Indicators of adaptability of representatives of the genus Acer in an urban environment

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Abstract. A topical task has been set to assess the state of arboreal vegetation used in the landscaping of the city on the example of five species of the genus *Acer*. The main physiological and biochemical characteristics associated not only with the functionality of plants, but also involved in the formation of the plant's response to stress are involved for evaluation. It is shown that species differ in their physiological and biochemical characteristics and different reactions are observed in species to anthropogenic stressors. A significantly lower number of all groups of photosynthetic pigments was observed in species *A. negundo* and *A. saccharinum, A. negundo* it also differs in low indicators of the specific surface area of the sheet. In all five maple species in the urban environment, there was a significant increase in the total fund of green and yellow pigments compared to the background; there is an increase in the ratio Σchl / Σcar by 1.1-1.7 times, mainly due to a decrease in the level of chlorophylls and an increase in the proportion of carotenoids. A. negundo has significantly lower water deficiency and water loss by leaf tissues. The highest values of ascorbic acid were noted in the species *A. saccharinum*. To interpret the responses of species to the stressors of an urbanized area, cluster analysis was used, which divided the species into two clusters; at the same time, common mechanisms of responses were identified in maples that are introduced from different habitats.

1 Introduction

Landscaping of urban areas is of great importance, as it not only creates an aesthetic background, but also determines the psychological, functional state of a person. However, urban plants are exposed to the strongest anthropogenic stress associated with both the anthropogenic load (the number of motor vehicles, the work of enterprises, physical load on the soil, etc.) and the unique soil and climatic conditions of cities (special soil regime, illumination, temperature and humidity inside urbanized areas, etc.).

First of all, the soils of cities have their own characteristics: as a rule, this is an anthropogenic transformation of soils associated with the accumulation of heavy metals [1]; the acidity of the soil shifts towards alkalinization due to the alkalinization of the snow cover

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during deicing measures in winter [2]. In spring, especially in areas of underground utilities, the soils warm up earlier, which stimulates an earlier exit of plants after winter dormancy [3].

Secondly, in cities there is a negative impact on the growth and development of green spaces, which has a higher air temperature, especially in summer, and constant illumination, shifting the phenological phases of plants, and disrupting the photosynthetic functions of the leaf [3, 4, 5]. In addition, plants in the city are exposed to drought in summer, as there is a lack of moisture in the soil due to the fact that precipitation does not accumulate in the compacted soil, but flows down watercourses into collectors bypassing the root zone. [6]. The lack of optimal water supply and wind processes lead to a decrease in air humidity and an even faster depletion of soil moisture, which becomes a serious problem for urban plants [2, 7-9].

Maykop is the capital of Adygea, located on the right bank of the Belaya River at the northern foothills of the Caucasian Ridge. It is characterized by a humid temperate climate, the average annual temperature here is about +11 ºC. Summer is not hot, the temperature ranges from +16 to +29 ºC, winter temperatures can drop to -5...-10 °C. In Maykop, strong winds are not uncommon, turning into dust storms. 720-770 mm of precipitation falls annually and long dry periods accompanied by dry winds are typical for summer [10]. The city, although it has a small population (about 140 thousand people according to data of the year 2022), is divided into many districts with developed infrastructure and a well-branched network of urban transport routes [11]. In addition, industry is developed in the city, for example, the Maykop Machine-building Plant located within the city, the Maykop Gear Plant, the Trust Metal enterprise, etc. However, Maykop is a fairly green area, which somewhat levels the negative weather conditions and anthropogenic load.

Despite the fact that woody plants are of undoubted importance for human health, no studies of plants functioning within cities have been conducted so far in the conditions of the Republic of Adygea. The problem of studying arboreal plants in the city remains very relevant, and therefore, we have set the task to assess the state of arboreal vegetation widely used for landscaping the city of Maykop (Republic of Adygea).

2 Objects and methods of research

2.1 Objects of research

We have selected five species of the genus maple as objects of research (*Acer*) Sapindaceae families (Sapindaceae): *Acer campestre* L. (field or plain maple), *A. negundo* L. (ash-leaved maple or box elder, boxelder maple, Manitoba maple), *A. pseudoplatanus* L. (sycamore maple), *A. argutum* Maxim. ex Miq. (pointed-leaf maple) and *A. saccharinum* L. (silver maple, creek maple, silverleaf maple, soft maple, large maple, water maple, swamp maple, or white maple). All types are widely used in the landscaping of the city.

Acer campestre L. represents a deciduous tree up to 25 m high (in the Caucasus) with a dense spherical crown, the trunk is covered with thin, brownish-gray bark. The upper side of the leaf is dark green or light green, slightly shiny, and the lower side is lighter, light green, finely pubescent. It is distributed in Europe, the Caucasus, Asia Minor and Iran. Relatively drought-resistant, shade-tolerant, thermophilic.

Acer negundo L. – deciduous tree up to 25 m, the trunk is short, often divided into several long, spreading processes at the base, covered with thin, gray or light brown bark. The leaves are light green at the top, pale silvery-white at the bottom, usually smooth to the touch. An introduction from North America. It has a high growth rate and is resistant to air pollution, winter-hardy.

Acer pseudoplatanus L. – a large deciduous deciduous tree, reaching 20-35 meters in height, with a wide domed crown. The trunk is covered with smooth, gray bark. The leaves are dark green, some cultivars have leaves of a purple or purple or yellowish hue. The species is distributed in its natural habitats in Central Europe, Southwest Asia, and northern Turkey. In the Caucasus, it is found throughout the forest zone. It grows quickly, does not tolerate drought, waterlogging and salinization. Shade-tolerant, thermophilic.

Acer argutum Maxim. ex Miq. – deciduous tree, reaching from 5 to 10 meters in height, often grows in the form of a bush. The trunk has a reddish pubescent bark, which subsequently becomes dark gray-green. The leaves are dark green above, somewhat wrinkled, lighter below and covered with white or gray fluff on the veins. It is a dioecious plant. Endemic to Japan.

Acer saccharinum L – deciduous fast - growing tree with a height of 27-36 m. The trunk is dark *chestnut* in color. The casts in the upper part are light green, in the lower pale, silvery-white. It grows in its natural habitats in the eastern part of North America – the USA and adjacent territories of Canada. Adapts easily to urban conditions.

Observations were carried out on maples growing in the urban environment (city) and in the artificial cenosis of the Arboretum on the territory of the botanical garden (background territory) of the Adygea State University.

2.2 Research methods

The research was carried out on the basis of the Departments of Botany and Physiology of the Adygea State University. The assessment of the condition of plants was carried out on the selected leaves of five maple species according to several indicators.

The content of photosynthetic pigments was estimated by the A.A. Shlyk method using absorption spectra (wavelengths for Chl *a* 665 nm, Chl *b* – 649 nm and Σcar – 440.55 nm), the concentration of chlorophylls was calculated using Vernon formulas, the content of carotenoids – according to the Wettstein formula [12].

The water status of plants was studied by the following indicators: water deficiency (WD), water-holding capacity (Sdhc) of leaf tissues, transpiration intensity (TI) [13]. The content of ascorbic acid (AA – a biochemical marker of resistance) was analyzed according to A. I. Ermakov [14]. The calculation of specific surface density of the leave (SSDL) was carried out according to the Mokronosov method [15]. Photosynthesis productivity (PhP) was determined by the accumulation of assimilates in the plant [15].

Statistical analysis was carried out using the ANOVA package in STATGRAPHICS Centurion XV (version 15.1.02, StatPoint Technologies) and MS Excel 2007 and included one-dimensional analysis of variance (a method of comparing averages using analysis of variance, t-test). Statistically significant is the significance of the difference between the mean values at $p < 0.05$. The differences between the repetitions were evaluated using an unpaired t-test. The results of the study are expressed as an arithmetic mean with a standard deviation. The analysis of the hydrothermal conditions of the current year was carried out according to the website www.pogodaklimat.ru.

3 Results and discussions

Studies have shown that species differ in their physiological and biochemical characteristics. For comparison, the species growing on the territory of the botanical garden (background territory) were analyzed where the urbanized load is minimized [16]. Thus, a significantly lower number of all groups of photosynthetic pigments was observed in *A. negundo* and *A. saccharinum* species (Table 1). *A. negundo* is also distinguished by low rates of UPR (4.96

mg/cm2), which leads to lower photosynthesis productivity (0.77 mg/cm2). The most active accumulation of photosynthetic pigments occurs in *A. campestre* and *A. argutum* (Table 1).

Table 1. Characteristics of some species of the genus Acer.

	Chl *a*, mg / g	**Chl *b*, mg / g**	**Σ*car*, mg / g**	**WD, %**	**WL, %**	**TI, mg / cm²*h**	**AA, mg%**	**SSDL, mg / cm²**	**PhP, mg / cm²**
Acer campestre L.									
city	2.73	1.21	0.46	36.34	50.63	13.98	57.11	4.53	1.68
botanical garden	2.31	0.90	0.42	26.70	44.77	17.49	111.01	6.23	1.89
Acer negundo L.									
city	1.46	0.61	0.21	17.78	38.77	10.98	93.17	4.64	1.83
botanical garden	0.99	0.36	0.18	14.39	37.45	8.66	164.94	4.95	0.77
Acer pseudoplatanus L.									
city	2.71	1.27	0.40	17.55	47.97	9.34	47.18	4.99	1.12
botanical garden	2.15	0.90	0.39	22.85	43.22	11.44	98.52	5.38	1.43
Acer argutum Maxim. ex Miq.									
city	2.82	1.40	0.41	20.40	38.37	8.04	70.10	4.42	1.12
botanical garden	2.39	1.08	0.48	26.47	33.24	10.36	129.98	5.23	1.78
Acer saccharinum L.									
city	2.43	1.00	0.49	19.83	40.01	6.51	130.35	4.23	1.07
botanical garden	1.15	0.42	0.38	22.68	29.33	8.44	327.40	5.86	2.45
LSD (0.05) (city)	*0.29*	*0.22*	*0.11*	*4.34*	*3.56*	*1.33*	*15.2*	*0.58*	*0.50*
LSD (0.05) (botan. gard.)	*0.23*	*0.13*	*0.04*	*7.54*	*4.80*	*3.59*	*37.9*	*0.54*	*0.81*

As is known, the integral indicator of the structural and functional elements of the mesostructure of the leaf is the value of the specific surface density of the leave (SSDL), which is genetically determined, but within the norm of the reaction can change under the influence of environmental factors. At the same time, plants with a higher specific surface density of the leaf use photosynthetically active radiation (PhAR) much efficiently [17, 18], which is observed in plants *Acer campestre* (Table 1).

Adaptation to the conditions of the urban environment requires changes in the physiological and biochemical characteristics of plants as a mechanism of adaptive reactions to anthropogenic stresses [19]. One of the active agents that worsen the condition of plants in the city is atmospheric air pollution, which causes oppression of the leaf apparatus, due to blockage of stomata, and a decrease in photosynthetic ability [20-22].

When studying the state of plants in an urban environment, attention is drawn to the fact that there is a different reaction to anthropogenic stressors in species. The pigment apparatus is the most sensitive, however, according to various sources (Fig. 1), both an increase in the content of chlorophylls and carotenoids can be observed in species [22, 23], and a decrease in their concentration [22, 24-26]. We have shown that all five maple species in the urban environment had a significant increase in the total fund of green and yellow pigments compared to the background (botanical garden) by 1.2 – 2.4 times (Table 1).

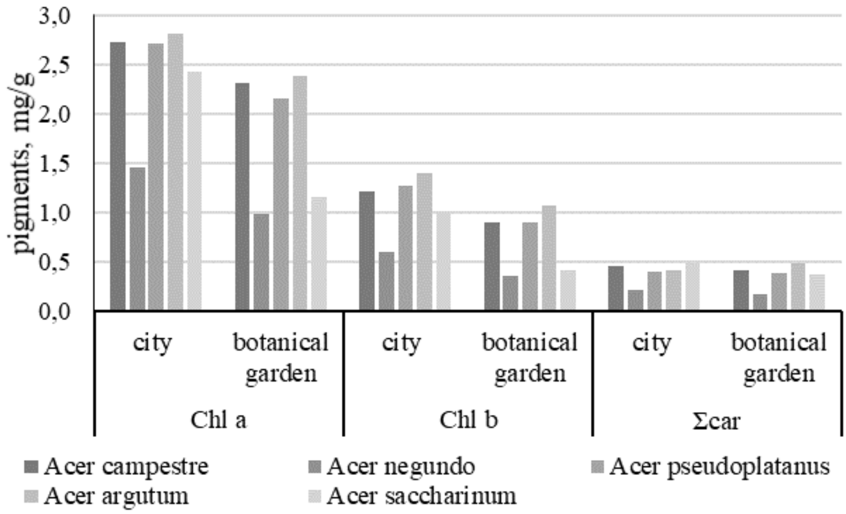

Fig. 1. The content of pigments in the leaves of maple species in Maykop.

The most informative is not the number of photosynthetic pigments in the leaf, but the ratio of the background of the green and yellow groups (Σchl / Σcar). Moreover, a decrease in the value may indicate the gas resistance of plants [20, 27-31]. We have shown that in urban conditions there is an increase in the ratio Σchl / Σcar by 1,1-1,7 times, mainly due to a decrease in the level of chlorophylls and an increase in the proportion of carotenoids. This process is more pronounced in *A. argutum* and *A. saccharinum*. This indicates a more efficient use of PhAR.

A feature of the species is the different degree and direction of correlation between physiological characteristics (Table 2). Thus, in Acer negundo, with significantly lower values of the amount of green pigments, water deficiency and water loss by leaf tissues are significantly lower, which can be explained by a denser epidermis. A significantly more optimal functional state of plants of this species under anthropogenic conditions, despite the genetically determined low amounts of photosynthetic pigments, leads to better synthetic activity, which is expressed in large values of photosynthetic productivity (1.83 mg/cm^2 at 1.07-1.68 mg/cm^2 in other species) (Table 1).

The calculation of the correlation coefficients of all the characteristics studied by us showed a dependence due to the participation of physiological and biochemical parameters in related metabolic processes: the funds of the pigment system are connected; indicators of synthetic processes and the water status of plants are connected. This fact is well-known. However, we were interested in the question of the relationship between the characteristics that form the protective reactions of plants [32], for example, the functional state of plants and the synthesis of ascorbic acid, which is one of the reliable biochemical markers of species resistance to urban conditions. It is shown that there is a close dependence of ascorbic acids (AA) accumulation with the water status of plants and the SSD of the leaf, moreover, the direction of the correlation is reversed (Table 2).

Table 2. Coefficients of pair correlation of parameters characterizing the state of species.

	Chl *a*	**Chl *b***	**Σ*car***	**WD**	**WL**	**TI**	**AA**	**SSDL**	**PhP**
Chl *a*	1								
Chl *b*	**0.97**	1							
Σ*car*	**0.85**	**0.71**	1						
WD	0.36	0.27	0.41	1					
WL	0.46	0.38	039	**0.66**	1				
TI	-0.11	-0.11	-0.23	**0.74**	**0.65**	1			
AA	-0.44	-0.55	0.03	-0.32	**-0.65**	-0.56	1		
SSDL	-0.03	0.06	-0.38	-0.20	0.49	0.34	**-0.74**	1	
PhP	**0.65**	**0.63**	**0.64**	0.41	0.15	**0.81**	-0.11	0.13	1

A number of scientists have noted a tendency to increase the synthesis of ascorbic acid in plants in an anthropogenic environment [22, 28]. We have shown that the involvement of AA in protective reactions is genetically determined (Fig. 2), the highest value AA flagged in species *Acer saccharinum* (from 130 to 327 mg%). However, the active synthesis of ascorbic acid is taken out on the territory of the botanical garden, while in the urban environment the accumulation of AA reduced by 1.7-2.5 times (Fig. 2).

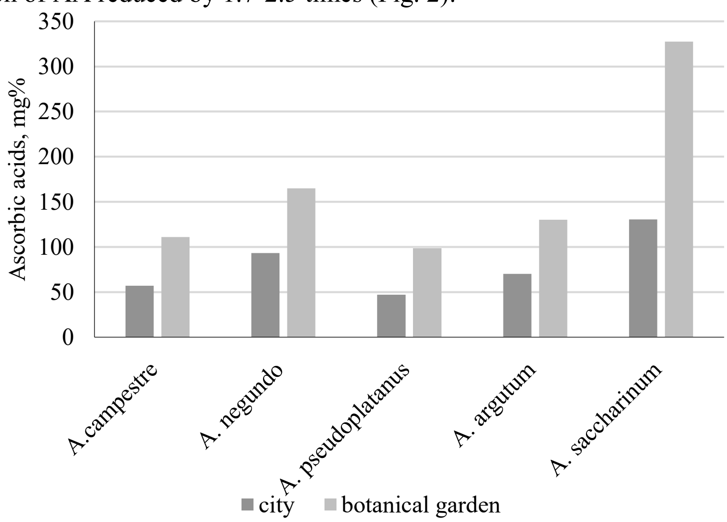

Fig. 2. The content of ascorbic acid (AA) in the leaves of maple species in Maykop

The establishment of the physiological and biochemical state of maple plants in the urban environment and in the background (botanical garden) led to the need to consider the similarity of the functional state in the context of the genetic characteristics of species [33, 34]. We used cluster analysis (Fig. 3), for which we took all the characteristics of species growing in an urban environment that we analyzed, since this gives us the opportunity to interpret the response of species to the stressors of an urbanized area.

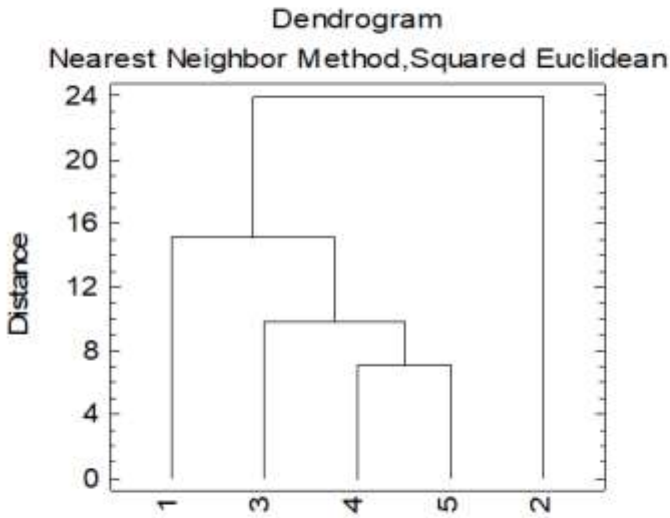

Fig. 3. Dendrogram of Acer species by similarity of physiological and biochemical characteristics

1 - *Acer campestre L.;* 2 – *Acer negundo L.;* 3 – *Acer pseudoplatanus L.;* 4 – *Acer argutum Maxim. ex Miq.,* and 5 – *Acer saccharinum L.*

The dendrogram was constructed using the Euclidean distance with full coupling. As can be seen in Figure 3, clusters 4 and 5 are the closest in terms of reactions to environmental factors (*A. argutum.* and *A. saccharinum*), and also the relationship of reactions with these species can be traced in cluster 3 – *A. pseudoplatanus*. Cluster 2, represented by the view *Acer negundo* it is the most distinguishable by physiological and biochemical characteristics from other studied species. The analysis showed an interesting picture, given that the species closest in the manifestation of protective reactions are *Acer argutum* and *Acer saccharinum* have different origins – one is endemic to Japan (*A. argutum*), and the other (*A. saccharinum*) – the eastern part of North America and the territory of Canada. In addition, the third type, similar in physiological characteristics (*A. pseudoplatanus*), it is more natural for the territory of the Caucasus. Despite the fact that another representative of North America – *Acer negundo* – showed a rather large difference in the characteristics of the functional state, standing out in an independent cluster (Fig. 3).

The cluster analysis data on phenotypic traits associated with physiological and biochemical characteristics showed the need for an analysis of plant genotypes followed by cluster analysis already based on SSR genotyping, which will allow to explain such similarity of physiological and biochemical reactions of plants to urban conditions.

4 Conclusion

Thus, we have studied the condition of five maple species growing in an urban environment and in a botanical garden. It is shown that species differ in their physiological and biochemical characteristics and different reactions are observed in species to anthropogenic stressors. All five maple species in the urban environment had a significant increase in the total fund of green and yellow pigments compared to the species growing on the territory of the botanical garden. A feature of the species is a different correlation of physiological characteristics, there is a close dependence of the accumulation of ascorbic acid with the aquatic status of plants and the SSD of the leaf, moreover, the direction of the correlation is reversed. The involvement of AA in protective reactions is genetically determined, the highest values of ascorbic acid were noted in the species *Acer saccharinum* (from 130 to 327 mg%). To interpret the responses of species to the stressors of an urbanized area, a cluster analysis was used, dividing the species into two clusters; at the same time, common mechanisms of responses were revealed in maples that are introduced from different areas.

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