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Anatomical and Morphological Features of the Leaves of *Tilia Cordata* Mill. As an Indicator of the Adaptive Capabilities of the Species to the Conditions of the Urban Environment

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Abstract. Study of the anatomical and morphological features of the photosynthetic apparatus of *Tilia cordata* Mill. showed that the volume of leaf mesophyll cells in an urbanized environment is higher than in natural plantings. The cells of the palisade mesophyll of the leaf have a greater variability of this indicator during the growing season as compared to the cells of the spongy mesophyll. Positive correlations of the indicator of the volume of cells of the palisade mesophyll with the indicator of the air pollution index, the content of phenol, formaldehyde, benzo(a)pyrene and negative correlations with the content of nitrogen dioxide were noted. The indicator of the volume of cells of the leaf spongy mesophyll positively correlates only with the indicator of the atmospheric pollution index and the content of formaldehyde.

1. Introduction

Revealing the adaptive capabilities of woody plant species to the conditions of an urbanized environment is one of the urgent tasks of modern biological science. Researchers are actively studying the mechanisms of adaptation of organisms to environmental conditions at various levels of organization. [1-4].

In the natural regions of the European part of Russia, as well as in the technogenic environment, one of the most common tree species in this area is *Tilia cordata* Mill. Linden is widely used in urban and park landscaping. The study of the adaptive capabilities of this species in an urban environment consists in assessing the relative vital state of plantings [5, 6], studying the features of anatomical and morphological structures [2, 3, 7, 8, 9], the features of physiological and biochemical processes [10-13]. It should be noted that among the publications there are widespread works on the study of the structure of the assimilation apparatus of *Tilia* on anatomical sections of leaf blades, but publications on the study of leaf mesophyll by the method of tissue maceration are rare [14], despite the possibilities of this method (obtaining by calculation additional indicators for assessing the organization photosynthetic apparatus).



2. Objects and methods

The studies were carried out in the city of Naberezhnye Chelny along urban roads with an estimated traffic intensity of more than 14,000 units/day on Mashinostroitel'naya Street and Khasan Tufan Avenue, characterized by high values of the atmospheric pollution index, from extremely dangerous to moderately dangerous levels of the total indicator of soil pollution (plants experience influence of anthropogenic factors). The Naberezhnye Chelny forestry served as a conditional control zone (low values of the atmospheric pollution index, the permissible level of the total indicator of soil pollution, plants are influenced by natural environmental factors).

During the research, we used standard methods for studying forest plantations [15]. Leaf samples were taken from individuals of *Tilia cordata* Mill. middle-aged generative state, good life state [16]. The samples were fixed with a 70% ethanol solution.

The study of the anatomical and mesostructural parameters of the leaf [14] was carried out on the cell suspensions obtained by the author's method [17]. The volume of leaf mesophyll cells was found using the cylinder formula with a correction factor [18] (1).

$$V = \frac{4}{3}\pi \frac{L}{2} \left(\frac{d}{2}\right)^2 \quad (1)$$

Interpretation of the obtained data was carried out by methods of descriptive statistics and correlation analysis (statistical package "Statistica 10").

3. Results

The research was carried out in the city of Naberezhnye Chelny, which is one of the centers of mechanical engineering in Russia. The largest manufacturer of heavy trucks, Public Joint Stock Company KAMAZ, is located nearby. The level of air pollution in Naberezhnye Chelny, according to the "State Report ..." [19], is characterized as "low" (emissions are relatively small, but their toxicity is high). Main pollutants: formaldehyde, benz(a)pyrene, phenol, etc.

The description of the species composition, phytopathological state of the stand on the studied territory was given in the previously published works of the authors [5, 20, 21].

When studying the anatomical and morphological features of linden leaves, we measured the linear dimensions of assimilation tissue cells [14]. Study of mesostructural parameters of the leaf apparatus of *Tilia cordata* Mill. allowed calculating the cell volumes of the palisade and spongy leaf mesophyll (Table 1).

During the growing season, differences were noted in the dynamics of the cell volume of the palisade mesophyll of the *Tilia* leaf under different growing conditions. In the conditions of the Chelny forestry, the cell volume decreased by 18% (by $163.9 \mu\text{m}^3$) only in August, and in urban plantings, a decrease in this indicator by 18.2% (by $256.7 \mu\text{m}^3$) was noted already in July.

The analysis of the obtained results showed that under the conditions of the urban environment the volume of cells of the palisade mesophyll of the leaf during the entire observation period was significantly higher by 55 - 64% in comparison with the plantations of the conditional control zone.

Correlation analysis of indicators of the volume of cells of the palisade mesophyll of the leaf and parameters of atmospheric air pollution showed positive correlations with the indicator of the atmospheric pollution index ($r = 0.51$ at $p < 0.01$), phenol content ($r = 0.43$ at $p < 0.01$), formaldehyde content ($r = 0.55$ at $p < 0.01$), benzo(a)pyrene content ($r = 0.37$ at $p < 0.05$) and negative - with the content of nitrogen dioxide ($r = -0.37$ at $p < 0.05$).

Table 1. Comparative characteristics of the anatomical and morphological parameters of the leaf blade of *Tilia cordata* Mill. in different growing conditions (Naberezhnye Chelny).

index	June	July	August
Chelny forestry (control)			
Volume of palisade mesophyll cells, μm^3	909.4 $\pm$ 51.2 ^a	784.9 $\pm$ 24.9	745.5 $\pm$ 20.4 ^b
The volume of cells of the spongy mesophyll, μm^3	600.6 $\pm$ 87.9	541.9 $\pm$ 34.8	496.8 $\pm$ 26.9
Highway landings			
Volume of palisade mesophyll cells, μm^3	1408.3 $\pm$ 59.5 ^c	1151.6 $\pm$ 35.1 ^{b,c}	1223.2 $\pm$ 29.0 ^{b,c}
The volume of cells of the spongy mesophyll, μm^3	1029.9 $\pm$ 72.1 ^c	966.7 $\pm$ 50.9 ^c	989.6 $\pm$ 45.4 ^c

^a – the average value of the indicator $\pm$ standard deviation ($p < 0.05$)

^b – significant differences in indicators in July and August compared to June

^c – significant differences in indicators in trunk plantings compared to the Naberezhnye Chelny forestry

We have studied a similar parameter in the cells of the spongy mesophyll of the linden leaf. The analysis showed that during the growing season, the volume of cells in the plantings of conditional control and in urban plantings did not change significantly (Table 1). It should be noted that the indicator of the volume of cells of the spongy mesophyll in urban plantings is higher: in June - by 42% (by 429.3 μm^3), in July - by 44% (by 424.8 μm^3), in August - by 50% (by 492.8 μm^3) in comparison with the indicators of plantings in the zone of conditional control.

When carrying out a correlation analysis of indicators of the volume of cells of the leaf spongy mesophyll and parameters of atmospheric air pollution, positive correlations were revealed only with the indicator of the atmospheric pollution index ($r = 0.59$ at $p < 0.01$) and formaldehyde content ($r = 0.59$ at $p < 0.01$).

Thus, in an urban environment in the leaves of *Tilia cordata* Mill. there is an increase in the volume of cells of the palisade and spongy mesophyll of the leaf, which leads to an increase in the area of contact of the cells of the photosynthetic tissue with the air environment of the intercellular space (the common inner surface). At the same time, the cells of the palisade mesophyll of the leaf have greater variability during the growing season compared to the cells of the spongy mesophyll.

4. Conclusions

Assimilation apparatus *Tilia cordata* Mill. has a high variability: in plantations along city highways, an increase in the volume of cells of photosynthetic tissue (palisade and spongy mesophyll) is observed. The species has a wide adaptive potential of the leaf apparatus, which makes it possible to recommend it for the creation and reconstruction of urban plantings.

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