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Variation in Sensitivity of Two Economically Important Plants to Thermal Power Plant Emissions, Angul District, Orissa, India

Nayak Rekha[1], Sett Rupnarayan[2] and Biswal Debasis[1]
[1]Kalyani Laboratories, 1867 Bomikhal, Bhubaneswar -751010, Orissa, INDIA
[2]Division of Forest Ecology and Rehabilitation, Tropical Forest Research Institute, Jabalpur- 482021, M.P. INDIA

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Abstract

In a study conducted, we evaluated two fruit trees of their responses to emissions from thermal power plants. The study was conducted in all directions within a perimeter of 2.5, 5.0, 10.0 and 15.0 kilometers from thermal power plant. In the study, fluctuations in total chlorophyll, phosphorus, sulphur, total soluble sugars and phenol content in leaves and percentage of leaf damage were studied as response parameters. The resultant data indicates that the degree of response increased with decreasing distance from the source of pollution in relativity to a reference site situated at 15 km. Both the plants exhibited different reactions to the power plant emissions. The sensitivity index calculated was based on the percentage of leaf injury and biochemical parameters. The sensitivity index for Mangifera indica found was 231.3 and that of Sizygium cumini was 250.9. Mangifera indica with a lower sensitivity index was a tolerant species than Sizygium cumini to power plant emissions.

Keywords: Sulphur dioxide, dust, particulate matter, leaf injury.

Introduction

Plant injury caused by air pollution is most common near large cities, smelters, refineries, thermal power plants, highways, incinerators, refuse dumps, pulp and paper mills etc. Thermal power plants are the major emission sources of sulfur dioxide and typical nitrogen. Due to the emission of these gases into the atmosphere, areas around industrial establishments are highly polluted. Industrial plantation, though a positive practice for prevention of air pollution, still have adverse effect on avenue trees, ornamental plants, fruit bearing plants and crops. Air pollution and particulate matters emitted as smoke from thermal power plants cause environmental stress on the nearby vegetation and thereby inhibiting normal growth of the plants[1-6].

Damage even becomes widespread, when pollutants spread long distances by wind currents. Factors that govern the extent of damage in a region are: i. Type and concentration of pollutants, ii. Distance from the source, iii. Length of exposure and iv. Meteorological conditions

Other important factors are city size and location, land topography, soil moisture and nutrient supply, maturity of plant tissues, time of year, and variety of plants.

Damage due to air pollution maximizes when exposed to high concentration of air pollutants. Some pollutants also cause damage at a concentration below the threshold limit. This shows that occurrence depends not only on the concentration of the particular pollutant, but also on factors like the length of exposure and its stage of development. Growth, development and reproductive potential of plants in a region depend upon their correlation with the surrounding ecosystem. The surrounding environment thus is a determining factor for the degree of sensitivity or resistance of plants to the environmental stress[7]. Plants obtain nutrition from the soil and additional supplements from the atmospheric resources. Availability of atmospheric nutrients in excess of metabolic demands and needs cause damages to cellular system and growth inhibition.

Atmospheric pollutants are reported to cause various physiological and metabolic imbalances in plants. These imbalances include reduction in photosynthetic pigments and imbalances in nutrient assimilation which leads to stress conditions. Under stress conditions, plants generate secondary metabolites that play significant mechanism in detoxifying the adverse effects in defense.

Use of foliar physicochemical parameters as a diagnostic tool for assessing the effect of air pollutants is in practice since long. This is useful in selecting the suitable species for afforestation in related areas. The present study aims at determining the susceptibility of two species of fruit bearing plants used in plantation around Talcher Thermal Power Station, District Angul, Orissa, India.

Material and Methods

Study area: This study was conducted at several grid points taking Talcher Thermal Power Station (TTPS) as the epicenter. Samples were taken at study grids located at 2.5 km, 5 km, 10 km and 15 km in north, south, east and west direction. Interference of additional polluting sources was also found in the surrounding. Towards 5.0 km West of TTPS, coal mines of

Mahanadi Coal Field Ltd. are situated. In the southwest direction of TTPS, Captive power plant of National Aluminium Corporation (NALCO) and NALCO smelter are situated at a distance of 7.0 km and 10.0 km respectively. Towards 15 km North of TTPS, Bindal sponge Iron Ltd is situated. The area consists of a cluster of industries and coalmines, which leads to a coherent air pollution effect in the region. The area is fast emerging as a big source of coal and thermal power in the country.

Climate: Average annual rainfall recorded in the district is 1321 mm. The climate in this region remains mostly dry and arid except in the southwest monsoon season. The climate of this region is characterized by extreme conditions, summer being intensely hot and winter cold. The most prevalent wind direction is North East, South East and East. The nearest water body is river Brahmani. The soil type is fine loamy, mixed and of iso-hyperthermic family. The soil have yellowish red, sandy loam 'A' horizons and yellowish red, clay loam to sandy clay loam 'B' horizons over hard vesicular laterite 'C' horizon.

Sampling Location: The sampling locations were selected in view of the distances from the power plant and the wind distribution patterns regulating the pollutant (figure-1). Ambient air monitoring was conducted at all grid points for two consecutive years in summers, winters and rainy seasons at a frequency of two days per week. The total suspended particulate matters (TSPM) was monitored by respirable dust samplers (Envirotech, Model. No. APM 351), operated continuously for 24 hours. SO_2 (Oxides of Sulphur) was monitored for 8 hours[8]. The samples for SPM (captured in glass fiber filter paper) were carefully packed in plastic packets and transported to the laboratory for analysis. Absorbed samples of SO_x were transported to the laboratory for analysis in plastic bottles that were kept cool in the icebox.

Two species of evergreen plants were selected in the study sites. These plant species are extensively used as industrial plantations and are available at all the study sites. Samples were collected in three different seasons i.e. summer, winter and rainy seasons. The concentration of different elements and physiological imbalances within the leaf interior found, vary with tissue age and plant parts[9]. Hence recently matured leaves of matured plants were only sampled. At each site 5 replicate samples from each species were collected from 5 individual plants. Plants, each separated from the other one by a distance of at least 5 meters were randomly selected. Healthy and fully expanded leaves facing the thermal power plant and devoid of any injury symptoms were collected from a height of more than 2 meters from the ground.

Leaves were transported to the laboratory in lightly woven and clean polythene packs in cooled conditions. Leaves for analysis were washed with de-ionized water. Samples were refrigerated until the analysis of all biochemical parameters was completed.

Total chlorophyll content and total phenols was estimated colorimetrically[10]. Total soluble sugar content was analyzed by Ferri cyanide Method[11].

Dried and ground plant material was digested in perchloric acid ($HClO_4$), HNO_3 and H_2SO_4 at lower temperature. This solution was used for the estimation colorimetric determination of phosphorous[12]. Leaf Sulphur content was analyzed by turbidimetric method[13].

Dust per unit area of leaf surface were measured by removing dust particles from upper as well as lower surfaces separately with the help of a clean camel hair brush and de-ionized water, filtered in a pre-weighed filter paper and then the filter paper was dried and weighed in an electrical balance up to the fourth place of decimal.

$$\text{Content (mg/cm}^2\text{)} = \frac{\text{(Final wt. of the filter paper − Initial wt. of the filter paper)}}{\text{Total leaf area (cm}^2\text{)}}$$

The injured leaves were brought to the laboratory and the injury in the affected area of the leaf was diagnosed. The total leaf area was calculated using graph sheets and percentage damage was computed.

Results and Discussion

To find out the most probable sampling location at the grid points Ground Level Concentration (GLC) at the most affected receptor was estimated from air pollution modeling exercise using standard regulatory air pollution model considering all pollution control equipment in their highest efficiencies. Concentration of particulate matter was found to range between 116 - 343 $\mu g/m^3$ in summers, 121 – 284 $\mu g/m^3$ in winters and 119 – 254 $\mu g/m^3$ in rainy seasons. The average values of SO_2 found was within the range of 52 – 71 $\mu g/m^3$ and NO_x within 24 -33 $\mu g/m^3$ during the study period.

Pollutant concentration varied season-wise with higher concentrations being observed during the summer season. The maximum concentration of sulphur and nitrogen dioxide was observed during the winter and summer seasons. Comparatively lower concentrations of these pollutants were observed in rainy season. This may be due to wash out of pollutants from the atmosphere due to precipitation. Significant variations in the SO_2, NOx and SPM were observed at a distance of 5.0 km NE from the power plant.

Dust deposition on plants was significantly high during the summer season and mostly consists of flyash particulates and fine coal dust. Dust deposition rates were in the range of 0.17 to 1.02 gm/cm^2 in case of leaves of *Mangifera indica* and were high during the summer season. In case of *Syzizium cumini* dust deposition on leaves was in the range of 0.12 to 1. 12 gm/cm^2 during winter season. A significant correlation between dust deposition and degradation of chlorophyll content in *Mangifera indica* (r^2 = 0.83, p<0.01) *and Syzizium cumini* (r^2 = 0.80, p<0.01) was discovered. There also exists a direct relationship between the concentration of SPM in air and amount of dust deposited on leaf surfaces. Maximum dust deposition was observed on *M. indica* plants. Leaf of *M. indica* is different from that of *S. cumini* leaf in regard to surface area and texture. The former possess a larger and comparatively rough surface than the latter. However many factors, including wind strength and precipitation, may influence particulate deposition[14].

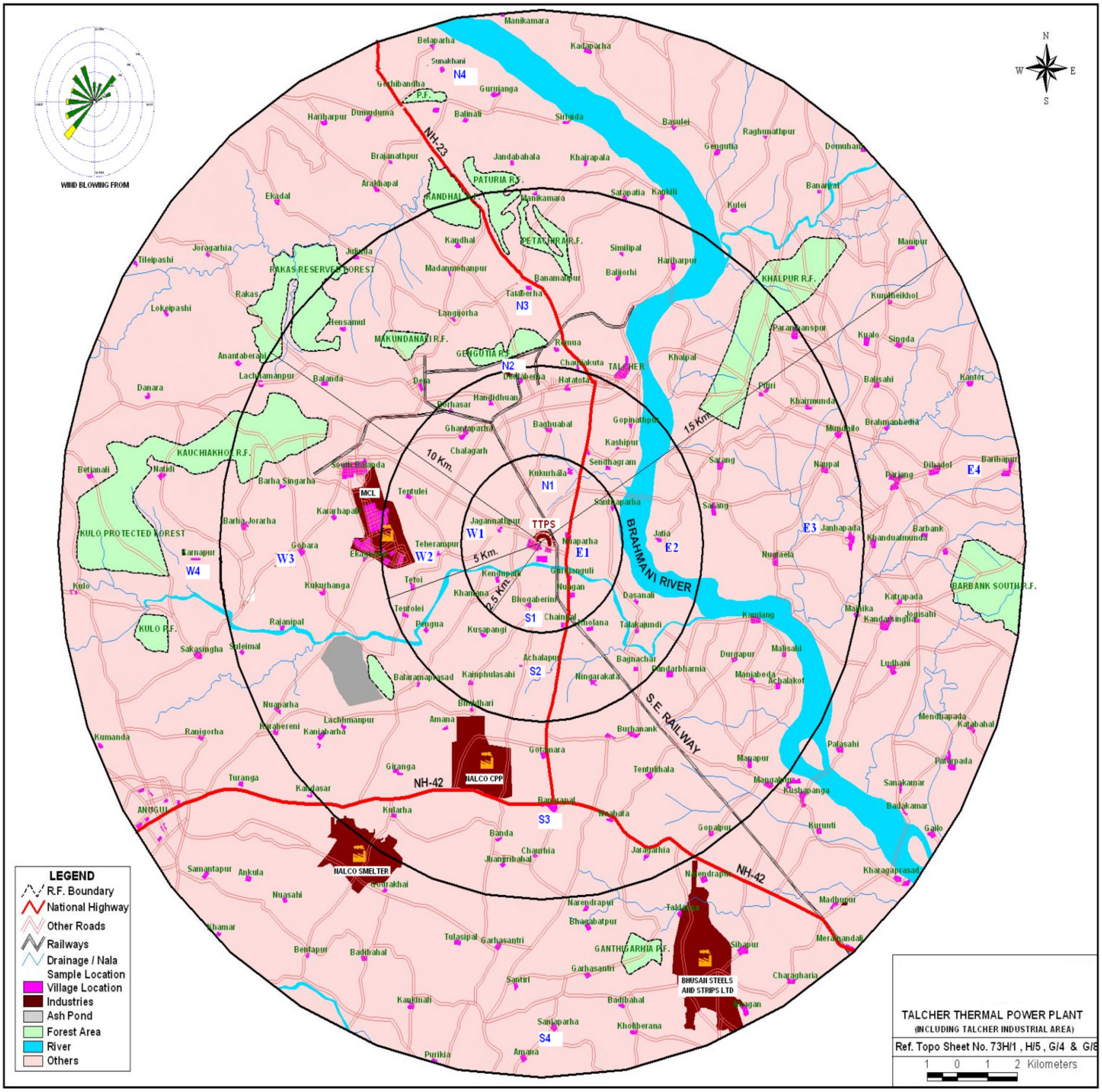

Figure-1
Sampling location map around 10 km radius of Talcher Thermal Power Station, Angul, Orissa, India

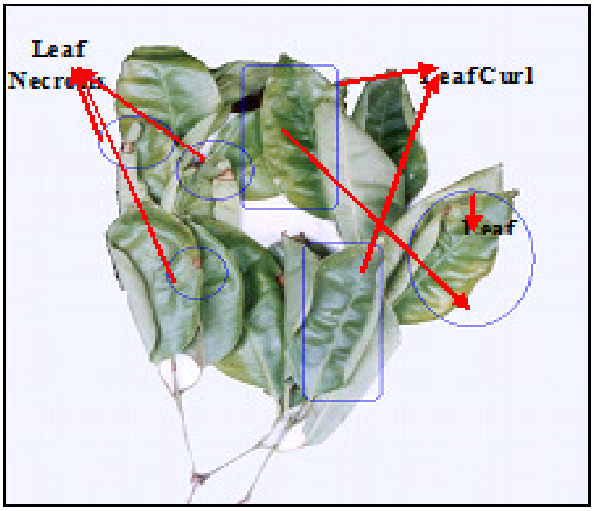

Figure – 2a
Injury symptoms in leaves of *Sizygium cumini* in the study sites.

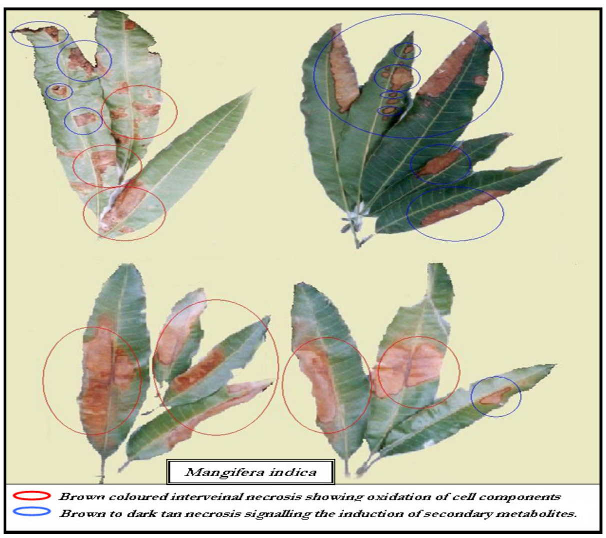

Figure – 2b
Injury symptoms in leaves of *Mangifera indica* in the study sites.

Characteristic leaf area damage of about 40 - 47 % was observed in *M. indica* at a distance of 2.5 km and 5.0 km in all the directions (table -1). Trees at a distance of 10 km and 15 km from the power plants were devoid of any injury symptoms. *S. cumini* exhibits leaf injury symptoms in 32-36 % of the leaf area. Leaf injury symptoms were prominent in *M. indica* establishing the fact that it is more susceptible to leaf damage. These symptoms were more pronounced during summer season, followed by winter and rainy. Leaf injury symptoms varied from brown patches, yellow patches, black spots, surface lesion, curling, insect eating, parasitic galls and growth retardation. Prominent leaf injury symptoms such as chlorotic and necrotic patches were observed in leaves of the plants. Distinct necrotic symptoms in the form of water soaked, grayish white patches, yellow, brown, reddish brown to dark tan patches progressing from leaf margins towards interveinal areas were observed in *Mangifera indica and Syzygium cumini* (figure-2a and b). In case of *M. indica* leaf injury is characterized by brown to dark tan colored interveinal necrosis resembling oxidation of cell components. Leaf injury symptoms in case of *S. cumini* were observed in the form of Leaf curl, leaf yellowing and marginal necrosis. Alteration of leaf morphology and anatomy as a result of air pollution were also studied by many workers[15-16].

In *S. cumini* concentration of total chlorophyll was in a lower range of 0.86 to 1.11 (mg g^{-1} dry wt.) as compared to 2.22(mg g^{-1} dry wt.) at the control site. Chlorophyll content was lower at a distance of 2.5 km and 5.0 km from the power plant (table-2). In case of *M. indica* chlorophyll content found ranges from 0.98 to 1.14 mg g^{-1} at a distance of 2.5 km and 5.0 km from the power plant. Percentage of degradation in total chlorophyll was highest in summer (80 %) whereas in *S. cumini* higher rate of degradation is noticed during summer and winter season (65 %). Total chlorophyll content was significantly negatively correlated to inorganic sulfur content in plants.

Reduction in chlorophyll content has evidence-based correlation with particulate matter (figure-3). This evidenced the reduction in chlorophyll synthesis and chlorophyll degradation due to deposition of highly alkaline dust particles and crust formation causing denaturation of chloroplast and subsequent decrease in chlorophyll content[17]. Considerable reduction in chlorophyll content and an increase in sugar content in leaves of *Mangifera indica* and *Shorea robusta* was found due to emissions from nearby thermal power plant[18].

Inorganic Sulphur (S) content in both the tree species were found to increase with decrease in distance from the power plant (table-3). It was observed that increase in S content was 4 times as compared to control in *S. cumini* whereas 4 to 5 times in *M. indica*. Accumulation of inorganic S is higher in *M. indica* (0.27-1.17%) than *S. cumini* (0.24 to 1.15 %). The foliar sulfur levels shows significant positive correlation with ambient SO_2 levels ($r = 0.69$, $p<0.05$) and negative correlation with total chlorophyll ($r = -0.74$, $p<0.01$). Both the plant species reacts differently to the seasonal effect of pollutants. This shows that the uptake of SO_2 by leaves is more than that can be utilized in sulphate metabolism.

Significant reduction in Phosphorous (P) content of leaves was observed at sites closer to the power plant (table-3). Leaf P content was found to have significant positive correlation with chlorophyll content**.** Maximum reduction in N content was found in *Mangifera indica* (91%). The reason of reduced P content of leaves at sites nearer to the power plant can be due to deleterious effect of sulphite exposure on Glyceraldehyde – 3 – phosphate dehydrogenase and alcohol dehydrogenase[19-20]. Summary of correlations established between ambient air quality and foliar parameters at study sites in *Sizygium cumini* and *Mangifera indica* is presented in table-4.

Environmental stress such as nutrient deficits and impact of air pollutants results in biosynthesis of secondary metabolites that are involved in stress signaling and defense against abiotic stress[21-22]. Total phenols of leaf showed increase towards the power plant as compared to control (table-5). Higher concentration of total phenols was found in summer seasons in *Mangifera indica (1.2 %)* than *Sizygium cumini (0.98%).* There was a 5 fold increase in phenol contet as compared to the control. Accumulation of phenols on plants was higher in summer season followed by winter and rainy.

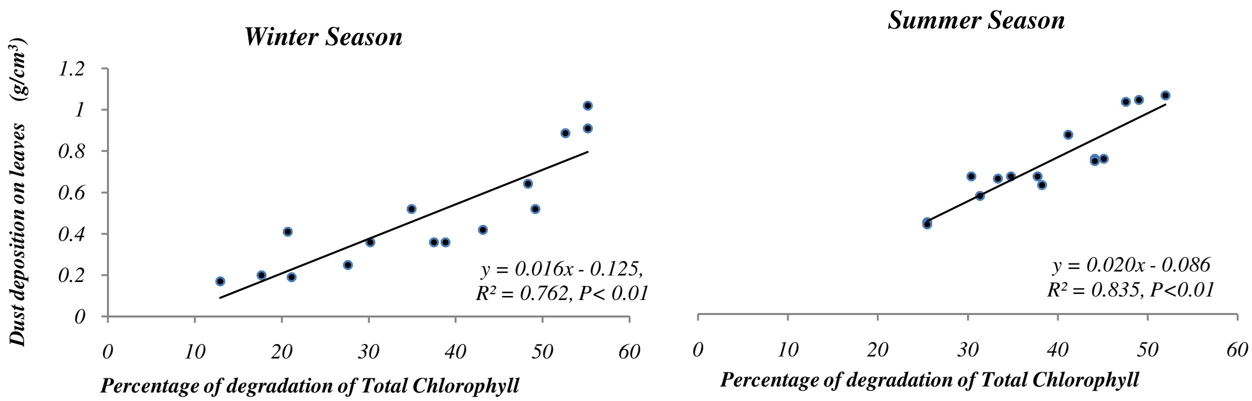

Figure - 3a

Correlation between dust deposition on leaves and percentage degradation of total chlorophyll in *Mangifera indica*

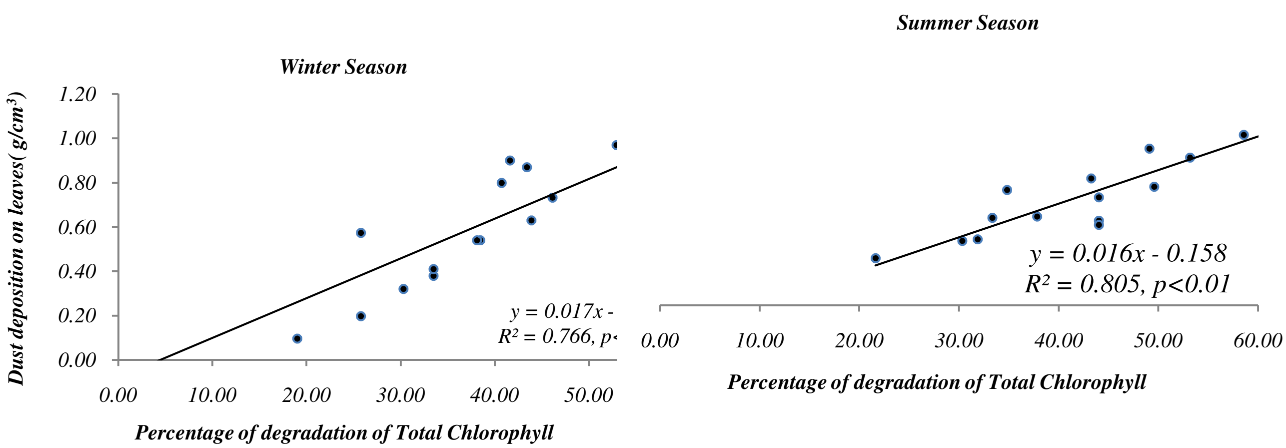

Figure - 3b

Correlation between dust deposition on leaves and percentage degradation of total chlorophyll in *Syzizium cumini*

Table-1
Percentage of leaf area damaged during different seasons in *Mangifera indica* and *Sizygium cumini* at the study sites

Study Sites	**Percentage of Damaged Leaf Area**					
	Mangifera indica			***Sizygium cumini***		
	S	***W***	***R***	***S***	***W***	***R***
North						
1	40	35	20	25	25	19
2	42	36	19	27	27	21
3	25	24	15	12	14	15
4	12	7.2	-	-	15	7
West						
1	33	25	14	27	33	21
2	25	15	15	28	33	25
3	14	14	-	-	-	16
4	-	-	-	-	-	-
South						
1	44	14	16	32	25	18
2	45	15	17	35	26	21
3	-	-	-	-	-	-
4	-	-	-	-	-	-
East						
1	47	37	12	33	32	15
2	41	24	12	36	31	17
3	-	-	-	-	-	-
4	-	-	-	-	-	-

Table-2
Changes in total chlorophyll content in two plant species growing near thermal power plant.

		Total Chlorophyll (mg g^{-1})					
		Syzizium cumini			***Mangifera indica***		
Direction	**Distance in km from the emission source**	**Rainy**	**Winter**	**Summer**	**Rainy**	**Winter**	**Summer**
North	2.5	1.354	1.19	1.13	1.69	1.2	1.33
	5.0	1.71	1.26	0.86	1.61	1.2	1.2
	10.0	1.88	1.64	1.243	1.97	1.45	1.64
	15.0	1.95	1.83	1.26	2.18	1.71	1.85
West	2.5	1.71	1.47	1.447	1.15	1.04	0.980
	5.0	1.75	1.54	1.113	1.19	1.1	1.07
	10.0	1.81	1.64	1.513	1.27	1.18	1.14
	15.0	1.92	1.79	1.74	1.59	1.42	1.36
South	2.5	1.78	0.78	1.34	1.85	1.51	1.04
	5.0	1.81	1.25	1.12	1.87	1.62	1.12
	10.0	2.17	1.36	1.243	1.94	1.68	1.27
	15.0	2.19	1.47	1.547	2.36	2.34	2.04
East	2.5	1.353	1.29	0.92	1.97	1.84	1.14
	5.0	1.37	1.31	1.243	2.11	1.91	1.26
	10.0	1.54	1.37	1.38	2.34	2.11	1.52
	15.0*	2.36	2.21	2.22	2.56	2.32	2.04

*Control Site; Differences in total chlorophyll content due to study sites, season, and interaction between study sites and seasons were significant at $p < 0.01$.

Table-3
Annual Average elemental concentration of *Sizygium cumini* and *Mangifera indica* at the study sites

Distance (km) and direction from TTPS	*Sizygium cumini*		*Mangifera indica*	
	P Content (mg/g)	S Content (%)	P Content (mg/g)	S Content (%)
North				
2.5	0.11 (0.02)	0.75 (0.06)	0.13 (0.03)	0.98 (0.06)
5.0	0.02 (0.05)	1.00 (0.06)	0.03 (0.02)	1.17 (0.06)
10.0	0.22 (0.03)	0.33 (0.07)	0.21 (0.02)	0.43 (0.07)
15.0	0.12 (0.04)	0.61 (0.06)	0.04 (0.05)	0.63 (0.08)
West				
2.5	0.03 (0.04)	0.68 (0.05)	0.09 (0.03)	0.66 (0.06)
5.0	0.02 (0.04)	1.15 (0.05)	0.02 (0.04)	0.94 (0.06)
10.0	0.04 (0.03)	0.58 (0.06)	0.04 (0.01)	0.62 (0.07)
15.0	0.17 (0.02)	0.41 (0.05)	0.08 (0.01)	0.46 (0.08)
South				
2.5	0.05 (0.03)	0.47 (0.05)	0.03 (0.05)	0.58 (0.08)
5.0	0.02 (0.03)	0.84 (0.06)	0.09 (0.05)	0.83 (0.08)
10.0	0.12 (0.02)	0.45 (0.04)	0.11 (0.03)	0.83 (0.07)
15.0	0.16 (0.02)	0.30 (0.04)	0.44 (0.02)	0.57 (0.07)
East				
2.5	0.07 (0.02)	0.66 (0.04)	0.39 (0.03)	0.76 (0.06)
5.0	0.12 (0.05)	0.81 (0.07)	0.17 (0.02)	0.95 (0.06)
10.0	0.44 (0.05)	0.51 (0.07)	0.51 (0.02)	0.67 (0.07)
15.0	0.69 (0.03)	0.24 (0.06)	1.03 (0.04)	0.27 (0.05)

Table-4
Summary of correlations established between ambient air quality and foliar parameters at study sites in *Sizygium cumini* and *Mangifera indica* at *5% level (p=0.05) and **10% level (p=0.1)

Sizygium cumini			*Mangifera indica*		
Air Quality Parameter	**Season**	**Foliar Parameter**	**Air Quality Parameter**	**Season**	**Foliar Parameter**
SPM	Summer	T. Chl**, P*, S**, Leaf injury**	SPM	Summer	T. Chl**, P*, S**, Leaf injury*
	Winter	T. Chl**, P**, S**, Leaf injury*		Winter	T. Chl**, P**, S**, Leaf injury*
	Rainy	T. Chl** P**, S*, Leaf injury*		Rainy	T. Chl*, P**, S*, Leaf injury*
SO_2	Summer	T. Chl**, P**, S**, Leaf injury**	SO_2	Summer	T. Chl**, P*, S**, Leaf injury**
	Winter	T. Chl**, P**, S**, Leaf injury**		Winter	T. Chl**, P*, S*, Leaf injury**
	Rainy	T. Chl*, P**, S**, Leaf injury*		Rainy	T. Chl**, P*, S*, Leaf injury**
NO_2	Summer	T. Chl**, P*, S**, Leaf injury*	NO_2	Summer	T. Chl**, P*, S**, Leaf injury*
	Winter	T. Chl** P*, S**, Leaf injury*		Winter	T. Chl*, P*, S**, Leaf injury*
	Rainy	T. Chl*, P*, S*, Leaf injury*		Rainy	T. Chl*, P*, S**, Leaf injury**
Dust content	Summer	T. Chl*, P*, S**, Leaf injury**	Dust content	Summer	T. Chl**, P*, S**, Leaf injury**
	Winter	T. Chl*, P*, S**, Leaf injury*		Winter	T. Chl*, P*, S**, Leaf injury*
	Rainy	T. Chl*, P*, S**, Leaf injury*		Rainy	T. Chl**, P*, S**, Leaf injury*

Table-5
Seasonal fluctuations in Phenol (%) in leaves of *Sizygium cumini* and *Mangifera indica*

Location	W	R	S	W	R	S
N1	0.61	0.52	0.98	0.63	0.51	1.12
N2	0.43	0.4	0.87	0.61	0.42	1.2
N3	0.41	0.36	0.74	0.56	0.36	0.95
N4	0.32	0.37	0.67	0.48	0.21	1.10
W1	0.65	0.62	0.86	0.56	0.41	1.07
W2	0.56	0.75	0.81	0.4	0.52	1.11
W3	0.39	0.43	0.65	0.33	0.32	0.89
W4	0.3	0.41	0.52	0.27	0.3	0.77
S1	0.75	0.67	0.72	0.57	0.55	0.54
S2	0.7	0.59	0.78	0.49	0.51	0.65
S3	0.65	0.33	0.58	0.31	0.44	0.41
S4	0.62	0.31	0.41	0.26	0.36	0.35
E1	0.76	0.75	0.55	0.94	0.45	0.56
E2	0.66	0.6	0.4	0.88	0.51	0.41
E3	0.45	0.41	0.38	0.55	0.36	0.36
E4	0.25	0.29	0.22	0.32	0.23	0.3
	S. cumini			***M. indica***		

W - Winter, R - Rainy, S – summer

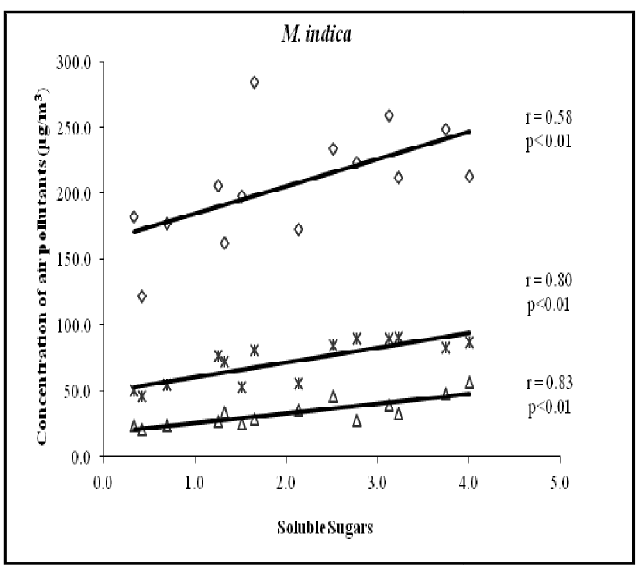

Figure – 4a
Correlation between concentration of air pollutants and total soluble sugars in *M. indica*

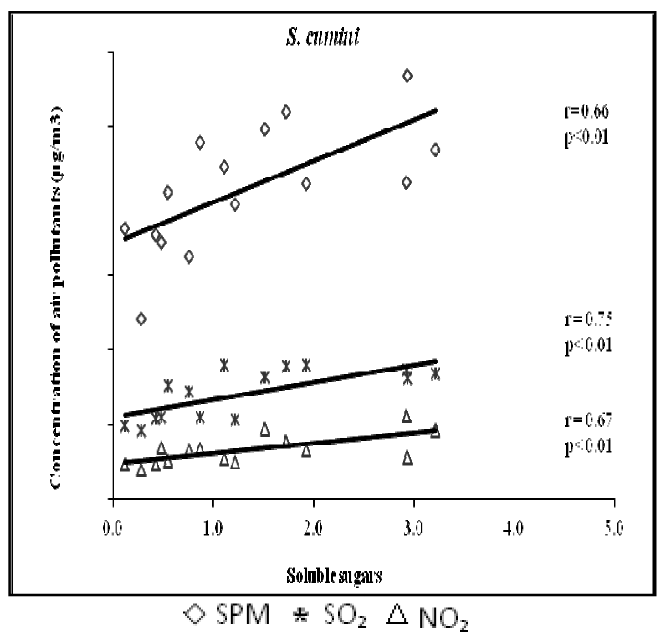

Figure – 4b
Correlation between concentration of air pollutants and total soluble sugars in *S. cimini.*

Concentration of SO_2 + NO_x was positively correlated with total phenols concentration of plant leaves at $p<0.01$ level of significance. Environmental stress, such as a deficit in nutrients and the impact of air pollutants have resulted in to biosynthesis of secondary metabolites which are usually involved in physiological plant mechanisms such as signaling and defense against abiotic factors[23]. Phenols due to their strong antioxidant properties are known to diffuse the toxic free radicals[24].

Total soluble sugars concentrations in the plant foliages are higher nearer to the power plant (4.0 – 7.0 %) and decreases towards the control (0.2 – 0.5 %). A higher positive correlation with SO_2 and NOx showed the combined effects of these pollutants on the soluble sugar release (figure-4a and b). The increase in soluble sugar was reported in *Albizia lebbeck* and *Callistemon citrinus* grown in industrial areas[25]. Studies on resistance of *Dodonea viscosa* and *Prosopis juliflora* to industrial air pollution were carried out and results showed increase in soluble sugar[26-27].

On the basis of percentage of leaf injury and biochemical parameters sensitivity index was calculated by assigning 100 points to the highest value of each parameter and finding total score for each species. The sensitivity index for *Mangifera indica* was found to be 231.33 and that of *Sizygium cumini* to be 250.9. *M indica* with a lower sensitivity index was found to be a tolerant species than *S cumini*. In another work the sensitivity index for nine tree species were carried out and *M. Indica* was found to be tolerant than *S. Cumini*[28].

Conclusion

It is evident from the present study that even with stress-tolerant mechanisms, trees inherit considerable amount of damage due to pollution. The subtle effect of air pollutants on plants triggered changes in physico-chemical characteristics of leaves and visible injury symptoms in some areas in both the plants. In the present study, physical damage of leaves as a result of dust deposition, degradation of chlorophyll and imbalances in nutrient content could be observed. There is a spatial influence on effects of pollutants. Trees closer to the power plant had the greatest effects as compared to distant ones. A direct relationship was established between the increase in the amount of S, and decrease in chlorophyll content of plants. The study suggests that differential sensitivity of plants to SO_2 may be used in evaluating the air pollution impact around emission sources and *M. indica* plants can be used as an indicator plant for quantifying biological changes.

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