Journal of Environmental Biology
©Triveni Enterprises, Lucknow (India)
Free paper downloaded from: www.jeb.co.in

31 379-386 (**May** 2010)
For personal use only
Commercial distribution of this copy is illegal

Evaluation of air pollution tolerance index of selected plant species along roadsides in Thiruvananthapuram, Kerala

S. Jissy Jyothi* and D.S. Jaya

Department of Environmental Sciences, University of Kerala, Kariavattom P.O., Thiruvananthapuram - 695 581, India

(Received: February 04, 2009; Revised received: May 02, 2009; Accepted: May 22, 2009)

Abstract: *To develop the usefulness of plants as bioindicators requires an appropriate selection of plant species which entail an utmost importance for a particular situation. In the present study a periodic evaluation of air pollution tolerance index [APTI] of selected tree species such as Polyalthia longifolia, (Sonner) Thw., Alstonia scholaris, R. Br., Mangifera indica, L., and shrubs Clerodendron infortunatum, L., Eupatorium odoratum, L., and Hyptis suaveolens, (L.) Poit., growing adjacent to the National Highway – 47 passing through Thiruvananthapuram District which lies on the south-west coast of India, was carried out with a view to find out the air pollution tolerance as well as sensitivity of the plant species during different seasons. Among the trees in the roadside areas studied, Polyalthia longifolia, (Sonner) Thw., expressed highest APTI values and proved to be a tolerant variety and the others as sensitive species to air pollutants. In the case of shrubs, Clerodendron infortunatum, L., exhibited highest APTI values (7.34) and found to be more tolerant compared to the other two shrub species studied.*

Key words: *Chlorophyll, Ascorbic acid, Air pollution tolerance index, Biomonitors*
PDF of full length paper is available online

Introduction

Plants are an integral basis for all ecosystems and also most likely to be affected by airborne pollution which are identified as the organisms with most potential to receive impacts from ambient air pollution. Also the effects are most often apparent on the leaves which are usually the most abundant and most obvious primary receptors of large number of air pollutants. Biomonitoring of plants is an important tool to evaluate the impact of air pollution. Hence in the latest years urban vegetation became increasingly important not only for social reasons but mostly for affecting local and regional air quality. The response of plants towards air was assessed by air pollution tolerance index. The usefulness of evaluating APTI for the determination of tolerance as well as sensitiveness of plant species were followed by several authors (Agrawal and Tiwari, 1997; Dwivedi and Tripathi, 2007; Liu and Ding, 2008; Dwivedi *et al.,* 2008). These studies provided valuable informations for landscapers and greenbelt designers to select the sensitive as well as tolerant varieties of plant species for using them to identify the pollution loads of urban/industrial areas, and also to use the tolerant varieties for curbing the menace of air pollution. The results of these studies showed that the plants with higher APTI values were found to be resistant to air pollution. In the present study, a periodic evaluation of air pollution tolerance index of some selected plant species (trees and shrubs) growing adjacent to the National Highway-47 passing through Thiruvananthapuram District, the capital of Kerala State and lies on the south-west coast of India, was carried out with a view to find out the tolerance as well as sensitivity of the common plant species subjected to vehicular pollution.

Materials and Methods

The entire study area extends from Parassala to Kadambattukonam (75 km) and is geographically located between longitude 76° 40' to 77° 18' E and latitude 8° 8' to 8° 56' N in Thiruvananthapuram District of Kerala State. For this study nine sampling stations were selected at an interval of 8 km along the roadsides of National Highway-47 and these stations are also the busy traffic junctions of the highway. These include Kallambalam (Station-1), Attingal (Station-2), Mangalapuram (Station-3), Kazhakoottam (Station-4), Ulloor (Station-5), Thampanoor (Station-6), Nemom (Station-7), Neyyattinkara (Station-8) and Parassala (Station-9) and a site inside Karyavattom campus was selected as station-10 (control) which is in a benign environment.

The study was conducted during summer (March), monsoon (July) and winter (November) seasons in the year 2006-2007. Three species each of evergreen dicotyledonous trees and dicotyledonous shrubs, which are common in all the ten stations in the study area were selected for the purpose. *Polyalthia longifolia*, (Sonner) Thw., *Alstonia scholaris*, R. Br. and *Mangifera indica*, L., were the evergreen trees and *Clerodendron infortunatum*, L., *Eupatorium odoratum*, L. and *Hyptis suaveolens*, (L.) Poit., were the shrubs selected for the study. Traffic intensity in the study stations were also determined by counting the number of vehicles plying

* **Corresponding author:** jissyjyothi@gmail.com

through the National Highway-47, and were converted to Passenger Car Units (PCU) for the purpose of interpretation of the results (Khanna and Justo, 2001).

Fully mature leaves in triplicates were collected in morning hours from the selected evergreen trees of almost same diameter at breast height (DBH) and from the shrubs of almost same height. Utmost care was taken that the samples from each study site were collected from plants growing in isoecological conditions. The fresh leaf samples were analyzed for total chlorophyll, ascorbic acid, leaf extract pH and relative water content using the standard procedures of Arnon (1949), Sadasivam and Manickam (1996), Varshney (1992) and Barr and Weatherly (1962) respectively for the evaluation of air pollution tolerance index. Chlorophyll was extracted in 80% acetone and the absorption at 663 nm and 645 nm were read in a spectrophotometer. Using the absorption coefficients, the amount of chlorophyll was calculated. For the determination of ascorbic acid content, a homogenate was prepared by using 4% oxalic acid, and was dehydrogenated by bromination. The dehydroascorbic acid was then reacted with 2, 4-dinitrophenyl hydrazine to form osazone and dissolved in sulphuric acid to give an orange-red colour solution which was measured at 540 nm. Fresh leaf (0.5 g) sample was homogenized using 50 ml deionized water and the supernatant obtained after centrifugation was collected for detection of pH using digital pH meter. The percentage relative water content was calculated by using the initial weight, turgid weight and dry weights of leaf samples.

The air pollution tolerance index [APTI] was computed by the method suggested by Singh and Rao (1983) using the equation,

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

where A - ascorbic acid (mg g^{-1} FW), T - total chlorophyll (mg g^{-1} FW), P - leaf extract pH and R - relative water content (%) of the leaves.

The results were statistically analyzed and interpreted by three way ANOVA using SIGMA STAT software version 3.5. To isolate which group(s) differ from the others with respect to the seasons, plants and study stations; pairwise Duncan's new multiple range comparison procedure and multivariate interaction tests were also carried out.

Results and Discussion

All the parameters studied exhibited significant variation ($p<0.001$) from species to species, station to station and season to season. The pairwise multiple comparisons for factors: season, plant and location was also found significant at $p<0.05$.

Changes in total chlorophyll content: The total chlorophyll content of selected plant species during summer, monsoon and winter seasons are illustrated fresh weight (FW) graphically in Fig. 1a,b and c respectively. Among the tree species studied, *Polyalthia longifolia*, (Sonner) Thw., showed higher baseline levels of total chlorophyll with a least square mean (LSM) value of about 3.65 mg g^{-1} FW followed by *Alstonia scholaris*, R. Br. (1.91 mg g^{-1} FW) and *Mangifera indica*, L., (1.22 mg g^{-1} FW). Among the shrubs, higher baseline levels of chlorophyll was observed in the leaves of *Clerodendron infortunatum*, L., in which the LSM value was 2.85 mg g^{-1} FW followed by *Eupatorium odoratum*, L. (1.37 mg g^{-1} FW) and in *Hyptis suaveolens*, (L.) Poit. (1.14 mg g^{-1} FW). Regarding the study stations, the LSM value for chlorophyll was higher at station-10 (3.06 mg g^{-1} FW), which is the control station and the value was lowest at station-6 (1.50 mg g^{-1} FW). The chlorophyll value was highest during monsoon season (2.48 mg g^{-1} FW) and the chlorophyll content found decreased to about 1.94 mg g^{-1} FW during winter and 1.65 mg g^{-1} FW during summer. From the analyses of the results of chlorophyll, it has been obvious that all the plant species at station-10 (control station) possess highest concentrations of chlorophyll irrespective of season. A considerable significant reduction was found at all other stations compared to the control station during the entire study period and the highest reduction was attributed at station-6 which was the urban centre (Thampanoor) with the highest traffic intensity among the study stations.

Chlorophyll content of plants signifies its photosynthetic activity as well as the growth and development of biomass. It is well evident that chlorophyll content of plants varies from species to species; age of leaf and also with the pollution level as well as with other biotic and abiotic conditions (Katiyar and Dubey, 2001). Degradation of photosynthetic pigment has been widely used as an indication of air pollution (Ninave *et al*., 2001). Present study revealed that chlorophyll content in all the plants varies with the pollution status of the area *i.e.* higher the pollution level in the form of vehicular exhausts lower the chlorophyll content. It also varies with the tolerance as well as sensitivity of the plant species *i.e.* higher the sensitive nature of the plant species lower the chlorophyll content. Studies (Mir *et al*., 2008; Tripathi and Gautam, 2007) also suggest that high levels of automobile pollution decreases chlorophyll content in higher plants near roadsides. In all the plant species, chlorophyll content was higher in monsoon season which might be due to the washout of dust particles from the leaf surface (which will increase photosynthetic activity), low level of pollution and water content of soil as suggested by Shyam *et al.* (2006). Low chlorophyll content in winter season might be due to the high pollution level, temperature stress, low sunlight intensity and short photoperiod. Irrespective of study stations, higher baseline levels of total chlorophyll was observed in *Polyalthia longifolia*, (Sonner) Thw., among the evergreen trees studied and *Clerodendron*

Table - 1: Air pollution tolerance index of selected plants during different seasons [The values are mean of three replications ± SD]

Station	*Mangifera indica*	*Alstonia scholaris*	*Polyalthia longifolia*	*Clerodendron infortunatum*	*Eupatorium odoratum*	*Hyptis suaveolens*
Summer						
S1	6.96 ± 0.505*	5.80 ± 0.180*	13.03 ± 0.193*	5.07 ± 0.260*	3.15 ± 0.225*	2.50 ± 0.180*
S2	7.14 ± 0.124	6.90 ± 0.157*	13.49 ± 0.206	5.13 ± 0.194*	3.29 ± 0.239*	3.57 ± 0.194*
S3	7.59 ± 0.112	7.38 ± 0.106*	13.22 ± 0.453	5.60 ± 0.255*	3.48 ± 0.352*	2.57 ± 0.233*
S4	7.46 ± 0.325	5.77 ± 0.229*	13.65 ± 0.246	5.35 ± 0.145*	3.39 ± 0.227*	2.80 ± 0.241*
S5	6.22 ± 0.142*	5.51 ± 0.170*	13.38 ± 0.081	5.30 ± 0.220*	3.62 ± 0.188*	3.19 ± 0.135*
S6	5.04 ± 0.230*	4.72 ± 0.292*	13.57 ± 0.145	6.02 ± 0.247	3.19 ± 0.294*	2.45 ± 0.176*
S7	6.33 ± 0.153*	5.44 ± 0.182*	13.72 ± 0.049	5.18 ± 0.332*	3.79 ± 0.227*	3.21 ± 0.157*
S8	6.51 ± 0.094*	6.29 ± 0.155*	12.97 ± 0.100*	5.36 ± 0.134*	4.21 ± 0.119	3.09 ± 0.124*
S9	7.72 ± 0.297	5.39 ± 0.208*	13.09 ± 0.091*	5.10 ± 0.156*	3.66 ± 0.192*	3.12 ± 0.1298
S10 (Control)	7.54 ± 0.139	9.11 ± 0.182	13.61 ± 0.212	6.28 ± 0.166	4.65 ± 0.186	4.14 ± 0.129
Monsoon						
S1	8.45 ± 0.144*	7.91 ± 0.207*	13.77 ± 0.327*	6.86 ± 0.131*	7.10 ± 0.144	5.70 ± 0.116
S2	8.00 ± 0.154*	8.13 ± 0.175*	13.21 ± 0.285*	7.11 ± 0.228	7.03 ± 0.200	5.69 ± 0.223
S3	9.07 ± 0.183*	8.20 ± 0.123*	14.17 ± 0.212	7.21 ± 0.148	7.26 ± 0.190	5.86 ± 0.107
S4	7.73 ± 0.152*	8.12 ± 0.072*	13.41 ± 0.271*	6.95 ± 0.151	7.17 ± 0.159	5.71 ± 0.192
S5	6.72 ± 0.235*	6.91 ± 0.329*	13.48 ± 0.151*	6.90 ± 0.182*	6.86 ± 0.242	5.69 ± 0.339
S6	6.50 ± 0.309*	6.51 ± 0.129*	13.88 ± 0.146*	7.15 ± 0.119	6.86 ± 0.167	5.65 ± 0.249
S7	7.64 ± 0.206*	7.54 ± 0.082*	13.88 ± 0.236*	7.17 ± 0.182	7.06 ± 0.237	5.74 ± 0.156
S8	9.16 ± 0.216*	8.02 ± 0.249*	13.76 ± 0.339*	6.91 ± 0.298*	7.19 ± 0.345	5.51 ± 0.326
S9	8.28 ± 0.162*	8.41 ± 0.132*	14.01 ± 0.262	6.98 ± 0.137	7.01 ± 0.223	5.81 ± 0.294
S10 (Control)	9.70 ± 0.174	8.87 ± 0.202	14.53 ± 0.111	7.34 ± 0.227	7.19 ± 0.207	5.92 ± 0.111
Winter						
S1	7.31 ± 0.179*	6.25 ± 0.236*	13.44 ± 0.141	5.82 ± 0.361	4.10 ± 0.438*	3.96 ± 0.147*
S2	7.12 ± 0.173*	5.28 ± 0.256*	13.26 ± 0.178*	5.74 ± 0.163	4.97 ± 0.126*	4.51 ± 0.245*
S3	8.04 ± 0.186	7.47 ± 0.247*	13.50 ± 0.137	5.88 ± 0.137	5.03 ± 0.314*	4.26 ± 0.187*
S4	7.94 ± 0.176	5.40 ± 0.249*	13.14 ± 0.218*	5.70 ± 0.225	4.82 ± 0.195*	3.75 ± 0.227*
S5	7.20 ± 0.146*	5.11 ± 0.007*	13.43 ± 0.142	6.26 ± 0.121	4.34 ± 0.170*	3.22 ± 0.175*
S6	5.83 ± 0.219*	5.62 ± 0.178*	13.44 ± 0.236	6.19 ± 0.131	3.65 ± 0.197*	3.54 ± 0.105*
S7	6.57 ± 0.108*	5.79 ± 0.156*	13.11 ± 0.143*	6.01 ± 0.070	3.93 ± 0.294*	3.67 ± 0.172*
S8	7.09 ± 0.173*	6.13 ± 0.189*	13.29 ± 0.220*	5.93 ± 0.223	4.14 ± 0.170*	3.95 ± 0.102*
S9	7.68 ± 0.172*	5.81 ± 0.089*	13.22 ± 0.107*	5.86 ± 0.215	5.07 ± 0.343*	4.19 ± 0.238*
S10(Control)	8.23 ± 0.066	8.71 ± 0.176	13.80 ± 0.226	6.02 ± 0.191	6.23 ± 0.178	5.18 ± 0.199

*The values differ significantly at $p<0.05$

infortunatum, L., among the shrubs studied, and this higher levels of total chlorophyll observed may be due to its tolerance nature (Beg *et al*., 1990).

Changes in ascorbic acid content: Fig. 2a,b and c are the graphical illustrations of leaf ascorbic acid contents in the selected plant species during summer, monsoon and winter seasons. An increasing trend was observed in the case of ascorbic acid concentration compared to the control station (station-10 with LSM 1.45 mg g^{-1} FW) and the increase was found maximum at station-6 (LSM 2.79 mg g^{-1} FW). Among the tree species studied, *Polyalthia longifolia*, (Sonner) Thw., exhibited higher baseline levels (LSM 5.29 mg g^{-1} FW) followed by *Mangifera indica*, L., 2.46 mg g^{-1} FW and *Alstonia scholaris*, R. Br., 2.06 mg g^{-1} FW. The LSM value of about 1.42 mg g^{-1} FW (for *Eupatorium odoratum*, L.) was found maximum followed by 1.08 mg g^{-1} FW (for *Clerodendron infortunatum*, L.) and 0.58 mg g^{-1} FW (for *Hyptis suaveolens*, (L.) Poit.) in the case of shrub species studied. The season specific LSM for ascorbic acid was found higher during summer (2.63 mg g^{-1} FW) followed by a winter season (2.20 mg g^{-1} FW) and monsoon (1.62 mg g^{-1} FW).

Being a very important reducing agent, ascorbic acid also plays a vital role in cell wall synthesis, defense and cell division (Conklin, 2001). Present study showed elevation in the concentration of ascorbic acid with respect to the control station (station-10) in all the plant species selected. Pollution load dependent increase in ascorbic acid content of all the plant species may 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 absorbed. Chaudhary and Rao (1977) and Varshney and Varshney (1984) are of the opinion that higher ascorbic acid content of the plant is a sign of its tolerance against sulphur dioxide pollution. In the present

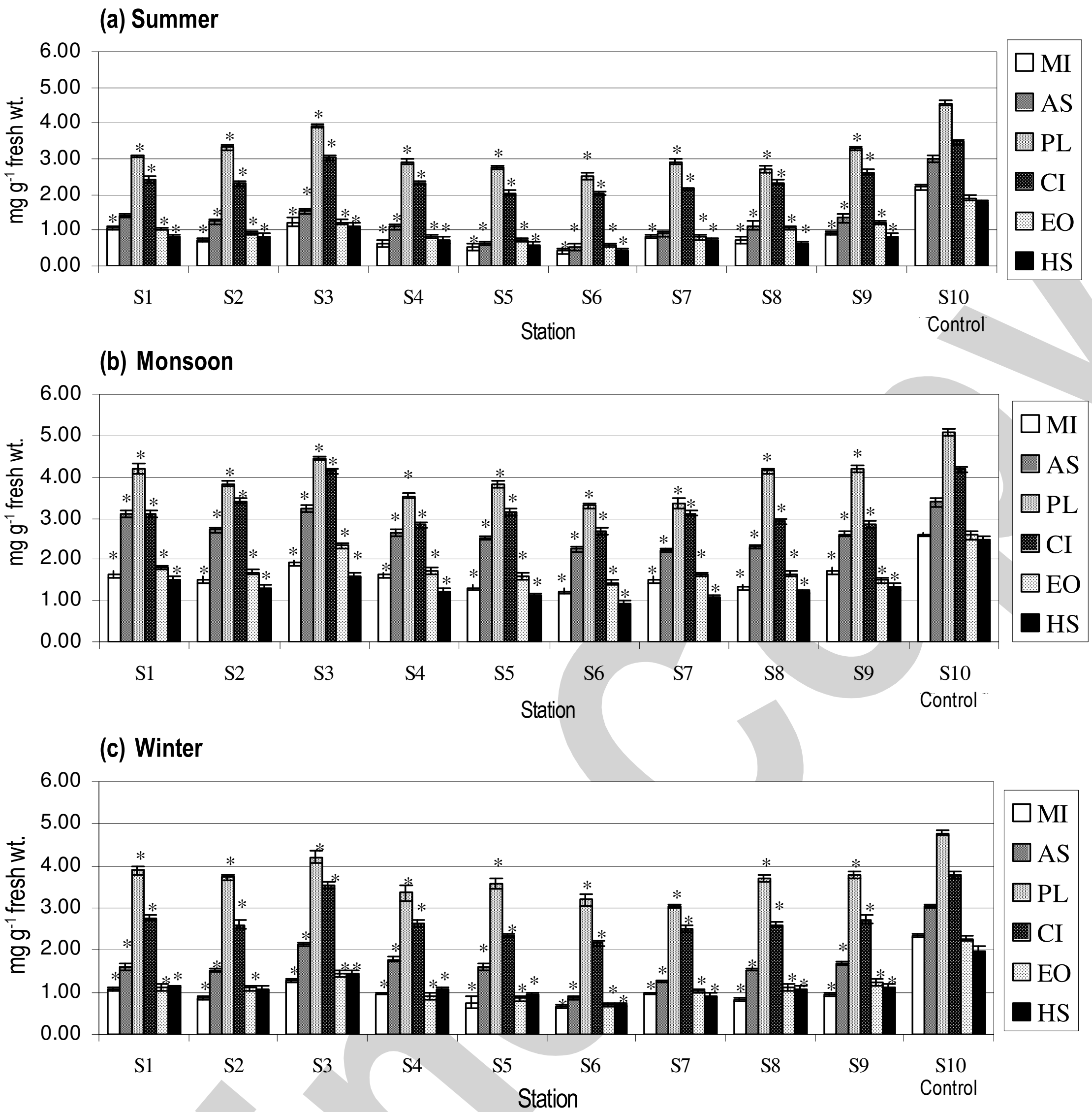

Fig. 1: Total chlorophyll content during different seasons - (a), (b) and (c) the bars represent the average of three replications ± SD, *The values differ significantly at 5% level, MI - *Mangifera indica*, AS - *Alstonia scholaris*, PL - *Polyalthia longifolia*, CI - *Clerodendron infortunatum*, EO - *Eupatorium odoratum*, HS - *Hyptis suaveolens*

study higher baseline levels of ascorbic acid content in the leaves of *Polyalthia longifolia*, (Sonner) Thw., among the evergreen trees and *Clerodendron infortunatum*, L., among the shrubs studied suggests its tolerance towards the pollutants which are normally affecting the roadside vegetations. Lower ascorbic acid contents in the leaves of other plant species studied supports the sensitive nature of these plants towards pollutants particularly automobile exhausts. Tripathi and Gautam (2007) also reported increase in the concentration of ascorbic acid in the leaves of *Mangifera indica*, L., near roadsides due to enhanced pollution loads of automobiles.

Changes in leaf extract pH: The leaf pH values of the selected plant species for different seasons are depicted in Fig. 3a,b and c. A reduction in leaf pH was observed among the plant species studied with respect to the control station (station-10). The LSM value for leaf pH showed the maximum during monsoon (5.10) with a gradual reduction through winter (4.72) reaching the summer value as 4.37. Among the evergreen tree species, *Polyalthia longifolia*, (Sonner) Thw., showed higher LSM leaf pH levels (5.70) followed by *Alstonia scholaris*, R. Br. (4.79) and *Mangifera indica*, L. (4.25). *Clerodendron infortunatum*, L., showed higher baseline pH (5.43) among the shrubs studied followed by *Hyptis suaveolens*, (L.) Poit. (4.24) and *Eupatorium odoratum*, L. (3.97). Scholz and Reck (1977) have reported that in presence of an acidic pollutant, the leaf pH is lowered and the decline is greater in sensitive species. A shift in cell sap pH towards the acid side in presence of an acidic pollutant might decrease the efficiency of conversion of hexose sugar to ascorbic acid. However

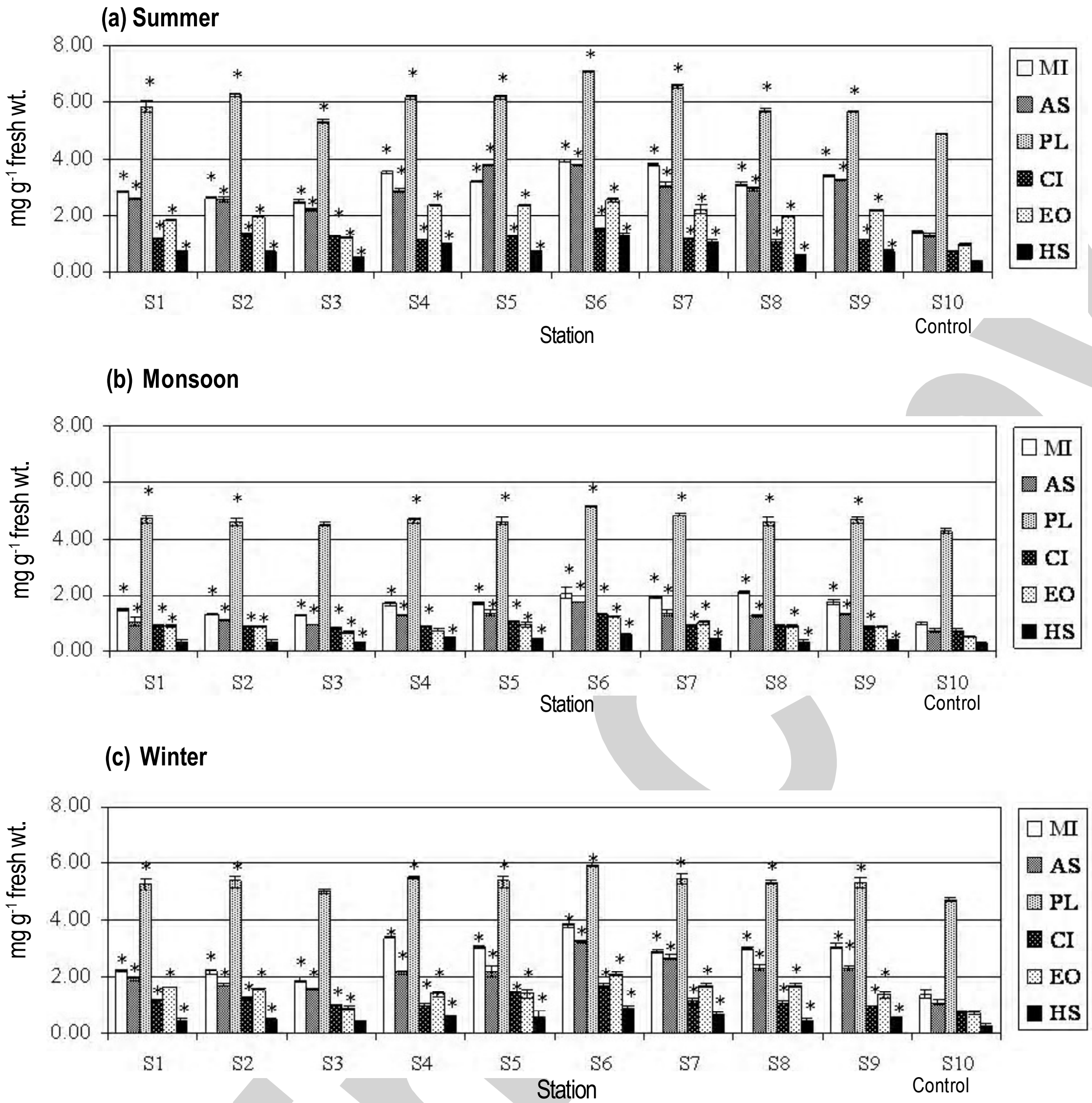

Fig. 2: Leaf ascorbic acid content during different seasons, (a), (b) and (c) the bars represent the average of three replications ± SD, *The values differ significantly at 5% level, MI - *Mangifera indica*, AS - *Alstonia scholaris*, PL - *Polyalthia longifolia*, CI - *Clerodendron infortunatum*, EO - *Eupatorium odoratum*, HS - *Hyptis suaveolens*

the reducing activity of ascorbic acid is pH dependent being more at higher and lesser at lower pH. Hence the leaf extract pH on the higher side gives tolerance to plants against pollution (Agrawal, 1988).

Changes in relative water content: The relative water content was high among the plant species studied during monsoon (LSM 70.31 %) with a decline in the level during winter (53.63 %) followed by summer (48.57 %) which is exemplified graphically in Fig. 4a,b and c. *Polyalthia longifolia*, (Sonner) Thw., well-expressed high LSM values of relative water contents (86.83 %) subsequently *Mangifera indica*, L. (62.81 %) and *Alstonia scholaris*, R. Br. (55.72 %). Among the shrubs studied, high relative water contents were observed in the leaves of *Clerodendron infortunatum*, L. (53.46 %) after that *Eupatorium odoratum*, L. (45.29 %) and *Hyptis suaveolens*, (L.) Poit. (40.89 %). A station specific decrease in the value of relative water content was also found in the leaves of studied plant species with the highest values (68.14 %) at station-10 (control station) and the lowest (50.58 %) at station-6. Relative Water Content (RWC) of a leaf is the water present in it relative to its full turgidity. Relative water content is associated with protoplasmic permeability in cells causes loss of water and dissolved nutrients, resulting in early senescence of leaves (Agrawal and Tiwari, 1997). Therefore the plants with high relative water content under polluted conditions may be tolerant to pollutants.

Air Pollution Tolerance Index: The results of air pollution tolerance index [APTI] calculated for each plant species studied during different seasons is depicted in Table 1. *Polyalthia longifolia*, (Sonner) Thw.,

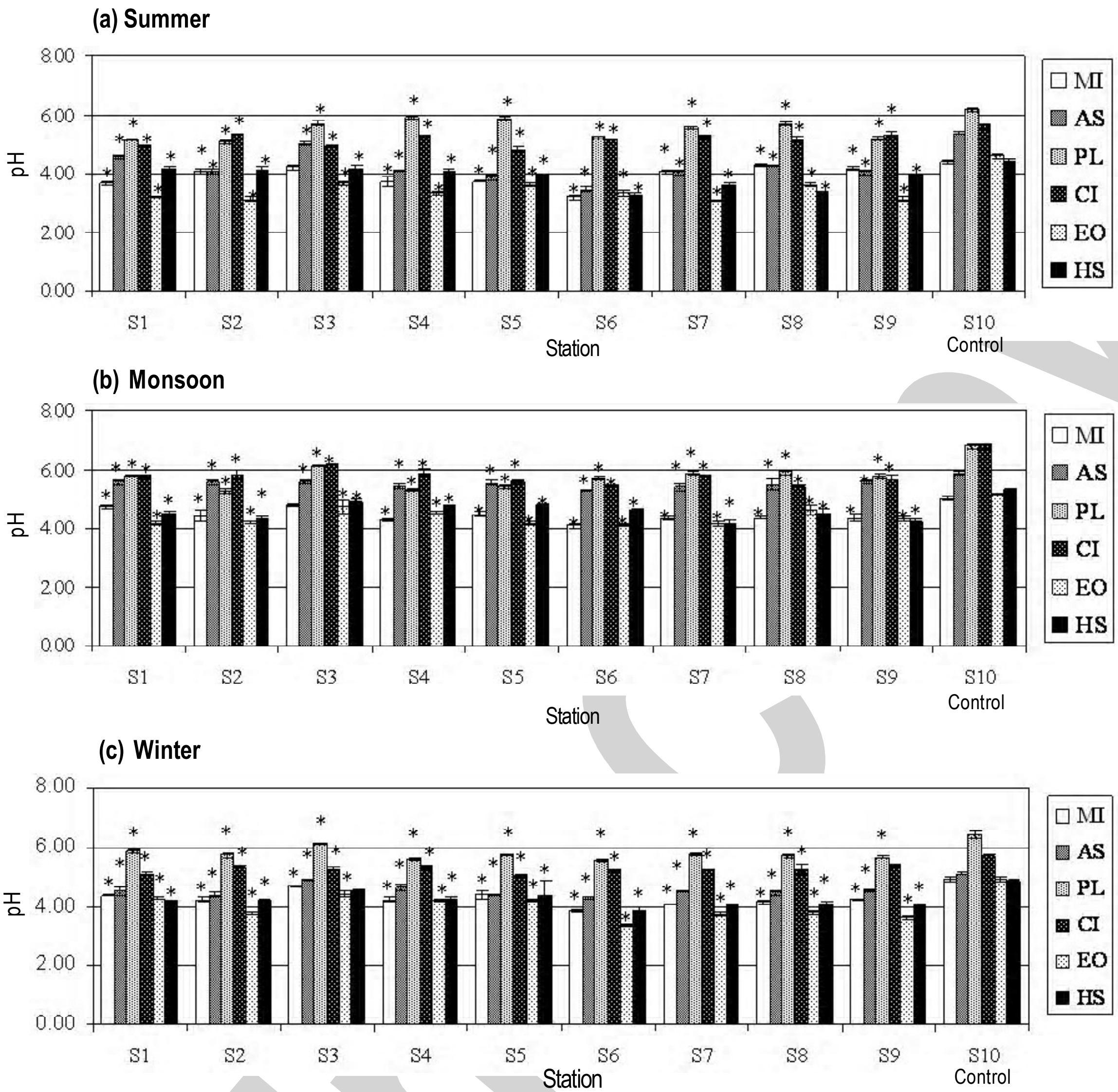

Fig. 3: Leaf extract pH during different seasons, (a), (b) and (c) the bars represent the average of three replications ± SD, *The values differ significantly at 5% level, MI - *Mangifera indica*, AS - *Alstonia scholaris,* PL - *Polyalthia longifolia*, CI - *Clerodendron infortunatum*, EO - *Eupatorium odoratum*, HS - *Hyptis suaveolens*

among the evergreen trees exhibited the highest APTI value (LSM) of about 13.59 followed by *Mangifera indica*, L. (7.56) and *Alstonia scholaris*, R. Br. (6.84). Among the shrubs studied, highest APTI value (LSM) of about 6.23 was observed in the leaves of *Clerodendron infortunatum*, L., followed by *Eupatorium odoratum*, L. (5.23) and *Hyptis suaveolens*, (L.) Poit. (4.39).

Different plant species shows considerable variation in their susceptibility to air pollution. The plants with high and low APTI can serve as tolerant and sensitive species respectively. Also the sensitivity levels of plants to air pollutants differ for herbs, shrubs and trees. With identical values, a tree may be sensitive but a shrub or a herb may be tolerant to a given pollutant. Therefore, the indices for different plant types should be considered separately (Singh and Rao, 1983). In the present study, among the tree species *Polyalthia longifolia*, (Sonner) Thw., with highest APTI was found tolerant to automobile pollutants where as *Mangifera indica*, L., and *Alstonia scholaris*, R. Br., were susceptible to the same. In the case of shrubs, *Clerodendron infortunatum*, L., showed highest APTI values and found to be more tolerant compared to the other shrub species studied. High dust collecting capacity may be one of the reasons for the sensitive plant species studied to become highly susceptible to the auto-exhaust pollutants, making reduction or increase of different biochemical and physiological parameters (Singh, 2005). In this study, *Polyalthia longifolia*, (Sonner) Thw., was found as the least sensitive plant species. Based on the tolerance nature, the evergreen trees can be arranged in the order as *Polyalthia longifolia*, (Sonner) Thw. > *Mangifera indica*, L. > *Alstonia scholaris*, R. Br., and the shrubs as

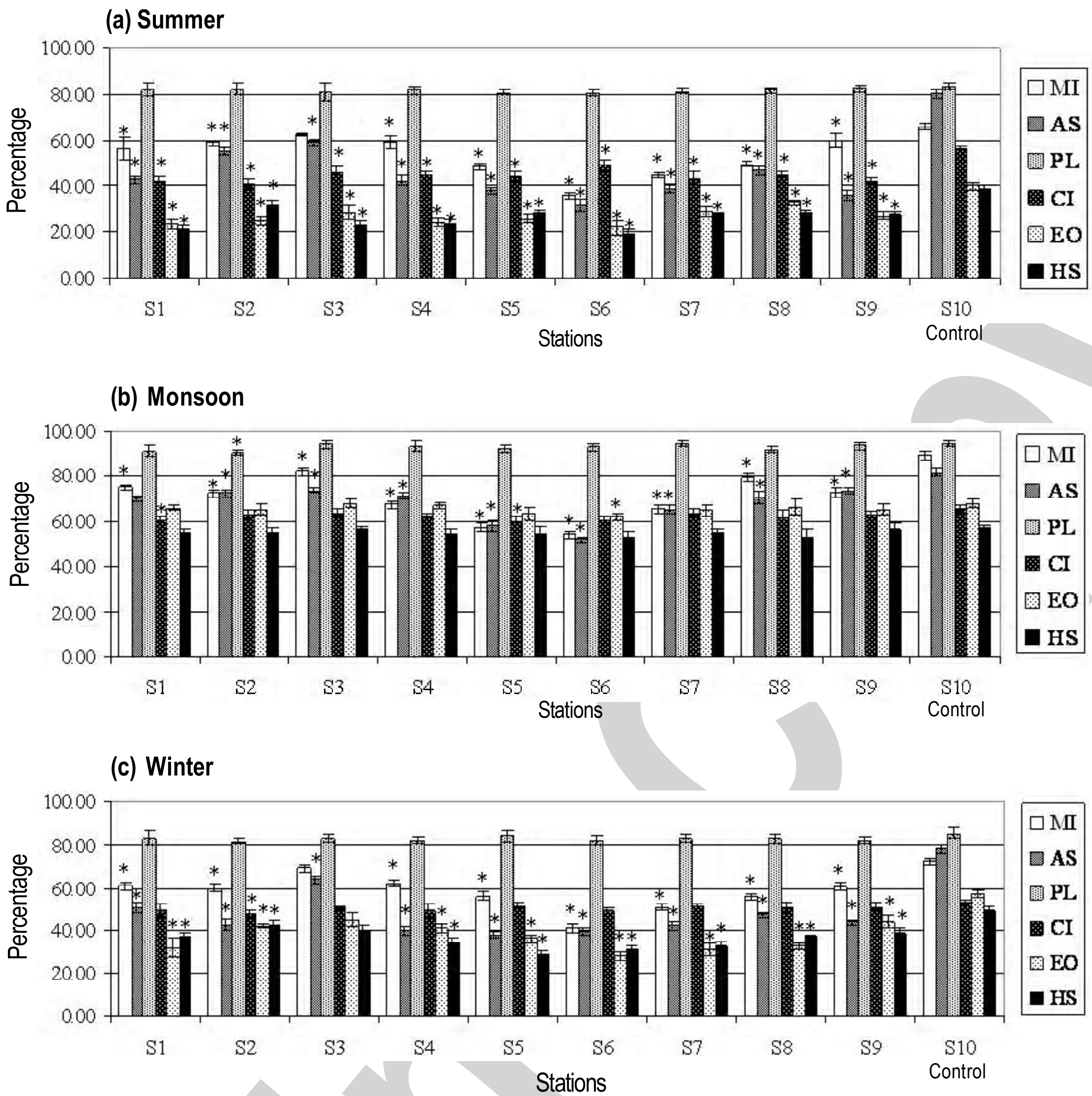

Fig. 4: Relative water content during different seasons, (a), (b) and (c) the bars represent the average of three replications ± SD, *The values differ significantly at 5% level, MI - *Mangifera indica*, AS - *Alstonia scholaris,* PL - *Polyalthia longifolia*, CI - *Clerodendron infortunatum*, EO - *Eupatorium odoratum*, HS - *Hyptis suaveolens*

Clerodendron infortunatum, L. > *Eupatorium odoratum*, L. > *Hyptis suaveolens*, (L.) Poit.

The observations in this study suggest that plants have the potential to serve as excellent quantitative and qualitative indices of pollution. Since biomonitoring of plants is an important tool to evaluate the impact of air pollution on plants, the *Mangifera indica*, L., *Alstonia scholaris*, R. Br., *Eupatorium odoratum*, L., and *Hyptis suaveolens*, (L.) Poit., can be used as biomonitors of vehicular pollution stress. Among the different plant species selected for this study, the tolerant plant species *Polyalthia longifolia*, (Sonner) Thw., among the trees and *Clerodendron infortunatum*, L., among the shrubs can effectively be used in the air pollution amelioration purposes.

Acknowledgments

The financial assistance by the Kerala State Council for Science Technology and Environment as JRF to Ms. Jissy Jyothi, is gratefully acknowledged. The authors also thank Dr. V. Sobha, Professor and Head, Dept. of Environmental Sciences for providing facilities to carry out this study.

References

Agrawal, A.L.: Air pollution control studies and impact assessment of stack and fugitive emissions from CCI Akaltara Cement Factory. Project Report, Project sponsored by M/s. CCI Akaltara Cement Factory. NEERI, Nagpur (1988).

Agrawal, S. and S.L. Tiwari: Susceptibility level of few plants on the basis of Air Pollution Tolerance Index. *Indian Forester*, **123**, 319-322 (1997).

Arnon, D.I. : Copper enzymes in isolated chloroplasts. *Plant Physiol.*, **24**, 1-15 (1949).

Barr, H.D. and P.E. Weatherly: A re-examination of the relative turgidity technique for estimating water deficit in leaves. *Aust. J. Biol. Sci*., **15**, 413-428 (1962).

Beg, M.U., M. Farooq, S.K. Bhargava, M.M. Kidwai and M.M. Lal : Performance of trees around a thermal power station. *Environ. Ecol.,* **8**, 791-797 (1990).

Chaudhary, C.S. and D.N. Rao: Study of some factors in plants controlling their susceptibility to sulphur dioxide pollution. *Proc. Ind. Natl. Sci. Acad. Part B*., **46**, 236-241 (1977).

Conklin, P.L.: Recent advances in the role and biosynthesis of ascorbic acid in plants. *Plant Cell Environ.,* **24**, 383-394 (2001).

Dwivedi, A.K. and B.D. Tripathi: Pollution tolerance and distribution pattern of plants in surrounding area of coal-fired industries. *J. Environ. Biol*., **28**, 257-263 (2007).

Dwivedi, A.K., B.D. Tripathi and Shashi: Effect of ambient air sulphur dioxide on sulphate accumulation in plants. *J. Environ. Biol.,* **29**, 377-379 (2008).

Katiyar, V. and P.S. Dubey: Sulphur dioxide sensitivity on two stage of leaf development in a few tropical tree species. *Ind. J. Environ. Toxicol.* **11**, 78-81 (2001).

Khanna, S.K. and C.E.G. Justo: Highway Engineering. 8th Edn. Nem Chand and Bros, Roorkee (2001).

Liu, Y. and H. Ding: Variation in air pollution tolerance index of plants near a steel factory: Implications for landscape-plant species selection for industrial areas. *WSEAS Trans. Environ. Develop.,* **4**, 24-32 (2008).

Mir, Q.A., T. Yazdani, A. Kumar, K. Narain and M. Yunus: Vehicular population and pigment content of certain avenue trees. *Poll. Res.,* **27**, 59-63 (2008).

Ninave, S.Y., P.R. Chaudhri, D.G. Gajghate and J.L. Tarar: Foliar biochemical features of plants as indicators of air pollution. *Bull. Environ. Contam. Toxicol.* **67**, 133-140 (2001).

Sadasivam, S. and A. Manickam: Biochemical methods. 2nd Edn. New age International Publishers, New Delhi (1996).

Scholz, F. and S. Reck: Effects of acids on forest trees as measured by titration invitro inheritance of buffering capacity in Picea-Abies. *Water, Air Soil Pollut.,* **8**, 41-45 (1977).

Shyam, S., H.N. Verma and S.K. Bhargava: Air pollution and its impact on plant growth. New India Publishing Agency, New Delhi (2006).

Singh, P.K.: Plants as indicators of air pollution - An Indian experience. *Indian Forester*., **131**, 71-80 (2005).

Singh, S.K. and D.N. Rao: Evaluation of plants for their tolerance to air pollution. *In*: Proceedings of symposium on air pollution control. Indian Association for Air Pollution Control. New Delhi, 218-224 (1983).

Tripathi, A.K. and M. Gautam : Biochemical parameters of plants as indicators of air pollution. *J. Environ. Biol*., **28**, 127-132 (2007).

Varshney, C.K.: Buffering capacity of Trees growing near a coal-fired thermal power station. *In*: Tropical ecosystems: Ecology and Management (*Eds*.: K.P. Singh and J.S. Singh), Wiley Eastern Ltd., New Delhi (1992).

Varshney, S.R.K. and C.K. Varshney: Effects of sulphur dioxide on ascorbic acid in crop plants. *Environ. Pollut.,* **35**, 285-291 (1984).