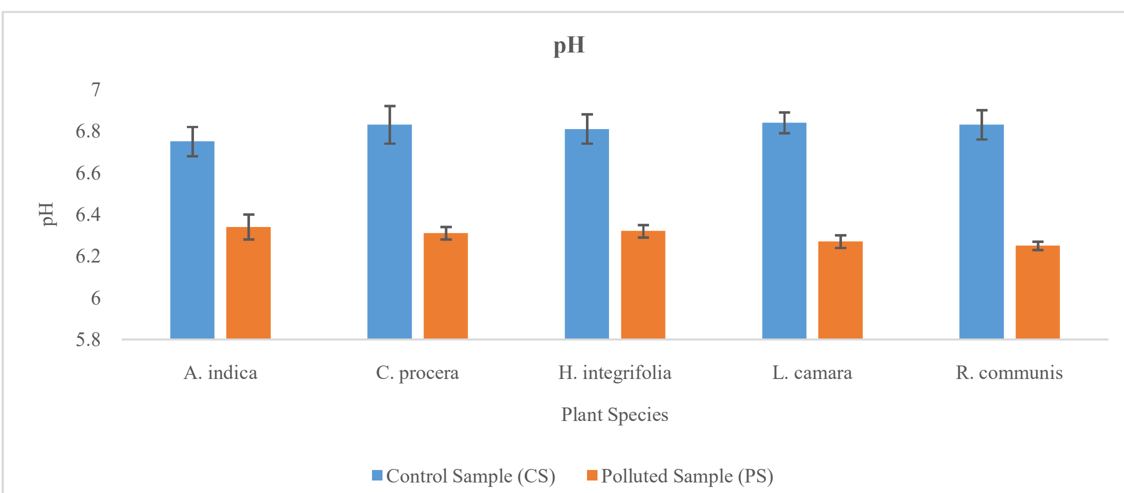

Fig 3: pH Values at Control Sample (CS) and Polluted Sample (PS)

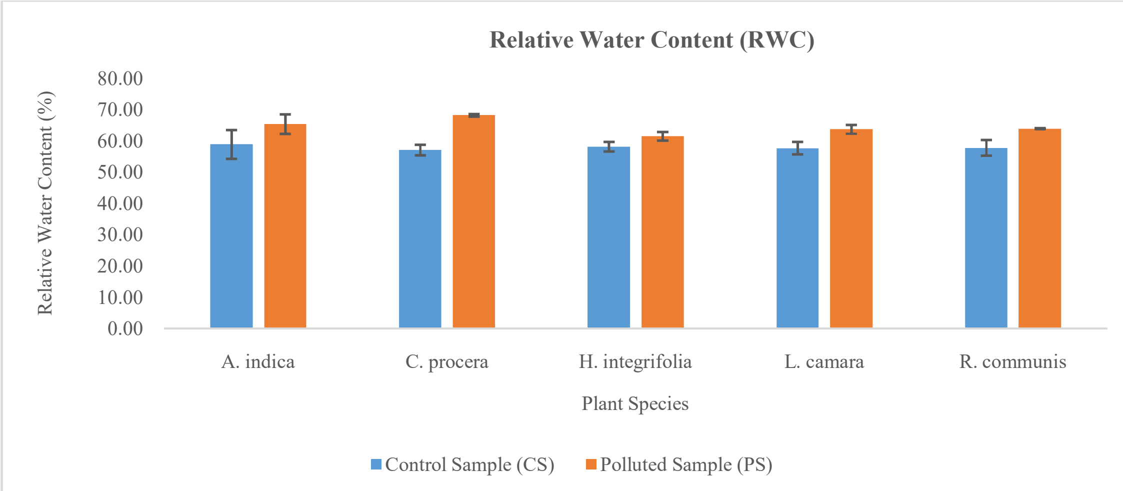

Fig 4: Relative Water Content (RWC) at Control Sample (CS) and Polluted Sample (PS)

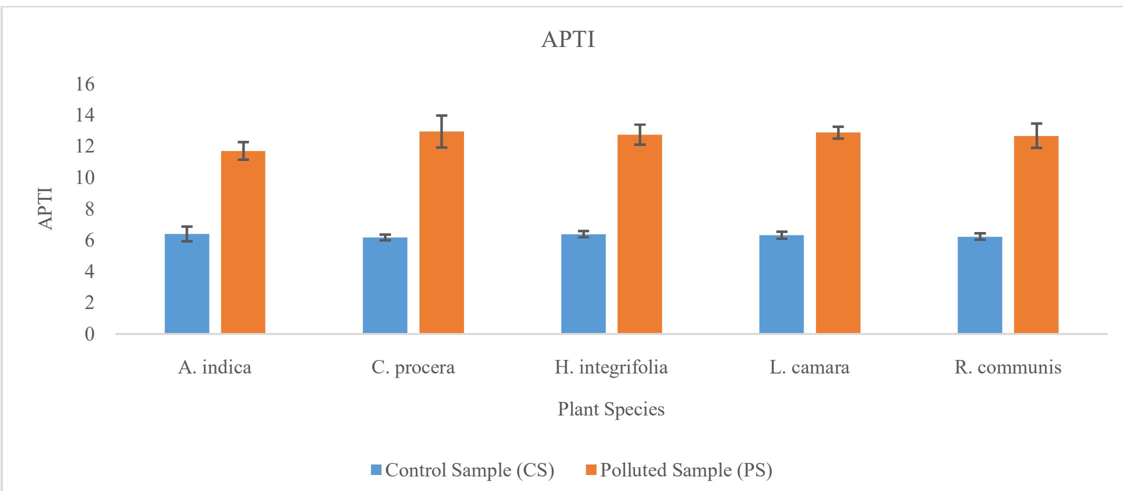

Fig5: Air Pollution Tolerance Index (APTI) Values at Control Sample (CS) and Polluted Sample (PS)

selected plant species at PS compared to CS (Fig 1). Usually, chlorophyll content decreases under pollution stress due to deposition of particulate matter on leaf surface[17] and the presence of sulfur dioxide (SO_2) in the environment in higher concentration. The SO_2 ruptures the chloroplast membranes and consequently degrade the chlorophyll content of leaves[18]. A polluted and dusty leaf surface causes a reduction in photosynthetic activity and thus a decline in chlorophyll content[19].

For PS, the ascorbic acid ranged from 10.13 ± 0.45mg/g (*H. integrifolia*) to 9.24 ± 0.56mg/g (*C. procera*) and for CS, it ranged from 0.73 ± 0.18mg/g (*A. indica*) to 0.60 ± 0.25mg/g (*R. communis*) (Table 1). The ascorbic acid content was highest in *H integrifolia* (10.13 ± 0.45mg/g) followed by *R. communis* (9.84 ± 0.69mg/g), *L. camara* (9.75 ± 1.00mg/g), *A. indica* (9.51 ± 0.68mg/g) and *C. procera* (9.24 ± 0.56mg/g) for PS and it was found maximum in *A. indica* (0.73 ± 0.18mg/g) followed by *L. camara* (0.64 ±

0.14mg/g), *C. procera* (0.61 ± 0.21mg/g), *H. integrifolia* (0.61 ± 0.38mg/g) and *R. communis* (0.60 ± 0.25mg/g) for CS (Fig2).

Ascorbic acid is an anti-oxidant present in great quantities in blooming plant parts that functions as a plant's resistance to adverse environmental conditions. In the present study, the ascorbic acid is observed much higher in all the selected plant's sample of PS as compared to CS, which might be owing to amplified production of reactive oxygen species (ROS) by photo-oxidation process, being influenced by pollution level[20]. Furthermore, ascorbic acid has strong reducing power that helps convert sulphite to hydrogen sulphide to reduce the toxicity of SO_2[21].

The value of pH ranged from 6.34 ± 0.06(*A. indica*) to 6.25 ± 0.02(*R. communis*) for PS, while it ranged from 6.84± 0.05(*L. camara*) to 6.75 ± 0.07(*A. indica*) for CS (Table 1). The pH value was maximum for *A. indica*(6.34 ± 0.06) followed by *H. integrifolia* (6.32 ± 0.03), *C. procera* (6.31 ± 0.03), *L. camara* (6.27 ± 0.03) and *R. communis* (6.25 ± 0.02) for PS.For CS, the highest value of pHwas recorded for *L. camara*(6.84± 0.05) followed by *C. procera* (6.83 ± 0.09),*R. communis* (6.83 ± 0.07), *H. integrifolia*(6.81 ± 0.07) and*A. indica*(6.75 ± 0.07)(Fig 3).

The pH value of all plants was observed lesser in PSas compared to CS. In PS,the deposition of particulate matter (PM) and gaseous pollutants like oxides of sulphur (SO_x) on the surface of leaves may react with the water content of leaves and form acids, which mighthave lowered the pH of leaves of selected plants. Plants with low pH levels have trouble photosynthesizing.

The relative water content (RWC) ranged from 68.24 ± 0.41 % (*C. procera*) to 61.51 ± 1.42 % (*H. integrifolia*) for PS and 58.90 ± 4.57 % (*A. indica*) to 57.11 ± 1.72 % (*C. procera*) for CS (Table 1). The RWC was highest in *C. procera* (68.24 ± 0.41 %) followed by*A. indica* (65.39 ± 3.12 %),*R. communis* (63.95 ± 0.14%), *L. camara* (63.72 ± 1.40 %) and*H. integrifolia* (61.51 ± 1.42%) for PS. For CS, the maximum RWC was observed in *A. indica* (58.90 ± 4.57 %) followed by *H. integrifolia* (58.17 ± 1.52%),*R. communis* (57.81 ± 2.48 %), *L. camara* (57.70 ± 2.01%),*C. procera* (57.11 ± 1.72%) (Fig 4).

The relative water content is a valuable measure of a plant's water equilibria. It emphasizes the ultimate volume of water required by the plant to achieve artificially induced total saturation[22]. In this investigation, relative water content was found higher in all plant species samples of PS than CS, which may be due to stress on plants under polluted conditions at brick kiln industries (Fig 4). Plants are under stress when exposed to air pollution. Their transpiration rate becomes extremely high; having an enhanced relative water content helps them retain their physiological equilibrium[12]. Higher relative water content increases drought resistance capacity in plants.

The APTI value fell between 12.95 ± 1.02(*C. procera*) to 11.71 ± 0.56(*A. indica*) for PS and 6.41 ± 0.47(*A. indica*) to 6.18 ± 0.19(*C. procera*) for CS (Table 1). The maximum APTI value was observedin*C. procera* (12.95 ± 1.02) followed by *L. camara* (12.88 ± 0.38), *H. integrifolia*(12.75 ± 0.64), *R. communis* (12.68 ± 0.78) and *A. indica* (11.71 ± 0.56) for PS. In comparison, it was recorded highest in*A. indica* (6.41 ± 0.47) followed by *H. integrifolia* (6.39 ± 0.20), *L. camara* (6.32 ± 0.23), *R. communis* (6.24 ± 0.21) and *C. procera* (6.18 ± 0.19) for CS (Fig 5).

Through this study, APTI value was found higher at PSfor allselectedplant samples as compared to CS, which points out the air pollution status around the brick kiln industries and also indicated the air pollution tolerance level of these plants because they are growing naturally in the vicinity of brick kiln industries and act as a sink for air pollutants. The present finding resembles the outcomes of previous studies[12,23-24].

Conclusions

This studyobserved that plant species found in the vicinity of brick kiln industries have more APTI value than individuals of the same species of forest area. Based on this research, it was concluded that plants found in brick kiln vicinity have more tolerance to air pollutants and act as a sink for air pollutants. Air pollutantsgeneratesstress on plants and alter the biochemical parameters like chlorophyll, ascorbic acid, pH and relative water content.

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Conflicts of interest

The authors declare that there is no conflict of interest.

References

1. Bhattacharya T, Kriplani Land Chakraborty S 2013. Seasonal Variation in Air Pollution Tolerance Index of Various Plant Species of Baroda City. *Universal Journal of Environmental Research and Technology*. 3 **2** 199-208.
2. Chauhan A, Pawar M, Kumar R and Joshi PC 2010. Ambient Air Quality Status in Uttarakhand (India): A Case study of Haridwar and Dehradun using Air Quality Index. *Journal of American Science*. 6 **9** 564-574.
3. EPA 2012. What Are the Six Common Air Pollutants? Environmental Protection Agency. Retrieved from http://www.epa.gov/air/urbanair/
4. Brosnan DAand John PS 1998. Environmental regulations and their effect on ceramic manufacturing in North America, Qualicer. General Conferences and Communications, Castellon, Spain. 1 215-224.
5. Elampari K, Chithambarathanu T andSharma KR 2010. Examining the variations of ground-level ozone and
6. nitrogen dioxide in a rural area influenced by brick kiln industries. *Indian J. Sci. Technol*. 3 **8** 900-903.
7. Hassan M, Waseem M, Ihtisham R, Waqar A, Adil S and Ali SS 2012. Application of air dispersion model for the estimation of air pollutants from coal-fired brick kilns samples in Gujarat.*Sci Int*. 24 **4**141-145.
8. Maithel S, Uma R, Bond T, Baum E and Thoa VTK 2012. Brick kilns performance assessment, emissions measurements & a roadmap for cleaner brick production in India, Study report prepared by Green Knowledge Solutions, New Delhi.
9. EPA 2007. Air pollution in Peshawar. NWFP-Pakistan.
10. Saxena RM 1991. Effect of motorway pollution on seed health of some vegetable crops. *Ind.J. Environ. Hlth.* 33 385-387.
11. Lohe RN, Tyagi B, Singh V, Tyagi PK, Khanna DR and Bhutiani R 2015. A comparative study for air pollution tolerance index of some terrestrial plant species. *Global J. Environ. Sci. Manage.* 1 **4** 315-324.
12. Dohmen GP, Loppers A and Langebartels C 1990. Biochemical Response of Norway spruce (Piceaabies (L) Karst) toward 14-Month Exposure to Ozone and Acid Mist, effect on amino acid, Glutathione and Polyamine Titers. *Environmental Pollution*. 64 **3-4** 375-383.
13. Rathore DS, Kain T and Gothalkar P 2018. A Study of Air Pollution Status by Estimation of APTI of Certain Plant Species around Pratapnagar Circle in Udaipur City. *International Journal of Agriculture, Environment and Biotechnology.* 11 **1** 33-38.
14. Anake WU 2018. Ambient air pollution control using air pollution tolerance index and anticipated performance index of trees. *Int J Civil Eng Technol.* 9 417-425.
15. Maclachlan S and Zalik S 1963. Plastid structure, chlorophyll

16. concentration and free amino acid composition of chlorophyll mutant barley. *Can J Bot.* 10531062.
17. Sadasivam S and Balasubramanian T 1987. In: Practical Manual in Biochemistry.Tamil Nadu Agricultural University Coimbatore.
18. Singh SK and Rao DN 1983. Evaluation of plants for their tolerance to air pollution. In: Proc Symp on Air Pollution Control at IIT Delhi. 218-224.
19. Dipti K, Malik N and Padhy PK 2016.Effects of Industrial Air pollution on Biochemical parameters of Shorearobusta and Acacia auriculoformis. *Research Journal of Recent Sciences.* 5 **4** 29-33.
    Pandey AK, Pandey M and Tripathi BD 2016. Assessment of air pollution tolerance index of some plants to develop vertical gardens near street Canyons of a polluted tropical city. *Ecotoxicology and Environmental Safety*. 134 **2**358–364.
20. Kalyani V and Singaracharya MA 1995. Biomonitoring of air pollution in Warangal city (A.P.). *Act Botanica indica.* 23 21-23.
21. Tripathi AK and Gautam M 2007. Biochemical parameter of plants as indicator of air pollution, *J. Environ. Bio.*28 127-132.
22. Varshney SRK and Varshney CK 1984. Effects of sulphur dioxide on ascorbic acid in crop plants. *Environ. Pollut.* 35 **4** 285-290.
23. Gonzalz L and Vilar MG 2001. Determination of Relative water content. M. J. Reigosa Roger, *Handbook of Plant Ecophysiology Techniques.* 207-212.
24. Agbaire P and Esiefarienrhe E 2009. Air pollution tolerance indices (APTI) of some plants around otorogun gas plant in Delta State, Nigeria. *Journal of Applied Sciences and Environmental Management.*13 **1**11–14.
25. Hamal JandChettri M 2017. Air pollution tolerance index of some selected gymnosperm species along the road side of Kathmandu Valley, Nepal. *Ecoprint: An International Journal of Ecology*. 24 13–19.
26. Shrestha S, Baral B, Dhital NB and Yang HH 2021. Assessing air pollution tolerance of plant species in vegetation traffic barriers in Kathmandu Valley, Nepal. *Sustainable Environment Research*31**1** 3–11.