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Seasonal Variations in Biochemical Parameters of Plants and their Air Pollution Tolerance in Industrial Area of Himachal Pradesh

KASHISH WALIA* and S. K. BHARDWAJ

Department of Environmental Science, Dr YSP University of Horticulture & Forestry Nauni, Solan (HP) India.

Abstract

In order to assess the biochemical parameters of plants and their tolerance to air pollution in Baddi industrial hub of Solan district of Himachal Pradesh a field survey was conducted in Baddi industrial region. To determine spatial effect of industrialization three commonly occurring plant species namely *Azadirachta indica, Leucaena leucocephala* and *Dalbergia sissoo* were selected at different distances *viz*. 0-100 m, 100-200 m, 200-400 m, 400-800 m and > 800 m. To assess the effect of seasons on the response of plants to air pollution summer, rainy and winter months were taken. The field experiment was arranged in factorial randomized block design by taking a total of 45 treatment combinations which were replicated four times. The biochemical parameters like ascorbic acid, chlorophyll, pH and relative water content were studied by using standard methods and based on these parameters the air pollution tolerance index (APTI) was evaluated during rainy, winter and summer seasons. The plant species wise variation in leaf ascorbic acid, total chlorophyll, pH and relative water content was in the range of 5.08-8.42 mg g^{-1},1.36-1.59 mg g^{-1},6.25-6.36 and 65.69-67.63% respectively. All the selected plants exhibited spatial and seasonal variations in their biochemical parameters. Leaf chlorophyll, pH and RWC increased with increasing distance and leaf ascorbic acid decreased with increasing distance. The APTI of the plants species followed the order *A .indica > L .leucocephala > D.sissoo* with respective values of 13.08, 11.61, 10.68. *A.indica* with highest index emerged as tolerant species and therefore should be selected for developing green belt in the industrial area.

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Keywords

Ascorbic Acid, Chlorophyll, Ph, Relative Water Content, Air Pollution Tolerance Index.

CONTACT Kashish Walia kashish7969@gmail.com Department of Environmental Science, Dr YSP University of Horticulture & Forestry Nauni, Solan (HP) India.

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Introduction

Air pollution is an inevitable harmful by product of rapid industrialization and urbanization and is responsible for variety of deleterious effects on both human and plant communities. Air quality has now become a major environmental concern since the beginning of industrialisation, resulting in a greater release of gaseous and particulate pollutants into the atmosphere[1]. In Asian countries including India the increasing urban population growth, industrial activities and automotive traffic have caused serious deteoriation of air quality and is considered the most dangerous, as its control is more complex than any other type of environmental problems and its amelioration is not feasible by physical and chemical methods[2,3]. However, plantation with suitable species have been considered as one of the best suitable abatement technique for its control. In plants the effects of poor air quality are often apparent on the leaves which are usually the most abundant and obvious primary receptors of large number of pollutants and provide an enormous area for impingement, absorption and accumulation of pollutants, thereby decreasing the pollutant level in the environment[4].

Plants vary in their sensitivity and tolerance to various kinds of toxins and hence their characterization helps in using them as a bio-indicator for monitoring atmospheric pollution[5]. Consequently bio monitoring of plants is now being considered as an important tool to evaluate the impact of air pollution[6]. In order to adapt to deteriorating air quality *viz.* stresses plants undergo many physiological and biochemical changes before any visible change in their morphology. The ability of each plant species to absorb and adsorb pollutants on their foliar surface varies greatly and depends on several biochemical,physiological and morphological characteristics[7]. Based on these biochemical parameters such as ascorbic acid, chlorophyll, leaf extract pH and relative water content APTI is calculated to determine the tolerance and sensitivity of plants to air pollution and is effective in evaluating the effects and the ways to combat these effects[8,9]. Since industrialization and urbanization has now become the way of life in the economy and Himachal Pradesh is no exception. Therefore, present study was conducted to screen out the tolerant plants in the industrial region by evaluating their APTI so that suitable plants may be screened for taking up plantations in such regions to breath quality air.

Material and Methods

The study was conducted in major industrial area of Himachal Pradesh located at Baddi in the foothills of Shiwalik range. The industrial town lies on the border of Punjab and Harayana states. It is situated in south-western side of Solan district and is about 45 km west of Solan. A detailed survey was conducted in the industrial area of Baddi to study the distribution of industries and vegetation in the region. Keeping in view the distribution of industries in the region five distances from (0-100 m), (100-200 m), (200-400 m), (400-800m), (> 800m) from the central location of the industrial cluster were selected. To compare the effect at different distances the site falling at > 800m was considered as control. At each distance the commonly occurring plant species namely *Azadirachta indica, Dalbergia sissoo* and *Leucaene leucocephala* were selected. In total there were 45 treatment combinations which were replicated four times i.e. at each distance four replications were taken in all the directions of industrial hub. Under each replication four plants were considered. The observations were recorded during three seasons summer (March-April), monsoon (July-August) and Winter (November-December) months respectively.

Sample Collection and Sample Analysis

In order to maintain the uniformity mature plants growing at iso-ecological conditions were selected for the study. To assess the APTI fully matured leaves of selected species were collected in the morning hours. The collected leaf samples were transported to laboratory for further analysis in ice box and were analyzed using following standard procedures for various physiological and biochemical parameters namely ascorbic acid[10], total chlorophyll content[11], leaf extract pH[12] and relative water content[13]

Ascorbic Acid

To estimate leaf ascorbic acid content of selected plant species 10g of the sample was taken. The sample was homogenized in metaphosphoric acid (3%) and filtered. The volume of the filtrate was made to 100ml by metaphosphoric acid (3%). The aliquot measuring 10ml was taken and titrated against standardized dye to an end point of pink

Table 1: Seasonal variation in leaf ascorbic acid content (mg g^{-1}) of plant species growing at different distances (m) in industrial area

	Season															
	Rainy				Winter				Summer							
Distance/ Species	***Azadirachta indica***	***Dalbergia sissoo***	***Leucaena leucocephala***	**Mean**	***Azadirachta Indica***	***Dalbergia sissoo***	***Leucaena leucocephala***	**Mean**	***Azadirachta indica***	***Dalbergia sissoo***	***Leucaena leucocephala***	**Mean**	***Azadirachta indica***	***Dalbergia sissoo***	***Leucaena leucocephala***	**Mean**
0-100	8. 12	4.69	6.3	**6.37**	9.29	5.78	7.32	**7.46**	10.05	6.68	8.65	**8.46**	9.15	5.71	7.42	**7.43**
100-200	7.49	4.47	5.83	**5.93**	8.75	5.68	6.82	**7.08**	9.66	6.11	8.27	**8.01**	8.63	5.42	6.97	**7.01**
200-400	7.26	4.35	5.48	**5.69**	8.13	5.44	6.34	**6.63**	9.55	5.62	7.85	**7.67**	8.31	5.14	6.55	**6.67**
400-800	7.18	4.27	5.1	**5.52**	7.89	4.79	5.79	**6.15**	9.34	5.45	7.62	**7.47**	8.14	4.83	6.17	**6.38**
> 800	7.08	3.89	4.55	**5.17**	7.39	4.46	5.37	**5.74**	9.13	4.61	7.39	**7.04**	7.86	4.31	5.77	**5.98**
Mean	**7.42**	**4.33**	**5.45**	**5.74**	**8.29**	**5.23**	**6.33**	**6.61**	**9.55**	**5.69**	**7.96**	**7.73**	**8.42**	**5.08**	**6.58**	

$LSD_{0.05}$	Species	:	0.04
	Season	:	0.04
	Distance	:	0.06
	Species × Season	:	0.08
	Species × Distance	:	0.1
	Season × Distance	:	0.1
	species × season × distance	:	0.17

colour as per the standard procedure outlined by Association of Official Agricultural Chemists[10]. The ascorbic acid content was expressed in milligrams per grams ($mg\ g^{-1}$.)

Ascorbic acid (mg/100g) = Dye factor × Titre reading × Volume made × 100 / Weight of leaves taken × Volume taken for estimation

Total chlorophyll

For the estimation of total chlorophyll content of the leaves, 10mg of the leaf sample was homogenized with 7ml dimethyl sulphoxide and was kept in oven at a temperature of 60-65ºC for 30-35mins. The samples were filtered and volume was made to 25ml by dimethyl sulphoxide. The absorbance was measured at 663nm and 645nm in spectrophotometer and chlorophyll was estimated using the following equation given by Hiscox and Istaelstam[11]

$$\text{Total chlorophyll (mg g}^{-1}\text{)} = \frac{20.2\ A_{645} + 8.02\ A_{663}\ \text{x}V}{a \times 1000 \times w}$$

Where;
V is volume of extract made
a is length of light path in cell (usually 1cm)
W is weight of sample
A_{645} is absorbance at 645nm
A_{663} is absorbance at 663nm

Leaf extract pH

Leaf extract pH of the sample was analyzed by the method suggested by Barrs and Weatherly[12]. Fresh leaf sample (10g) was homogenized using deionised water (50ml) and the supernatant obtained after centrifugation was collected for the determination of pH using a digital pH meter.

Relative water content

Relative water content of the samples was estimated using the method proposed by Singh[13] and was computed by using following equation

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

Where;
RWC is relative water content (%)
FW is fresh weight of leaf sample
DW is dry weight of leaf sample
TW is turgid weight of leaf sample

Air pollution tolerance index (APTI)

The Air pollution tolerance index based on leaf biochemical parameters was computed by using the following formulae given by Singh and Rao[14].

$$APTI = [A\ (T + P)] + R / 10$$

Where;
A is ascorbic acid ($mg\ g^{-1}$) of leaf sample
T is total chlorophyll ($mg\ g^{-1}$) of leaf sample
P is leaf extract pH of leaf sample
R is relative water content (%) of leaf sample

Statistical Analysis

The results were analyzed using RBD factorial by OP stat software and the treatment means were compared by means of LSD.

Results and Discussion

After performing and analyzing all the bio-chemical parameters of plant leaves and resultant APTI, following results has been concluded and the average values of the data has been presented in tabular form.

Ascorbic acid content

The plant species growing around industrial hub of Baddi were found to exhibit significant variation in the leaf ascorbic acid content (Table 1). Significantly, highest ascorbic acid content of 8.42 $mg\ g^{-1}$ was recorded in *A.indica* followed by *L. leucocephala* (6.58 $mg\ g^{-1}$) whereas, lowest of 5.08 $mg\ g^{-1}$ was noticed in *D. sissoo*. The ascorbic acid of this range in *A. indica* has also been reported by Trapathi *et al.*[15]. The higher ascorbic acid content in the leaves of *A.indica* as compared to other species may be probably due to its higher adaptive capacity to tolerate air pollution and other stresses. The increase in leaf ascorbic acid may also be due to improvement in the defense mechanism of the plants which has also been reported to vary with different plants[16]. The results are in conformity with Cocklin[17] and Aguiar-Silva *et al.*[18] who advocated that higher ascorbic acid content of the plant is a sign of its tolerance against pollution. The concentration of leaf ascorbic acid content during different seasons varied from 5.74 - 7.73 $mg\ g^{-1}$. Significantly, maximum ascorbic acid content of 7.73 $mg\ g^{-1}$ was noticed in summers followed by winters (6.61 $mg\ g^{-1}$) and rainy (5.74 mg

Table 2: Seasonal variation in leaf chlorophyll content (mg g-1) of plant species growing at different distances (m) in industrial area

	Season															
	Rainy				Winter				Summer							
Distance/ Species	***Azadirachta indica***	***Dalbergia sissoo***	***Leucaena leucocephala***	**Mean**	***Azadirachta Indica***	***Dalbergia sissoo***	***Leucaena leucocephala***	**Mean**	***Azadirachta indica***	***Dalbergia sissoo***	***Leucaena leucocephala***	**Mean**	***Azadirachta indica***	***Dalbergia sissoo***	***Leucaena leucocephala***	**Mean**
0-100	1.92	2.12	2.34	**2.13**	0.64	0.77	0.91	**0.77**	0.6	0.72	0.74	**0.69**	1.05	1.2	1.33	**1.2**
100-200	2.26	2.58	2.44	**2.42**	0.81	0.83	1.02	**0.88**	0.75	0.88	0.76	**0.8**	1.27	1.43	1.41	**1.37**
200-400	2.31	2.7	2.49	**2.5**	1.02	0.93	1.34	**1.1**	0.81	0.91	0.88	**0.86**	1.38	1.51	1.57	**1.49**
400-800	2.41	2.86	2.78	**2.68**	1.11	1.12	1.68	**1.3**	0.82	0.93	0.92	**0.89**	1.45	1.64	1.79	**1.62**
> 800	2.57	3.14	2.8	**2.84**	1.41	1.21	1.79	**1.47**	0.95	1.02	0.94	**0.97**	1.64	1.79	1.84	**1.76**
Mean	**2.29**	**2.68**	**2.57**	**2.51**	**1.19**	**0.98**	**1.35**	**1.11**	**0.79**	**0.89**	**0.85**	**0.84**	**1.36**	**1.51**	**1.58**	

$LSD_{0.05}$	Species	:	0.05
	Season	:	0.05
	Distance	:	0.06
	Species × Season	:	0.08
	Species × Distance	:	NS
	Season × Distance	:	0.11
	species × season × distance	:	0.19

g^{-1}) season respectively. The higher production of ascorbic acid in the leaves of selected plant species might be due to relatively more stress conditions during summers followed by winters and rainy season. The, season wise variation in the ascorbic acid content is in agreement with the findings of Jyothi and Jaya[19]. The leaf ascorbic acid content of plant species growing at different distances ranged from 5.98 – 7.43 mg g^{-1} which decreased with the increase in distances from the central hub of the industrial area. Significantly, highest ascorbic acid content of 7.43 mg g^{-1} was noticed in plants growing at 0-100 m and the distance wise order of ascorbic acid content in plants was 0-100 > 100-200 > 200-400 > 400-800 > 800 m (control). The higher pollution near the industries in the Baddi area (0-100 m) might have hastened the ascorbic acid content of the leaves of the selected plants as a part of the defence mechanism of the species against the stress caused due to pollution load. The results are in line with the findings of Bhattacharya *et al.*[20] who have also recorded higher values of ascorbic acid in plant leaves at polluted sites. Pollution load dependent increase in ascorbic acid content of all the plant species may also be due to the increased rate of production of reactive oxygen species (ROS) during photo-oxidation of SO_2 to SO_3 where sulfites are generated from SO_2 as noticed by Aghajanzadeh *et al.*[21]. The interaction between species x season and distance was also found to be statistically significantly, highest content of 10.05 mg g^{-1} was recorded in *A. indica* growing at a distance of 0-100 m during summer season which was followed by 9.66 and 9.55 mg g^{-1} content at the same distance and during same season whereas, minimum content of 3.89 mg g^{-1} was recorded in *D. sissoo* at the control site during rainy season.

Chlorophyll Content

The leaf chlorophyll content of selected plant species growing around industrial hub of Himachal Pradesh exhibited significant variation. The highest leaf chlorophyll content of 1.59 mg g 1 was recorded in *L. leucocephala* followed by *D. sissoo* (1.51 mg g^{-1}) whereas, minimum (1.36 mg g^{-1}) was noticed in *A. indica*. (Table 2).The results are in line with findings of Katiyar and Dubey[22] and Ninave *et al.*[23] Similarly, seasons of the year also exerted significant influence in leaf chlorophyll content of the plants growing in the industrial area. The highest chlorophyll content of 2.51 mg g^{-1} was recorded during rainy season followed by 1.11 mg g^{-1} content in winter and minimum (0.84 mg g^{-1}) in summer season. Similar results were obtained by Jyothi and Jaya[19] who also reported high chlorophyll content in plants during rainy followed by winter and summer seasons. The chlorophyll content was higher in rainy season which may be due to the washout of dust particles from the leaf surface, low level of pollution in the atmosphere and sufficient moisture in the soil. Low chlorophyll content in winter season may be due to the high pollution level, temperature stress, low sunlight intensity and short photoperiod. The plants growing at different locations from the industrial hub were found to differ significantly in their leaf chlorophyll content. The leaf chlorophyll content of plants growing at different distances from the industrial hub ranged from 1.20 -1.76 mg g^{-1} the leaf chlorophyll was found to increase with the increasing distance and the order was 0-100 < 100-200 < 200-400 < 400-800 < 800 m (control). The results are in line with Mir *et al.*[24] and Tripathi and Gautam[25] who also observed in their studies that high level of automobile pollution reduce chlorophyll pigmentation in leaves of plants near roadside. The present results are also in line with the observations of Wang and Lu[26] and Karmakar *et al.*[27]. The three way interaction between species x season and distance had a statistically significant variation in leaf chlorophyll content the highest leaf chlorophyll content of 3.14 mg g^{-1} was recorded during rainy season in *D. sissoo* growing away from the industrial area, i.e., > 800m (control), whereas, minimum (0.60 mg g^{-1}) was noticed during summer months in *A. indica* growing nearer to industry, i.e., at distance of 0-100 m. In all the species the leaf chlorophyll content tended to increase with the increase in distance from the industrial hub and from the stress period of summer and winter months to rainy season.

Leaf Exract pH

The significant variations in the leaf extract pH under study is presented in (Table 3). The significantly highest leaf extract pH was found in *A. indica* (6.36) which was statistically at par with *D. sissoo* (6.32) and minimum (6.25) was recorded in *L. leucocephala*. The results are in line with Horaginamani *et al.*[28] who reported same range of leaf extract pH in *D. sissoo*. Significantly, highest leaf extract pH of 6.48 irrespective of the species was noticed in rainy

Table 3: Seasonal variation in leaf extract pH of plant species growing at different distances (m) in industrial area

	Season															
	Rainy				Winter				Summer							
Distance/ Species	***Azadirachta indica***	***Dalbergia sissoo***	***Leucaena leucocephala***	**Mean**	***Azadirachta Indica***	***Dalbergia sissoo***	***Leucaena leucocephala***	**Mean**	***Azadirachta indica***	***Dalbergia sissoo***	***Leucaena leucocephala***	**Mean**	***Azadirachta indica***	***Dalbergia sissoo***	***Leucaena leucocephala***	**Mean**
0-100	6.46	6.34	6.26	**6.36**	6.38	6.29	6.23	**6.3**	5.87	6.14	5.85	**5.95**	6.24	6.26	6.11	**6.2**
100-200	6.51	6.35	6.38	**6.41**	6.46	6.32	6.3	**6.36**	5.9	6.15	5.92	**5.99**	6.29	6.27	6.2	**6.25**
200-400	6.56	6.41	6.44	**6.47**	6.47	6.33	6.34	**6.38**	6.09	6.18	5.95	**6.07**	6.37	6.31	6.24	**6.31**
400-800	6.6	6.47	6.52	**6.53**	6.48	6.37	6.41	**6.42**	6.18	6.2	5.98	**6.12**	6.42	6.34	6.3	**6.36**
> 800	6.68	6.58	6.62	**6.63**	6.56	6.43	6.49	**6.49**	6.25	6.23	6.06	**6.18**	6.5	6.41	6.39	**6.43**
Mean	**6.56**	**6.43**	**6.44**	**6.48**	**6.47**	**6.35**	**6.35**	**6.39**	**6.06**	**6.18**	**5.95**	**6.06**	**6.36**	**6.32**	**6.25**	

$LSD_{0.05}$	Species	:	0.05
	Season	:	0.05
	Distance	:	0.06
	Species × Season	:	0.08
	Species × Distance	:	NS
	Season × Distance	:	NS
	species × season × distance	:	NS

season whereas, lowest (6.06) was in summer season and the order was rainy > winter > summer. The higher pH of 6.48 in rainy season may be due to washing effect of rains to the acidic pollutants. Jyothi and Jaya[19] also reported the maximum pH during monsoon season with gradual reduction through winter and minimum in summer. The leaf pH of selected plants species growing at different distances from the industrial hub ranged from 6.20 - 6.43. The plants growing at non polluted site (control) i.e., at a distance of more than 800 m exhibited significantly highest leaf pH (6.43) which was therefore, statistically at par with (6.32) and minimum leaf pH (6.20) was recorded at a distance of 0-100 m which was however statistically at par with the plants growing at 100-200 m distance from industrial hub.The pH increased with the increasing distance and the order was 0-100 < 100-200 < 200-400 < 400-800, which may be due to more pollution load near the industries which might have induced more acidity in the leaves of the plants. The results are in line with the finding of Singare and Talpade[29] and Subramani and Devaanandan[30] who reported that pH followed an exponential decrease with increase in the traffic pollution and drifted towards acidic range. The interaction between species x season and distance with respect to leaf extract pH was found statistically non significant.

Leaf Relative Water Content

The relative water content of the selected plant species growing in and around the industrial area of Baddi varied significantly (Table 4). In species relative water content ranged from 65.69-67.63 %. The highest relative water of 67.63% was recorded in *D. sissoo* followed by *A. indica* (66.66 per cent) whereas, lowest of 65.69% was found in *L. leucocephala*. These results are similar to those of Nwadinigwe[31] who reported that relative water content is due to the difference among plant species. The maximum relative water content of *D. sissoo* may be attributed to its tolerant nature towards pollution. These results are in conformity with findings of Gholami *et al.*[32] who reported that transpiration rates are frequently high under polluted conditions therefore, maintenance of relative water content by the plant may determine its relative tolerance to pollution. Likewise, seasons also exerted a significant influence on leaf relative water content of the selected plants. The maximum relative water content of 80.10 per cent was recorded during rainy season followed by winter (64.43 per cent) and minimum of 55.45 per cent was recorded in summer season. The trend was in line with the results reported by Jyothi and Jaya[19] who also observed highest relative water content in monsoon season followed by winter and rainy season. Significant variations were found in the relative water content of the leaves of plants growing at different distances in the industrial area. The leaf relative water content of plant species growing at different distances was found to decrease with the increase in distances from the central hub of the industrial area and was in the order of 0-100 > 100-200 > 200-400 > 400-800 > control. The higher relative water content near the industrial hub (0-100 m) may be ascribed to higher pollution load which might have resulted in increased water content in the leaves to maintain protoplasmic permeability under stress conditions. This is in agreement with the findings of Jyothi and Jaya[19] who reported that the plants have ability to adapt by enhancing leaf relative water content under polluted conditions. Similar results have also been reported by Tanee *et al.*[33] who pointed out that plants at polluted site absorbed more water, which could be a physiological mechanism of the plants to withstand the effect of pollution in its environment. The study concluded that during rainy season *D. sissoo* growing at 0-100 m distance contained relative water content to the tune of 86.05 per cent which was significantly higher as compared to other treatment combinations. The interaction between species x season and distance showed minimum relative water content of 48.45 per cent in *A. indica* during summer season at non polluted site (control) which was however, found to be statistically at par with *D. sissoo* and *A. indica* growing at control site and at 400-800 m distance during summer season.

Air Pollution Tolerance Index (APTI)

Among the plants growing in and around industrial area *A. indica* irrespective of seasons and distances registered the highest APTI value of 13.08 followed by *L. leucocephala* (11.61) and *D .sissoo* (10.68). The highest APTI of *A. indica* (13.08) indicated its higher tolerance level to air pollution (Table 5). Singh and Rao[14] reported that plants which have higher index value are tolerant to air pollution and can be used as sink to control pollution, while plants with low index value show less tolerance and can be used to indicate levels of air pollution.

Table 4: Seasonal variation in leaf relative water content (%) of plant species growing at different distances (m) in industrial area

	Season															
	Rainy				Winter				Summer							
Distance/ Species	***Azadirachta indica***	***Dalbergia sissoo***	***Leucaena leucocephala***	**Mean**	***Azadirachta indica***	***Dalbergia sissoo***	***Leucaena leucocephala***	**Mean**	***Azadirachta indica***	***Dalbergia sissoo***	***Leucaena leucocephala***	**Mean**	***Azadirachta indica***	***Dalbergia sissoo***	***Leucaena leucocephala***	**Mean**
0-100	81.83	86.05	84.75	**84.21**	69.48	68.75	71.24	**69.82**	60.85	62.36	58.81	**60.87**	70.72	72.36	71.6	**71.57**
100-200	80.06	85.52	81.26	**82.28**	69.24	68.63	67.91	**68.59**	55.47	61.73	55.22	**57.47**	68.23	71.96	68.13	**69.45**
200-400	78.22	80.25	78.74	**79.07**	68.92	67.7	64.4	**67**	54.29	56.62	54.95	**55.29**	67.14	68.19	66.03	**67.12**
400-800	78.15	79.06	77.16	**78.12**	67.6	59.43	55.87	**60.97**	53.15	55.13	53.08	**53.79**	66.3	64.54	62.04	**64.29**
> 800	75.96	78.43	76.14	**76.85**	58.22	55.29	53.85	**55.79**	48.45	49.58	52	**55.01**	60.88	61.1	60.66	**60.88**
Mean	**78.84**	**81.86**	**79.61**	**80.1**	**66.69**	**63.96**	**62.65**	**64.43**	**54.44**	**57.08**	**54.81**	**56.48**	**66.66**	**67.63**	**65.69**	

$LSD_{0.05}$	Species	:	0.44
	Season	:	0.44
	Distance	:	0.6
	Species × Season	:	0.8
	Species × Distance	:	1
	Season × Distance	:	1
	Species x season x Distance	:	1.72

Table 5: Seasonal variation in leaf APTI of plant species growing at different distances (m) in industrial area

Distance/ Species	Season															
	Rainy				Winter				Summer							
	Azadirachta indica	*Dalbergia sissoo*	*Leucaena leucocephala*	Mean	*Azadirachta indica*	*Dalbergia sissoo*	*Leucaena leucocephala*	Mean	*Azadirachta indica*	*Dalbergia sissoo*	*Leucaena leucocephala*	Mean	*Azadirachta indica*	*Dalbergia sissoo*	*Leucaena leucocephala*	Mean
0-100	14.98	12.57	13.9	**13.82**	13.46	10.95	12.35	**12.25**	12.59	10.82	11.59	**11.66**	13.68	11.45	12.61	**12.58**
100-200	14.57	12.54	13.26	**13.46**	13.28	10.92	11.78	**11.99**	11.97	10.46	11.04	**11.16**	13.27	11.31	12.03	**12.2**
200-400	14.25	11.99	12.76	**13**	12.98	10.72	11.31	**11.67**	12.01	9.65	10.86	**10.84**	13.08	10.78	11.64	**11.83**
400-800	14.29	11.89	12.46	**12.88**	12.75	9.53	10.27	**10.85**	11.85	9.39	10.56	**10.6**	12.96	10.27	11.09	**11.44**
> 800	14.15	11.62	11.9	**12.55**	11.71	8.93	9.83	**10.16**	11.41	8.3	10.38	**10.03**	12.42	9.62	10.71	**10.91**
Mean	**14.45**	**12.12**	**12.85**	**13.14**	**12.84**	**10.21**	**11.11**	**11.38**	**11.97**	**9.72**	**10.88**	**10.86**	**13.08**	**10.68**	**11.61**	

$LSD_{0.05}$	Species	:	0.1
	Season	:	0.1
	Distance	:	0.12
	Species × Season	:	0.16
	Species × Distance	:	0.21
	Season × Distance	:	0.21
	species × season × distance	:	0.37

Similar results are also reported by Gholami *et al.*[32] and Lohe *et al.*[34] that APTI is a species dependent plant attribute which expresses the inherent ability of plants to encounter stress arising from pollution. The variation in tolerance in the plants of a region to air pollutant has also been reported by Karthiyayini *et al*[35], Agbaire and Esiefarienrhe[36], Begum and Harikrishna[37]. The Seasonal variations of the APTI of selected plants were also found to be significant. The maximum APTI value of 13.14 was recorded during rainy season followed by winter (11.38) and summer (10.86) season. The plant species growing at various distances from the industrial hub of Baddi also exhibited significant variations in their APTI values. The plants growing at 0-100 m distance found to have maximum APTI value of 12.58. Whereas, those growing at a control site (> 800 m) registered minimum value of 10.91. The results are in line with the findings of Randhi and Reddy[38] who revealed that plant species in the polluted environment improve their capacity to survive and become tolerant to air pollution. Relatively less APTI value of plants growing away from industrial hub and at control site may be ascribed to less level of industrial pollution. The interaction between species x season and distance was found to be statistically significant, out of the three selected species *A. indica* growing within 0-100 m distance registered highest APTI value of 14.98 during rainy season. On the other hand minimum APTI value of 8.30 was noticed in case of *D.sissoo* growing at the control site (> 800 m) during summer season.

Conclusion

The plants growing near the industrial region developed tolerance to air pollution by adjusting their biochemical parameters as compared to those growing at farther distances. Relatively *A.indica* emerged as tolerant species among the selected species and therefore should be recommended for developing green belt in the industrial region of Himachal Pradesh.

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