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THE INFLUENCE OF URBAN AND SUBURBAN ENVIRONMENTAL CONDITIONS ON THE MORPHOLOGICAL CHARACTERISTICS OF EUROPEAN BEECH LEAVES IN THE BELGRADE AREA

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Abstract: *The research of morphological characteristics of leaves in urban and suburban conditions of the city of Belgrade has been carried out in this paper, in order to determine whether there is significant difference of these parameters on trees in urban and suburban zone of the city, i.e. the influence of urban and suburban environmental conditions on morphological characteristics of beech leaves in the territory of Belgrade. The research was performed on two sites in the territory of the city of Belgrade: Natural monument "Faculty of Forestry Arboretum" (urban zone) and "Area of Outstanding Natural Landscape Avala" (suburban zone). All the average values of the morphological parameters of leaves sampled in Arboretum are larger and show significant difference compared to morphological parameters of leaves sampled on Avala. This can be explained, besides the origin of the seeds, by the fact that the trees growing in Arboretum are protected from the negative anthropogenic influence and agrotechnical measures are regularly applied, in contrast to the beech trees in the natural stand of submontane beech forest on Avala, which does not have such protection.*

Keywords: european beech, morphological characteristics of leaves, urban and suburban environmental conditions, Belgrade

UTICAJ GRADSKIH I PRIGRADSKIH USLOVA SREDINE NA MORFOLOŠKE KARAKTERISTIKE LIŠĆA BUKVE NA PODRUČJU BEOGRADA

Sažetak: *U radu su izvršena istraživanja morfoloških karakteristika lišća bukve u gradskim i prigradskim uslovima Grada Beograda, kako bi se utvrdilo da li postoji signifikantna razlika ovih parametara na stablima u urbanoj i suburbanpoj zoni grada, odnosno uticaj gradskih i prigradskih uslova sredine na morfološke karakteristike lišća bukve na području Beograda. Istraživanja su vršena na dva lokaliteta na području Grada Beograda: Spomenik prirode „Arboretum Šumarskog fakulteta“ (gradska zona) i „Predeo izuzetnih odlika Avala“ (prigradska zona). Sve prosečne vrednosti morfoloških parametara listova uzorkovanih u Arboretumu su veće i pokazuju signifikantno značajnu razliku u odnosu*

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na morfološke parametre listova uzorkovanih na Avali. Ovo se može objasniti, pored porekla semena, time što su stabla rasla u Arboretumu zaštićena od negativnog antropogenog uticaja i redovno se primenjuju agrotehničke mere, za razliku od stabala bukve u prirodnoj sastojini brdske bukove šume na Avali, koja nema takvu vrstu zaštite.

Ključne reči: bukva, morfološke karakteristike listova, gradski i prigradski uslovi sredine, Beograd

1. INTRODUCTION

European beech (*Fagus sylvatica* L.) is one of the most abundant broad-leaved tree species in Switzerland and elsewhere in Europe, and it has an important economic and environmental role in sustainable forest management (Hlásny et al., 2014).

Beech as the most widespread woody species in Serbia has a great importance in forest ecosystems. The size of a leaf is of vital importance in direct correlation with the production of total biomass and for the role in air purification (Mitrović et al., 2022). Therefore, this species is important in urban environments, both as individual tree in the parks and as a species represented in urban and suburban forests. In addition to aesthetical, its role in preserving the environment is very important.

Beech leaf morphology was studied from various aspects by researchers worldwide and in Serbia. In recent years, leaf morphological traits and leaf nutrient concentrations of European beech across a water availability gradient in Switzerland was studied by Salehi et al. (2020), leaf morphological traits of beech (*Fagus sylvatica* L.) along an altitudinal gradient was studied by Adamidis et al. (2021). Boutsios et al. (2021) studied leaf morphology in beech populations of South Rhodope Mountains. Morphological and phenological variability of European beech (*Fagus sylvatica* L.) in international provenance test in Bosnia and Herzegovina was studied by Memišević Hodžić and Ballian (2021), variability of morphological characteristics of beech leaves in Switzerland was studied by Zhu et al. (2022), the relation of morphometric characteristics and drought stress by Mathes et al. (2023) and others. In Serbia morphological characteristics of beech leaves were studied by Šijačić-Nikolić et al. (2013), Nonić (2016), Nonić et al. (2019) and others.

The research of morphological characteristics of beech leaves in urban and suburban conditions of the city of Belgrade has been carried out in this paper, in order to determine whether there is significant difference of these parameters on trees in urban and suburban zone of the city, i.e. the influence of urban and suburban environmental conditions on morphological characteristics of beech leaves in the Belgrade area.

2. METHODOLOGY

The analysis of morphological characteristics of leaves was carried out during the summer of 2019 on two sites in the territory of the city of Belgrade (Figure 1): Natural monument "Faculty of Forestry Arboretum" (urban zone) and "Area of Outstanding Natural Landscape Avala" (suburban zone) (Figure 1). The analysed

beech trees in Arboretum are planted, while beech trees on the site on Avala are from natural population.

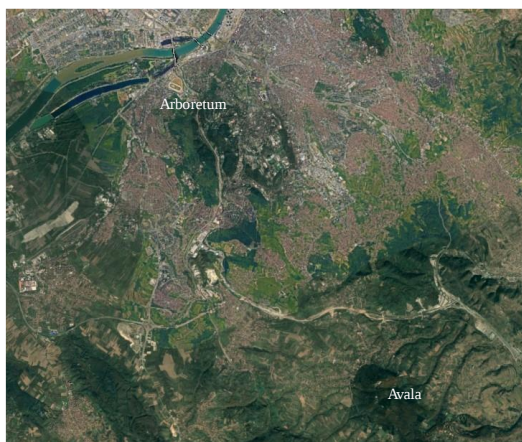


Figure 1. Sites on the territory of the city of Belgrade

While collecting the material primary selection was carried out in order for the sample to be as homogenous as possible, both for the samples within one tree and for all the trees of the studied species. The collection of leaves on the site was carried out by the random sampling method, in the part of growing season when these vegetative organs are completely developed. Thirty healthy undamaged leaves per tree were sampled from the trees.

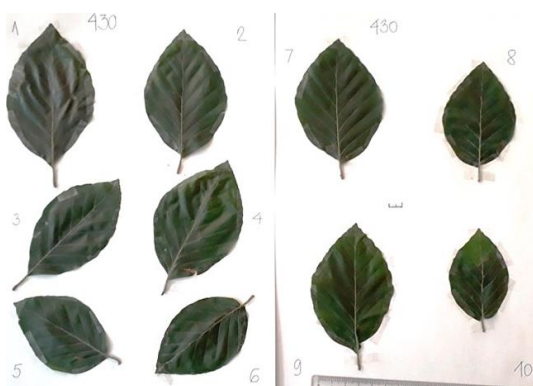


Figure 2. Herbarized plant material

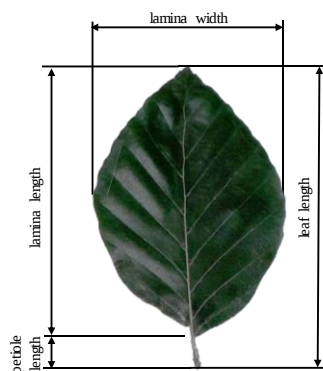


Figure 3. Display of measured morphometric parameters

The leaves were collected from the same part of the crown (outer part of the crown on the southern side) and from approximately same height (4-6 m). They were put in plastic bags and transported to the laboratory of the Institute of Forestry immediately. Leaves were then herbarized (Figure 2), and on such herbarized material measurements of morphological parameters were carried out with the precision of 0.1-1.0 mm.

Morphometric parameters on the collected samples (Figure 3), which were measured or derived, were the following: lamina length (cm), lamina width (cm), petiole length (cm), lamina thickness (mm), leaf length (cm), lamina width/lamina length ratio.

Statistical processing of the obtained data was carried out by using the software *Microsoft Office* and *Statistica 7*. The estimates of statistical importance of various factors of variation of the monitored characteristics were carried out by applying the analysis of variance (ANOVA). The basic parameters of descriptive statistics, mean value ($\bar{X}$), minimum and maximum value ($X_{\min}$ and $X_{\max}$), standard deviation (Sd) and coefficient of variation (CV%) were done separately for each sample. Fisher LSD test was used for confirmation of importance of differences of arithmetic means between individual measured and derived parameters. In order to determine the existence of connection between all measured morphometric parameters, a regression analysis was performed.

3. RESULTS AND DISCUSSION

The research was carried out on two sites: Faculty of Forestry Arboretum and Area of Outstanding Natural Landscape Avala.

Faculty of Forestry Arboretum in Belgrade represents created botanical value. Spatially and functionally it is connected into system of urban greenery. It is recognizable primarily by educational and scientific purpose, bioecological and sanitary-hygienic as well as cultural and aesthetic. Arboretum is located in urban zone of Belgrade, so it is exposed to various influences of urban functions as sources of pollution: traffic, sewerage (soil pollution by waste water as a consequence of bad infrastructure), housing (in the immediate vicinity the construction of high-rise residential objects is pronounced). The research was carried out in the specific conditions of arboretum, which stands on the habitat of former mixed autochthonous forests of Hungarian oak and Turkey oak (*Querceto-frainetto cerris* subass. *aculeatetosum* Jov. = syn. *Rusco-Quercetum frainetto-cerris* Jovanović, 1951) (Plan of management of Natural monument Faculty of Forestry Arboretum), at the elevation of 120 m.

The area of mountain Avala has experienced protection of its natural and cultural assets for a very long time. Avala is protected by the current legislation as the Area of outstanding natural landscape. This shows in the best way the importance that this natural entity has for the citizens of Belgrade as the closest mountain and forecourt of the urbanized area of capital city. The resource of preserved nature and cultural sights provides to this area a large touristic potential. However, due to such a great importance it has for the population of Belgrade, preservation of biodiversity of this area and sustainable touristic and also population development of Avala can be cited as the imperative (Bakić and Radić, 2019). The research was carried out in submontane beech forest (*Tilio-Fagetum submontanum* (Janković et Mišić 1960) Mišić 1972), at the elevation of 480 m.

Morphometric parameters of leaves from the trees of selected deciduous species (with simple leaves in terms of structure) from two sites are presented in the table.

Table 1. *Morphological traits of beech leaves*

Locality	Traits	Mean	Max	Min	Range	Sd	Cv
Arboretum	a	9.27	10.80	7.10	3.70	0.94	10.14
	b	5.99	6.80	4.60	2.20	0.60	9.99
	c	1.21	1.60	0.90	0.70	0.17	14.41
	d	10.48	12.40	8.00	4.40	1.08	10.27
	e	0.10	0.11	0.08	0.03	0.01	8.21
	f	0.65	0.70	0.55	0.15	0.03	5.09
Avala	a	7.80	9.30	6.40	2.90	0.79	10.18
	b	4.68	6.00	3.90	2.10	0.60	12.72
	c	0.72	1.00	0.50	0.50	0.12	16.62
	d	8.52	10.10	6.90	3.20	0.86	10.14
	e	0.08	0.08	0.07	0.01	0.00	6.40
	f	0.60	0.67	0.56	0.11	0.03	4.53

Morphological traits:

a - lamina length, b - lamina width, c - petiole length, d - leaf length, e - lamina thickness, f - lamina width/lamina length

On the site Faculty of Forestry Arboretum morphometric parameter lamina length for beech has an average value of 9.27 cm, and ranges from 7.10 to 10.80 cm. The average lamina width is 5.99 cm, the smallest measured is 4.60, and the largest 6.80 cm. The petiole length has an average value of 1.21 cm, and ranges from 0.90 to 1.60 cm. The average total length of beech leaf is 10.38 cm, and ranges from 8.00 to 12.40 cm. The average lamina thickness is 0.10 mm, the smallest measured is 0.08, and the largest 0.11 mm. The average value of the ratio of lamina width and lamina length is 0.64, ranging from 0.55 to 0.70. The value of the coefficient of variation is the highest for the petiole length parameter (17.57%), and the lowest for the ratio of lamina width and lamina length (6.44%).

On the site Avala, the average lamina length for beech is 7.90 cm, and ranges from 6.40 to 9.30 cm. The average lamina width is 4.75 cm, the smallest measured is 3.90, and the largest 5.90 cm. The average petiole length is 0.72 cm, and ranges from 0.50 to 1.00 cm. The average total length of beech leaf is 8.62 cm, and ranges from 6.90 to 10.10 cm. The average lamina thickness is 0.08 mm (0.07-0.08 mm). The average value of the ratio of lamina width and lamina length amounts to 0.60, and ranges from 0.57 to 0.63. The value of the coefficient of variation is the highest for the parameter petiole length (19.42%), and the lowest for the parameter ratio of lamina width and lamina length (3.37%).

Table 2. *Correlation analysis of the studied morphological characteristics*

Arboretum						
	a	b	c	d	e	f
a	1.00					
b	0.86*	1.00				
c	0.74*	0.53*	1.00			
d	0.99*	0.84*	0.81*	1.00		

e	0.49*	0.58*	0.29	0.48*	1.00	
f	-0.31	0.21	-0.42	-0.34	0.14	1.00
Avala						
a	1.00					
b	0.93*	1.00				
c	0.53*	0.46*	1.00			
d	0.99*	0.92*	0.63*	1.00		
e	0.32	0.39	0.31	0.34	1.00	
f	0.34	0.65*	0.2	0.33	0.35	1.00
*Marked correlations are significant at $p < 0.05$						

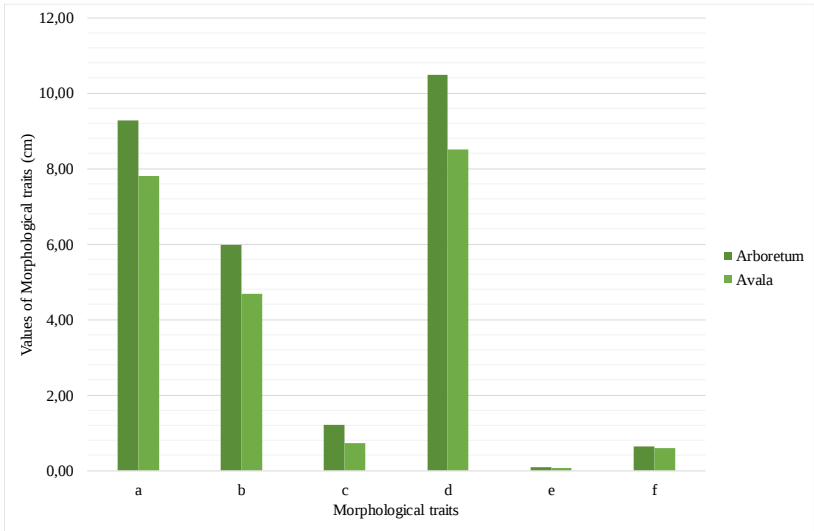
Morphological traits:
a - lamina length, b - lamina width, c - petiole length, d - leaf length, e - lamina thickness, f - lamina width/lamina length

Correlation analysis on the site Faculty of Forestry Arboretum shows that between lamina length and all other studied morphological characteristics, except the ratio of lamina width and lamina length, there is significant absolutely positive correlation. The strongest relation is with lamina length (0.99), and the weakest with the total length of the leaf (0.35). A large interdependence of lamina width and lamina thickness was recorded (0.84) and of lamina thickness and petiole length (0.68).

On the site Avala the strongest relation of lamina length is also with lamina thickness (0.99), as with leaves sampled in Arboretum. The weakest correlation of lamina length is with petiole length (0.53). A large interdependence of lamina width and lamina thickness (0.92) and lamina thickness and petiole length (0.68) was recorded also on this site.

In his research of morphological characteristics of beech leaves from the site Belgrade, Municipality Savski Venac, Dedinje – White Court, Nonić (2016) recorded average lamina length of 8.57 cm, lamina width 5.48 cm, petiole length 0.95 cm, average total leaf length of 9.52 cm, which is within the range of the values obtained during this research. The lamina width, lamina length and petiole length of beech leaves sampled on Fruška Gora and Kopaonik (Šijačić-Nikolić et al., 2013) have smaller dimensions than the leaves from the researched sites.

A comparative overview of morphometric parameters of leaves from the selected beech trees on the researched sites is presented on the graph below.



Morphological traits: a - lamina length, b - lamina width, c - petiole length, d - lamina thickness, e - leaf length, f - lamina width/lamina length

Graph 1. Comparative overview of morphometric parameters of leaves from the selected beech trees on the researched sites

Table 3. Results of statistical analysis of morphological parameters of beech leaves from the researched sites

	a	b	c	d	e	f
Arboretum	9.27a	5.99a	1.21a	10.48a	0.10a	0.65a
Avala	7.80b	4.68b	0.72b	8.52b	0.08b	0.60b

Morphological traits:

a - lamina length, b - lamina width, c - petiole length, d - leaf length, e - lamina thickness, f - lamina width/lamina length

Fisher's LSD (least significant difference) post-hoc comparisons test (ANOVA, $p < 0.05$) (the same letters associate parameters with no statistically significant differences)

By comparative analysis of morphological characteristics of beech leaves from two sites, it can be determined that there is statistically significant difference for all the measured and derived parameters (Table 3). The values of all the morphometric parameters of leaves sampled on the site Arboretum are higher. This difference in leaf morphology can be explained by the origin of seeds, it can be the result of the phenotypic plasticity of beech trees, but also of the adaptation of beech populations to different environmental conditions. Faculty of Forestry Arboretum is the object where mowing and watering is constantly carried out and agrotechnical measures are applied. The latter can also explain significant difference between the researched parameters. On the other hand, trees in the forest ecosystem of the Area of Outstanding Natural Landscape Avala, near Belgrade, are exposed to a higher level of human threats, due to their specific location and surroundings (Popović et al., 2022). The research of Nonić (2016) also shows that the beech leaves in urban environment have larger dimensions than the ones in natural stands. Salehi et al. (2020) in their research of morphological characteristics of beech leaves on 12 sites in the main geographical regions of Switzerland state that the length of leaves tended to decrease with the increase of elevation. Boutsios et al. (2021) state that the trend of change of morphology of leaves in the direction West-East in South Rhodope

Mountains in the territory of northeast Greece also can be the result of phenotypical plasticity of beech trees or adaptation of beech populations to different environmental conditions.

5. CONCLUSION

Morphological characteristics of leaves are considered to be appropriate indicators of plant functioning, such as photosynthetic and respiratory functions (Wright et al., 2004, Poorter et al., 2009). Their morphology directly affects their physiology (Fitter and Hay, 2002).

Regarding the correlation of certain morphological parameters, on both sites this correlation is strongest between the properties lamina length and leaf length. All the average values of morphological parameters of leaves sampled in Arboretum are larger and they show significant difference compared to morphological parameters of leaves sampled on Avala. This can be explained, besides the origin of the seeds, by the fact that the trees growing in Arboretum are protected from the negative anthropogenic influence and agrotechnical measures are regularly applied, in contrast to the beech trees in natural stand of submontane beech forest on Avala which does not have such protection.

Wide ecological amplitude and growth on elevations from 50 to over 2,000 m indicate great adaptability of the species to different environmental conditions. Beech trees can stand the air pollution in urban environments, in parks, where care and protection measures are constantly applied.

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Summary

Beech as the most widespread woody species in Serbia has a great importance in forest ecosystems. The size of the leaf is of vital importance, in direct correlation with the production of total biomass, and also has a role in air purification. (Mitrović et al., 2022). Therefore, this species is important in urban environments, both as individual tree in parks and as a species represented in urban and suburban forests. In addition to aesthetic, its role in preservation of environment is also important. The research of morphological characteristics of leaves in urban and suburban conditions of the city of Belgrade is carried out and presented in this paper, in order to determine whether there is a significant difference of these parameters on trees in urban and suburban zone of the city, i.e. influence of urban and suburban environmental conditions to morphological characteristics of beech leaves in the territory of Belgrade. The research was carried out on two sites in the territory of the city of Belgrade: Natural Monument Faculty of Forestry Arboretum (urban zone) and Area of Outstanding Natural Landscape Avala (suburban zone). Regarding the correlation of certain morphological parameters, on both sites this correlation is the strongest between the properties lamina length and leaf length. All the average values of morphological parameters of leaves sampled in Arboretum are higher and show significant difference compared to morphological parameters of leaves sampled on Avala. This can be explained, in addition to the phenotypical plasticity of beech trees or adaptation of beech populations to different environmental conditions, by the fact that the trees growing in Arboretum are protected from negative anthropogenic influence and agrotechnical measures are regularly applied, in contrast to the beech trees in the natural stand of submontane beech forest on Avala, which does not have that kind of protection.

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Rezime

Bukva kao najrasprostranjenija drvenasta vrsta u Srbiji ima veliki značaj u šumskim ekosistemima. Veličina lista je od vitalnog značaja, u direktnoj korelaciji sa proizvodnjom celokupne biomase, ali i ulogom u prečišćavanju vazduha (Mitrović et al., 2022). Zato je ova vrsta značajna u gradskim sredinama, kako kao pojedinačno stablo u parkovima, tako i kao vrsta zastupljena u gradskim i prigradskim šumama. Pored estetske, veoma je važna njena uloga u očuvanju životne sredine. U radu su izvršena istraživanja morfoloških karakteristika lišća u gradskim i prigradskim uslovima Grada Beograda, kako bi se utvrdilo da li postoji signifikantna razlika ovih parametara na stablima u urbanoj i suburbanjoj zoni grada, odnosno uticaj gradskih i prigradskih uslova sredine na morfološke karakteristike lišća bukve na području Beograda. Istraživanja su vršena na dva lokaliteta na području Grada Beograda: Spomenik prirode „Arboretum Šumarskog fakulteta“ (gradska zona) i „Predeo izuzetnih odlika Avala“ (prigradska zona). Što se tiče korelacije pojedinih morfoloških parametara, na oba lokaliteta ova korelacija je najjača između svojstava dužina liske i dužina lista. Sve prosečne vrednosti morfoloških parametara listova uzorkovanih u Arboretumu su veće i pokazuju signifikantno značajnu razliku u odnosu na morfološke parametre listova uzorkovanih na Avali. Ovo se može objasniti, pored fenotipske plastičnosti bukovih stabala ili adaptacije populacija bukve na različite uslove životne sredine, time što su stabla rasla u Arboretumu zaštićena od negativnog antropogenog uticaja i redovno se primenjuju agrotehničke mere, za razliku od stabala bukve u prirodnoj sastojini brdske bukove šume na Avali, koja nema takvu vrstu zaštite.