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ORIGINAL PAPER

# Harmful effects of air pollution on physiological activities of *Pongamia pinnata* (L.) Pierre

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**Abstract** Air pollution tolerance of the plant *Pongamia pinnata* (L.) Pierre, as well as, its effect on metabolic activities of the plant was studied with reference to concentration of air pollutants on comparative basis in selected sites around Udaipur city in polluted and unpolluted areas. The tree species being very common in and around Udaipur city of Rajasthan, India as roadside plant. The quality of air in terms of RSPM, SPM, $SO_2$ and $NO_2$ on respective sites along with biochemical parameters of the leaves, i.e., chlorophyll content, total carbohydrate, total protein, dust-capturing capacity, leaf size and enzyme activity were assessed in experimental sites. The data obtained were further subjected to ANOVA, which gave significant values. Our studies confirm that industries are the prominent sources of the elevated level of air pollutants that affect flora and health of local population.

**Keywords** Sensitive species · Air pollutants · Metabolic activities · Pollution tolerance

## Introduction

Epidemiological studies throughout the world have established a close association between urban pollution and human diseases where ambient air quality was much more above the National standards (Dockery et al. 1993; Samet et al. 2000). Air pollution is complex mixture of various gases, particulates, hydrocarbons, transition metals, etc. More comprehensive assessment of the potential effect of the air pollution complex might lead to better environment for human habitation and existing flora. Urban air pollutants cause a wide range of acute and chronic effects on the respiratory system. Exposure to automobile exhaust is associated with increased respiratory symptoms and may impair lung function. The health risk from particulate pollution is high for some susceptible groups, i.e., the children and the elderly persons those suffering from diseases of the heart and lungs (Ulrich et al. 2002; Siddique et al. 2010a, b). Plants on the basis of field and laboratory studies can be classified as sensitive and tolerant. Prasad et al. (2000) studied the effect of fly ash on germination behaviour and seedling survival of certain cultivated legumes. Rana et al. (2000) observed effect of various concentrations of $SO_2$ on the quantity of free proline in the anthers of *Brassica juncea* L. Ahmad and Ahmad (2003) studied sulphur accumulation in plant foliage due to coal smoke pollution. Gokhale and Patil (2004) studied size distribution of aerosols ($PM_{10}$) and lead (Pb) near traffic intersections in Mumbai (India). Swami et al. (2004) studied effect of air pollution on *Shorea robusta* and *Mallotus phillipinensis* in Himalayan valley. Tiwari et al. (2006) studied impact of ambient air pollution on carrot plants at a sub-urban site using open top chambers. However, increase in industrialization, unplanned urbanization, increasing horn in vehicles, population growth and under-estimated future plan of city development are the major triggers for the increases in the air pollution level in any city (Jayanthi and Krishnamoorthy 2006). Dwivedi and Tripathi (2007) studied pollution tolerance and distribution pattern of plants in and around coal-fired industries. Joshi et al. (2009) studied impact of industrial air pollutants on

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some biochemical parameters and yield of wheat and mustard plants. The plants which are tolerant can be used as scavengers, for identification and impact of combating air pollution in the city's polluted area where concentration of air pollutants is higher than desirable.

Green belt plantation around the air polluting units can never be a claim for the removal of air pollutants at the region, but effectively planted trees in the green belt may potentially remove the toxic gases in considerable amount, for abatement of city's air pollution. Plantation of tolerant tree species will have a marked effect on varied aspects of the quality of the urban environment and the cleanliness of life in a city. Aim of this study was to identify tolerant plant species and to investigate harmful effect of air pollutants on physiological activities of the tree species under study.

## Materials and methods

### Study area

The city of lakes, Udaipur (state Rajasthan, India) is situated about 600 m above the sea level and is located amongst the lush green hills of Aravali range between 24°35′ N latitude and 73°42′ E longitude (see Fig. 1). There are many lakes around Udaipur and within, e.g., Pichhola, Fateh Sagar and Swaroop Sagar which are deeply involved in social, cultural and economic activities of the city. The city is also known as 'Venice of the East' and has been rated as the 'World's beautiful city no. 1' by the travellers and the media worldwide. The city has a population around 0.6 million and a distinct tropical climate with marked monsoonal effect. The year is divided into three seasons, i.e., summer (April–June), rainy (July–October) and winter (November–March). The average temperature ranges from 5°C in winter to maximum of 41°C in summers, normally. The annual average rainfall ranges between 62.5 and 125 cm during normal monsoon regime. In order to assess the status of air pollution on the biochemical and physiological parameters of plant growth along with morphological changes three sites were selected, viz., urban area (Surajpole, lying at 24°34′ 45.95″ N and 73°41′ 46.31″ E and elevation 612 m), industrial area (Madri industrial area, lying at 24°35′ 01.23″ N and 73°44′ 59.52″ E and elevation 600 m) and forest area (Kevede ki Naal, lying at 24°25′ 00.90″ N and 73°46′ 05.40″ E and elevation 449 m). The effect of ambient air quality was studied using tree species mainly found in the area out of

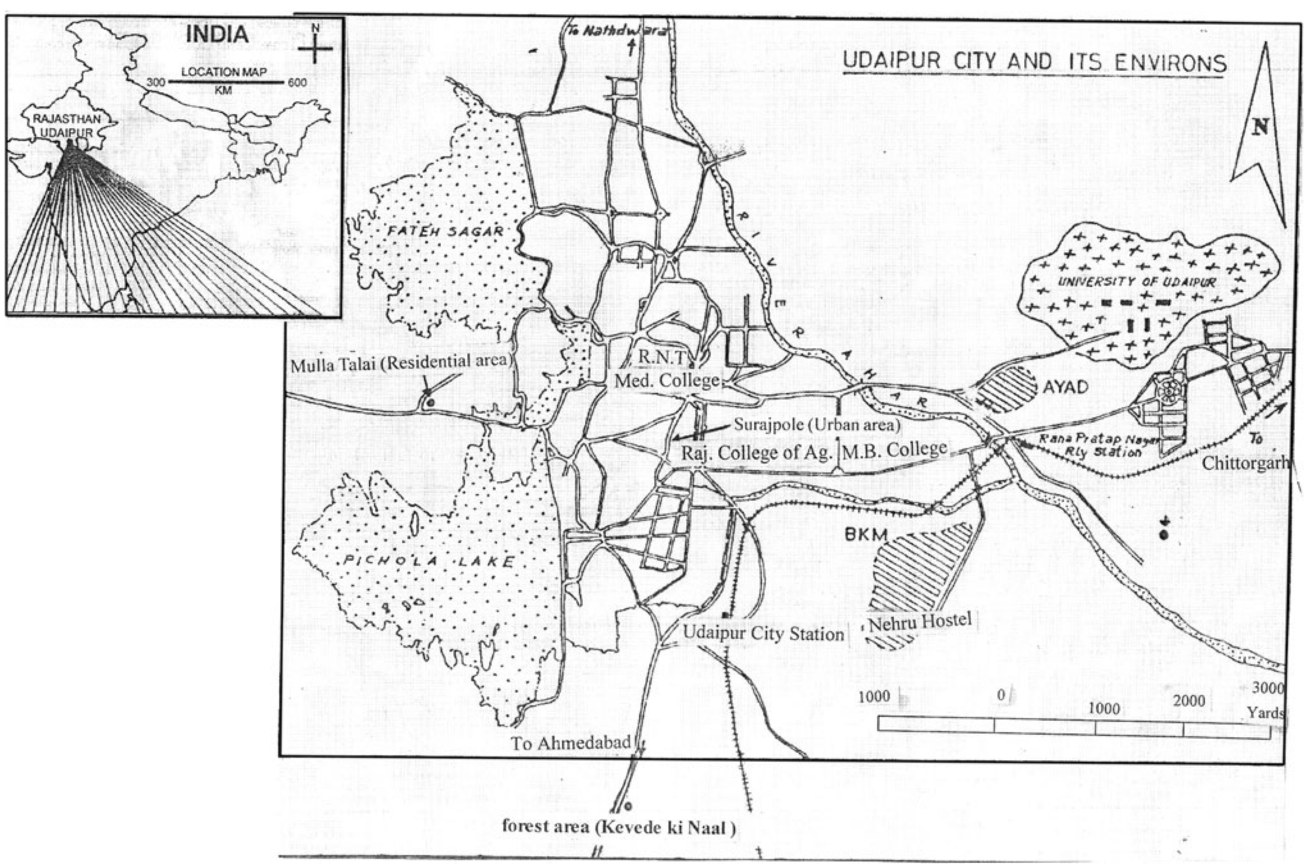


Fig. 1 Map of the study area showing different study sites

these one is *Pongamia pinnata* (L.) Pierre (Indian Beech tree, Honge tree, Pongan tree, *Milletia pinnata)* which belong to order Fabales and family Fabaceae of Dicotyledons. It is a tree thought to have originated in India and is found throughout Asia.

Sample collection

The concentration of different air pollutants viz., $SO_2$, $NO_x$, SPM and RSPM was monitored into 100 transects (100 × 100 m) with a difference of 10 m were ascertained and observations taken indicate mean value of all these sites, on the basis of recording in a day at different times, i.e., morning (07:00 h), noon (12:00 h) and evening (18:00 h). The leaves of the samples were brought in polythene bags to the laboratory and activity of enzymes was studied immediately. For further analysis, these were preserved at −14°C in freezer till analysed for different parameters within 24 h of their harvesting.

Methodology

The parameters studied were amount of chlorophyll a, chlorophyll b, total chlorophyll and carotenoids using 80% acetone as blank. Absorbance measured by spectrophotometer Systronix UV–Vis 108 model in visible range (Jenson 1978). Total carbohydrate and total protein of the plant samples as a soluble fraction were determined (Dubois et al. 1956; Lowry et al. 1951). The ambient air quality and toxic effect of air pollutants on the tree species as above were investigated at these points for two consecutive years, i.e., from September 2007 to October 2009 on bimonthly basis. The activities of two oxidative enzymes peroxidase and polyphenol oxidase were also studied along with the above parameters in the described schedule (Mahadevan and Sridhar 1982). Increased activity of these two enzymes has been found in plants, facing pollution. Dust-capturing capacity of the leaves of sample trees was another parameter which substantiated our data on the effect of ambient air pollution and its monitoring. The concentration of $SO_2$ was measured by modified West and Gaeke (1956) and $NO_x$ was measured by the modified method Jacobs and Hochheiser (1958). The SPM and RSPM concentration were measured using filter paper method (Rehme et al. 1984).

## Results

The ambient air quality data are presented in graphical forms (Figs. 2, 3, 4, 5, 6, 7). Comparative studies were carried out in six tree species commonly found in study area (Kapoor et al. 2009a, b). In our investigations, we

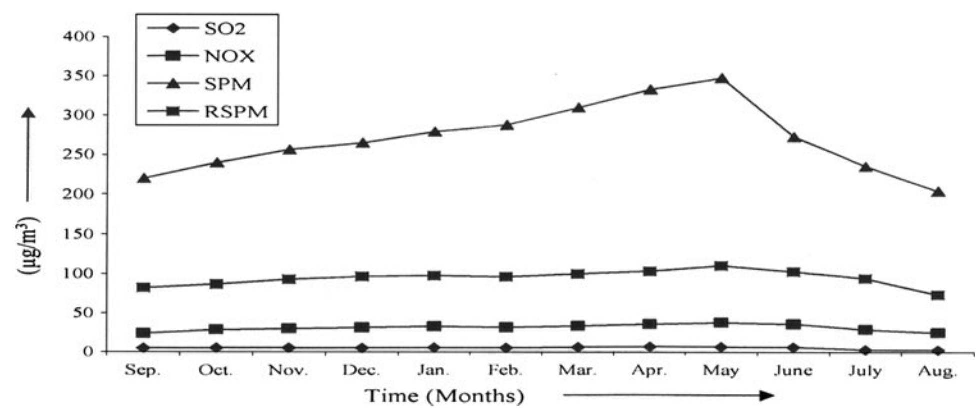


**Fig. 2** Mean values of various parameters of ambient air quality in forest area (Kevede ki naal) of Udaipur city during first year of study

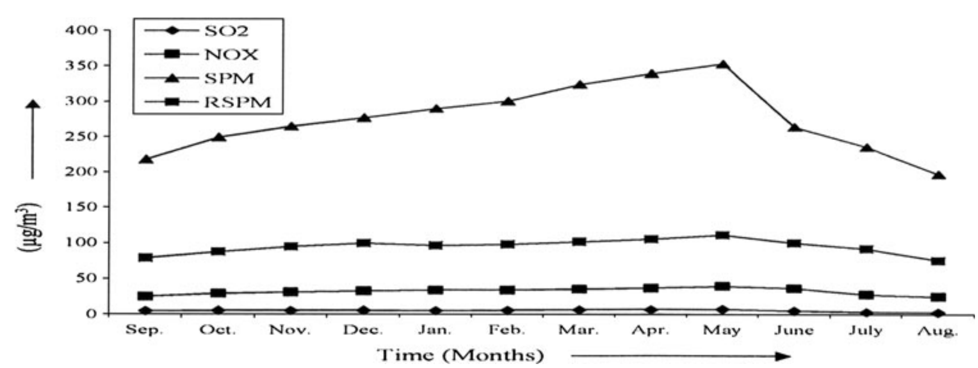


**Fig. 3** Mean values of various parameters of ambient air quality in forest area (Kevede ki naal) of Udaipur city during second year of study

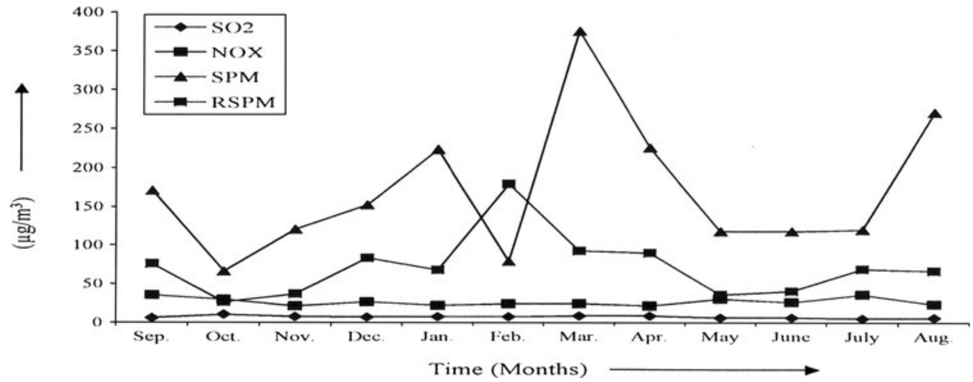


**Fig. 4** Mean values of various parameters of ambient air quality in urban area (Surajpole) of Udaipur city during first year of study

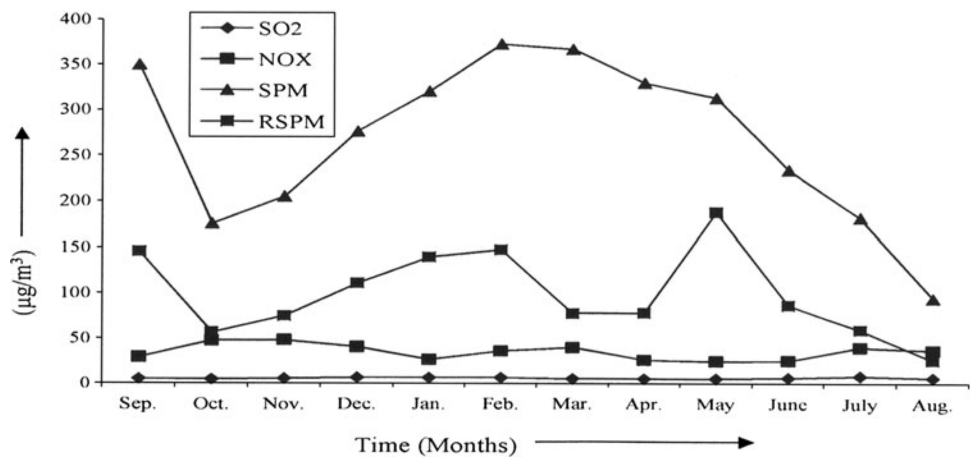


**Fig. 5** Mean values of various parameters of ambient air quality in urban area (Surajpole) of Udaipur city during second year of study

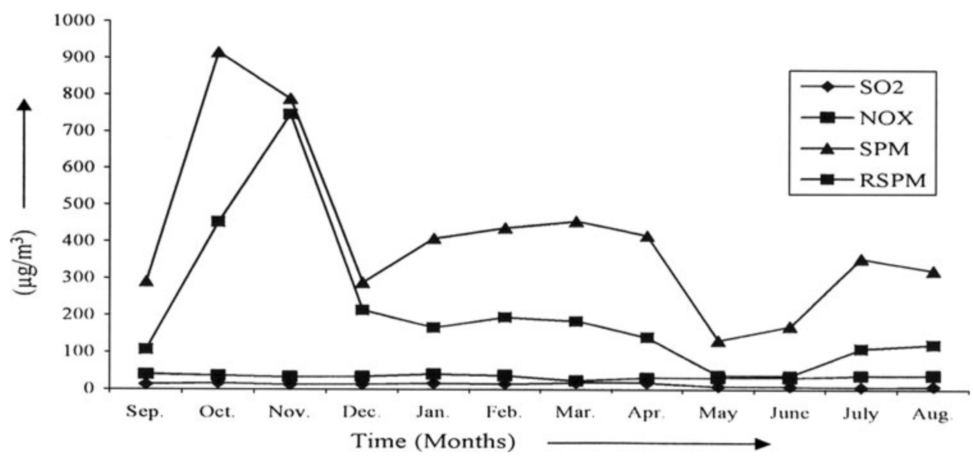


**Fig. 6** Mean values of various parameters of ambient air quality in industrial area (Madri) of Udaipur city during first year of study

have found that level of air pollution, i.e., $SO_2$, $NO_x$, SPM and RSPM was minimum in forest areas, higher on roads being affected by vehicular traffic and highest in industrial area of the parameters studied. Hence, the only alternative which is feasible and which helps us to combat air pollution from all sources is to plant more and more tolerant trees and vegetation which will lead to maintain higher amount of relative moisture into the atmosphere thereby, more rainfall during monsoon season in addition to its protective role.

Biochemical parameters

During first year of study, analysis of various biochemical parameters of *Pongamia pinnata* (L.) Pierre at different sites of Udaipur city revealed values as indicated serially (biochemical parameter, maximum and minimum of different samples, Table 1): chl a 0.060–1.200 mg/g, chl b 0.002–1.575 mg/g, total chl 0.033–2.284 mg/g, carotenoids 0.04–0.237 mg/g, total carbohydrate 1.040–10.10 mg/g, total protein 1.040–10.110 mg/g, dust-capturing capacity

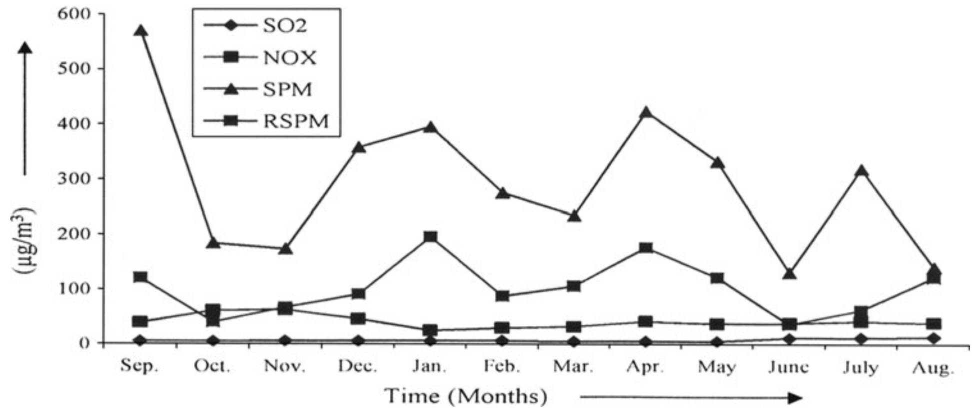


**Fig. 7** Mean values of various parameters of ambient air quality in industrial area (Madri) of Udaipur city during second year of study

**Table 1** Biochemical parameters of *Pongamia pinnata* (L.) Pierre at different investigation sites of Udaipur city during first year (September 2007–August 2008) of study

| Parameter studied | Sites | Sep–Oct 2007 | Nov–Dec 2007 | Jan–Feb 2008 | March–April 2008 | May–June 2008 | July–Aug 2008 |
|---|---|---|---|---|---|---|---|
| Chl a (mg/g) | Urban | 0.259 | 0.620 | 0.300 | 0.172 | 0.241 | 0.760 |
| | Industrial | 0.189 | 0.320 | 0.184 | 0.129 | 0.060 | 0.311 |
| | Forest | 0.620 | 1.200 | 0.436 | 0.230 | 0.736 | 1.017 |
| Chl b (mg/g) | Urban | 0.346 | 0.175 | 0.242 | 0.019 | 0.190 | 0.815 |
| | Industrial | 0.229 | 0.0338 | 0.148 | 0.002 | 0.040 | 0.234 |
| | Forest | 0.640 | 0.585 | 0.303 | 0.445 | 0.659 | 1.268 |
| Total chlorophyll (mg/g) | Urban | 0.570 | 0.970 | 0.610 | 0.152 | 0.431 | 1.575 |
| | Industrial | 0.401 | 0.492 | 0.327 | 0.033 | 0.101 | 0.545 |
| | Forest | 1.225 | 1.810 | 0.710 | 0.574 | 1.395 | 2.284 |
| Carotenoids (mg/g) | Urban | 0.090 | 0.211 | 0.154 | 0.057 | 0.108 | 0.191 |
| | Industrial | 0.061 | 0.149 | 0.145 | 0.510 | 0.04 | 0.118 |
| | Forest | 0.180 | 0.237 | 0.191 | 0.105 | 0.207 | 0.235 |
| Total carbohydrates (mg/g) | Urban | 4.950 | 5.600 | 4.600 | 3.550 | 4.050 | 3.650 |
| | Industrial | 4.100 | 4.300 | 4.300 | 2.200 | 2.950 | 0.400 |
| | Forest | 6.400 | 5.910 | 4.940 | 20.380 | 7.300 | 5.580 |
| Total protein (mg/g) | Urban | 7.900 | 8.270 | 8.300 | 2.600 | 5.840 | 7.240 |
| | Industrial | 5.800 | 6.190 | 7.200 | 1.040 | 5.560 | 6.080 |
| | Forest | 10.100 | 10.110 | 10.980 | 7.050 | 9.200 | 7.840 |
| Dust-capturing capacity (mg/cm$^2$) | Urban | 0.720 | 1.466 | 5.900 | 1.478 | 3.540 | 0.559 |
| | Industrial | 1.800 | 7.100 | 5.970 | 6.092 | 3.666 | 1.632 |
| | Forest | 0.574 | 0.657 | 0.470 | 0.518 | 1.422 | 0.496 |
| Leaf size (cm$^2$) | Urban | 52.200 | 46.000 | 49.000 | 38.530 | 39.500 | 40.250 |
| | Industrial | 34.520 | 43.000 | 45.000 | 37.750 | 30.000 | 36.750 |
| | Forest | 56.230 | 62.500 | 50.000 | 38.590 | 56.250 | 52.580 |

0.470–7.100 mg/cm$^2$, leaf size (mean area) 30–62.500 cm$^2$. It was observed that the amount of chlorophyll-a was higher in November–December, 2007; similarly in the samples of industrial and forest, respectively. Chlorophyll b was recorded higher during July–August 2008 in the samples of urban area and lower during March–April 2008 in the samples of urban and industrial areas and during January–February 2008 in the samples of forest area. Similarly, total chlorophyll content was also recorded higher during July–August 2008 in the samples of all the sites. Carotenoid content was found to be highest during November–December 2007 and lowest during March–April 2008 in urban and forest areas and during May–June 2008 in industrial area. Of all the three sites, and total carbohydrate content was recorded highest in forest area during first year of study in March–April 2008. In industrial area, it was higher during November 2007–February 2008 and lower during July–August 2008. In urban area, the highest and lowest values were observed in November–December 2007 and March–April 2008, respectively. During January–February 2008, the amount of protein was recorded higher in the samples of all the three sites in urban, industrial and forest area, respectively, and during March–April 2008, it was lower in all the three sites. Dust-capturing capacity was found to be higher during May–June 2008 in the leaves of urban and forest areas and during November–December 2007 in the leaves of industrial area. Highest leaf size was recorded in forest area during November–December 2007 and lowest in industrial area during May–June 2008. Oxidative enzymes of plants turn more active when plant is subjected to any stress, in this case it is the stress developed by the presence of various kinds of pollutants in the ambient air of the study sites, i.e., urban, industrial and forest areas. The two enzymes studied are polyphenol oxidase and peroxidase. The activity of polyphenol oxidase in samples of urban area (Surajpole) was at lowest level during months of September–October 2007. Whilst it was definitely higher in other months of the year in the order of March–April 2008 (highest activity) > May–June 2008 > July–August 2008 > November–December 2007 > January–February 2008. Whilst in samples of Madri industrial area, the activity was at lowest level during months of January–February 2008. Whilst it was higher in other months of the year in the order of July–August 2008 > September–October 2007 > May–June 2008 >March–April 2008 > November–December 2007. In the samples of forest area (Kevede ki Naal), the activity of the enzyme was at lowest possible ebb during months of November–December 2007. Whilst it was higher in other months of the year in the order of January–February 2008 > May–June 2008 > July–August 2008 > March–April 2008 > September–October 2007. In leaf samples of urban area (Surajpole), the activity of peroxidase increased from initial level to highest level during all months studied. The order of increased activity was January–February 2008 followed by March–April 2008, July–August 2008, November–December 2007, May–June 2008 and September–October 2007 (highest activity). In the samples of Madri industrial area, the activity of peroxidase was observed to increase from initial level to highest level and highest activity occurred in the months of January–February 2008 followed by September–October 2007, July–August 2008, March–April 2008, May–June 2008 and November–December 2007 (lowest activity observed). In the samples of forest area (Kevede ki Naal), the activity of the enzyme was found to increase from initial level to highest level and highest activity occurred during months of September–October 2007 followed by January–February 2008, May–June 2008, July–August 2008, March–April 2008 and November–December 2007 (lowest activity observed). The tabulated values of ANOVA of first year data were 1.620, 2.087, 3.072 and 1.775 at 5% and 1.969, 2.292, 4.987 and 2.324 at 1% level of significance (Tables 2, 3).

During second year of study, analysis of various biochemical parameter of at different sites of Udaipur city revealed values as indicated (Table 4): chl a 0.057–1.355 mg/g,

**Table 2** Statistical analysis of various biochemical parameters of *Pongamia pinnata* (L.) Pierre of Udaipur city during first year of study

| Treatment | Chl a | Chl b | Total Chl | Total carotenoids | Total carbohydrate | Total protein | DCC | TLS | Total | Mean |
|---|---|---|---|---|---|---|---|---|---|---|
| Urban area | 2.352 | 1.787 | 4.308 | 0.811 | 26.400 | 40.150 | 13.663 | 265.480 | 354.951 | 59.159 |
| Industrial area | 1.193 | 0.687 | 1.899 | 1.023 | 18.250 | 31.870 | 26.260 | 227.020 | 308.202 | 51.367 |
| Forest area | 4.239 | 3.900 | 7.998 | 1.155 | 50.510 | 55.280 | 4.137 | 316.150 | 443.369 | 73.895 |
| Total | 7.784 | 6.374 | 14.205 | 2.989 | 95.160 | 127.300 | 44.060 | 808.650 | | |
| Mean | 2.595 | 2.125 | 4.735 | 0.996 | 31.720 | 42.433 | 14.687 | 269.550 | | |

*DCC* dust-capturing capacity, *TLS* total leaf size

**Table 3** Analysis of variance

| S.O.V | d.f. | SS | MSS | *F*-cal | S/NS | *F*-tab 5% | *F*-tab 1% | SEM+ | CD5% | CD1% |
|---|---|---|---|---|---|---|---|---|---|---|
| Treatment | 23 | 30207.249 | 1313.359 | 167.022 | * | 1.620 | 1.969 | 1.145 | 3.205 | 4.238 |
| C | 7 | 196.343 | 28.049 | 3.567 | * | 2.087 | 2.792 | 0.467 | 1.309 | 1.730 |
| A | 2 | 29354.441 | 14677.221 | 1866.528 | * | 3.072 | 4.787 | 0.661 | 1.851 | 2.447 |
| C × A | 14 | 656.465 | 46.890 | 5.963 | * | 1.775 | 2.234 | 1.145 | 3.205 | 4.238 |
| Error | 120 | 943.605 | 7.863 | | | | | | | |
| Total | 143 | 31150.854 | | | | | | | | |
| Mean | 7.684 | | | | | | | | | |
| CV% | 36.43 | | | | | | | | | |

*represents value significant at 1 % and 5 % level of significance

**Table 4** Biochemical parameters of *Pongamia pinnata* (L.) Pierre at different investigation sites of Udaipur city during second year (September 2008–August 2009) of study

| Parameter studied | Sites | Sep–Oct 2008 | Nov–Dec 2008 | Jan–Feb 2009 | March–April 2009 | May–June 2009 | July–Aug 2009 |
|---|---|---|---|---|---|---|---|
| Chl a (mg/g) | Urban | 0.267 | 0.612 | 0.343 | 0.315 | 0.836 | 0.624 |
| | Industrial | 0.180 | 0.330 | 0.177 | 0.294 | 0.057 | 0.192 |
| | Forest | 0.613 | 1.207 | 0.424 | 1.218 | 1.156 | 1.355 |
| Chl b (mg/g) | Urban | 0.326 | 0.167 | 0.258 | 0.006 | 0.195 | 0.460 |
| | Industrial | 0.240 | 0.035 | 0.140 | 0.003 | 0.079 | 0.161 |
| | Forest | 0.628 | 0.597 | 0.294 | 0.383 | 0.371 | 0.959 |
| Total chlorophyll (mg/g) | Urban | 0.593 | 0.960 | 0.602 | 0.291 | 1.206 | 0.940 |
| | Industrial | 0.420 | 0.497 | 0.318 | 0.118 | 0.422 | 0.353 |
| | Forest | 1.241 | 1.805 | 0.719 | 0.321 | 1.715 | 1.815 |
| Carotenoids (mg/g) | Urban | 0.098 | 0.209 | 0.144 | 0.118 | 0.226 | 0.192 |
| | Industrial | 0.067 | 0.145 | 0.136 | 0.061 | 0.101 | 0.082 |
| | Forest | 0.170 | 0.232 | 0.183 | 5.950 | 0.293 | 0.272 |
| Total carbohydrate (mg/g) | Urban | 5.200 | 5.700 | 4.500 | 5.350 | 4.000 | 2.800 |
| | Industrial | 4.600 | 4.600 | 4.250 | 5.000 | 3.000 | 2.700 |
| | Forest | 6.300 | 5.950 | 4.850 | 5.950 | 7.200 | 3.600 |
| Total protein (mg/g) | Urban | 8.000 | 8.480 | 8.480 | 10.200 | 5.780 | 8.100 |
| | Industrial | 5.440 | 6.120 | 7.600 | 8.300 | 5.500 | 2.300 |
| | Forest | 10.400 | 10.08 | 10.600 | 11.300 | 9.300 | 10.200 |
| Dust-capturing capacity (mg/cm$^2$) | Urban | 0.723 | 1.473 | 5.940 | 0.396 | 1.204 | 0.487 |
| | Industrial | 1.777 | 7.050 | 5.948 | 0.784 | 1.411 | 0.496 |
| | Forest | 0.563 | 0.661 | 0.454 | 0.392 | 0.421 | 0.183 |
| Leaf size (cm$^2$) | Urban | 53.250 | 47.500 | 48.500 | 50.500 | 41.500 | 41.000 |
| | Industrial | 33.750 | 42.500 | 44.000 | 25.500 | 41.000 | 40.250 |
| | Forest | 55.250 | 60.500 | 48.750 | 76.500 | 63.750 | 54.500 |

chl b 0.003–0.959 mg/g, total chl 0.118–1.815 mg/g, carotenoids 0.061–5.950 mg/g, total carbohydrate 2.700–7.200 mg/g, total protein 2.300–11.300 mg/g, dust-capturing capacity 0.183–7.050 mg/cm$^2$, leaf size (mean area) 25.500–63.750 cm$^2$. It was observed that the amount of chlorophyll a recorded highest in the samples of forest area and lowest in samples of industrial area during May–June 2009. Chlorophyll b was recorded lowest in March–April 2009 in the samples of industrial and urban areas and in January–February 2009 in forest area. The highest value of total chlorophyll content was recorded in May–June 2009 in urban area, November–December 2008 in industrial area and during July–August 2009 in forest area. In urban area, the amount of carotenoids was recorded highest in the month of May–June 2009 and lowest during September–October 2008. Whereas in industrial area, it was higher in November–December 2008 and lower during March–April 2009. In the forest area, the highest and lowest values were recorded during March–April 2009 and September–October 2008, respectively. The amount of total carbohydrate was recorded highest during May–June 2009 in the samples of forest area and lowest during July–August 2009 in the samples of industrial area. The protein content was higher during March–April 2009 in urban, industrial and forest area, and lower during May–June 2009, July–August 2009 and May–June 2009. Of all the three sites, dust-capturing capacity of the leaves of industrial area were the highest in November–December 2008 and lowest in the forest area in July–August 2009. Leaf size was recorded highest during September–October 2008 in urban area and in January–February 2009 in industrial area and March–April 2009 in forest area. Then lowest values were recorded during July–August 2009, September–October 2008 and January–February 2009 in urban, industrial and forest area, respectively. The activity of polyphenol oxidase in samples of urban area (Surajpole) in months of March–April 2009, was at low ebb. Whilst it was definitely higher in other months of the year in the order of May–June 2009 > July–August 2009 (abnormally low activity at 120 s) > November–December 2008 > January–February 2009 > September–October 2008 (with abnormal high activity at 60 s). In samples of Madri industrial area, the activity of polyphenol oxidase was at low ebb during months of January–February 2009 but it increased in other months of the year in the order of November–December 2008 < March–April 2009 < May–June 2009 < September–October 2008 < July–August 2009 (highest activity observed). In the samples of forest area (Kevede ki Naal), the activity was lowest during months of

November–December 2008. Whilst it was definitely higher in other months of the year in the order of September–October 2008 < July–August 2009 < May–June 2009 < March–April 2009 < January–February 2009 (highest initial and final activity observed). The activity of peroxidase increased from initial level to highest level and increased further in the order of January–February 2009, July–August 2009, November–December 2008, May–June 2009, September–October 2008 and March–April 2009 (highest activity observed in urban area). In the samples of Madri industrial area, the activity of peroxidase increased from initial level to highest level and increased further up to 180 s in the order of March–April 2009, November–December 2008, May–June 2009, July–August 2009, September–October 2008, and January–February 2009 (highest activity observed). In the samples of forest area (Kevede ki Naal), the activity of peroxidase increased from initial level to highest level in all the months and it was lowest during months of November–December 2008. In other cases, it was in the increasing order from July–August 2009, March–April 2009, January–February 2009, May–June 2009 and September–October 2008 (highest activity). The tabulated values of ANOVA of second year data were 1.620, 2.087, 3.072 and 1.775 at 5% and 1.969, 2.292, 4.987 and 2.324 at 1% level of significance (Tables 5, 6).

## Discussion

Kondo et al. (1980) reviewed sulphite oxidizing activities in plants with reference to air pollution. Chlorophyll a is found to be more sensitive to gaseous pollutants like $SO_2$ than chlorophyll b (Lauenroth and Dodd 1981; Ayer and Vedi 1986; Shahare and Varshney 1994; Tiwari and Bansal 1994). In view of the cytotoxic effect of cement kiln dust and as a mutagen (Kaushik 1996), the features as result of dust deposition on foliar parts can be used as bio-indicators of dust pollution (Singh 2000). The road side plants serve as sink for air pollutants as these absorb, detoxify and tolerate high level of pollution and in addition serve as dust platform (Nivane et al. 2001; Kapoor et al. 2009a, b). Joshi and Sikka (2002) indicated maximum reduction in both the traits in industrial area as due to the effect of air pollution. Ramakrishnaiah and Somasekhar (2003) reported the effect of cement dust on soybean (*Glycine max* L. merr.) and maize (*Zea mays* Linn.). Siddique and Ansari (2005) reported the genotoxic effect of pollutants from thermal power plant on *Solanum melongena*. Thus, on the basis of above studies commonly growing trees are categorized into tolerant, moderately tolerant and sensitive plant species according to their values. Our results indicate that minimum losses in total chlorophyll content were recorded in

**Table 5** Statistical analysis of various biochemical parameters data of *Pongamia pinnata* (L.) Pierre of Udaipur city during second year (September 2008–August 2009) of study

| Treatment | Chl a | Chl b | Total Chl | Total carotenoids | Total carbohydrate | Total protein | DCC | TLS | Total | Mean |
|---|---|---|---|---|---|---|---|---|---|---|
| Urban area | 2.997 | 1.412 | 4.592 | 0.987 | 27.550 | 49.040 | 10.223 | 282.250 | 379.051 | 63.175 |
| Industrial area | 1.230 | 0.658 | 2.128 | 0.594 | 24.150 | 35.260 | 17.466 | 227.000 | 308.486 | 51.414 |
| Forest area | 5.973 | 3.232 | 7.616 | 7.100 | 33.850 | 61.880 | 2.674 | 359.250 | 481.575 | 80.263 |
| Total | 10.200 | 5.302 | 14.336 | 8.681 | 85.550 | 146.180 | 30.363 | 868.500 | | |
| Mean | 3.400 | 1.767 | 4.779 | 2.894 | 28.517 | 48.727 | 10.121 | 289.500 | | |

*DCC* dust-capturing capacity, *TLS* total leaf size

**Table 6** Analysis of variance

| S.O.V | d.f. | SS | MSS | *F*-cal | S/NS | *F*-tab 5% | *F*-tab 1% | SEM+ | CD5% | CD1% |
|---|---|---|---|---|---|---|---|---|---|---|
| Treatment | 23 | 35646.694 | 1549.856 | 190.394 | * | 1.620 | 1.969 | 1.165 | 3.261 | 4.312 |
| C | 7 | 315.629 | 45.090 | 5.539 | * | 2.087 | 2.792 | 0.476 | 1.331 | 1.760 |
| A | 2 | 34081.208 | 17040.604 | 2093.337 | * | 3.072 | 4.787 | 0.672 | 1.883 | 2.489 |
| C × A | 14 | 1249.857 | 89.276 | 10.967 | * | 1.775 | 2.234 | 1.165 | 3.261 | 4.312 |
| Error | 120 | 976.829 | 8.140 | | | | | | | |
| Total | 143 | 36623.524 | | | | | | | | |
| Mean | 8.119 | | | | | | | | | |
| CV% | 35.142 | | | | | | | | | |

*represents value significant at 1 % and 5 % level of significance samples from forest area in the tree species investigated. Into the urban areas, the loss was lesser in comparison to the forest areas, whereas highest loss in total amount of chlorophyll in industrial area was evident hence, maximum chlorosis was observed. Carotenoid contents of the plant followed the same trend which is obvious as carotenoids protect chlorophyll from photo-oxidative destruction. Total carbohydrate and total protein content were recorded highest in forest areas followed by urban and least in industrial areas. Dust-capturing capacity was found to be minimum in September–October and maximum in the month of March. The activity of two oxidative enzymes peroxidase and polyphenol oxidase recorded maximum in industrial areas because the activity was found to increase during unfavourable season due to pollution stress. Dust retaining activity continues on limited scale due to automobile pollution, local climatic changes in forest and urban areas. In industrial area, size and structure of leaf is another factor which favours the deposition of dust and other particulate matter. Dense vegetation naturally cleanses the atmosphere by absorbing gases and some particulate matter through leaves. Trees have a very large surface area and their leaves function as an efficient pollutant-trapping device. Plants differ considerably with reference to their responses towards pollutants, some being highly sensitive and others being hardy and tolerant so plants have been classified according to their degree of sensitivity and tolerance towards various air pollutants. Sensitive plant species are suggested to act as bio-indicators. Levels of air pollution tolerance vary from species to species, depending on the capacity of plants to withstand the effect of pollutants without showing any external damage. Our finding supports the study of Nouchi (2002), Rajput and Agrawal (2005), Joshi et al. (2009) and Arya (2009).

## Conclusion and recommendations

The effectiveness of a green belt in intercepting and retaining atmospheric pollutants depend on several factors, viz., shape, size, moisture level, surface texture and nature (soluble or insoluble) of both the particulate matter. This study examines the selection of plant species which can be grown around industrial/urban areas in India to minimize effects of air pollutants. *Pongamia pinnata* (L.) Pierre may successfully be grown in towns and forest areas; these attractive plants are not only tolerant of pollution, but supply firewood and timber as well and beautify the landscape. Whilst selecting plant species for plantation in industrial urban areas these must be evaluated for various biological and socio-economic, as well as, a few biochemical characteristics, viz., plant habit, canopy structure, type of plant, laminar structure and economic value, etc. On the basis of this study, this pollution tolerance species can be recommended for greenbelt development in industrial urban areas for control and mitigation of air pollution.

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