DIFFERENCES IN NORWAY MAPLE LEAF MORPHOLOGY AND ANATOMY AMONG POLLUTED (BELGRADE CITY PARKS) AND UNPOLLUTED (MALJEN MT.) LANDSCAPES

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Abstract

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Norway maple (*Acer platanoide*s L.) is often used for urban landscaping because it is considered to be tolerant to different ecological conditions. This study examined leaf anatomy and morphology, and leaf damage symptoms (using the light and SEM microscopy) of maple tree growing in three Belgrade city parks (high polluted sites: park "Hall Pioneer" and Botanical garden "Jevremovac" within City industrial zone, and low polluted Kalemegdan park), and control site (unpolluted) at Maljen Mt. during a two-year period. Microscopic measures included thickness of leaves, upper and lower epidermis, palisade and spongy mesophyll and stomatal density. Differences in leaf attributes varied significantly among sites. Leaves in parks within industrial zone were thicker (with changes most expressed by the thickening of palisade mesophyll), smaller, heavier and more voluminous from the control ones. Leaf damage were noted only in the urban zone, expressed in form of light to dark colour chloroses, and reddish-brown marginal necroses related to toxic effect of elevated concentrations of particulate matter, SO_2, and Pb, Zn and Ni in city air. Damage ranged from lesions to the last stadium of necrosis of whole mesophyll. SEM microscopy indicated erosive damage of the cuticle and stomata. We concluded that the sensitivity to air pollution of *A. platanoides* leaves is related to its leaf structure, low leaf volume and large intercellular spaces. In the same time, the leaf structural change (due thickening of mesophyll and increasing of leaf volume) follows the course of developing xeromorphic adaptations to the stressful conditions of urban environment.

Key words: Acer platanoides, air pollution, leaf anatomy, leaf damage symptoms

Introduction

Natural forests in large industrial regions and urban forests function as a filter for atmospheric deposition, which significantly reduces the toxic effects of pollutants and mitigate the impact of other stress factors in such environments (Baker, 1993; Beckett et al., 1998). At the same time atmospheric pollution represents a major and serious challenge for plants. An intensive and continuous deposition of toxic substances causes disturbances in the plant physiological processes, visible damage symptoms, decay of individuals, and even disappearance of certain species from the sites exposed to pollution.

Trees in urban environment have shortened life span, lower vitality, sparser foliage, and leaf, stem and root injuries, in comparison to the trees in natural sites. With regard to tree life length, the U.S. experience estimates an efficient permanence for the tree plantings up to 10 years, with 50% of mortality in the first year after planting (Berrang, Karnosky, 1983), while in Great Britain about 56% of trees get dry (Gilbertson, Bradshaw, 1985).

Plants react to air pollution induced stress with a variety of active morphological and anatomical responses, which include the thickening of the cell walls and the mesophyll (Paakkonen et al., 1995; Moss et al., 1998), and the thickening of the cuticular and epidermal layer (Bussoti et al., 1998). These responses indicate that the plants make metabolic investments to avoid, compensate and/or repair cellular injuries induced by pollution (Winner, 1994; Larcher, 1995). Dimensions of anatomical and morphological attributes of leaves can influence physiological response to changes in environment over time. Linking structural attributes of leaves to site conditions provide a clearer understanding of changes in anatomy and morphology of species when exposed to pollution in urban landscapes. Thus different plant species vary in their sensitivity to pollution stress. The tolerance or resistance is based on continuous development of biochemical, physiological, and morphological changes, which enables them to survive even in verry polluted sites (Matyssek et al., 1991). At the same time, such changes i.e. adaptations increase plant tolerance to other stress factors in urban environment, such as drought, high temperatures and radiation, or pathogenic activity.

The species of genus *Acer* L. are considered to be tolerant to the variability of site conditions as they have moderate requirements for mineral elements, and showed considerable efficiency in tolerating the high pollutant concentrations. This could be the reason why it is so much and so often planted in urban zones (Baker, 1993). Norway maple belongs to the group of tolerant or medium sensitive species to the activity of various types of pollutants, which justifies the plantation of this species in order to improve the air quality in urban environment (Smith, Dorchinger, 1976; Supuka, 1994). According to previous studies, Acer platanoides is resistant (Davis, Wilhour, 1976; Däbler, 1991), or sensitive to SO_2 (Legge et al., 1998), intermediary (Davis, Wilhour, 1976), i.e., sensitive to NOx (Taylor et al., 1975).

The hypothesis tested in this study was that the sensitivity of *Acer platanoides* leaves to stress of urban environment (based on visible damage symptoms) is related to their relevant morphological and anatomical attributes. In order to examine the potential endangerment of this species in city parks exposed to different levels of air pollution, the present study will investigate the foliar response of an *A. platanoides* in three Belgrade city parks. The research included plants from their natural site (as control) within the beech forest zone at Maljen Mt. (Western Serbia).

Site description

Belgrade (lat. 44^0 48' N long. 20^0 28' E), average altitude of 132 m (60–253 m), the mean annual temperature is 12.0 ^{o}C (mean temperature minimum is in January of 1.2 ^{o}C, and mean temperature maximum in July of 22.1 ^{o}C), mean annual precipitation is 688 mm, a semi-arid period occurs during July and August (Fig. 1).

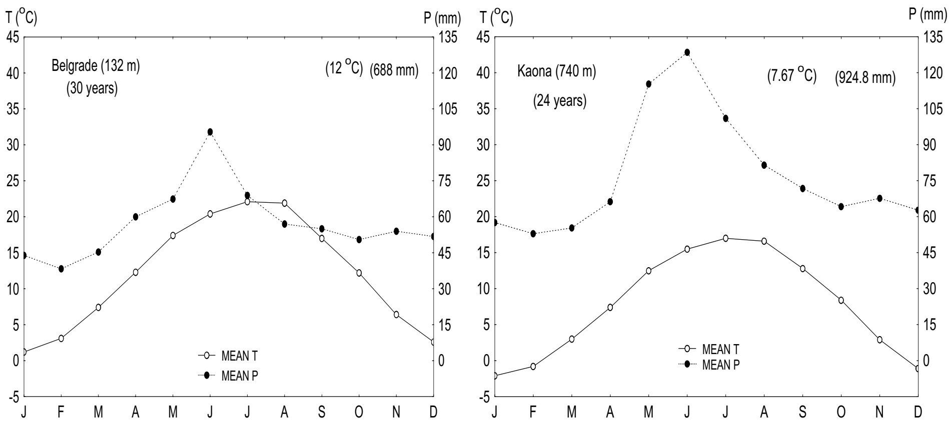

Fig. 1. Climatic diagrams of Belgrade city and Maljen mountain (locality Kaona). Ordinate gives 5 ^{0}C or 15 mm rainfall for each interval; abscissa gives the months of the year from January to December. Curve T (-o-) is the mean monthly temperature, P (——) the mean monthly precipitation.

In Belgrade city industrial facilities (chemical, pharmaceutical, metallic industry) are randomly distributed, in the central parts of the city, and its surroundings where there are large industrial complexes which represent, together with city traffic and coal-electric power plants, the sources of various types of pollutants. In the surroundings, within the distance of 50 km to the west, three coal-electric power plants are located, with the highest emission of SO_2; to the east there is a factory of nitric fertilisers and a refinery, to the south there is an iron smelter. The highest influence on total emission of SO_2 is made by the electric power plants (up to 70%), while traffic is the most important source of emission of the NO_x (up to 60%), (according to reports 1985–2001 of the Institute for Health Protection of Serbia).

The field research was done in the "Hall Pioneer" park and in the Botanical Garden "Jevremovac" in the vicinity of the City industrial zone, which is (according to the data of the City Laboratory for Human Ecology, Republican Institute for Health Protection and the Meteorological Institute, annual reports for 1997–1998) one of the most polluted City areas. This is the industrial zone in which chemical and pharmaceutical industries are located. During the 1985–2001 elevated concentrations of particulate matter, SO_2, NO_2, soot, Zn in soot deposition, also Ni and Pb in suspended particles were measured (Table 1). The least polluted was the third locality "Kalemegdan" park located within an old fortress, on the plateau above the confluence of the river Sava into the Danube.

Control site was at Maljen Mountain (lat. 44^0 $10'$ N long. 20^0 $5'$ E) in Western Serbia, Kaona locality, at 740 m a.s.l. the beech forest zone. No industry or any other source of pollution is present in that area. Climatic conditions are moderate continental and are characteristic of the hilly zones of middle-European deciduous forests. The mean annual temperature is 7.67 °C (temperature minimum is in January of -2.1 °C, and temperature maximum in July of 17 °C). Average annual precipitation is 924.8 mm (Fig. 1). Both climatic diagrams are constructed according to Walter (1973) and Unkašević (1994).

Material and methods

The research was carried out during the June and October 1997–1998 period. The maple individuals included in the research were 40–50 years old and up to 10 m high. Sampling was always carried out by taking leaves from the most exposed, border parts of the crown from the height of 2 m. The control samples were taken from the individuals (the same age and height) coming from natural site at mountain Maljen.

The morphological analysis included weight measurements of fresh (fw) and dry leaves (dw), of the leaf area (la) and leaf thickness (lt); the leaf volume (v = la x lt) was calculated. The light microscopy analysis of the leaf anatomical parameters: the thickness of entire leaf, the upper epidermal layer, palisade mesophyll layer, spongy mesophyll layer, and lower epidermis layer, from the control and the urban sites was done on the cross-sections of central leaf portions, up to 15 mm thick, cut on the slide microtome (Leica SM 200 R) and stained with safranine and alcian blue. Leaf cross-sections (20 samples chosen for each year, 10 for June and 10 for October) were analysed and photographed using the method of light microscopy (Leica DMRB equipped with a calibrated micrometric grid), with the description and dynamics of appearance of the leaf tissue damages. The total numbers of stomata were counted on the lower leaf

T a b l e 1. Allowed concentrations, minimum and maximum measured concentrations of pollutants present in the city air (1997–1998), data provided by the City Laboratory for Human Ecology and the Republican Institute for Health Protection

Years	Particulate matter [mg/m²day]	Zn [µg/m²]	Soot [µg/m³]	SO_2 [µg/m³]	NO_2 [µg/m³]	Particles <10µm [µg/m³]	Pb [ng/m³]	Ni [ng/m³]
Allowed	450	400	50	50	85	120	1000	2.5
1997	51.3–2544.2	53–1807	28.1–376	27–205	17–62	96.5–749.8	15–1607.1	1–259.7
1998	75.1–1101.2	11–1272	23.1–315	17–191	19–119	73.6–532	22–533	2–96

surface in the same 20 leaf samples randomly selected fields of view and given in n/mm^2 leaf area. Also, the state of the leaf lower surfaces and internal leaf tissues (on the cross-sections) were analysed by the SEM (JOEL JSM-35) microscopy.

Results

Differences in leaf morphological and anatomical attributes among sites

By analysis of morphological parameters of the maple leaves differences were noted in relation to leaf area, weight, thickness and volume between the control and urban samples. Leaves from the urban sites were heavier, thicker and more voluminous. Similar differences occurred between the early summer and autumn leaf samples. Urban leaves had lower leaf volume due large intercellular spaces in June, and expressed an intensive thickening during a season in comparison to the control ones. The most pronounced seasonal differences in weight, thickness and volume between two samplings were observed in "Hall Pioneer" park in the industrial city zone (Table 2).

T a b l e 2. Leaf morphometric parameters in June and October (Mean ± SE)

Sample	Month	Maljen (control)	Hall Pioneer	Botanical Garden	Kalemegdan
Leaf area [mm^2]	June	10500 ± 2012	10400 ± 3250	10100 ± 3150	10280 ± 3120
	October	12485 ± 2652	7000 ± 2650	9000 ± 3520	9900 ± 3550
Fresh weight [mg]	June	9980 ± 420	10072 ± 239	9280 ± 322	11800 ± 320
	October	1084 ± 267	15220 ± 490	12210 ± 424	13870 ± 475
Dry weight [mg]	June	2880 ± 120	4490 ± 103	4130 ± 107	3360 ± 140
	October	3830 ± 93	7650 ± 254	5570 ± 201	4450 ± 168
Leaf thickness [mm]	June	0.11 ± 0.03	0.12 ± 0.04	0.12 ± 0.04	0.12 ± 0.04
	October	0.12 ± 0.03	0.161 ± 0.02	0.14 ± 0.03	0.13 ± 0.03
Volume [mm^3]	June	13200 ± 5210	11390 ± 3487	10498 ± 5190	11878 ± 4996
	October	14204 ± 4885	16188 ± 7208	12584 ± 5753	12362 ± 5719

n = 20

The analysis of the leaf anatomical parameters in June has shown the significant difference in whole leaf thickness level ($p < 0.05$) only between control site and "Hall Pioneer" park. In mesophyll thickness there were similar differences (palisade parenchyma thickness differed significantly from control ($p < 0.001$); spongy parenchyma thickness also, $p < 0.01$). Leaf upper epidermis in "Hall Pioneer" park and Botanical garden was significantly thicker ($p < 0.001$) in comparison to control site. Leaf lower epidermis thickness differed significantly ($p < 0.01$; $p < 0.001$) between control samples and three city parks. The number of stomata was almost the same in all samples measured (Table 3). Mean

T a b l e 3. Maple leaf anatomical parameters from control and three urban sites in June and October, ANOVA; Mean (SD); tissue thickness is given in µm; number of stomata is given per mm^2 of leaf area

Sample	Months	Control site	Hall Pioneer	Botanical Garden	Kalemegdan
Whole leaf	June	113.7 (13.7)	125.8 (14.8)*	120.9 (16.7)^{ns}	118.9 (12.6)^{ns}
	October	118.2 (19.7)	161.6 (14.1)***	148.9 (19.8)***	136.0 (14.8)**
Palisade tissue	June	37.6 (7.1)	47.7 (7.4)***	37.6 (5.6)^{ns}	41.0 (10.1)^{ns}
	October	40.0 (10.8)	83.8 (9.6)***	53.8 (11.2)***	62.1 (7.0)***
Spongy tissue	June	45.2 (8.6)	41.3 (5.7)**	47.4 (13.4)^{ns}	42.8 (8.6)*
	October	50.0 (11.8)	48.3 (9.8)^{ns}	60.5 (12.7)***	40.7 (10.9)^{ns}
Upper epidermis	June	15.6 (2.6)	20.4 (2.9)***	23.4 (5.7)***	16.9 (4.6)^{ns}
	October	19.1 (3.9)	17.0 (2.2)^{ns}	18.7 (2.6)^{ns}	23.2 (3.5)***
Lower epidermis	June	8.5 (2.4)	11.0 (2.3)**	11.1 (2.1)***	11.3 (1.7)***
	October	10.2 (2.1)	13.9 (1.5)***	11.6 (2.3)^{ns}	12.1 (1.4)**
Stomata	June	127 (17.5)	134 (16.8)^{ns}	132 (12.8)^{ns}	133 (17.2)^{ns}
	October	134 (17.1)	152 (16.1)**	137.6 (13.8)^{ns}	147 (10.5)**

n = 20, ns – no significant, $p^{*} < 0.05$, $p^{**} < 0.01$, $p^{***} < 0.001$

stomata size (height by width) in control samples was 4-5x3.1 mm, in the "Hall Pioneer" park 4x3.1 mm, in Botanical garden 4-5x3.1 mm, and in Kalemegdan park 5-6x 3.1 mm. Since there were no statistical differences between two examined years we put all measured values as a whole.

Due to the ripening of the leaves, as the vegetation season progresses, maple leaves became thicker with regard to the control ones, particularly in the two parks within the industrial zone.

In autumn samples the most significant differences were found between the control site and all urban localities of the whole leaf and palisade parenchyma thickness level. The most distinguished statistical differences ($p < 0.001$) were stated in "Hall Pioneer" park and Botanical garden. Also the most intensive seasonal thickening of the palisade is measured on the leaves from the industrial zone (in June 47.7 mm and in October 83.8 mm), (Table 3). Opposite to mesophyll thickening there was a decrease in the thickness of the upper epidermis in autumn. The number of stomata was higher in comparison to the control samples and is statistically proven ($p < 0.01$) in samples from the "Hall Pioneer" and Kalemegdan park (Table 3). The average size of stomata (height by width) remained the same in control samples: 4-5x3.1 mm, in "Hall Pioneer" park 3x3.1 mm, in Botanical garden 4x3.1 mm, and in Kalemegdan park 4-5x3.1 mm.

Differences in leaf morphological and anatomical symptoms of injury among sites

In the city parks leaves were covered by soot during the whole growing season, and the first symptoms of injury already appeared in early summer of 1997. For 1998 similar patterns developed but ample rainfall postponed the appearance of damage for a couple of weeks.

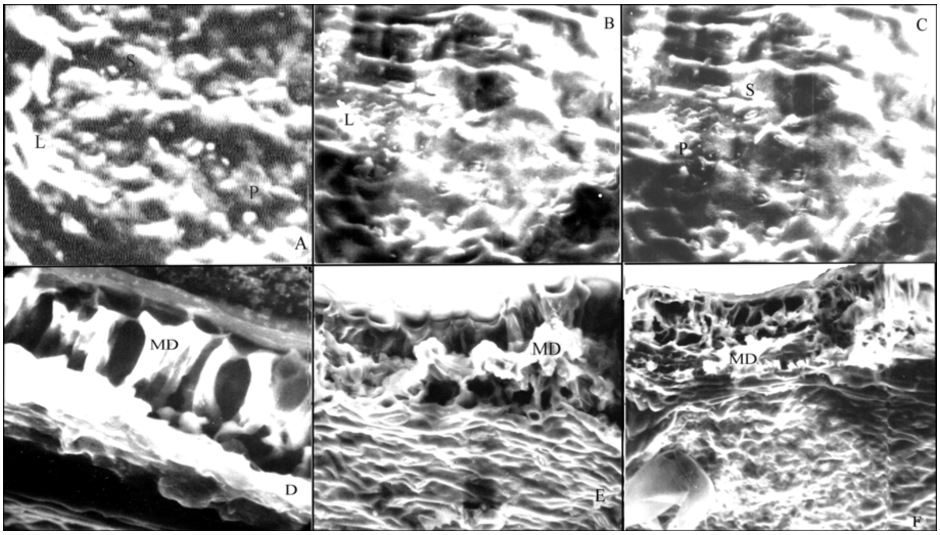

Fig. 2. SEM micrography of maple leaf lower surface: A – from “Hall Pioneer” park (x500), L – lesion, P – atmospheric particles; B – from Botanical garden (x500), L – lesion; C – from Kalemegdan park (x500), S – stomata, P – atmospheric particles. Leaf cross-section SEM migrography: D – from Hall Pioneer park (x600), MD – mesophyll damage; E – from Botanical Garden (x300), MD – mesophyll damage; F – from Kalemegdan park (x300), MD – mesophyll damage.

In the “Hall Pioneer” park, the marginal necroses occurred, first on the tops and then, during the season, they spread out towards the middle part of the leaves. At the same time, chlorotic spots appeared that also spread out – by the end of the season they covered large leaf surface area. SEM micrographs of lower leaf surface showed cuticle erosive damage, epidermis lesion, and atmospheric particles and their aggregates presence (Fig. 2A).

Sparse marginal and leaf top necroses occurred, chlorotic spots of brownish colour that cover large parts of the leaf, and tiny chloroses of yellowish colour are developed on leaves during the summer in the Botanical Garden. The trails of pathogenic activity (fungi of genus Chapnodium, plant lice) were evident. The SEM micrographs of leaf lower surface showed the erosion of cuticle and deep lesions in epidermis (Fig. 2B).

In the Kalemegdan park the leaf tops necroses appeared in July, and are light green to yellowish-brown at the end of summer, and light spot-like chloroses. The atmospheric particle deposition was also evident on the lower leaf side (Fig. 2C).

The maple leaves from the control site had no tissue damage (Fig. 3A).

Leaf tissue damage in urban environment ranged from very mild to very intensive. In the “Hall Pioneer” park they were expressed mostly in the form of interveinal necroses (Fig. 3C). Light and SEM micrographs through necroses showed damage from mild (Fig. 3B) to complete destruction of mesophyll parenchyma (Fig. 2D). The maple leaves in the Botanical Garden were also damaged in a different degree. There was a gradation in mesophyll necrotization also, ranging from the altered structure of the spongy tissue (Fig.

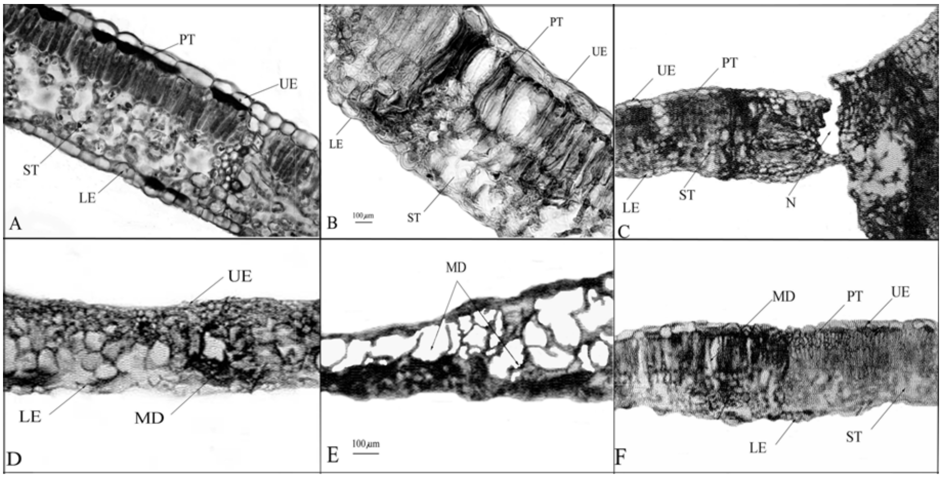

Fig. 3. Light microscopy of maple leaf cross sections: A – from Maljen Mt. (x200), UE – upper epidermis, LE – lower epidermis, PT – palisade tissue, ST – spongy tissue; B – from "Hall Pioneer" park (x400), UE – upper epidermis, LE – lower epidermis, PT – palisade tissue, ST – spongy tissue; C – necrotic leaf from "Hall Pioneer" park (x200), UE – upper epidermis, LE – lower epidermis, PT – palisade tissue, ST – spongy tissue, N – necrosis; D – from Botanical Garden (x200), UE – upper epidermis, LE – lower epidermis, MD – mesophyll damage; E – necrotic leaf from Botanical Garden (x200), MD – mesophyll damage; F – from Kalemegdan park (x200), UE – upper epidermis, LE – lower epidermis, PT – palisade tissue, ST – spongy tissue.

3D) to the last stadium of necrosis of the whole mesophyll, when it loses function (Fig. 3E). SEM micrograph of the leaf cross-section showed injuries of cuticle and epidermis as well as necroses of mesophyll (Fig. 2E). The lowest degree of the leaf damage had been noted in the Kalemegdan park. On the leaf cross-section a clear border was visible between the damaged and undamaged leaf parts (Fig. 3F). The mesophyll damage was similar to the ones already described in previous samples, but expressed in a milder form. SEM micrograph showed the damage of the spongy tissue (Fig. 2F).

Discussion

Differences between the analysed morphometric parameters of the maple leaves from natural and urban landscapes reflect the adaptations to different ecological conditions. In the natural sites maple grows in colder, more humid climate, and within shade beech forest zone (thin leaves, low leaf volume and large intercellular spaces) in comparison to more warm, more drought and polluted urban sites (heavier and thicker leaves, higher leaf volume).

Maple leaf changes in urban environment are expressed in a form of leaf area reduction and an increase of leaf weight and thickness, and are connected mostly to the impact of pollution stress (Eleftheriou, 1987; Rey, Jarvis, 1997). A gradation in the leaf thickness among the sites is established: the thinnest ones are measured in the maple from the control site (unpolluted), than from Kalemegdan park (low polluted), than in Botanical Garden and in "Hall Pioneer" park were the thickest (heavy polluted). Such changes are pronounced due to intensive thickening of the palisade parenchyma, pointing out the key place of possible leaf xeromorphisation in urban leaves as the response to the drought and pollution, which is in correspondence to Fahn (1990) that in angiosperms the palisade is specialized to increase the photosynthetic efficiency, as a basic prerequisite for survival and functioning of plants in unfavourable environment. The palisade tissue in urban leaves ("Hall Pioneer" park within industrial zone) is very developed and accounts nearly half the overall thickness of the whole leaf. This anatomical feature is associated with the capacity of intense gaseous exchanges and thus with a marked uptake of toxic gaseous and consequently with extent of tissue damage. The studies of both mesomorphic and xeromorphic species, as an adaptation to the urban conditions, point out the thickening of photosynthetic parenchyma (Karenlampi, 1986) as it is in maple. As opposite, seasonal thinning of upper epidermis in urban samples from industrial zone is attributed to erosive damage caused by continuous particulate atmospheric deposition.

Changes, noted as leaf xeromorphic adaptations also lead to reduction of ratio between the outside surface and leaf volume, as well as the decrease of cells size, thickening of cell walls, increase of density of the vascular elements and stomata. Such changes point out the mobilization of compensatory mechanisms under stress conditions in the polluted environment (Winner, 1994; Larcher, 1995), which enable the deciduous species, as it is maple, in the urban environment to maintain a satisfactory photosynthetic efficiency, and to satisfy the requirements necessary for the urban landscaping. Kloeppel, Abrams (1995) reported that Norway maple showed superior invasive ability and growth due to higher leaf thickness in two urban oak forests.

The similar stomatal density between natural and urban samples in June, correspond to Kloeppel et al. (1993). The increase of stomatal density and decrease of stomatal size in autumn samples might be also an adaptation of maple exposed to the summer water deficiency and pollution, which on one side restrict the water loss, and on the other the absorption of toxic gases, i.e., reduces the pollution stress (Beerling, Kelly, 1997; Vanhatalo et al., 2001).

Results obtained showed the sensitivity of *A. platanoides* to air pollution in urban environment. The marginal necroses and chloroses are connected to the toxic effects of elevated SO_2 and heavy metals (Kozlowski, Constantinidou, 1986; Hrdlicka, Kula, 1998). Damage of mesophyll parenchyma point out the toxic activity of elevated SO_2 concentrations, while the injury of cuticle, epidermis and stomata are rather related to the chemical and erosive impact of particulate pollution (Huttunen, Ruonala, 1994).

Microscopic observations showed that the necroses and chloroses correspond to the damage of the mesophyll cells, the palisade cells in particular. This finding is in agreement with a pattern of foliar injury as described for dorsiventral leaf type, such as maple leaf (Legge et al., 1988; Legge, Krupa, 2002). In the injured leaves the progression of the damage is quite dependent from the site exposure to pollution. The most pronounced damage in the leaves have been noted in the parks in almost all the examined individuals in the parks located in the city industrial zone (the "Hall Pioneer" park and the Botanical Garden), while in the Kalemegdan park, which is less polluted, they are expressed in the milder form. Our results corresponds to Burns, Manion (1984) indication to the endangered position of maple in urban areas, and Apple, Manion (1986) findings that Norway maple decline is a long-term pollution stress process.

The variability in the complex of maple leaf alterations arises from the combination of the underlying stress from air pollutant emissions and additional disturbances caused by climatic, edaphic and biotic stress factors. In the two-years of our study we found that anatomical changes in urban environment develop in the direction of leaf xeromorphisation, as the result of long-term multiple stresses. Our analyses correspond with earlier findings, which showed that Norway maple holds an intermediate position with regard to pollution. Results obtained also confirmed an increased susceptibility of this species to industrial zone pollution. According to our findings maple should not be planted in avenues and parks of Belgrade zones exposed to elevated pollution, but that it should be replaced in these areas with a more resistant species.

In summary, this study distinguished two Belgrade zones, in which maple shows different levels of adaptability, on the basis of determined leaf attributes. In the zone of severe pollution ("Hall Pioneer" park and Botanical garden) this species experiences extensive injury of photosynthetic tissues, on the basis of which it can be concluded that in this zone maple is at the very verge of survival. Despite its large adaptability capacity, in these areas maple overcomes environmental capacity with great difficulty. As a consequence of this there is a great decrease of vitality, year in year out, and often ends in its drying out and extinction. Pronounced leaf damage observed in parks within city industrial zones is the result of raised concentrations of air pollutants due to industry and traffic. Within the zone of low pollution (Kalemegdan park), maple expressed lesser leaf damage and higher vitality, which recommends Kalemegdan park as the only suitable urban site for maple.

Translated by the authors

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Mitrović M., Pavlović P., Djurdjević L., Gajić G., Kostić O., Bojović S.: **Rozdiely v morfológii a anatómii listu javora v znečistenej (mestské parky Belehradu) a v neznečistenej krajine (pohorie Maljen).**

Javor mliečny (*Acer platanoides* L.) sa často vyskytuje v mestskom krajinárstve, pretože sa voči rôznym ekologickým podmienkam správa tolerantne. V tejto štúdii skúmame v rozpätí dvoch rokov anatómiu a morfológiu listu a symptómy listového poškodenia (použitím svetelného a SEM mikroskopu) u javora rastúceho v belehradských mestských parkoch (veľmi znečistené miesta: park "Hall Pioneer", botanická záhrada "Jevremovac" v mestskej priemyselnej zóne a málo znečistený park u "Kalemegdan") ako aj na kontrolných plochách (neznečistených) v pohorí Maljen. Mikroskopicky sme merali hrúbky listov, spodný a nižší epidermis, palisádový a hubovitý mezofyl a priedušnú hustotu. Rozdiely v listových atribútoch sa medzi stanovišťami významne líšili. Listy v parkoch v priemyselnej zóne boli hrubšie (zmeny v zhrubnutí palisádového mezofylu), menšie, ťažšie a objemnejšie ako na kontrolnom stanovišti. Poškodenie listov vo forme chlorózy od svetlej po tmavú sme zaznamenali iba v mestskej časti, červenohnedej okrajovej nekrózy ako dôsledok toxického vplyvu zvýšenej koncentrácie špeciálnych materiálov, SO2 a Pb, Zn a Ni v mestskom vzduchu. Stupeň poškodenia je od lézií po posledné štádium nekrózy celého mezofylu. SEM mikroskopia indikuje erozívne poškodenie kutikuly a stómy. Zistili sme, že citlivosť listov u *Acer platanoides* na znečistenie sa týka ich štruktúry, nízkej objemnosti listov a veľkého intercellulárneho priestoru. Priebeh rozvojových xeromorfných adaptácií na stresové podmienky mestského prostredia má vplyv na štrukturálne zmeny listu (kvôli zhrubnutiu mezofylu a rastu objemu listu).