Glasnik Šumarskog fakulteta Univerziteta u Banjoj Luci 33, 2023, 33–46

Original scientific paper / Originalni naučni rad
DOI 10.7251/GSF2333003H
UDK 630*11:582.732

MORPHOMETRIC CHARACTERS OF *Platanus × acerifolia* (Aiton) Willd. LEAVES UNDER THE HETEROGENEOUS URBAN ENVIRONMENTS IN THE REPUBLIC OF SRPSKA

MORFOMETRIJSKE KARAKTERISTIKE LISTOVA *Platanus × acerifolia* (Aiton) Willd. U RAZLIČITIM USLOVIMA URBANIH SREDINA U REPUBLICI SRPSKOJ

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Abstract

Urban environments are often polluted with numerous contaminants originating from extensive traffic, industry and heating systems. London planetree (*Platanus × acerifolia* (Aiton) Willd.) is considered as a tree species resistant to air pollutants and climate changes in urban environments. Its resistance is based on the traits of adaptation to dry and warm conditions, bioindication of the degree of urban pollution and plant species with an important role in the nature-inspired solutions for urban areas sustainability. Therefore, this study aims to determine the differences in the morphometric traits of the leaf blade of London planetree, regarding the urban conditions of several cities in the Republic of Srpska. The study was carried out during May-June 2019. Trees for leaf sampling were selected in urban parks and alleys surrounded by high-traffic density streets. At the morphological level, the following leaf blade traits were analyzed: leaf blade length (L), maximum width of the axis of the midrib (W), distance from the midrib to the right margin (X), distance from the midrib to the left margin (Y), distance from the right lateral vein to the main vein (WR), distance from the left lateral vein to the main vein (WL), length of the right lateral vein (RL) and length of the left lateral vein (LL). The results showed that foliar comparisons have been useful in the determination of morphological differences of urban trees influenced by contrasting urban environments. Our results indicate that, based on leaf blade morphometric characters, Bijeljina was distinguished as a separate urban area, Doboj and Prijedor were grouped, while Banja Luka and Trebinje formed the second group. The results indicate the importance of applied analysis in the biological monitoring of the pollution level of urban environments.

Key words: air pollution, leaf morphology, plane tree, urban areas

1. INTRODUCTION / UVOD

Contamination of soil, water and air in urban areas is a problem of the greatest concern, endangering the global sustainability of cities worldwide (Shi et al., 2008; Tóth et al., 2016; Yang et al., 2022). Metropolitan areas have higher concentrations of contaminants than rural zones (Cichowicz & Stelęgowski, 2019; Sawidis et al., 2011). Oxides of carbon (C), sulfur (S), nitrogen (N), particulate matter (MP_{10}), lead (Pb), cadmium (Cd), and nickel (Ni), released from motor vehicle exhausts, industry and heating systems, represent a major source of pollution in urban environments (US EPA, 2015). In addition, they are identified as the pollutants of major concern that negatively affect the health of humans, plants and animals (Pathak & Mandalia, 2011; Sawidis et al., 2011; US EPA, 2015; WHO, 2006).

In recent years, a new concept known as nature-based solutions (NBS) has drawn much attention for the mitigation of air pollution in cities worldwide (Mata et al., 2021; Menon & Sharma, 2021). It refers to the actions that are "inspired by, supported by, or copied from nature" (Bourguignon, 2017; Castellari et al., 2021). The application of NBS for air pollution mitigation in urban areas is based on the plant's ability to absorb and catabolize airborne pollutants (Joshi et al., 2020; Prigioniero et al., 2021). Vegetation that covers the large sections of cities (urban forests, parks, resting and recreational zones, avenues, green corridors, etc.) plays an important role in the sustainable development and improvement of air quality in urban environments (Barwise & Kumar, 2020; Santiago, & Rivas, 2021). Green infrastructure is increasingly used to reduce air pollution (Greater London Authority, 2019; Hewitt et al., 2020; Jayasooriya et al., 2017). Dendroremediation, the use of the trees to clean up polluted air, soil and water, represents a phytotechnology with great potential for the restoration of contaminated environments (González-Oreja et al., 2008; Kőmíves & Gullner, 2006). Trees have the highest percentage sink of air pollutants in urban areas (Jayasooriya et al., 2017), related to the traits considered as the most relevant for pollution mitigation and remediation: long lifespan, large aboveground biomass, stable root system (Kőmíves & Gullner, 2006), high canopy density, foliage morphology and anatomy, high effective water-use strategy, and significant absorption of air pollutants (Grote et al., 2016; Lu et al., 2018; Pourkhabbaz et al., 2010). The morphological characteristics of leaves are the factors that influence the ability of different urban tree species to capture heavy metals and other atmospheric pollutants (Beckett et al. 2000; Vordoglou et al., 2019). Numerous studies have also observed that tree species growing in polluted urban areas develop different morphological modifications of leaves, as a response to damaging environmental factors (Dineva, 2004; Gratani et al., 2020; Kurteva & Dimitrova 2014; Lu et al., 2018; Pourkhabbaz et al., 2010). These changes depend on the plant's morphological, biochemical and physiological parameters, sensitivity and ability to minimize stress caused by the increased concentrations of pollutants (Dineva, 2004; Rai, 2016).

Earlier studies of the influence of aero pollutants on woody plants in the cities in the Republic of Srpska were mainly focused on the urban area of Banja Luka, and showed that the increased presence of nitrogen oxides, ozone, soot and particulate matter significantly disrupts the process of photosynthesis and the functioning of the stomata (Janjić et al., 2016, 2017; Janjić & Maksimović, 2018; Oljača et al., 2008, 2009). However, data on other urban areas and woody plants on the territory of Republic of Srpska are scarce.

Among tree species that build green infrastructure, London planetree (*Platanus* × *acerifolia* (Aiton) Willd) is strongly recommended as the tree species suitable for urban areas (Dineva, 2004; Gratani et al., 2020), due to its traits of fast growth, good tolerance to urban microclimate conditions, resistance to frost, drought, soil compaction and air pollution (Dineva, 2004; Pourkhabbaz et al., 2010; Sanusi & Livesley, 2020). As a result, it is a very popular tree grown in urban greenery worldwide (Cariñanos et al., 2020). The high capacity of leaves of London planetree to capture particulate matter in polluted air is linked to the morphological traits of leaf blades (Li et al., 2019; Popek et al., 2013). Therefore, this paper aimed to determine differences in morphological characters of the leaf blade of London planetree growing in different urban environments in the Republic of Srpska.

2. MATERIAL AND METHODS / MATERIJAL I METOD RADA

2.1 Characteristics of study area / Karakteristike istraživanog područja

The plant material was collected from urban parks in the following cities: Banja Luka (44°78′ N; 17°20′ E), Bijeljina (44°75′ N; 19°21′ E), Doboj (44°73′ N; 18°08′ E), Prijedor (44°98′ N; 16°70′ E) and Trebinje (42°71′ N; 18°34′ E) during May and June 2019 (Table 1; Figure 1).

Table 1. Characteristics of the study sites / **Tabela 1**. Karakteristike istraživanih lokaliteta

City	Size of green area (ha)	City population	% of total population
Banja Luka	13.6	180 053	15.4
Bijeljina	11.4	103 874	8.9
Doboj	9.5	68 516	5.9
Prijedor	8.5	80 916	6.9
Trebinje	2.8	28 239	4.7

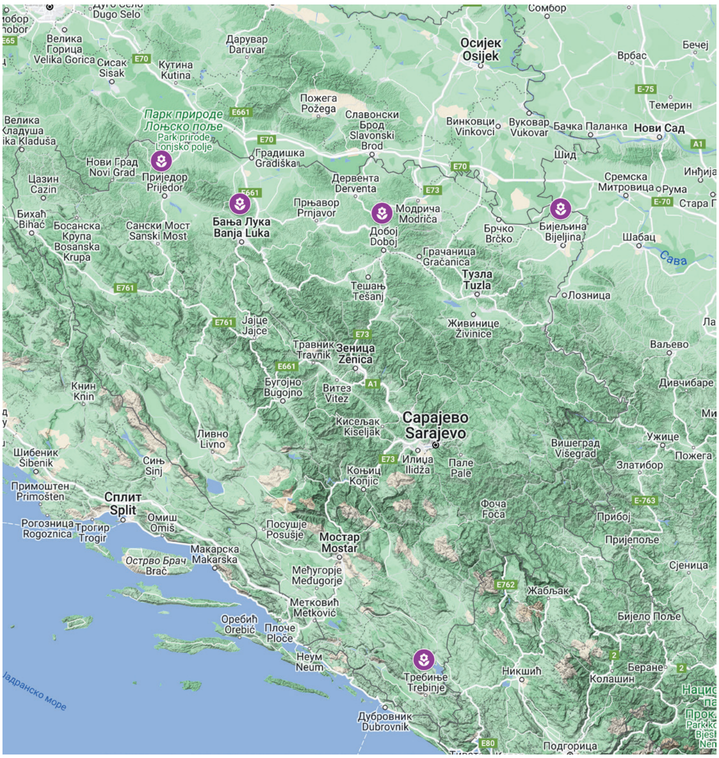

Figure 1. Map of the studied sites. Source: Google My Maps / **Slika 1**. Karta istraživanih lokaliteta. Izvor: Google My Maps

Banja Luka and Bijeljina are the most populated cities in the Republic of Srpska (The Biggest Cities In Bosnia And Herzegovina, n.d.). Concentrations of the most common air pollutants in the investigated urban sites are reviewed in Table 2. Considering pollution sources across the country, traffic and heating systems can be identified as the most important. Other potential sources, such as industry, do not exist due to the 1992–1995 war when almost all industries ceased. The average age of cars in the Republic of Srpska is 16 years, and over 60% of the cars are older than 18 years (Bihamk, 2019), due to the weak economic situation. This represents a significant source of pollution, particularly in urban areas. Heating systems (public and individual) mostly contribute to air and soil contamination in winter. Soils in the studied parks belong to the type of urbic technosols or urbosoils, that are characterized by heterogeneous structure (a combination of natural and anthropogenic components) and disturbed soil profiles (Bakhmatova et al., 2022). The depth range is 45-80 cm, the texture is loamy, and the soil reaction is mostly neutral to slightly alkaline. The studied green areas differ in size (Table 1), but other characteristics are similar. One of the most important functions of the urban green infrastructure is recreation for local people. Each green area is surrounded by three or four streets with different traffic loads.

Table 2. Concentration of air pollutants in the investigated sites during the period 1.1.2019 – 31.12.2019. (Data taken from the Republic Hydrometeorological Institute of the Republic of Srpska) / **Tabela 2**. Koncentracija aerozagađivača na istraženim lokalitetima za period 1.1.2019. – 31.12.2019. (podaci su preuzeti od Republičkog hidrometeorološkog zavoda Republike Srpske (2019))

Aero pollutants	**Average annual concentration**					**Limit concentration for calendar year ****
	Banja Luka*	Trebinje	Prijedor	Bijeljina	Doboj	
CO (mg/m^3)	0.7	-	0.8	0.7	0.5	5
SO_2 (µg/m^3)	9	15	8	18	19	50
NO_2 (µg/m^3)	28	13	15	28	13	46
PM_{10} (µg/m^3)	31	21	39	13	45	40
Heavy metals	**Average annual concentration**					**Maximal average annual concentration****
Pb (µg/m^3)	0.0208	-	-	0.0006	-	0.0291
Cd (ng/m^3)	0.42	-	-	<0.05	-	0.67
Ni (ng/m^3)	13.89	-	-	16.95	-	18.29

Note. *Data are given for agglomerations (regions), according to Hydrometeorological Institute of the Republic of Srpska & Decree on Zone Separation and Agglomerations („Official Gazette of the Republika Srpska“, No. 100/12); **Hydrometeorological Institute of the Republic of Srpska & Decree on Air Quality Values („Official Gazette of the Republic of Srpska“ No. 124/12). PM – particulate matter.

2.2 Plant material / Biljni materijal

At each studied site (Table 1), fresh leaves of London planetree were sampled from trees dispersed in the urban parks and along high-traffic streets surrounding these parks. Samples of the leaves were collected randomly (Hao & Xiangrong, 2006) from the exterior, south part of the crown oriented towards the street, at 2 m above the ground. The trees selected for leaf sampling were of different ages. Leaf samples (10 young leaves per tree and 3 trees from each site) were taken using ceramic scissors and polyethylene gloves, without touching by hands. The leaves collected in a particular site were pooled into a single sample. Leaves were pressed, dried and scanned at 300 dpi, before the measurement of morphometric traits. Measurements were performed on the scanned leaves by ImageJ Software Version 1.54 (http://rsbweb.nih.gov/ij/). To understand the impact of heterogeneous urban environments, with different climatic characteristics as one of their important parameters on the morphology of leaf, the following morphometric characters of the leaf blades (cm) were measured: leaf blade length (L), the maximum width of the axis of the midrib (W), distance from the midrib to the right margin (X), distance from the midrib to the left margin (Y), distance from the right lateral vein to the main vein (WR), distance from the left lateral vein to the main vein (WL), length of the right lateral vein (RL) and length of the left lateral vein (LL) (Figure 1). Data were statistically processed in software Past Version 4.03. (Øyvind Hammer, 2017) and presented as descriptive statistics. The significance of differences in measured parameters among different sampling sites was determined by the analysis of variance (one-way ANOVA) followed by Duncan's post-hoc test ($p < 0.05$). Site grouping was tested using Discriminant analysis.

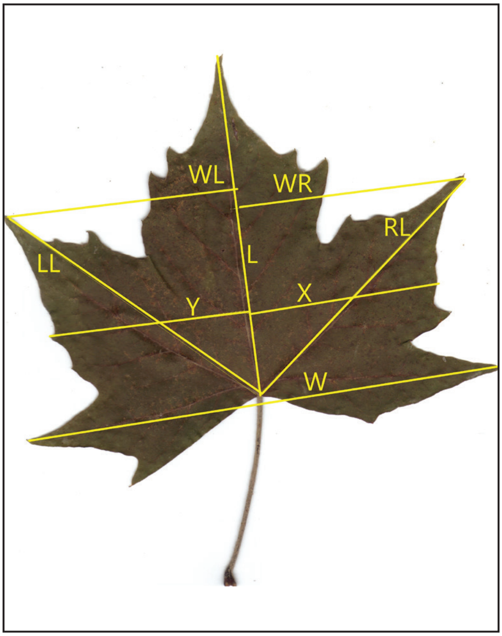

Figure 2. Measured morphometric characters of London plane (*Platanus* × *acerifolia*) leaf blade / **Slika 2**. Izmjereni morfometrijski karakteri liske javorolisnog platana (*Platanus* × *acerifolia*)

3. RESULTS / REZULTATI

Results of the analysis of leaf blade morphometric characteristics of London plane, sampled at five different urban sites, are presented in Table 3. As it can be seen, the mean values of leaf blade length (L) ranged from a sample collected in Bijeljina with a minimal mean value (11.80 cm) to a sample from Prijedor, with a maximal mean value (15.34 cm). Banja Luka, Trebinje and Doboj had similar values of character L. The mean values of the maximum width of the axis of the midrib (W) ranged from 10.70 cm in a sample collected in Doboj to 18.57 cm in a sample from Banja Luka. The measured values of distance from the midrib to the right margin (X) were minimal in the Doboj sample (6.55 cm) and maximal in the Bijeljina sample (11.53 cm). Distance from the midrib to the left margin (Y) ranged from 6.29 cm (Doboj) to 8.24 cm (Banja Luka). For distance from the right lateral vein to the main vein (WR), measured values were in the interval from 5.73 cm (Doboj) to 8.74 cm (Banja Luka). The minimal mean value of the distance from the left lateral vein to the main vein (WL) is measured in Doboj (5.83 cm), while the maximal mean value characterized the leaf blade sample from Banja Luka (8.58 cm). The mean value of the length of the right lateral vein (RL) ranged from 6.93 (Bijeljina) to 12.68 cm (Prijedor). The minimal mean value of the length of the left lateral vein (LL) was measured in a sample collected in Trebinje (10.60 cm), while a sample of leaf blade from Prijedor had a maximal mean value (12.67 cm).

Duncan's multiple-range test indicated statistically significant differences in the leaf blade samples collected at different urban sites. Banja Luka and Prijedor showed significant and maximal mean values for most of the measured parameters. According to the trait leaf blade

Table 3. Morphometric traits of the leaf blade of London planetree at five different sampling sites. Data displayed as descriptive statistics / **Tabela 3**. Morfometrijski karakteri liske javorolisnog platana sa pet različitih lokaliteta uzorkovanja. Podaci predstavljaju deskriptivnu statistiku

Sites	N	Mean	Minimum	Maximum	Standard error	Coefficient of variability (%)
leaf blade length (L)						
Banja Luka	30	14.12	9.71	18.24	0.43	16.95
Bijeljina	30	11.80	8.19	15.27	0.32	15.15
Doboj	30	13.41	10.3	18.85	0.39	16.15
Prijedor	30	15.34	12.77	18.24	0.30	10.89
Trebinje	30	13.57	8.19	19.78	0.46	18.79
maximum width of the axis of the midrib (W)						
Banja Luka	30	18.57	11.07	25.06	0.65	19.23
Bijeljina	30	15.41	11.9	19.63	0.33	12.06
Doboj	30	10.70	8.22	17.25	0.44	22.70
Prijedor	30	13.11	9.87	17.25	0.38	16.09
Trebinje	30	15.55	8.18	23.04	0.62	21.93
distance from the midrib to the right margin (X)						
Banja Luka	30	8.59	5.92	13.15	0.34	21.88
Bijeljina	30	11.53	5.18	16.93	0.64	30.59
Doboj	30	6.55	4.82	9.99	0.26	22.31
Prijedor	30	7.85	5.82	10.02	0.23	16.16
Trebinje	30	7.87	4.82	14.60	0.41	29.00
distance from the midrib to the left margin (Y)						
Banja Luka	30	8.24	5.87	12.54	0.31	21.00
Bijeljina	30	6.31	3.39	8.68	0.25	22.49
Doboj	30	6.29	4.61	11.08	0.30	26.52
Prijedor	30	6.32	9.23	7.88	0.17	11.91
Trebinje	30	7.92	5.53	13.96	0.34	23.54
distance from the right lateral vein to the main vein (WR)						
Banja Luka	30	8.74	4.43	11.56	0.31	19.78
Bijeljina	30	6.24	4.09	8.66	0.20	17.68
Doboj	30	5.73	3.27	9.14	0.27	26.20
Prijedor	30	8.08	6.08	10.10	0.23	16.02
Trebinje	30	6.18	3.50	13.68	0.40	35.71
distance from the left lateral vein to the main vein (WL)						
Banja Luka	30	8.58	5.68	12.19	0.32	20.62
Bijeljina	30	6.96	2.79	10.53	0.29	23.58
Doboj	30	5.38	2.84	8.79	0.27	28.01
Prijedor	30	8.12	6.67	10.00	0.19	13.38
Trebinje	30	6.47	3.60	12.87	0.40	34.13
length of the right lateral vein (RL)						
Banja Luka	30	12.05	9.00	15.44	0.33	15.32
Bijeljina	30	6.93	4.89	11.98	0.32	25.58
Doboj	30	11.29	8.94	16.43	0.35	17.30
Prijedor	30	12.68	8.91	15.14	0.28	12.30
Trebinje	30	10.37	5.55	14.19	0.40	21.55
length of the left lateral vein (LL)						
Banja Luka	30	11.72	8.69	15.19	0.34	15.98
Bijeljina	30	12.03	8.46	16.67	0.36	16.61
Doboj	30	11.01	7.56	15.06	0.37	18.79
Prijedor	30	12.67	10.41	14.76	0.24	10.54
Trebinje	30	10.60	4.69	14.56	0.44	22.88

Table 4. Grouping five different urban sites according to the statistical significance of the mean values of morphometric leaf blade traits of London planetree / **Tabela 4**. Grupisanje pet različitih urbanih lokaliteta prema statističkoj značajnosti srednjih vrijednosti morfometrijskih karaktera liske javorolisnog platana

	Statistically significant differences in measured morphometric traits of the leaf blade of London planetree, sampled from five urban sites							
Sampling sites	leaf blade length (L)	maximum width of the axis of the midrib (W)	distance from the midrib to the right margin (X)	distance from the midrib to the left margin (Y)	distance from the right lateral vein to the main vein (WR)	distance from the left lateral vein to the main vein (WL)	length of the right lateral vein (RL)	length of the left lateral vein (LL)
Banja Luka	b*	a	b	a	a	a	ab	ab
Bijeljina	c	b	a	b	b	b	d	ab
Doboj	b	d	c	b	b	c	bc	bc
Prijedor	a	c	b	a	a	a	a	a
Trebinje	b	b	b	a	b	b	c	c

Note. * Different small letters indicate statistically significant differences between analyzed sites according to Duncan's multiple-range test ($p<0.05$).

length (L), Bijeljina and Prijedor form individual separate groups, while Banja Luka, Doboj and Trebinje form one group. Based on the mean values of the maximum width of the axis of the midrib (W), Bijeljina and Trebinje form one group, while other sampling sites form individual separate groups. The mean values of distance from the midrib to the right margin (X) separate Bijeljina and Doboj as individual groups, and other sites as one common group. The sites Banja Luka, Prijedor and Trebinje form one group according to the statistical significance of the distance from the midrib to the left margin (Y), while Bijeljina and Doboj form other group. Banja Luka and Prijedor have the same level of statistical significance of mean value for the distance from the right lateral vein to the main vein (WR) and thus form one group. The sites Bijeljina, Doboj and Trebinje form the second common group according to morphometric traits (WR). Banja Luka and Prijedor also form a common group according to the statistical significance of mean value for the distance from the left lateral vein to the main vein (WL). Bijeljina and Trebinje form a second common group, while Doboj forms a separate group. Statistical significance of mean values of the length of the right lateral vein (RL) provides a separate group only for the Bijeljina site. The mean value of the length of the left lateral vein (LL) did not provide a form of statistically significant different and separate groups.

Discriminant analysis showed which morphometric traits, related to the leaf blade, contributed the most to the discrimination of the studied sites. The maximum width of the axis of the midrib (W), distance from the midrib to the right margin (X), distance from the midrib to the left margin (Y) and length of the right lateral vein (RL) loaded on the first axis. Maximum width of the axis of the midrib (W) together with the length of the left lateral vein (LL) loaded on the secondary axis. Parameters that loaded on the third axis were distance from the midrib to the left margin (Y), distance from the right lateral vein to the main vein (WR) and distance from the left lateral vein to the main vein (WL). Distance from the midrib to the left margin (Y) and length of the right lateral vein (RL) loaded on the fourth axis (Table 5). As shown in Figure 2, the Bijeljina site was separated based on leaf blade morphometric characters, primarily distance from the midrib to the right margin (X). Doboj and Prijedor were grouped along the positive part of the first discriminant axis, while Banja Luka and Trebinje were grouped along the negative part of the second discriminant axis.

Table 5. Morphometric traits of the leaf blade and the loads of the first four discriminant axes. Bold values represent standardized correlation coefficients between variables and canonical (discriminant) functions from the correlation matrix that are highlighted according to the values > 0.7000 / **Tabela 5**. Morfometrijski karakteri liske i opterećenje prve četiri diskriminacijske ose. Podebljane vrijednosti predstavljaju standardizovane koeficijente korelacije između varijabli i kanoničkih (diskriminantnih) funkcija iz matrice korelacije koji su istaknuti prema vrijednostima > 0.7000

Morphometric traits	Axis 1	Axis 2	Axis 3	Axis 4
L	-0.2176	-0.1642	-0.2293	0.3450
W	**-0.8418**	**1.5050**	-0.1027	-0.3315
X	**-1.1215**	-0.5564	-0.0903	-0.5089
Y	**1.4384**	0.1517	**-1.3545**	**1.1452**
WR	0.3323	0.3045	**0.9153**	-0.4152
WL	-0.4806	-0.0404	**0.7951**	0.5425
RL	**1.2085**	0.0597	0.2096	**-0.7992**
LL	-0.3721	**-1.0366**	0.5051	0.5191
Eigenvalue	7.2428	2.3800	0.9259	0.1442
Cumulative percentages of the vectors	0.6773	0.2226	0.0866	0.0135

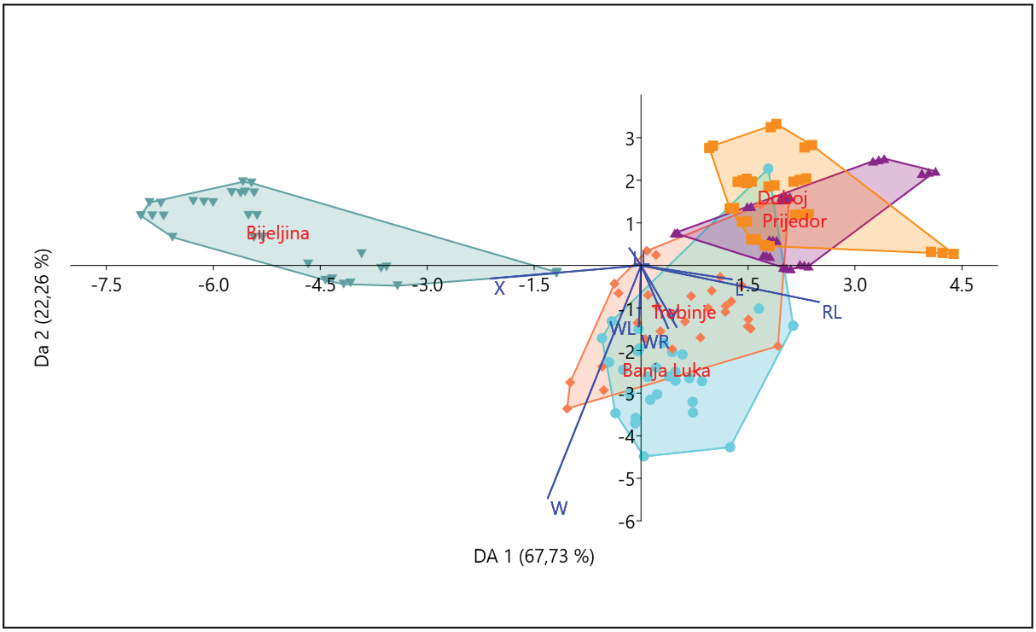

Figure 3. The results of a discriminant analysis showing the separation of five urban sites in the space of the first two discriminant axes, based on the morphometric traits of the leaf blade of London plane / **Slika 3**. Rezultati diskriminantne analize pokazuju razdvajanje pet urbanih lokaliteta u prostoru prve dvije diskriminantne ose, prema morfološkim osobinama liske javorolisnog platana

4. DISCUSSION / DISKUSIJA

Resistance of plants to environmental pollution is determined by biological characteristics of the species and ecological conditions. Atmospheric pollution is one of crucially significant factors that negatively affect the resistance of tree species and parameters of leaves (Kurteva & Dimitrova, 2014). London planetree, *Platanus × acerifolia*, is a particularly resistant tree species to stress factors, including pollution in various urban areas (Dineva, 2004; Gratani et al., 2020, 2021; Pourkhabbaz et al., 2010). The results of the present study showed statistically significant differences in analyzed morphometric traits of the leaf blade of London planetree in response to different environmental conditions (differences in population density, concentrations of air pollutants, traffic loads) of five distinct urban locations. The most prominent statistically significant differences among investigated sites were obtained for the measured values of the maximum width of the axis of the midrib (W), followed by values of leaf blade length (L), distance from the left lateral vein to the main vein (WL) and distance from the midrib to the right margin (X). Banja Luka and Prijedor were characterized by the maximal average values of most traits of the leaf blade samples. Such data can be explained by the effects of most common aero pollutants, including CO, SO_2, NO_2, PM_{10} on the morphological traits of the leaves of urban trees (Corada et al., 2021; Rodríguez-Santamaría et al., 2022). Data taken from the Hydrometeorological Institute of the Republic of Srpska showed that average annual concentration of main air pollutants did not exceed maximal annual values, except Doboj, where concentration of particulate matter was above the limit level in 2019 when the samples were collected. However, the daily limit and tolerant concentration values of pollutants listed in Table 2, were exceeded multiple times during the year of sampling in all of the observed sites (data shown in Appendix (Table A1), especially in agglomerations Bijeljina and Trebinje. It can be assumed that the air pollutants were filtered by London planetree from urban sites, resulting in differences in the measured morphometric traits. Similar results were obtained for morphological traits of *Platanus × acerifolia* leaves in response to different pollution levels in Rome: the values of leaf area were significantly higher in historical parks and high-traffic density streets with larger water availability (Gratani et al., 2021). Differences in leaf traits sampled in different urban conditions can be linked to the phenotypic plasticity of plants in response to environmental conditions (Gratani, 2014; Li et al., 2021). Many researchers provided data that indicate the negative impact of increased concentration of toxic pollutants in urban air on morphological and anatomical characteristics of leaf blades of different trees in industrial and urban conditions: *Salix alba* (Wuytack et al., 2010); *Aesculus hippocastanum*, *Castanea sativa* and *Cydonia oblonga* (Kurteva & Dimitrova, 2014); *Azadirachta indica*, *Cassia fistula*, *Ficus religiosa* and *Ficus virens* (Chaudhary & Rathore, 2016); *Tilia cordata* and *Tilia platyphyllos* (Janjić & Maksimović, 2018); *Platanus × acerifolia*, *Celtis occidentalis*, *Tilia argentea*. and *Quercus robur* (Greksa et al., 2019); *Ginkgo biloba* and *Platanus occidentalis* (You et al., 2021); *Ligustrum lucidum* (Zhao et al., 2021).

The decrease of leaf area, excluding the petiole, in *Platanus × acerifolia* in urban sites with high-traffic density may be explained by the fact that the leaf expansion represents a reaction to factors of urban environments (Gratani et al., 2021), particularly traffic emissions (Pourkhabbaz et al., 2010). For example, variations in leaf morphology are observed in *Platanus orientalis* leaves sampled in heavily polluted city areas of Istanbul (Baycu et al., 2006).

Our study was unable to assess the data of leaf morphology of London planetree in rural and unpolluted areas, due to the specific requirements of sampling, methodology of research that focused primarily on city areas and distribution of studied species. London planetree is a species exclusively distributed as an ornamental tree in urban areas in the Republic of Srpska and, so far, there are no known data on whether the species is spread in unpolluted or rural areas. However, to compare, the leaves of *Platanus × acerifolia* show larger morphological and anatomical parameters, notably leaf area, total leaf thickness, and thickness of palisade and spongy layers, in unpolluted sites opposite to the sites with high air pollution levels caused by high-traffic density (Gratani et al., 2020). Wang et al. (2022) have indicated *Platanus × acerifolia* is tolerant of air pollution and suggested that it should be used more in urban areas exposed to particulate matter pollution, especially in the middle of the cities and on edges of streets/roads with heavy traffic loads. In addition, mature leaves of related species *Platanus orientalis* from the urban area were smaller than those from the rural sites indicating the influence of air pollution on the development of leaves (Pourkhabbaz et al., 2010). However, leaf morphological traits, including leaf length and width, indicated *Platanus × acerifolia* as the most efficient species in capturing particulate matter in sites with high pollution levels (Wang et al., 2022).

Measurements of morphometric traits of the leaf allow the separation of populations, species and even localities into different groups in the same region, as previously identified by Pourkhabbaz et al. (2010) and Galván-Hernández et al. (2015). Our data of discriminant analysis distinguished Bijeljina as a distinct group, based on measured leaf traits of London planetree: maximum width of the axis of the midrib, distance from the midrib to the right margin and length of the left lateral vein.

The obtained data showed that foliar comparisons have been a useful tool in the assessment of the influence of contrasting urban environments on green infrastructure, particularly tree species. Hence, it may be concluded that London planetree is impacted by urban pollution but can play a significant role in the biological monitoring of the extent of pollution in urban environments. To determine the tolerance of *Platanus × acerifolia* to air pollutants from traffic exhaust in studied sites, and its significance in improving air quality, further researches have to be performed in the future, which should include chemical, physiological and anatomical analyses of leaves and chemical analysis of urban air and soil. Thus, to complete the results of the work, it is important to establish the permanent monitoring on a significantly larger number of samples. It is also necessary to do analyses in unpolluted zones, i.e. rural environment, considering the age of trees and the phase of leaf growth. In this way, the image of the role of London planetree as a part of NBS in urban areas would be completed.

5. CONCLUSION / ZAKLJUČAK

The results obtained in this paper showed that the investigated species *Platanus × acerifolia* reacted differently to the toxic aero pollutants in different urban conditions. The morphological characteristics of the London planetree leaf blade varied between the samples collected from urban green spaces originating from five different cities. Statistically significant differences among investigated samples were obtained for the maximum width of the axis of the midrib (W), leaf blade length (L), distance from the left lateral vein to the main vein (WL) and distance from the midrib to the right margin (X). Banja Luka and Prijedor were characterized by maximal average values of most leaf traits. Such data can be explained by the exceeded average concentrations of particulate matter as the most common aero pollutants. In all the observed sites, the daily limit of tolerant concentration of PM_{10} was exceeded multiple times during the year of sampling. Hourly tolerant values of SO_2 and NO_2 concentration in the air of agglomeration Bijeljina were exceeded multiple times. In such urban conditions, the impact of the air pollutants on the leaf blade of London planetree resulted in differences in the measured morphometric traits.

The obtained results indicate that it is necessary to establish the permanent biomonitoring of air quality, including a greater number of urban sites and detailed morpho-anatomical and physiological analyses of London planetree. In this way, a database of plant traits that are the most relevant for the assessment of air pollution and potential use in NBS for sustainable cities, can be established.

Acknowledgement / Zahvala

This research was supported by the Ministry of Science -Technological Development, Higher Education and Information Society of the Republic of Srpska, Grant No. 19/6-020/961-43/18.

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Sažetak

U ovom radu smo istražili razlike u morfometrijskim karakterima liski javorolisnog platana, *Platanus* × *acerifolia* (Aiton) Willd., uzorkovanih u različitim uslovima urbanih sredina Banja Luke, Bijeljine, Prijedora, Doboja i Trebinja. Analiza izmjerenih parametara je pokazala da postoje statistički značajne razlike između uzoraka sakupljenih na različitim lokacijama, koje su najizraženije u uslovima Banja Luke i Prijedora. Najveće statistički značajne razlike između uzoraka su dobijene za sljedeće morfometrijske karaktere liske: maksimalna širina liske izmjerena pod pravim uglom u odnosu na centralni nerv (W), dužina liske (L), rastojanje lijevog bočnog nerva od centralnog nerva (WL) i rastojanje centralnog nerva od desnog ruba liske (X). Diskriminantna analiza je pokazala da se na osnovu morfometrijskih karaktera liske posebno izdvaja lokalitet Bijeljina, što je u skladu sa uticajem zagađenja vazuha u ovoj aglomeraciji na razvoj liske platana. Glavni cilj naših analiza bio je da ukažemo na značaj analize morfometrijskih karaktera liske drvenastih vrsta u različitim urbanim uslovima, što može biti koristan alat u praćenju stepena aerozagađenja. Dalja detaljna istraživanja koja bi obuhvatila detaljniju analizu anatomskih i morfofizioloških karaktera, ne samo platana, već i drugih drvenastih vrsta, poslužila bi u procjeni osjetljivih i otpornih vrsta na zagađenje gradskog vazduha. Podaci bi takođe poslužili za uspostavljanje baze podataka za razvoj rješenja na bazi prirode koja imaju ulogu u biomonitoringu zagađenja i održivom upravljanju urbanim sredinama.

Ključne riječi: morfologija lista, platan, urbana područja, zagađenje vazduha