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Influence of urban environment factors on morphometric parameters and accumulation of secondary metabolites in *Cercis canadensis* L. and *Cercis siliquastrum* 'Alba'

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Abstract. Consideration of the role of green spaces in urban landscaping is extremely important, as they not only decorate the urban landscape, but also effectively reduce air pollution, regulate the microclimate and play an important role in improving the ecology and quality of life of residents. The purpose of the study was to determine the influence of urban environmental factors on the development and secondary metabolism of plants of the genus *Cercis* L. Plants growing in Kyiv (Ukraine) under conditions with different air humidity, anthropogenic load, and excess or lack of insolation were selected for the study. Plant growth processes were studied by morphometric parameters of annual shoots of *Cercis siliquastrum* 'Alba' and *Cercis canadensis* L. growing under different conditions. Morphometric methods, fluorescence microscopy, high-performance thin-layer chromatography and regression analysis were used in the study. The research data show that insufficient sunlight has a negative impact on shoot growth. The specificity of the phenolic profiles that can be used to distinguish between the species *Cercis canadensis* L. and *Cercis siliquastrum* 'Alba' was established. The principal component analysis confirmed that phenolic profiles depend on habitat conditions and affect plant growth and development. The Gaussian model was used to analyse the growth dynamics of annual shoots during the growing season, which allowed us to describe the specifics of internode formation during the growing season quite accurately. This model allowed us to detect the phenomenon of the last internodes falling off at the end of the growing season, which caused the deviation of the morphometric parameters of metameres from the normal distribution along the time axis. Anatomical studies confirmed that the separation of one or more of the last internodes was due to active corking of the internal tissues of the stem, blocking of the xylem and formation of a separating layer, which led to the fall of the shoot tip. This phenomenon shows signs of plant adaptation to low temperatures in winter. The tops of the shoots often do not have time to lignify and accumulate the required amount of cryoprotectants. With the formation of a separating layer, the available energy resources are redistributed to the lateral buds, which receive the necessary resources to prepare for the winter period and provide new growth in the next growing season. The adaptive potential of the two species of the genus *Cercis* L. confirms the prospects of their use in urban ecosystems, which can positively affect the conservation of biodiversity in general

Keywords: Judas-tree; environmental factors; green spaces; flavonoids; adaptation

Introduction

Green spaces in the urban greening system play a crucial role in the landscape and architectural, sanitary and hygienic, utilitarian and decorative, and other aspects of urban autecological relations. In particular, all green spaces reduce the level of gas and dust pollution, improve the microclimate by reducing the ambient temperature and increasing humidity, but different species cope with these tasks in different ways, so the question arises of the correct selection of plants for urban landscaping in accordance with their environmental characteristics.

Due to climate change and a significant increase in anthropogenic impact, it is necessary to expand the range of planting materials when creating urban plantings. As noted by N. Seyidoğlu Akdeniz (2020), the use of plants of the genus *Cercis* L. for urban landscaping with white, pink, and purple colours gives a sense of calm, continuity and vitality, which, in turn, plays an important role in the recreation of urban populations.

Results of the study by N. Nuzhyna *et al.* (2022) on determining plant drought resistance, based on the indicators of leaf water content and moisture loss per unit time, indicate that *Cercis canadensis* L. is quite drought-resistant. The paper reveals new aspects of plant adaptation to changing environmental conditions, and considers strategies for plant survival in a rapidly changing climate. According to A. Nejad *et al*. (2018), lead exposure at a dose of 30 mg/l had a negative effect on the development of *C. siliquastrum* L.: the area of the leaf blade, the length of shoots, and the water content in the leaves decreased. However, this effect was offset by the use of nitrates (100 mg/l). These results indicate the importance of studying plant interactions with toxic metals and possible measures to reduce their exposure. According to F. Vignoli *et al.* (2021), the use of lawns alone reduces the temperature of the asphalt surface by 0.5°C, and in combination with trees and shrubs – by about 0.9°C, which reduces the negative impact of "heat islands" in the urban environment. In addition, such an ecosystem approach to the arrangement of lawns, trees and shrubs contributes to improving air quality and the overall urban climate. Green spaces help absorb water and reduce the risk of flooding, helping to create a more sustainable and environmentally balanced environment. These positive properties of green spaces confirm the importance of their implementation for achieving sustainable development and improving the quality of life in cities.

Moreover, according to H. Bahri (2021), concentration of flavonoids in flowers of *Cercis siliquastrum* L. decreases as they develop, and the content of terpenes, on the contrary, increases, which may indicate changes in secondary metabolism depending on the phase of plant development. These detected changes in the chemical composition of flowers of *Cercis siliquastrum* L., in particular, reduction in the concentration of flavonoids and increase in the content of terpenes may also be of practical importance in the context of using these plants in landscape design or urban landscaping, based on their characteristics and adaptive properties. Given that changes in secondary metabolism may be associated with growth and development phases, further study of these mechanisms may help develop strategies to optimise growing conditions of *Cercis siliquastrum* L. to increase the biological activity and stability of these plants in various environmental conditions.

The study by A. Delbari *et al*. (2019) on the absorption of cadmium and lead by the roots of two plant species of the genus *Cercis* L. helped to identify the difference between them in resistance to soil contamination with toxic metals. It is evident that *Cercis siliquastrum* L. exhibit various reactions to the presence of these toxic metals, which may be of practical importance for their use in phytoextraction or phytostabilisation programmes of contaminated soils. Consideration of these interactions can be important for sustainable management of the urban environment and the effective use of plants in phytoremediation processes.

The purpose of the study is to investigate the bioecological features of plants of the genus *Cercis* L. and the correlation between morphometric and biochemical parameters.

Materials and Methods

The research was conducted between January 2023 and September 2023.

Conditions for the growth of research objects. The selected research objects were located in Kyiv, in particular, in the Shevchenkivskyi district (Fig. 1). The city's climate is moderately continental, with mild winters and rather hot summers. The average temperature in July and January was +22°C and -2.8°C, respectively (Osadchyy *et al.*, 2013).

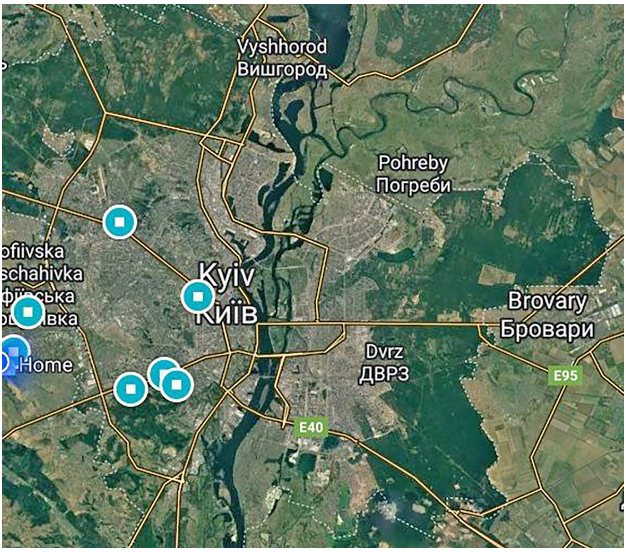


Figure 1. Layout of *Cercis* L. plantations in Kyiv
Source: compiled by the authors

The habitats of all plants can be conditionally divided according to the influence of external factors, such as air pollution, solar insolation, and soil salinity. For example, plants growing in the O.V. Fomin Botanical Garden were exposed to an average level of insolation (the amount of direct sunlight is about 6 hours per day) and air pollution, and the absence of soil salinity. Trees growing near the Beresteyska metro station had a high level of insolation (direct sunlight for about 10 hours a day) and were exposed to high levels of air pollution because they were located on the southern border of the Nyvky park. The plants growing on Tabirna Street were in shady conditions (the amount of direct sunlight was about 3 hours per day). The level of salinity was determined conditionally, depending on the distance of plants from pedestrian paths or highways. In particular, the plants growing in the park on Kirponos Street were characterised by a high level of insolation and soil salinity, as the plants grew in close proximity to the roadway and pedestrian path.

During the survey of plants of the genus *Cercis* L., their condition was evaluated on a 5-point scale for assessing the condition of woody plants in outdoor plantings according to the method (Kuznetsov *et al*., 2000):

- 5 points (trees without suppressed growth, with a full leaf surface);
- 4 points (trees with growth that generally correspond to the norm and with approximately 20-25% of the inactive surface);
- 3 points (trees with weakened growth, which have about 50% of the inactive leaf surface);
- 2 points (trees with suppressed growth, the growth rate of current growth is almost nonexistent, have about 75-80% of the inactive leaf surface);
- 1 point (dead and drying, without current growth of trees with 100% inactive leaf surface).

Morphometric method. The analysis of morphometric parameters of shoots was carried out to assess the features of plant growth processes depending on the growing conditions. Sampling was carried out in 5 localities. A total of 15 plants were used in the experiment. The length and diameter of internodes of annual shoots of 14 *C. canadensis* L. plants and shoots of 1 *C. siliquastrum* 'Alba' plant (n = 75) were measured.

Secondary metabolite profiling method. The separation of substances was performed by high-performance thin-layer chromatography (HPTLC) on Silicagel G 60 (Merck) plates in a solvent system: ethyl acetate-formic acid-acetic acid-water (v/v/v/v – 100:11:11:25). The resulting chromatograms were treated with 0.5% NP reagent in ethyl acetate, followed by treatment with 1.0% PEG (polyethylene glycol) 400 and heating at 90°C for 1 min. Flavonoids and other polyphenols on the chromatogram were detected in ultraviolet light (λ max = 365 Nm). The Rf (retention index) values of individual compounds were determined photodensitometrically using the Sorbfil TLC Videodensitometer computer programme.

Autofluorescence of shoot tissues was studied on an inverted microscope using a multichannel fluorescent imaging system (EVOS FL System, ThermoFisher Scientific, USA).

Method of statistical data processing. The measurement results are presented as the average value ± standard error (x±SE). The significance of the difference ($p<0.05$) between the obtained data was determined by variance analysis (one-way ANOVA) using Tukey's post-hoc test in the XLSTAT software suite (Addinsoft Inc., USA, 2010). Principal component analysis (PCA) and cluster analysis were performed in the XLSTAT software suite. Sigma Plot 12.0 (Systat Software, Inc.) was used for regression analysis.

Object of study – the object of study is the external state of plants *C. canadensis* L. and *C. siliquastrum* 'Alba' and their sensitivity to urban environmental factors. The study was conducted in compliance with the Convention on Biological Diversity (1992) and the Convention on the Trade in Endangered Species of Wild Fauna and Flora (1973).

Annual shoots were collected from plants growing within the city of Kyiv. Sample preparation included cleaning of dirt and removal of unnecessary plant residues, followed by determining metric parameters (internode length and diameter). The parameters were measured using a caliper and the results were recorded in Microsoft Excel, followed by analysis of the data.

Results

Cercis canadensis L. – a tree up to 18 m high, with a spreading crown and a black and grey crust, sometimes it is a large shrub, which makes it attractive and versatile in terms of use in landscape compositions (Fedorovskyi *et al.*, 2013). Young shoots are reddish-brown. The leaves are cordate and rounded, 6-12 cm wide. Like the European species, it blooms before the leaves open in May. Flowers are pink to purple in colour, 1.0-1.2 cm long, in bunches on branches or on trunks (cauliflory – development of flowers from dormant buds on the trunk), very decorative (Domshyna & Shcherbak, 2015). Its natural habitat is North America. It most often grows on rich soils in lowlands and near marshes, and is moisture-loving. It is found in undergrowth, in valleys on the edges, in sparse forests. In the conditions of Kyiv, it regularly flowers and bears fruit (Kalinichenko, 2003; Zayachuk, 2014)

The general condition of the plantings varies: the condition of the plantings growing near the Beresteyska metro station was approximately 35 years old and rated at 4 points (dry branches, trunk damage or stunted development); trees growing on Tabirna Street were approximately 15-20 years old and rated at 3 points; the condition of plantings growing on Kirponos Street and the territory of the Institute of Horticulture of the NAAS of Ukraine was approximately 15-25 years old and rated at 4-5 points. The condition of *C. canadensis* L. and *C. siliquastrum* 'Alba' growing on the territory of O.V. Fomin Botanical Garden is rated as "good" – there is a small number of dry branches and the trees are about 40-45 years old and 20 years old, respectively (Fig. 2). Detailed evaluation information for each tree is provided in Table 1.

a b c d

Figure 2. General view of plantings of *Cercis canadensis* L.
Note: a – group of plants near the Beresteyska metro station; b – a plant on Tabirna Street; c – group of plants on Kirponos Street; d – cauliflory phenomenon
Source: photo by the authors

Table 1. Condition and location coordinates of the plants under study

No.	Coordinates	Code	Plant condition assessment	Location	Type of plantings
1	50.3831696 30.5027045	S1	4	O.V. Fomin Botanical Garden*	Single planting
2	50.3831696 30.5027045	S7	4	O.V. Fomin Botanical Garden	Group
3	50.351953 30.442145	S8	5	Institute of Horticulture of NAASU	Single planting
4	50.459376, 30.419858	S9	3	Beresteiska metro station	Group
5		S2	4		
6		S10	4		
7		S3	4		
8		S4	4		
9		S5	4		
10		S11	2		
11	50.459444 30.421137	S13	3	Tabirna Street	Single planting
12		S14	3	Tabirna Street	Single planting
13	50.3831696 30.5027045	S15	5	Kirponos Street	Group
14		S12	3		
15		S6	4		

Note: **Cercis siliquastrum* 'Alba'; NAASU – National Academy of Agrarian Sciences of Ukraine
Source: compiled by the authors

The dynamics of shoot development and growth during the growing season is quite accurately described by the Gaussian function, which under ideal conditions is bell-shaped with a peak in the centre or close to it:

$$f = a \cdot \exp^{\left(-0{,}5 \cdot \left(\frac{(x-x^0)}{b}\right)^2\right)}. \qquad (1)$$

As can be seen from the regression models below (Fig. 3), the peaks of the curves are shifted to the right, which may indicate that the plants do not have enough sum of active temperatures to complete the processes of lignification of shoots and a full transition to winter. In addition, during the observation of plants during the growing season, it was found that *Cercis canadensis* L. is characterised by the separation and falling of one or more of the last internodes.

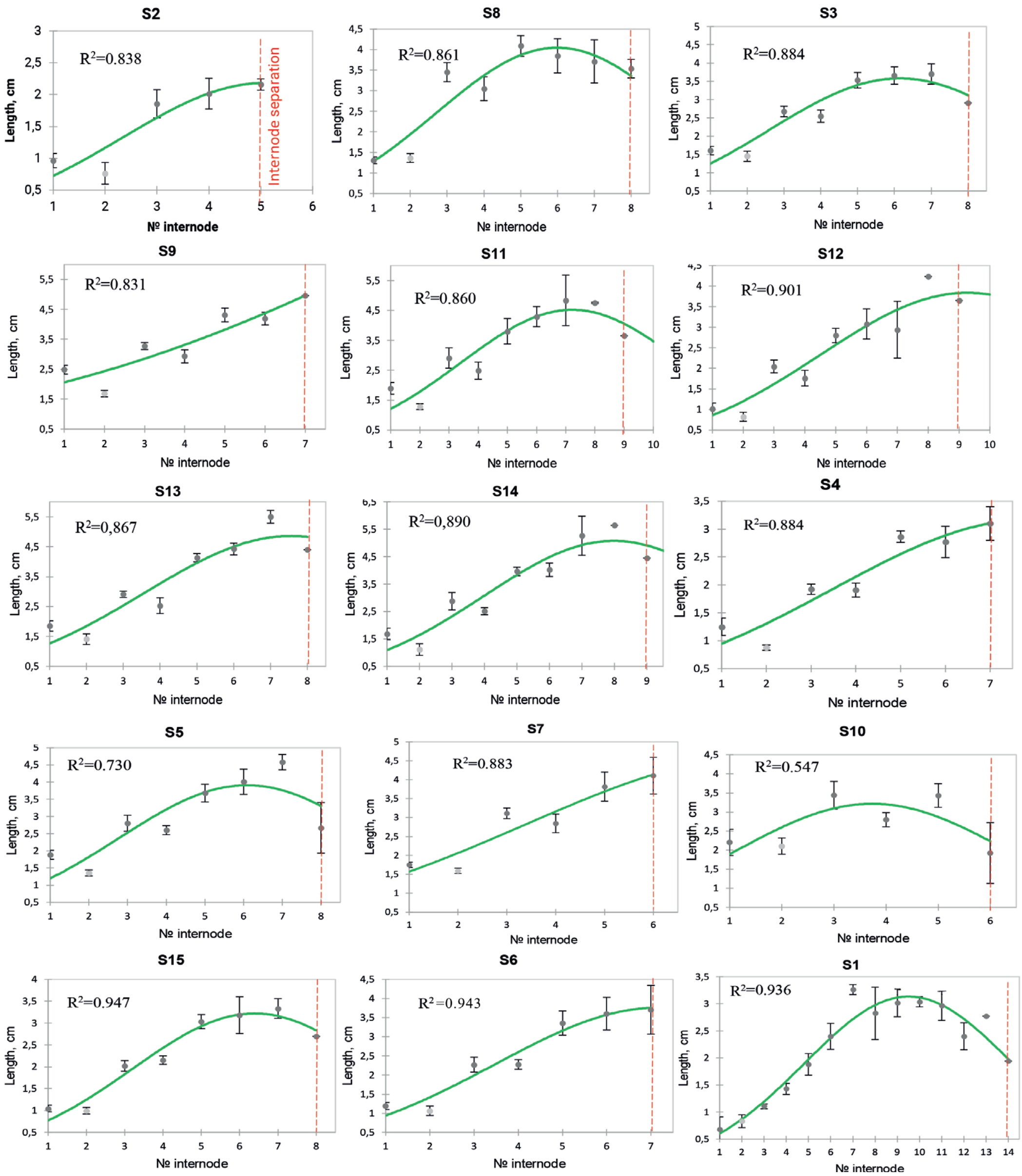


Figure 3. Dynamics of changes in the length of internodes of annual shoots during the growing season

Source: developed based on the authors' research

A decrease in the approximation coefficients of the Gaussian model describing the dynamics of changes in the length of internodes is associated with a shift of the maximum growth peak to the right in the time coordinate. Indicators of the length and diameter of internodes of annual shoots and their ratio, depending on the place of plant growth, are shown in Table 2.

Table 2. Morphometric parameters of plants *Cercis* L. (x±SE, n=5)

Location and code	Number of internodes, units	Internode length (l), cm			Diameter (d), cm			l/d			Total length, cm
		1	3	5	1	3	5	1	3	5	
A_1(S2)	4.8	0.96 ±0.11	1.86 ±0.22	2.16 ±0.09	0.21 ±0.005	0.18 ±0.008	0.14 ±0.011	4.57 ±0.48	10.13 ±0.96	15.28 ±0.72	7.32
A_2(S9)	5.8	2.48 ±0.14	2.93 ±0.22	4.96 ±0	0.25 ±0.022	0.20 ±0.014	0.17 ±0.0	10.21 ±0.38	14.84 ±0.67	29.18 ±0.0	18.20
A_3(S10)	5.6	2.20 ±0.34	2.80 ±0.19	1.92 ±0.79	0.21 ±0.011	0.17 ±0.009	0.12 ±0.011	10.35 ±1.39	16.22 ±0.31	26.96 ±1.66	15.90
A_4(S3)	5	1.61 ±0.12	3.53 ±0.21	2.91 ±0.0	0.28 ±0.029	0.20 ±0.022	0.15 ±0.0	5.96 ±0.76	18.46 ±2.07	19.40 ±0.0	19.01
A_5(S4)	6.2	1.25 ±0.16	1.91 ±0.12	3.10 ±0.3	0.24 ±0.018	0.19 ±0.016	0.13 ±0.01	5.33 ±0.78	10.30 ±1.02	23.81 ±0.48	12.28
A_6(S5)	7.2	1.88 ±0.13	3.68 ±0.26	2.67 ±0.74	0.28 ±0.018	0.21 ±0.02	0.14 ±0.01	6.73 ±0.43	17.70 ±1.34	18.52 ±3.69	20.79
A_7(S11)	7	1.89 ±0.2	3.80 ±0.42	3.65 ±0.0	0.26 ±0.025	0.19 ±0.028	0.15 ±0.0	7.35 ±0.74	20.40 ±1.66	24.33 ±0.0	21.33
B_8(S13)	6.6	1.85 ±0.18	4.13 ±0.14	4.40 ±0.0	0.26 ±0.016	0.19 ±0.018	0.12 ±0.0	7.36 ±0.98	23.06 ±2.95	36.67 ±0.0	20.54
B_9(S14)	6.8	1.68 ±0.21	3.96 ±0.15	4.45 ±0.0	0.26 ±0.031	0.20 ±0.031	0.18 ±0.0	6.40 ±0.19	21.32 ±2.66	24.72 ±0.0	20.53
C_1(S15)	7	1.05 ±0.08	3.03 ±0.16	2.70 ±0.0	0.28 ±0.009	0.21 ±0.013	0.15 ±0.0	3.70 ±0.2	14.96 ±1.14	18.00 ±0.0	15.64
C_2(S12)	6.8	1.02 ±0.14	2.80 ±0.17	3.65 ±0.0	0.24 ±0.029	0.19 ±0.029	0.17 ±0.0	4.71 ±0.91	16.38 ±2.13	21.47 ±0.0	14.25
C_3(S6)	6.2	1.19 ±0.09	2.28 ±0.13	3.71 ±0.64	0.26 ±0.026	0.22 ±0.023	0.17 ±0.005	4.71 ±0.55	10.88 ±1.14	22.59 ±4.53	14.53
D(S8)	7	1.31 ±0.08	4.09 ±0.25	3.54 ±0.23	0.26 ±0.019	0.19 ±0.018	0.14 ±0.015	5.13 ±0.45	21.85 ±1.14	26.33 ±1.26	20.74
E_1(S1)	10.2	0.68 ±0.23	2.83 ±0.48	1.94 ±0.0	0.42 ±0.033	0.28 ±0.029	0.22 ±0.0	1.58 ±1.07	9.96 ±1.46	8.82 ±0.0	20.51
E_2(S7)	5.4	1.75 ±0.07	2.85 ±0.25	4.11 ±0.49	0.30 ±0.024	0.26 ±0.026	0.23 ±0.003	5.96 ±0.66	11.19 ±0.75	17.61 ±2.13	14.82

Note: A – Beresteyska metro station; B – Tabirna Street; C – Kirponos Square, D – Institute of Horticulture of NAAS of Ukraine; E - O.V. Fomin Botanical Garden (E1 – *Cercis siliquastrum* 'Alba'; E2 – *Cercis canadensis* L.); where "1", "3", "5" – first, middle, and last internodes
Source: compiled by the authors

Table 2 shows an inverse relationship between the length of the internode and its diameter. For plants growing in conditions of shading or high humidity, this ratio increases, which is generally typical for plants that usually grow in lighted areas. It was also found that in *Cercis* L. plants, probably due to the insufficient amount of the sum of active temperatures, the process of development of a separate cell layer begins, which blocks the transport system and the supply of nutrients to the top of the shoot (Fig. 4). This process was more active in plants in sunny areas, possibly due to the more intensive growth of annual shoots.

Figure 4. Process of separation of the last internodes on the tops of shoots of *Cercis canadensis* L.
Note: a – upper internode separation zone
Source: developed by the author

In the places of "scarring", and living parts of the internode and those that began to die, the development of a layer of cells similar to the periderm was observed. The overgrown periderm thickens in the area of the conductive bundles, which leads to a blockage of nutrient supply to the shoot apex. As a consequence of this process, the last internodes die off. Hypothetically, this process is genetically determined and is aimed at protecting the apical meristem during the dormant period of plants in winter (Fig. 5).

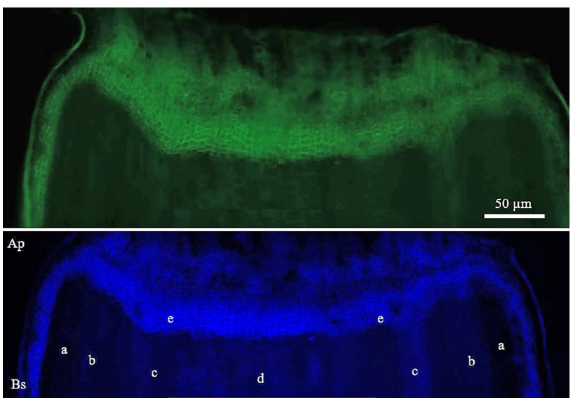
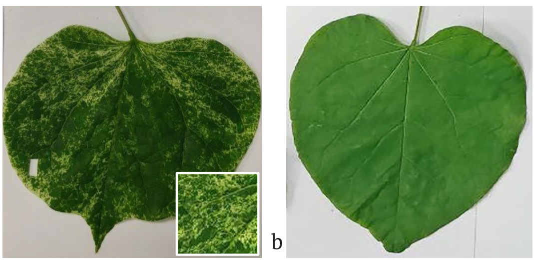


Figure 5. Autofluorescence of annual shoot node tissues in the zone of separating layer formation (radial section)
Note: a – cortex; b – phloem; c – xylem; d – core parenchyma; e – separation layer; Ap – apical part; Bs – basal part; DAPI (λexc=357/44 nm; λem=447/60 nm); GFP (λexc=482/25 nm; λem=524/24 nm)
Source: developed based on the authors' research

Biochemical profiling of secondary metabolites of periderm and bark of annual plant shoots of *Cercis canadensis* L. identified 15 substances that, according to Rf indicators and the specifics of autofluorescence in ultraviolet (UV) (λ=365 Nm), belong to phenol carboxylic acids, their conjugants and flavonoids. Based on the results of cluster analysis, according to the characteristics of phytochemical profiles, 3 main groups of plants were identified. For plants that have developed the first cluster, it is characteristic that they grow in sunny areas without signs of shading, but there are no substances with Rf~0.69 and Rf~0.77. Plants that are combined according to the biochemical profile in the second cluster are characterised by the presence of flavonoids with Rf~0.69 and Rf~0.77. Externally, these plants have no signs of growth suppression, without much damage to the trunk or tree as a whole. 3 out of 5 plants grow in a group planting, other plants also grow in a sunny area, and their age is in the range of 25-35 years. In addition, the plant under the code S5 is characterised by a fairly high concentration of the substance Rf~0.69 and Rf~0.77. This plant developed chlorophyll-deficient leaves during the growing season. There may be a certain relationship between the increased concentration of substances and depigmentation of the leaf plate, which requires additional research (Fig. 6).



a b

Figure 6. Chlorophyll-deficient (a) and normal (b) leaf
Source: developed by the authors

The third cluster was divided into 2 subclusters. In one of them, a substance with an Rf of~ 0.39 was found, which was not present in any sample of the bark and periderm of annual shoots. A reduced amount of phenolic compounds on the chromatogram is typical for plants that are united in the second subclaster of the third cluster.

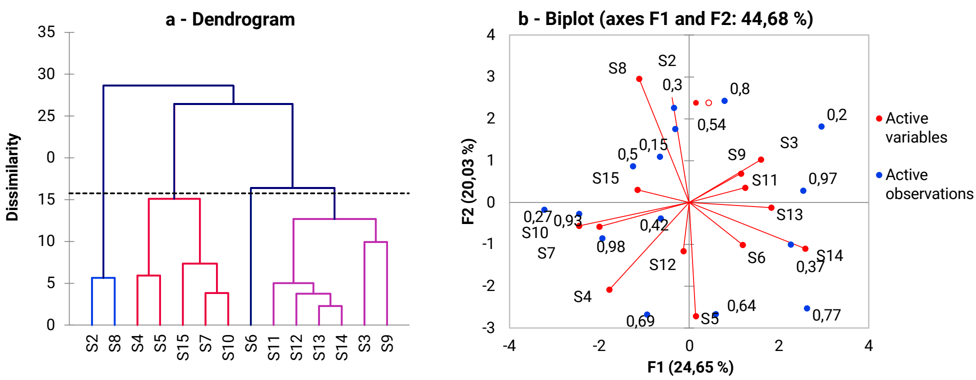


Figure 7. Results of cluster (AHC) (a) and biplot principal component analysis (PCA) (b)
Source: developed by the authors

These plants grow in shaded conditions and in drafts. Given a direct relationship between the lighting mode and the synthesis of phenols, phenolic compounds play an important role in protecting plants from ultraviolet radiation. And the synthesis centres of some of these substances are partially connected with chloroplasts. This explains the reduced concentration of substances in the periderm and bark of plants of this subclaster.

Based on the results of biplot analysis based on principal components (PCA), it was found that the total variance for the main components F1 and F2 is 44.68% (Fig. 7). According to the first main component, substances with a significant contribution to the total dispersion of Rf~ 0.97; 0.37 and Rf~ 0.93; 0.27 are distinguished.

Discussion

According to X.-C. Li *et al.* (2021), the centre of origin and further distribution of the genus *Cercis* L. are sub-tropical climate zones and southern warm temperate climates in Asia, southern Europe, and the southwestern United States. And the Paleogene fossils from Eurasia and North America indicate a long history of the genus. *Cercis* L. in the middle and low latitudes of the Northern Hemisphere. The modern natural range of the genus is part of the Holarctic realm, some areas of which are separated by The Atlantic and Pacific oceans, but as noted by L. Koldar *et al.* (2001), the similarity of species growing in North America and Southern Europe is explained by the fact that the flora of these territories has common features, which are due to the fact of the existence of Laurasia – the continent that united North America and Eurasia. In particular, this is the basis for the study by C. Davis *et al.* (2002), arguing that *Cercis canadensis* L. from the eastern part of North America is more closely related to *Cercis siliquastrum* L., which grows in the western part of Europe. The similarity of plants within the same genus is often confirmed by biochemical studies. This is due to the fact that the synthesis of secondary metabolites plays an important role in adaptation processes. The author of this study found similarities in the phenolic profiles of plants that grew in different parts of Kyiv. It is assumed that the similarity of phytochemical profiles is due not only to growing conditions and environmental factors, but also to genetic similarity. In addition to this, it is revealed that the process of separation of the last internodes is inherent not only for *Cercis canadensis*, but also for *Cercis siliquastrum* 'Alba'.

Flavonoids have a direct or indirect effect on plant nutrition and growth (Likhanov *et al.*, 2023). According to S. Hassan *et al.* (2012), flavonoids, depending on their structure, cause positive chemotaxis of rhizobia, are able to suppress root pathogens, chelate soil nutrients, etc. Under the conditions of pathological processes with the development of lifetime wood defects, the composition of flavonoids changes (Likhanov *et al.*, 2019). In particular, it was found that plants that grew under stressful conditions (shading, drafts, soil salinisation, etc.) had less saturated phytochemical profiles. During the studies, it was found that plants that grew in sunny areas have flavonoids with Rf~0.69 and Rf~0.77. According to A. Samanta *et al.* (2011), flavonoids protect plants from various biotic and abiotic stresses and can act as a unique UV filter, function as signalling molecules, allelopathic or antimicrobial protective compounds. In particular, as noted by A. Rehman *et al.* (2023), plant heat resistance depends on a complex interaction of various factors, including activation of heat stress responses, signalling pathways, and plant hormone biosynthesis. This intricate network of mechanisms leads to the production of several secondary metabolites that play a crucial role in improving plants' ability to cope with high temperature stress. E. Koç *et al.* (2023) indicate that an increase in the content of secondary metabolites in the plant may indicate a close relationship between secondary metabolites and tolerance to biotic and abiotic factors. J. Al-Khayri *et al.* (2023) confirm that due to the action of secondary metabolites, plants can synthesise natural insecticides-repellents. Given that secondary metabolites perform a variety of functions, including mediating interactions between organisms, responding to environmental factors, and protecting plants from infections, pests, and herbivores. Similarly, plant microbiomes are directly or indirectly involved in many of the above processes, controlling plant metabolism. In particular, J. Herlina *et al.* (2022) concluded that plants can influence their microbiome by releasing various compounds, and also found that the microbiome can influence the host plant's metabolome. In addition to the protective function, flavonoids can be considered as unique indicators of plant condition, with the determination of growing conditions. According to the study by A. Salatino *et al*. (2000), the presence of kaempferol glycosides is characteristic of taxa *Cercis* L. from sufficiently moistened regions, while plants from arid growing conditions do not have them. According to E. Ewais (1997), various plant species are resistant to excessive heavy metal content in the soil. The researcher suggests that an integral indicator of the toxic effect of metals on plants is the inhibition of their growth and a decrease in vegetative mass. In addition, plants growing near roadways are exposed to increased negative effects of urban environmental factors. In these studies, *Cercis canadensis* trees growing directly near the roadway had a more depressed state than other specimens in group plantings. In the phytochemical profile of this plant, a substance (Rf~0.39) was found, the presence of which can be a marker of plant stress on the action of negative factors.

At the same time, under the conditions of optimising the care of plants, carrying out additional measures, creating lawns, they can improve the ecological state of the urban environment, in particular, reduce the temperature and increase humidity, retain small dust particles, etc. As noted by V. Shlapak (2006), plants of the genus *Cercis* L., although require optimal humidity, they are better able to tolerate a lack of moisture than an overabundance of it, since, according to the researcher, when the soil moisture is 80%, plant development is suppressed, which eventually leads to death. Plants growing in urban environments suffer not only from insufficient amounts of micro- and macronutrients, but also from the negative effects of heavy metals, which accumulate due to their absorption through the root system or leaves. Different plant species are resistant to excessive heavy metal content in the soil. An integral indicator of the toxic effect of metals on plants is the suppression of their growth and a decrease in vegetative mass.

L. Koldar *et al.* (2022) give an example that due to the dense crown and rather large leaf blade, plants of this genus can retain small particles of dust and heavy metals. According to L. Hakimi *et al.* (2015), *Cercis* L. can be an indicator of the presence of heavy metals in the soil, in particular cadmium, due to the plant's ability to accumulate it in the leaves. Based on the research data, it can be assumed that due to the high drought resistance, dense crown, and large leaves of the plant of the genus *Cercis* L., they are able to create large shady spaces, which will increase the level of comfort for urban residents.

Conclusions

A number of patterns were observed. In particular, when measuring the length and diameter, it was found that in plants that grew in shaded areas, the last internodes had signs of freezing. As a result of the conducted studies, the inverse relationship between the diameter of internodes and their length was established. During the observation, the effect of total death of the last internodes at the top of annual shoots was revealed. Phenolic profiles of experimental plants showed that the accumulation of secondary metabolites depends on environmental conditions, humidity, and the level of solar insolation. It was also experimentally confirmed that plants within the genus can be distinguished based on the variability of phenolic profiles.

Plants of the genus *Cercis* L. have fully adapted to the climatic and urban conditions of growth. It is possible that this is facilitated by the phenomenon of death of one or more upper internodes, as an adaptation to possible freezing of the ends of shoots. Based on anatomical and histological studies, it was found that in the shoots, at the points of separation, the conductive bundles are blocked due to the development of the periderm. Because of this, the supply of nutrients to the last 2-3 internodes stops. It is established that the profiles of phenolic compounds that accumulate in the periderm directly depend on the place of growth and the general condition of the plant, in particular, the accumulation of phenolic compounds occurs more intensively in plants growing in sunny areas. The relationship between the growth of shoots and the accumulation of secondary metabolites in them, as a reaction to plant growth conditions, is also given.

Lower saturation of phytochemical profiles and concentrations of individual compounds is characteristic of young plants and those with signs of suppressed growth in shaded areas. Plants of the genus *Cercis* L. require a high level of insolation. Perhaps this is due to the fact that the natural range of the genus is formed in territories with a Mediterranean and mild Atlantic climate. Thus, when landscaping urban areas, it is critical for plants of this genus to select habitat conditions that correspond to the plants' needs for high levels of insolation and sensitivity to drafts. In general, these species are resistant to air and soil pollution by heavy metals and can be recommended for urban landscaping.

Further research could include analysis of the variability of responses to different types of pollution in the urban environment and consideration of interactions between different elements of the urban landscape and plants. Understanding these aspects can help develop effective urban green space management strategies aimed at preserving biodiversity and improving the quality of the urban environment.

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Conflict of Interest

None.

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Вплив факторів міського середовища на морфометричні показники та накопичення вторинних метаболітів у пагонах *Cercis canadensis* L. та *Cercis siliquastrum* 'Alba'

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Анотація. Врахування ролі зелених насаджень у міському озелененні надзвичайно актуальне, оскільки вони не лише прикрашають міський ландшафт, а й ефективно зменшують забруднення повітря, регулюють мікроклімат та відіграють важливу роль у покращенні екології та якості життя мешканців. Метою дослідження було встановлення впливу чинників міського середовища на розвиток і вторинний метаболізм рослин роду *Cercis* L. Для досліджень було обрано рослини, які зростають у місті Київ (Україна) в умовах різної вологості повітря, антропогенним навантаженням, надлишком або нестачею інсоляції. Процеси росту рослин вивчали за морфометричними показниками однорічних пагонів *Cercis siliquastrum* 'Alba' та *Cercis canadensis* L., що зростають за різних умов. У дослідженнях використовували методи морфометрії, флуоресцентної мікроскопії, високоефективної тонкошарової хроматографії та методи регресійного аналізу. Дані досліджень свідчать, що недостатня кількість сонячного світла негативно впливає на ріст пагонів. Встановлена специфічність фенольних профілів за якими можна розрізняти види *Cercis canadensis* L. та *Cercis siliquastrum* 'Alba'. Аналіз головних компонент підтвердив, що фенольні профілі залежать від умов місцезростання та впливають на ріст і розвиток рослин. Для аналізу динаміки росту однорічних пагонів протягом вегетації використовували модель Гауса, яка дозволила доволі точно описати специфіку формування міжвузлів протягом вегетаційного періода. Ця модель дозолила виявити феномен відпаду останніх міжвузлів наприкінці вегетації, через що спостерігалось відхилення морфометричних показників метамерів від нормального розподілу по осі часу. Анатомічні дослідження підтвердили, що відділення одного або декількох останніх міжвузлів відбувалось через активне корковіння внутрішніх тканин стебла, блокування роботи ксилеми і формування віддільного шару, що призводило до відпадання верхівки пагона. Описаний феномен має ознаки адаптації рослини до низьких температур у зимовий період. Верхівки пагонів часто не встигають здерев'яніти і накопичити необхідну кількість кріопротекторів. За умов формування віддільного шару доступні енергетичні ресурси перерозподіляються в бічні бруньки, які отримують необхідні ресурси для підготовки до зимового періоду і забезпечують новий приріст у наступний вегетаційний період. Адаптивний потенціал досліджених видів роду *Cercis* L. підтверджує перспективність їх використання в озелененні міських екосистем, що може позитивно вплинути на збереження біорізноманіття в цілому

Ключові слова: юдине дерево; екологічні чинники; зелені насадження; флавоноїди; адаптація