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The Effects of Airborne Pollutants and Climatic Factors of Different Sections of Tehran Areas on Leaf Characteristics of Oriental Plane (*Platanus orientalis* L.) Trees

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ABSTRACT

Aims This study was carried out to determine the effects of urban gaseous pollutants (sulfur dioxide [SO_2], nitrogen dioxide [NO_2], and ozone [O_3]) and climatic factors (temperature and precipitation) on the morphological and anatomical reaction of *Platanus orientalis* L. in Tehran.
Materials & Methods Seven districts of this city with a wide spectrum of climatic conditions and diversity of elevation were selected, and gas concentration of SO_2, NO_2, and O_3 was determined. Then, morphological and anatomical parameters of this plant including leaf area, specific leaf area (SLA), wet and dry weight, leaf toughness and thickness, water content, lamina, and main vein were measured and the analysis of their correlations with environmental (climatic and pollutant) factors along with their *t*-tests were evaluated.
Findings The results showed that the climatic factors made significant ($P < 0.05$) changes on SLA, water content, wet and dry weight of green leaves of this plant. In addition, different levels of pollutant gases had significant ($P < 0.05$) effects on natural toughness, thickness, wet weight, number of spongy parenchyma layers, and the ratio of lamina mesophyll to subvein of leaves.
Conclusion The results explain that anatomical and morphological characteristics of *P. orientalis* leaves have been influenced by environmental stresses and changes in these factors show the resistance of the plant to the environmental conditions.

Keywords Air Pollution; Climate; *Platanus orientalis*; Specific Leaf Area

CITATION LINKS

[1] Air pollution-sources, effects and ... [2] Structural and micro morphological changes ... [3] Environmental study of heavy metals influence on soil ... [4] Morphological and anatomical studies of ... [5] Organic and anatomical studies of leaves of different plants affected by motor vehicles ... [6] Effects of air pollution on leaf structure and ... [7] Norway spruce and spruce shoot aphid as indicators ... [8] Leaf morphology and ozone sensitivity of two ... [9] Relationship between leaf life-span and photosynthetic ... [10] Influence of environmental pollution on leaf properties ... [11] A study on air pollution Induced biochemical ... [12] Effect of air pollution on the foliar morphology of some ... [13] Association of root, specific leaf area and ... [14] Leaf anatomical characteristics and physiological ... [15] Family variation in gas exchange, growth and ... [16] Studies upon wheat grown under ... [17] Basic growth analysis: Plant growth ... [18] A comparative study of the fracture ... [19] Leaf fracture toughness and sclerophylly ... [20] Meta-analysis of the relative sensitivity ... [21] Effects of ozone on the foliar histology of the mastic ... [22] Comparative studies of the leaf morphology ... [23] About the indicators of the durability of woody ... [24] Ozone sensitivity of leaves: Relationship ... [25] The effect of environmental pollution on internal structure and some biochemical and physiology ocalyptus spp. and Zizipus spp. In Khozestan ... [26] Growth reductions in Lolium multiflorum ... [27] Inoculation effects of standard and native ... [28] Studies in growth and biochemical responses ... [29] Effects of Riyadh cement industry pollutions on some physiological and morphological factors ... [30] Physiology of woody ... [31] The effects of coal dust on photosynthetic ... [32] Modelling biomass production and yield ... [33] Modelling leaf expansion in a fluctuating ... [34] The effects of climatically parameters on anatomical ... [35] Investigation of Artemisia sieberi Besser population ecological characteristic ... [36] Effect of salinity and drought stress on the seedling growth and physiological ... [37] Investigation the effect of drought stress on ion changes, Water content percentage, prolin ... [38] Biochemical changes in maize seedling exposed to drought stress conditions at different ... [39] Plant ...

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Introduction

Air pollution is a modern phenomenon that threatens not only the human health but also the health of other live organisms including plants.[1] Although plants play an effective role in reducing air pollution, they themselves are vulnerable to a wide range of pollutants. It is essential to investigate the negative effects of air pollution on stability and livability of plants and its close association with human health quality, whereas leaves are the primary photosynthetic organs of trees[2] and are exposed to gases and airborne pollutants more than any organs, they are the best subject for such investigation.[1] Reduced length, width, and area of the leaf of roadside plants can signify the adverse effects of environmental parameters on this organ.[3] The high temperature and low relative humidity of environment both have direct impacts on plants life and disrupt their physiological activities.[4] The relationship of pollution and quantitative changes of climate parameters with the plant leaves has been investigated in many studies. Jahan and Iqbal[5] conducted a number of anatomical and morphological studies on leaves of *Ficus*, *Guaiacum officinale* L., *Benghalensis* L., and *Eucalyptus* sp. to find such relationship between the exhaust gasses of vehicle engines and health of roadside trees in the city of Karachi. Royampaeng and Puangchit[6] studied the effects of air pollution on leaf characteristic and growth parameters (growth height, dry biomass, and leaf area) of *Pterocarpus indicus* buds. A study conducted by Viskari *et al.*,[7] in Finland reported a positive correlation between traffic density and changes in epistomatal wax structure. Ferdinand *et al.*[8] studied the relationship between leaf characteristic (morphology and anatomy) and their sensitivities to ozone gas of environment in two genotypes of *Prunus serotina* seedlings. Gratani[9] examined the anatomy (thickness of palisade and spongy parenchyma, thickness of upper and lower epidermis, and cuticle), and morphology (leaf thickness, leaf area, and specific leaf area [SLA]) of *Quercus ilex* in polluted areas of Rome. Pourkhabbaz *et al.*[10] investigated the effects of air pollution on anatomical characteristics (stomatal density, epidermal cell density, area of stomatal pores, and leaf parenchyma) and morphology (length, width, surface, and color) of the leaves of *Platanus orientalis* in Mashhad. Seyyedinejad and Koochak[11] studied the leaf area and petiole length in *Eucalyptus* species subjected to air pollution stress conditions. Ekpemerechi *et al.*[12] examined the leaf area and petiole length of 10 species of Euphorbiaceae family in southwestern Nigeria in regions ranging from less polluted (rural) to highly polluted (urban) environments.

The relationships between the climate and anatomical and morphological parameters have also been investigated in several studies.[13,14]

The polluted air of Tehran is one of the major difficulties of this city due to its high population and industrial activities. Destructive effects of air pollution and other climatic factors on the health of human and other live organisms make these studies inevitable. Since plane species of *P. orientalis* has an extensive distribution in Tehran's green environment, it was our objective to consider the destructive effects of air pollution and climate on anatomical and morphological characteristics of their leaves as an inevitable study.

Materials & Methods

Study area

Study area was the city of Tehran located between 51° 17 min and 51° 33 min east longitude, and between 35° 36 min and 35° 42 min north latitude. Authors selected seven study zones based on elevation [Table 1], and distribution of weather and air pollution monitoring stations. The site selection process was carried out such a way that greatest portion of the city would be covered in this study [Figure 1].

Data collection

Meteorological data was collected from the 5 nearest weather stations of Tehran, including Mehr-Abad, Dushan-Tappe, Geophysic Park, and Aminabad. The meteorological parameters including mean

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Table 1: Elevation and geographical coordinates of the study zones in Tehran city

Site Name	Tajrish	Shahrzad	Azadi	Bahman	Pardisan	Karim khan	Sorkhe hesar
Elevation (m)	1615	1408	1180	1103	1382	1238	1444
Latitude	35° 48' 18"	35° 48' 18"	35° 48' 18"	35° 48' 18"	35° 48' 18"	35° 48' 18"	35° 48' 18"
Longitude	51° 25' 25"	51° 25' 25"	51° 25' 25"	51° 25' 25"	51° 25' 25"	51° 25' 25"	51° 25' 25"

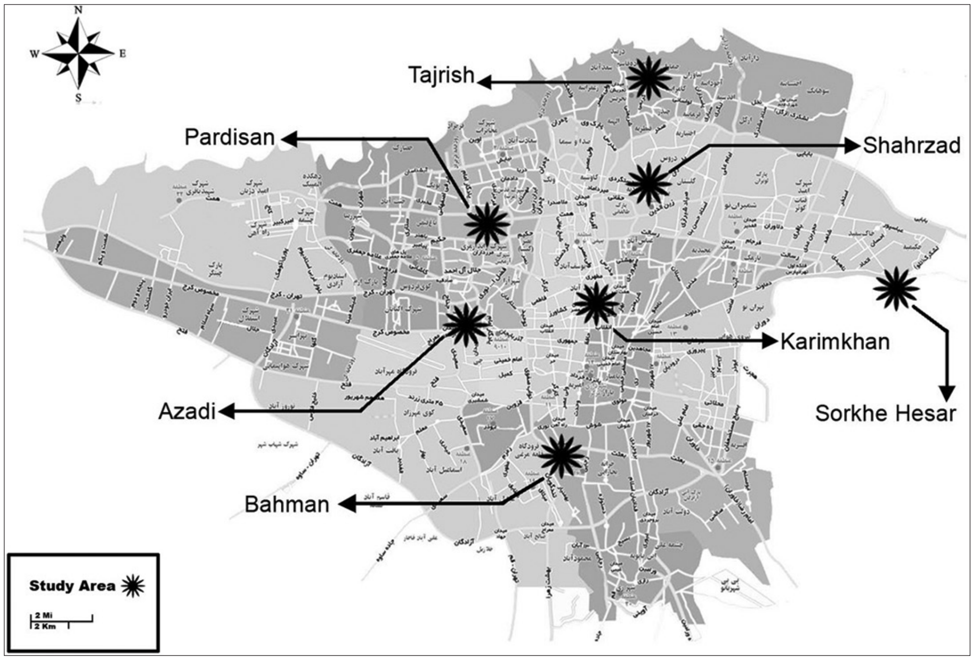

Figure 1: Map of the study zones in Tehran city

value of minimum temperature, mean value of maximum temperature, mean value of average temperature, average count of frost days, mean value of absolute minimum temperature, mean value of absolute maximum temperature, and mean annual precipitation were collected. Air pollution data were collected from air pollution monitoring stations of Iran's Environmental Protection Organization, and included hourly measurements pertaining to pollutants nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and ozone (O_3) [Table 2].

In each study zone, 5 randomly-selected, healthy, pest-free trees with symmetrical crown and equal diameter were sampled in mid-August. In each instance of sampling, six leaves were collected from the south-side middle-section of the crown. Morphological parameters such as leaf area, wet and dry weight, leaf toughness, and leaf thickness were measured. Wet weight was measured with a digital scale with 1 mg precision. Leaf area (cm^2) was then obtained using the area meter LI-COR and L1-3100. Leaf toughness (N/m) and leaf thickness (mm) were measured with a toughness meter and a leaf thickness tester, respectively. In the end, leaves were dried for 48 hours at temperature of 70°C and were then immediately weighted.[15] Next, wet and dry weights were substituted in equation (1)[16] to obtain the sample's water content.

$$\text{Water content} = \{(\text{wet weight} - \text{dry weight}) / \text{wet weight}\} \times 100 \quad (1)$$

It should be mentioned that SLA was obtained in cm^2 $dried^{-1}$ weight (g).[17]

The examined anatomical characteristics included lamina thickness and mesophyll, lamina veins, thickness and number of palisade and spongy layers, ratio thickness of the palisade layers to the thickness of the spongy layers (Rp/Rs), thickness of epidermis and cuticle,

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thickness and number of collenchyma and parenchyma of midrib, thickness of midrib, midrib vein and mesophyll, and number, and length of stomata on upper and lower surface. All anatomical studies were carried out using a light fluorescence microscope (Olympus BH2-RFCA).

Data analysis

Collected data were entered into the EXCEL software and were analyzed with the Minitab 14 Software to find statistically significant correlations between the morphological and anatomical characteristics of leaves and environmental factors (pollution and climate). An independent *t*-test also conducted to investigate the differences in leaves' morphological and anatomical characteristics for the study zones in which differences were significant in terms of only one environmental factor (either pollution or climate).

Findings

Table 3 shows the correlation between morphological characteristics of *P. orientalis* leaf and environmental (pollution and climate) parameters and indicates that only leaf toughness and leaf specific area were associated with ozone content (a pollution factor), and mean value of absolute minimum temperature (a climate factor), respectively.

This relationship indicates that in higher ozone levels, leaf toughness decreases, and leaves become more fragile ($r = -0.98$, $P < 0.05$); on the other hand, the SLA decreases with reduction of temperature ($r = -0.81$, $P < 0.05$).

Similarly, Table 4 shows the correlation between anatomical leaf characteristics of *P. orientalis* and environmental (pollution and climate) parameters. It indicates also that only the distribution of stomata on lower surface correlated with both climate and pollution factors. This parameter had positive correlation with increase in temperature and decrease in precipitation and had inversely correlation with increasing of pollution factors.

This means that as temperature increases or precipitation decreases, the number of stomata per unit area increases, and when pollution increase, the number of stomata decreases. Apart from the distribution of

Table 2: Air pollution data of study zones in Tehran

Study zone	Mean NO_2 (ppm)	Mean SO_2 (ppm)	Mean O_3 (ppm)	Max O_3 (ppm)
Tajrish	0.05	0.04	-	-
Shahrzad	0.04	0.04	0.02	0.10
Azadi	0.06	0.06	0.01	0.09
Bahman	0.08	0.02	-	-
Pardisan	0.05	0.02	0.01	0.32
Karim-khan	0.02	0.04	0.01	0.07
Sorkhe-hesar	0.02	0.01	0.02	0.12

NO_2: Nitrogen dioxide, SO_2: Sulfur dioxide, O_3: Ozone

Table 3: Correlation coefficients between morphological leaf characteristics of *Platanus orientalis* and environmental (pollution and climate) parameters

Parameters	Specific leaf Area (cm^2/g)	Wet weight (g)	Dry weight (g)	Moisture content	Leaf thickness (mm)	Leaf toughness (N/m)
Mean value of absolute minimum temperature (C°)	0.65	0.70	−0.71	0.88	0.84	−0.88*
Mean ozone (ppm)	−0.98*	−0.63	0.49	−0.88	−0.88	0.62

*$P < 0.05$; **$P < 0.01$

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Table 4: Coefficients of correlation between anatomical leaf characteristics of *Platanus orientalis* and environmental (pollution and climate) parameters

Parameters	Thickness of midrib (μ)	Thickness of upper epistomatal wax (μ)	Thickness of lower cuticle (μ)	Thickness of spongy/ palisade mesophyll	Lamina/ subvein mesophyll (μ)	Lamina subvein (μ)	Distribution of stomata on lower surface (Nmm^2)	Total size of vascular bundles	Total number of vascular bundles	Number of midrib veins	Ratio of midrib mesophyle to total size of vascular bundles	Midrib mesophyle/ midrib vein withsheath	Midrib vein withsheath (μ)	Midrib vein mesophyle (μ)	Number of lower collenchyma	Thickness of lower collenchyma (μ)
Mean value of maximum temperature (C°)	0.88*	0	0.24	0.33	0.48	−0.12	0.9*	0.91*	0.44	0.25	0.29	−0.74	0.94**	0.88*	0.18	0.4
Mean value of minimum temperature (C°)	0.53	0.47	0.44	−0.27	0.27	0.04	0.01	0.15	0.34	0.28	0.41	−0.11	0.49	0.53	0.85*	0.72
Mean value of average temperature (C°)	0.84*	0.21	0.45	−0.02	0.42	0	0.56	0.71	0.52	0.25	0.46	−0.56	0.87*	0.84*	0.56	0.64
Mean value of absolute maximum temperature (C°)	0.9*	−0.39	0.22	0.16	0.19	0.08	0.8	0.88	0.48	−0.11	0.3	−0.78	0.69	0.58	−0.28	0.01
Mean value of absolute minimum temperature (C°)	−0.12	0.52	0.19	0.16	0.67	−0.32	0.5	0.97***	0.21	0.45	0.18	−0.36	0.87*	0.9*	0.77	0.86*
Average count of frost days	−0.71	−0.44	−0.44	0.13	−0.39	0.03	−0.25	−0.36	−0.4	−0.34	−0.42	0.28	−0.69	−0.71	−0.81*	−0.76

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Table 4: *(Continued)*

Parameters	Thickness of midrib (μ)	Thickness of upper epistomatal wax (μ)	Thickness of lower cuticle (μ)	Thickness of spongy/palisade mesophyll	Lamina/subvein mesophyll (μ)	Lamina subvein (μ)	Distribution of stomata on lower surface (Nmm²)	Total size of vascular bundles	Total number of vascular bundles	Number of midrib veins	Ratio of midrib mesophyle to total size of vascular bundles	Midrib mesophyle/midrib vein withsheath	Midrib vein withsheath (μ)	Midrib vein mesophyle (μ)	Number of lower collenchyma	Thickness of lower collenchyma (μ)
Absolute maximum temperature (C°)	0.88*	0.02	0.16	0.16	0.51	−0.19	0.95*	0.87*	0.36	0.33	0.21	−0.71	0.94**	0.88*	0.15	0.37
Mean annual precipitation (mm)	−0.95*	−0.17	−0.26	0.45	−0.55	0.18	−0.89*	−0.79	−0.41	−0.45	−0.29	0.66	−0.99***	−0.96**	−0.39	−0.53
Mean value of nitrogen dioxide (ppm)	−0.18	0.16	0.23	0.85*	−0.02	−0.11	0.44	0.12	0.02	0.02	0.74	0.01	−0.16	−0.18	−0.22	−0.5
Mean value of sulfur dioxide (ppm)	−0.09	−0.63	0.85*	−0.24	−0.87**	0.96***	−0.04	−0.09	0.82*	0.1	0.84*	−0.13	−0.05	−0.09	−0.23	−0.26
Maximum value of ozone (ppm)	−0.14	0.89*	−0.27	0.83	0.45	−0.58	−0.52	−0.6	−0.4	0.2	−0.21	0.95*	−0.25	−0.14	0.63	0.1
Mean value of ozone (ppm)	−0.33	0.2	−0.61	0.41	0.45	−0.63	−0.99**	0.44	−0.3	−0.9*	−0.25	0.01	−0.32	−0.33	−0.29	−0.22

*$P < 0.05$; **$P < 0.01$; ***$P < 0.001$

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stomata, leaf midrib showed correlation with climate and six parameters related to leaf lamina and four parameters related to leaf midrib exhibited association with pollution.

Examinations of differences between study zones showed that there is no significant difference in climatic parameters of zones Azadi and Sorkhe-hesar, and the only significant environmental parameter affecting plant characteristics is air pollution (SO_2 and NO_2). Table 5 shows that Azadi zone had more polluted gases (NO_2 = 0.058; SO_2 = 0.057) than Sorkhe-hesar (NO_2 = 0.02; SO_2 = 0.009). However, there was no significant difference in gases pollution of Tajrish and Pardiasan zones, and they had only differences in their climatic conditions. In light of these results, the independent *t*-test was done to see the effects pollution and climatic factors on the anatomical and morphological characteristics of *P. orientalis* in Azadi, Sorkhe-hesar, Tajrish, and Pardiasan zones. The test results [Table 6] showed that samples taken from less polluted zone (Sorkhe-hesar) had higher moisture content, thickness, toughness, and more layers of spongy parenchyma than samples of more polluted zone. Furthermore, the samples taken from the zone with lower temperature and higher participation had higher leaf area indexes, moisture contents, and lower stomata distributions.

Discussion

Correlation between air pollution and anatomical and morphological characteristics of leaf

The results obtained between air pollution and anatomical and morphological characteristics of plant leaves indicates that increasing of air pollution reduced the leaf toughness and leaf became more fragile. Leaf toughness is a factor of cell walls' strength. Important factors determining leaf toughness include lignin[18] and sclerophylly index (protein/fiber).[19] When the contents of these compounds increase in the leaf, its toughness improve significantly. Since air pollution decreases the lignin content and protein/fiber ratio, consequently strength of cell walls is lowered, and leaves become more fragile.[20] In this study, one of the important factor which grows as pollution increased is ratio of Rp/Rs (Azadi area had more ratio thickness of the palisade layers to the thickness of the spongy layers (Rp/Rs = 1.77) than Sorkhe-hesar (Rp/Rs = 1.45), this association is reflected significantly by decreasing number of spongy parenchyma layers in samples of polluted areas. Reig-Arminana *et al.*[21] have also reported that in polluted areas there is a considerable change in transformation of spongy and palisade parenchyma in cells of tree leaves. Dineva[22] has reported that in polluted areas, thickness of spongy parenchyma of *Platanus acerifolia* Willd is significantly lower while thickness of its palisade parenchyma is higher. This decrease has been attributed to lamina structure, as it is the most important response factor of tree to air pollution. The spongy mesophyll of leaves is exposed to pollution, when polluted gases are entered into the plant through the natural openings (normally stomata), and passed through the stomata of lower epidermis.[23] Evans and Ting[24] believed that spongy mesophyll is less resistant to toxic gases than palisade mesophyll and this is because of larger size of spongy cells in comparison to palisade tissue. Considering the significant difference in the number of spongy parenchyma layers in the two study zones and higher RP/RS ratio and thickness of palisade parenchyma and lower thickness of spongy parenchyma in more polluted zone, the response of *P. orientalis* to pollution can be considered similar to findings of other studies. One of the observations that authors of this paper would like to highlight is the reduction of dry weight of leaf due to increasing of polluted gases in different zones. Asadi[25] studied the effect of gaseous pollutants on biochemical and physiological parameters of the two species of *Lotus* and *Eucalyptus* and showed a significant reduction in wet and dry weight of their leaves as a result of pollution. Ashenden and Williams[26]

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Table 5: Results of independent *t*-test conducted for study zones Sorkhe-hesar and Azadi, based on relationship morphological and anatomical leaf characteristics of *Platanus orientalis* and environmental (pollution and climate) parameters

Air pollution	Mean value for Sorkhe-hesar	Mean value for Azadi	*P*
Mean value of nitrogen dioxide (ppm)	0.021 ± 0.003	0.058 ± 0.016	0.005**
Mean value of sulfur dioxide (ppm)	0.009 ± 0.003	0.057 ± 0.039	0.023*
Mean value of ozone (ppm)	0.024 ± 0.012	0.013 ± 0.002	0.113^{ns}
Maximum value of ozone (ppm)	0.121 ± 0.037	0.094 ± 0.003	0.24^{ns}
Climate			
Mean value of minimum temperature (C°)	13.342 ± 0.788	13.272 ± 0.699	0.726^{ns}
Mean value of maximum temperature (C°)	23.189 ± 0.768	23.126 ± 0.762	0.793^{ns}
Mean value of average temperature (C°)	18.269 ± 0.73	18.196 ± 0.713	0.745^{ns}
Average count of frost days	29.67 ± 14.94	30.62 ± 12.98	0.827^{ns}
Absolute minimum temperature (C°)	−5.338 ± 1.893	−6.152 ± 2.363	0.225^{ns}
Annual precipitation (mm)	252.85 ± 72.54	240.8 ± 66.98	0.579^{ns}
Absolute maximum temperature (C°)	40.986 ± 1.264	41.048 ± 1.1	0.866^{ns}
Leaf characteristics			
Wet weight (g)	6.58 ± 0.98	5.83 ± 1.38	0.025***
Thickness (mm)	16.3 ± 2.86	13.74 ± 1.87	0.000***
Toughness (N/m)	2.21 ± 0.3	1.6 ± 0.31	0.000***
Lamina mesophyll/vein ratio	4.69 ± 0.99	3.14 ± 0.77	0.028***
Number of spongy parenchyma layers	2.4 ± 0.55	1.4 ± 0.55	0.02***

*$P < 0.05$; **$P < 0.01$; ***$P < 0.001$. ns: Not significant

have also pointed out the reduced dry weight of leaves of *Phleum pratense* and *Lolium multiflorum* in contact with NO_2 and SO_2 pollution. A study by Askari and Hosseinkhani[27] on the impact of SO_2 pollution on *Medicago sativa* has reported the significantly reduced leaf area, wet weight, and dry weight under that condition. The study of Bhardwaj *et al.*[28] has shown that when subjected to different SO_2 concentrations, *Capsicum annuum* exhibits a significant decrease in growth indices. Study of Salama *et al.*[29] on the effects of air pollution on morphological and physiological characteristics of *Datura innoxia* Mill. showed reduced leaf area, dry weight, and chlorophyll concentration as the result of pollution. Dry weight is often closely associated with growth analysis and has a positive relationship with growth parameters,[30] so reduced growth in the polluted area leads to reduced dry weight. In fact, air pollution and deposition of engine exhaust particles on the leaves reduce the rate of gas exchange through the leaf surface and decelerate the photosynthesis process by blocking stomata; this blockage reduces the plant growth[31] and leads to reduced leaf dry weight.

Correlation between climate and anatomical and morphological characteristics of leaf

SLA is a factor of leaf thickness and often is decreased in drought conditions.[32] Drought stress decelerates the plant's photosynthesis process, and since thicker leaves have a higher chlorophyll-protein density per unit area and higher photosynthesis capacity than thinner leaves, deceased SLA under drought stress can be attributed to plants adaption and resistance in response to this situation.[13] Hence, in this situation, plant develops thicker leaves with lower SLA. Thus, reduced SLA of xerophyte plants can be considered as a mechanism to compensate for reduced amount of photosynthesis.[33] Observations of this study in regard with reduction of SLA are consistent with the findings of previous studies. In this study, leaf thickness was found to be the only morphological characteristic associated with climatic factors, and it increased with

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Table 6: Results of independent *t*-test conducted for study zones Tajrish and Pardisan, based on relationship morphological and anatomical leaf characteristics of *Platanus orientalis* and environmental (pollution and climate) parameters

Air pollution	Mean value for Tajrish	Mean value for Pardisan	*P* value
Mean value of nitrogen dioxide (ppm)	0.053 ± 0.001	0.021 ± 0.051	0.887^{ns}
Mean value of sulfur dioxide (ppm)	0.041 ± 0.004	0.017 ± 0.011	0.135^{ns}
Mean value of ozone (ppm)	-	-	-
Maximum value of ozone (ppm)	-	-	-
Climate			
Mean value of minimum temperature (C°)	10.493 ± 0.538	13.504 ± 2.228	0.000***
Mean value of maximum temperature (C°)	20.6 ± 0.924	21.289 ± 0.496	0.011**
Mean value of average temperature (C°)	15.548 ± 0.699	17.039 ± 0.556	0.000***
Average count of frost days	55.548 ± 0.699	31.94 ± 11.36	0.000***
Absolute minimum temperature (C°)	−8.595 ± 2.368	−5.675 ± 2.038	0.000***
Annual precipitation (mm)	427.1 ± 111.9	316.1 ± 99.1	0.003**
Absolute maximum temperature (C°)	38.196 ± 1.126	36.281 ± 9.751	0.378^{ns}
Leaf characteristics			
Specific leaf area (cm^2/g)	158.99 ± 30.5	121.7 ± 18.8	0.000***
Wet weight (g)	4.056 ± 0.92	5.038 ± 0.95	0.000***
Dry weight (g)	1.526 ± 0.40	2.019 ± 0.424	0.000***
Water content (%)	62.66 ± 2.29	59.89 ± 3.55	0.002**
Stomata distribution	145.5 ± 38.7	159.7 ± 33.4	0.05*

**P* < 0.05; ***P* < 0.01; ****P* < 0.001. ns: Not significant

the increase in temperature and decrease in precipitation. This result is consistent with the findings of Songsri *et al.*[13] and Rabie *et al.*[34] reported the development of thicker leaves in drought conditions. The increased leaf thickness in dry condition may be due to a survival mechanism protecting internal veins against water loss and dehydration.[35] Increased leaf thickness in different conditions such as drought stress[13] signifies the plant's response to environmental stress in the form of adaptation to adverse conditions. The study of Rabie[35] on *Artemisia sieberi* in its natural habitat and farm environment reported that leaf water content in farm environment is higher than that in natural habitat. This observation was attributed to easier growth conditions, better access to water and lower temperature in farm environment in comparison to natural habitat. Furthermore, Akhzari and Ghasemi Aghbash[36] declared that aridity stress significantly decreased water content of leaves from 7% in control treatment to 5% and 4% at -6 to -10 aridity level. Decrease in water content of the leaf under drought stress may depend on plant vigor reduction. Under the condition of

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water deficit, cell membrane subjects to changes such as penetrability and decrease in sustainability. Microscopic investigations of dehydrated cells revealed damages including cleavage in the membrane and sedimentation of cytoplasm content. Probably, in these conditions, ability to osmotic adjustment is reduced. Hence, lower water content of leaves in the zones with higher temperature and lower precipitation can be explained.

Bagheri *et al.*[37] found drought as the limiting and unfavorable factor on growth and production of plants, it was concluded that as drought stress intensity increases the water content percentage decreases. This reduction leads to adjustment of osmosis pressure of the leaf cell. These changes are the short-term reaction of the plant to drought stress and are criteria to explain the ability of plant to survive in the condition of drought stress.[38]

Fahn[39] has stated that one characteristic of leaf of xerophyte species is the lower ratio of outer surface area to total volume and has explained that the plant can reduce this ratio by making changes such as increasing stomatal density or developing palisade mesophyll. On this basis, increased stomatal density and development of palisade parenchyma is a characteristic of arid plants, and this confirms and explains the findings of this study.

Conclusion

The results explain that anatomical and morphological characteristics of *P. orientalis* leaves have been influenced by biological stress and number of the reactions such as leaf toughness reduction, which is criteria of lowered strength wall cells and fragile leaves, leaf water content reduction, which shows the deficiency in plant ability, are the short-term reactions to environmental stresses. On the other hand, some other characteristics such as Rp/Rs increase in reaction to pollution, reduction in leaf specific area, increase in stomatal density in response to drought condition, show the resistance of the plant to the environmental conditions. Plants react to polluted gases by increasing the thickness of palisade parenchyma and decreasing the number of spongy parenchyma layers to stabilize inner space. Furthermore, increase the leaf thickness and stomatal density cause sustainability in drought condition to contribute to survival of the species under stress conditions.

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عکس‌العمل متغیرهای کمّی برگ درخت چنار *Platanus orientalis* در مقابل آلودگی هوا و اقلیم

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چکیده

اهداف: آلودگی هوا یکی از معضلات شهرهای صنعتی مانند تهران است. با توجه به تاثیرات منفی آلودگی هوا به همراه عوامل اقلیمی بر انسان و گیاهان، بررسی میزان تاثیرات آلودگی و اقلیم بر گیاهان لازم و ضروری است. لذا این تحقیق با هدف بررسی اثرگازهای آلاینده شهری شامل O_3, SO_2, NO_2 و اقلیم (دما و بارندگی) بر عکس‌العمل‌های متغیرهای کمّی درخت چنار در شهر تهران انجام شد.

مواد و روش‌ها: به منظور این بررسی هفت منطقه مطالعاتی با توجه به خصوصیات ارتفاعی، ایستگاه‌های سنجش آلودگی هوا و هواشناسی انتخاب گردید و خصوصیات ریخت‌شناسی سطح برگ، سطح ویژه برگ، وزن تر و خشک، درصد رطوبت برگ، کشش برگ، ضخامت برگ گیاه و خصوصیات ساختاری پهنک و دمبرگ اصلی برگ درخت مورد اندازه‌گیری و داده‌ها با استفاده از آنالیز همبستگی و آزمون T مورد بررسی قرار گرفت.

یافته‌ها: پارامترهای سطح ویژه برگ، وزن مرطوب و خشک و درصد رطوبت برگ دارای تفاوت معنی‌دار در دو منطقه با دمای بیشتر و بارندگی کمتر (پردیسان) و دمای کمتر و بارندگی بیشتر (تجریش) بوده و کشش برگ، وزن مرطوب، ضخامت برگ و تعداد لایه‌های پارانشیم اسفنجی و نسبت مزوفیل پهنک به آوند بدون اتصال پهنک دارای تفاوت معنی‌دار در دو منطقه با آلودگی بیشتر (منطقه آزادی) و آلودگی کمتر (منطقه سرخه حصار) بود.

نتیجه‌گیری: مشخصات آناتومی و مورفولوژی برگ درخت چنار تحت تاثیر استرس‌های محیطی قرار گرفته و این تغییرات نشان از پایداری گیاه به شرایط محیطی است.

کلیدواژه‌ها
آلودگی هوا؛
اقلیم؛
چنار؛
سطح ویژه برگ

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