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RESEARCH OF THE STATE OF WOODY AND BRUSHWOOD PLANTS UNDER ANTHROPOGENIC STRESS CONDITIONS

P.A. Kuzmin, T.V. Skoblikova, S.A. Gorovoy, O.V. Otto

Objective. *The study of anthropogenic impact on environmental components, primarily on woody and shrub plants, which are the main medium-forming element in natural and artificial ecosystems, is relevant. The subject of this study was the ecological and biological state of plants under conditions of technogenic stress.*

Materials and methods. *The article presents the results of a study of the life state of woody plants. For this, test plots were laid on the territory of sanitary protection zones of industrial enterprises and in the plantings of main plantings. The quantitative content of tannins and polyphenol oxidase in plant leaves during the active growing season was determined by spectrophotometry and titrimetric analysis.*

Results. *Vitality decreases in the following order: Betula pendula Roth.> Sorbus aucuparia L.> Rosa majalis Herrn.> Acer negundo L.> Tilia cordata Mill. In plantations of technogenic territories, an increase in damage to the leaf blade is noted, a greater number of dry branches appear in the crown of a tree, compared to the control zone. Thus, in the study area, the lowest life state scores were recorded in Tilia cordata Mill., And the highest vital state scores were recorded in silver birch. In mountain ash, wild rose and American maple, the vital state is average. The increase in the activity of polyphenol oxidase was observed in plantations of technogenic territories, which is a consequence of intensive anthropogenic load on woody plants. Increased activity of polyphenol oxidase helps to decrease the content of tannins in plant leaves. Betula pendula Roth. Sorbus aucuparia L. in the SPZ of industrial enterprises in July, the accumulation of tannins is more intense than in the control plantations.*

Conclusion. *Betula pendula Roth., Sorbus aucuparia L. in the SPZ of industrial enterprises in July, the accumulation of tannins is more intense than in the control plantations. Spectrophotometric determination of activity helps to understand the reasons why the content of tannins increases or decreases. This fact indicates the participation of tannins in the complex of adaptive reactions of plants, which are associated with protection from aerogenic pollutants. As a result of the study, the most resistant to anthropogenic stress plant species were identified: silver birch, cinnamon rose, and rowan tree.*

Keywords: *woody plants; tannins; polyphenol oxidase activity; life state*

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Научная статья | Защита растений

ИССЛЕДОВАНИЕ СОСТОЯНИЯ ДРЕВЕСНО-КУСТАРНИКОВЫХ РАСТЕНИЙ В УСЛОВИЯХ АНТРОПОГЕННОГО СТРЕССА

П.А. Кузьмин, Т.В. Скобликова, С.А. Горовой, О.В. Отто

Актуальность. *Изучение антропогенного воздействия на компоненты окружающей среды, в первую очередь на древесно-кустарниковые растения, которые являются основным средообразующими элементом в естественной и искусственной экосистеме, является актуальным.*

Материал и методы. *Предметом исследования являлось выявление реакции древесно-кустарниковых растений на условия произрастания в техногенной среде. В статье приведены результаты исследования жизненного состояния древесных растений, особенности динамики содержания метаболитом, участвующих в защите растений от негативных условий произрастания. Методами спектрофотометрии и титриметрического анализа было определено количественное содержание танинов и полифенолоксидазы в листьях растений в течение периода активной вегетации.*

Результат. *Жизненное состояние снижается в ряду: Betula pendula Roth.> Sorbus aucuparia L.> Rosa majalis Herrn.> Acer negundo L. >Tilia cordata Mill. В насаждениях техногенных территорий отмечается возрастания повреждений листовой пластинки, появляется большее количество сухих ветвей в кроне дерева, по сравнению с зоной контроля. Так в зоне исследований наименьшие* *баллы жизненного состояния зафиксированы у Tilia cordata Mill., а наивысшие баллы жизненного состояния – у березы повислой. У рябины обыкновенной, шиповника майского и клена американского жизненное состояние среднее. Показаны изменения в содержании танинов и активности полифенолоксидазы в листьях исследуемых растений. В насаждениях техногенных территорий отмечено повышение активности полифенолоксидазы, что является следствием интенсивной антропогенной нагрузки на древесные растения. Повышенная активность полифенолоксидазы способствует снижению содержания танинов в листьях растений.*

Выводы. *У Betula pendula Roth., Sorbus aucuparia L. в условиях СЗЗ промышленных предприятий в июле накопление танинов идет интенсивнее, чем в контрольных насаждениях. Спектрофотометрическое определение активности помогает понять причины по которым содержание танинов возрастает или уменьшается. Данный факт указывает на участие танинов в комплексе приспособительных реакций растений, которые связаны с защитой от аэрогенных загрязнителей. В результате исследования выявлены наиболее устойчивые к антропогенному стрессу виды растений: Betula pendula Roth., Sorbus aucuparia L., Rosa majalis Herrn.*

Ключевые слова: *древесные растения; дубильные вещества; активность полифенолоксидазы; жизненное состояние*

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Introduction

The rapid growth of industry and the number of vehicles leads to the significant pollution of the natural environment and changes in natural processes in the biosphere. Among the pollutants that are present in the air basin of urbanized areas are such substances as phenol, formaldehyde, benzo (a) pyrene, carbon and nitrogen oxides, hydrogen sulfide, ammonia, and suspended particles. Under conditions of technogenic stress, green plantations are constantly affected by a complex of adverse environmental and anthropogenic factors. Plant organisms are susceptible to environmental factors: abiotic, which include high and low temperatures, illumination, lack or excess of moisture, increased radiation levels, mechanical influences, pollution with salts, xenobiotics (gases, pesticides, industrial waste, heavy metals) and biotic, represented by pathogens: fungi, bacteria, viruses [18; 43; 47; 14; 25; 52; 17; 15; 39; 41; 6; 33].

Plants have enzymatic and non-enzymatic systems with antioxidant properties that can inhibit or eliminate the effects of negative substances. These systems provide comprehensive protection of biological polymers from reactive oxygen species [42; 13; 32; 52; 17; 39; 4; 21; 20; 34].

Thus under the conditions of the urban ecosystem of Delhi, using the example of the usual Indian roadside tree Nim (Azadirachta indica), showed an increase in secondary metabolites, including tannins [46].

Large industrial regions include a combination of certain natural and climatic conditions and a peculiar type of farming, which attract attention from an ecological point of view. The totality of the problems of such regions is associated with a high concentration of population, transport and a large number of industrial facilities. Technogenic territories are in a state of ecological imbalance. There is an accumulation of environmental debt due to the formation of toxic waste that enter the atmosphere, water and terrestrial ecosystems. The whole complex of environmental problems has an extremely negative effect on living systems. The growth of the city leads to a reduction in clean air, water, green space. Great damage is observed in areas where the natural environment shows low activity in self-purification from technogenic pollutants [52; 17; 39; 48; 22; 24].

For example, in the work of Z. Li, J. Yang, B. Shang, et al [28; 30]. Showed that elevated O3 levels alter the leaflet chemical profile of hybrid poplar, affecting the accumulation of foliar nitrogen, carbohydrates, and lignin. Meanwhile, the effects of increased O3 in foliar phytochemicals, especially carbohydrates and lignin, were improved by lowering soil water content, but not by N supplementation. Graphical vertical analysis has shown that popular strategies to increase its resistance to elevated O3 and water scarcity may include increasing nitrogen absorption or resorption, accelerating starch mobilization, and enhancing lignin synthesis. Reactions of foliar chemistry to increased O3 content and its interaction. Under water scarcity, the need to study the impact of environmental changes on phytochemistry, which can affect the processes of forest ecosystems, especially in multifactorial conditions, is emphasized, in order to optimize plantation management in accordance with future changes.

The results of their influence are a violation of the phenological growth and development rhythms, the formation and functioning of vegetative organs, and a decrease in plant productivity. Plantations of anthropogenic territories have reduced resistance to extreme conditions. The organization of green plantations is of particular importance in the process of technogenic territory optimization [27; 3; 44; 22; 21; 31; 50; 36].

For the optimal selection of the assortment of green plantations, it is necessary to study the bioecological state of various types of woody and brushwood plants thoroughly. For example, woody plants widely used in landscaping urbanized areas, such as *Tilia cordata* Mill., *Acer platnoides* L., *Populus balsamifera* L., *Betula pendula* Roth., *Malus baccata* (L.) Borkh., *Sorbus aucuparia* L. To perform this task, it is necessary to have an understanding of the adaptation mechanisms of various plant species at the physiological and biochemical levels. For example: the quantitative content of low molecular weight (ascorbic acid, tannins) and high molecular weight (peroxidase, polyphenol oxidase and ascorbinate oxidase activity) substances in the leaves of Betula pen-dula Roth. Growing in main plantings, plantings of sanitary protection zones of industrial enterprises. To do it, it is necessary to know the quantitative content of low-molecular and high-molecular compounds in plant leaves. Ascorbic acid is a representative of secondary metabolites that reflect the level of synthetic processes in plants. In the work of E.Yu. Kolmogorova [25] showed that in individuals of silver birch, the maximum content of ascorbic acid in the leaves was noted in July, and the minimum in August, regardless of the growth zone. It should be noted that the content of ascorbic acid in the plants of the control plantations was higher during the entire growing season. Many substances take part in plant adaptation, including condensed tannins and the polyphenol oxidase enzyme, which is the subject of this research work [8; 10; 22; 38].

The scientific novelty of the study lies in the use of an approach to assess the productivity of artificial plantings based on the identification of the joint functioning of high-molecular and low-molecular compounds of the antioxidant protection system in the studied woody plants.

This research aimed to study the ecological and biological features of woody and brushwood plants in an anthropogenic environment (through the example of the Kama economic region, the Republic of Tatarstan, Russia).

The aim of the study is to study the bioecological and biochemical features of the functioning of woody and shrubby plants in an anthropogenic environment in order to identify the most adapted species and form the scientific basis for the selection of species composition for the preservation of plantings of various functional purposes (on the example of the Kama Economic District, the Republic of Tatarstan, Russia).

Theoretical Analysis

In an urbanized environment, various metabolites – enzymes, tannins, and ascorbic acid – participate in the formation of adaptive plant reactions. In recent years, tannins and ascorbic acid are considered by scientists as important elements of the antioxidant defense system in woody plants under conditions of technogenic stress. Exposure to various air pollutants leads to numerous changes not only in the metabolic profile of trees but also in their symbiont activity [8; 2; 45; 51].

One of the important enzymes involved in plant respiration is copper-containing polyphenol oxidase, which in turn shows the level of hypoxia. Higher activity of polyphenol oxidase contributes to the neutralization of anthropogenic pollutants [26; 7].

In the works of scientists, a specific reaction of poplars and tea trees under stress conditions was revealed, which manifests itself in an increase in the activity of antioxidant enzymes and a decrease in the content of proline and abscisic acid. [13; 23; 28; 49].

The antimicrobial effects of tannins may also be important in protecting plants from pathogens, although evidence of this is scarce - the induction of CT biosynthesis in M. medusae-infected poplar leaves is the first indication that CTs are potential anti-pathogenic compounds in poplar. This hypothesis is supported by the fact that the high tannin P. tremuloides genotypes are more resistant to late blight in leaves. However, this correlation needs to be verified directly. In addition, it is possible that in some plants tannins play a role in protection against abiotic stresses such as aluminum toxicity [5].

Many studies indicate the relationship between the adaptive capabilities of the plant organism and the functioning of the enzymatic system, including the copper-containing enzymes of polyphenol oxidase and ascorbinate oxidase. These enzymes, in combination with phenolic substrates, are involved in the respiration process. In damaged plant tissues, when exposed to low temperatures, the activity of polyphenol oxidase increases. Technogenic pollution of the environment leads to an increase in the activity of this enzyme. In addition, polyphenol oxidase is involved in the regulation of metabolism during ontogenesis and adaptive reactions to negative environmental factors [16; 22; 21].

Among substances involved in plant resistance, much attention is paid to secondary metabolites, including phenolic compounds. They include tannins, which affect the growth and development of plants, phenols involved in the transport of electrons during respiration and photosynthesis, in lignin biosynthesis, and provide non-enzymatic oxidation of some compounds (amino acids, ascorbic acid, cytochromes, etc.). Phenolic compounds in the plant cell can play a significant role in plant adaptation to various stress factors [19; 53; 10; 29; 30].

Analysis of the biochemical and histoanatomical properties of species from various polluted and unpolluted areas of the Suceava district of Romania led to the following results: the range of antioxidant responses to the conditions of pollution from the Calimani, Tarnitsa and Krucha-Botusana mountains was different depending on the type of polluting interference in the environment. The highest reactivity of the antioxidant defense system was revealed under the action of U in all studied species in the Krusea-Botushan area, with the exception of Salix alba for turf and Populus tremula for POX. SOD, CAT, POX were positively stimulated by all types of contamination, and the level of enzymatic activity exceeded the level of enzymatic activity of leaf material collected from species in the control area [9].

A study on plants Taraxacum officinale, Plantago lanceolata, Betula pendula, and Robinia pseudoacacia growing in urban biotopes with different levels of heavy metal pollution in the city of Dabrowa Gornicza (southern Poland) showed a tendency towards an increase in proline content in biotopes associated with high permeability. A similar trend was observed for the content of ascorbic acid in plant foliage, as well as in T. officinalle in plantings associated with industrial emissions. The content of non-protein thiols increased, especially in the leaves of R. pseudoacacia in biotopes with high transport emissions, as well as in T. officinale in industrial plantations. The average values of APTI (air pollution resistance index) within the city of Dabrowa Gornicza for the studied plants were found in the following order of increasing P. lanceolata <R. pseudoacacia <B. pendula <T. officinale. B. pendula plants may be considered suitable plants in urban areas with significant soil and air pollution, especially heavy metals, are suitable plants in containment zones for air pollution control [40; 35].

Synergistic effects were assessed by plant exposure to high O3 concentrations in an urban site in the city of São Paulo. Confocal, wide-field and light microscopy were used to study the occurrence and characteristics of polyphenols. The spatial pattern of the distribution of polyphenols in plant leaves is subordinate to the synergism of the state in which the dense vacuolar aspect is the target of a cell doomed to death, was also observed in constitutive secretory cells before lysis. This similar structural pattern may be a case of homologous processes involving both constitutive (secretory ducts) and induced (photosynthetic cells) defenses [12].

Various studies have shown an increase in the content of condensed tannins and peroxidase activity in leaves and needles of plants from urban areas. Therefore, these biochemical parameters can be used as potential biomarkers of tree stress [1].

Materials and Methods

The Kama region of the Republic of Tatarstan is an example of a territory with a high degree of anthropogenic impact. This region includes four closely located cities with developed industry: Naberezhnye Chelny, Nizhnekamsk, Mendeleevsk, and Yelabuga. In Naberezhnye Chelny there are large automobile factories Kamaz and Solers-Naberezhnye Chelny; Special economic zone "Alabuga"; Chemical plant them. L. Ya. Karpova (Mendeleevsk); plant for the production of mineral fertilizers "Mendeleevskazot"; Oil refineries "TAIF-NK", "Nizhnekamskneftekhim", "Nizhnekamskshina".

3.1. Period and Samples (plants).

The research was conducted during the vegetation period (June, July, August) in 2017–2019. The study was concerned with woody and brushwood plants widely used for the forestry of Yelabuga, which grow in various ecological categories of green plantations: trunk plantations (Mira Avenue), buffer zone (near the territory of the "Alabuga" SEZ enterprises), and conventional control zone (Alexandrovsky Park). The plants selected for the study were: small-leaved linden (*Tilia cordata* Mill.), rowan tree (*Sorbus aucuparia* L.), cinnamon rose (*Rosa majalis* Herrn.), silver birch (*Betula pendula* Roth.), and ash-leaved maple (*Acer negundo* L.). These types of trees are widely distributed in the forestry of cities in the Kama region. Below are photographs of the research objects, the authors of which are the team of the article (Figure 1-5). The full species composition of the investigated plantations is presented in the table 1.

Table 1.

Species composition of the studied plantations

Plantation type	Type of a brushwood plant	Number of individuals, pieces	Number of individuals, %
conventional control zone (Alexandrovsky Park)	*Tilia cordata* Mill.	47	43,9
	Acer platnoides L.	37	34,5
	Picea abies L.	4	3,7
	Betula pendula Roth.	19	17,9
		107	100
buffer zone (near the territory of the "Alabuga" SEZ enterprises)	*Betula pendula* Roth.	19	18,4
	Acer platnoides L.	25	24,3
	Populus balsamifera L.	16	15,5
	Acer negundo L.	12	11,7
	Picea abies L.	4	3,9
	Malus baccata (L.) Borkh.	3	2,9
	Tilia cordata Mill.	24	23,3
		103	100
trunk plantations (Mira Avenue)	*Tilia cordata* Mill.	38	34,2
	Acer platnoides L.	15	13,5
	Populus balsamifera L.	13	11,7
	Acer negundo L.	9	8,1
	Betula pendula Roth.	14	12,6
	Ulmus laevis Pall.	1	0,9
	Sorbus aucuparia L.	5	4,5
	Malus baccata (L.) Borkh.	16	14,4
		111	100

Figure 1. Tilia cordata Mill.

Figure 2. Sorbus aucuparia L.

Figure 3. Rosa majalis Herrm.

Figure 4. Betula pendula Roth.

Figure 5. Acer negundo L.

3.2. Experimental studies

Samples were collected in the middle of the month, simultaneously from all sample plots. Sample collection time from 10:00 to 12:00. The samples were packed in special bags and quickly transported to the laboratory. In laboratory conditions, the activity of the enzyme was determined. Part of the material was left to dry naturally, excluding direct sunlight. Then weighed samples were prepared and the quantitative content of tannins was determined.

The life state of woody plants was determined visually by the degree of damage to the assimilatory apparatus and plant crowns [37]. The content of tannins in the leaves was determined by the titrimetric method. The polyphenol oxidase activity was determined by the spectrophotometric method, which is based on the optical density measurement of resultant products formed as a result of pyrocatechol oxidation during a particular period.

3.3. Description of research methods

For the experiments, the authors used 1/15 M phosphate buffer with a pH of 7.4; 0.05 M pyrocatechol solution; polyamide in a ratio of approximately 1:1 to the fresh weight subsample [11]:

The subsample of leaves of the studied plants weighing 100 mg was ground in a mortar with 100 mg of ready-made polyamide, with the addition of some buffer solution. Next, the resulting mass was transferred to a measuring flask at

25 cm^3 and the buffer solution was added to the mark. The mixture was centrifuged at 4000 rpm for 10 minutes. Further on, 0.5 cm^3 of the enzymatic extract, 2.0 cm^3 of the phosphate buffer with a pH of 7.4, and 0.5 cm^3 of the pyrocatechol solution were added to the experimental cuvette of the spectrophotometer. The same mixture was added to the control cuvette, only pyrocatechol was replaced with 0.5 cm^3 of distilled water. The first measurement was performed after 20 seconds. Values were recorded every 20 seconds for 3 minutes.

The optical density was measured at 420 nm. The enzyme activity was expressed in relative units per 1 g of fresh weight. The polyphenol oxidase activity was calculated by the formula:

$$A = \frac{(D_2 - D_1) \cdot 60V \cdot V_2}{(t_2 - t_1) \cdot V_1 \cdot H};$$

where D_1 – the optical density of the solution at the beginning of the experiment (the first measurement);

D_2 – the optical density of the solution at the end of the experiment;

t_1 and t_2 – the time at the beginning and end of the experiment, s;

Ss – the weight of the subsample, g;

V – the total volume of the enzymatic extract, cm^3;

V_1 – the volume taken for the reaction, cm^3;

V_2 – the total volume of liquid in the cuvette, cm^3;

60 – the coefficient for converting seconds to minutes.

The content of tannins was determined with the help of the permanganate metrical method (Leventhal method modified by Kursanov). For the experiments, the authors used: indigo carmine solution; 0.05 n solution of $KMnO_4$; distilled water.

To prepare the extract, the leaves of woody plants were crushed into pieces of 0.3–0.5 cm. Then, 0.5–2 g of crushed leaves were weighed (exact weight) and placed in a conical flask with a capacity of 100 ml. Then, 50 ml of boiling distilled water was poured and heated in a water bath for 30 minutes.

Further on, the resulting extract was carefully filtered through cotton wool into a 250 ml measuring flask, so that the raw material particles did not get on the cotton wool. The flask with raw material was re-filled with boiling distilled water (50 ml), heated in a water bath for 10-15 minutes, and the liquid was also filtered into the same 250 ml measuring flask.

Then, the liquid in the measuring flask was cooled and the volume of the extract was brought to the mark with water. Next, 10 ml of the resulting liquid was placed in a conical flask with a capacity of 100 ml; 75 ml of water and 3 ml of indigo carmine solution were added. After that, 0.05 n $KMnO_4$ was titrated to a golden yellow color. One milliliter of 0.05 n $KMnO_4$ corresponds to 0.0020785 g of tannin substances in terms of tannin.

At the same time, a control experiment was conducted by titrating 3 ml of indigo carmine in 85 ml of water.

The percentage of tannin substances (x) was calculated by the following formula:

$$x= ((V_2 - V_1) \cdot K \cdot D \cdot V \cdot 100 \cdot 100) / m \cdot V_3 \cdot (100 - W);$$

where D – the conversion factor to tannin: for hydrolyzable tannin substances – 0.0020785; for condensed tannin substances – 0.00291;

m – the weight of the subsample, g;

K – correction for titration;

V – the total volume of extract, ml;

V_1 – the volume of 0.05 n $KMnO_4$ used for control titration, ml;

V_2 – the volume of 0.05 n $KMnO_4$ used for titration, ml;

V_3 – the volume of the extract taken for titration, ml;

W – water content of raw material, %.

To prepare a buffer in 1 liter of distilled water, mix solutions of Na2HPO4x-2H2O - 11.876 g and KH2PO4 - 9.078 g. The ratio between the solutions is as follows: Na2HPO4x2H2O - 81.8 ml. and KH2PO4 - 18.2 ml.

Since the number of equivalents for potassium permanganate is 1, the normal concentration of the solution is equal to the molar concentration. We consider the mass of potassium permanganate knowing that it is 0.05 mol m = n * M = 0.05 * 158 = 7.9 grams. This means that to prepare such a solution, you need to take 7.9 grams of potassium permanganate, pour it into a liter or more flask and add water to the 1 liter mark [11].

3.4. Mathematical processing of results.

The analyses were performed at the Biology and Chemistry Department of the Mathematics and Natural Sciences Faculty of the Yelabuga Institute of Kazan Federal University.

Samples of the middle leaves of model trees were taken for laboratory biochemical analyses. Mathematical processing of the materials was performed using the statistical package Statistica 10.”. To interpret the obtained materials, the authors used methods of descriptive statistics and variance multiple factor analysis (using a cross-hierarchical scheme, with the subsequent evaluation of differences using the LSD-test multiple comparison method).

Results and Discussion

The climate is moderately continental, characterized by warm summers and moderately cold winters. The annual rainfall in the city averages 555 mm.

The warmest month of the year is July (+18...+20° C), the coldest is January (-13...-14° C).

The conducted agrochemical analysis showed that the soils in the plantations of conditional control zones have a neutral and slightly alkaline reaction, the content of organic matter from low to medium, the content of mobile phosphorus and exchangeable potassium from elevated to very high. The soils also have a high content of nitrate forms of nitrogen and a low content of ammonium forms of nitrogen.

In the main plantings, the soils had an alkaline reaction, a low content of organic matter at the level of 1.6%; from low to medium content of ammonium nitrogen (5.2-8.4 mg/kg), nitrate nitrogen (27-162) and mobile phosphorus (P_2O_5 = 27.1-50.2 mg/kg); from high to very high content of exchangeable potassium (K_2O = 209-311 mg/kg).

Weather conditions of vegetation periods are relatively stable and have a fairly favorable effect on the life of plants.

Urban vegetation indicates the state of the environment. Therefore, urban forestry requires species that can be tolerant of the maximum anthropogenic loads.

To determine the life state of woody plants, the authors used Nikolaevsky's scale (1999). This scale was based on the sensitivity of the assimilation apparatus.

The resulting data is shown in Figure 6.

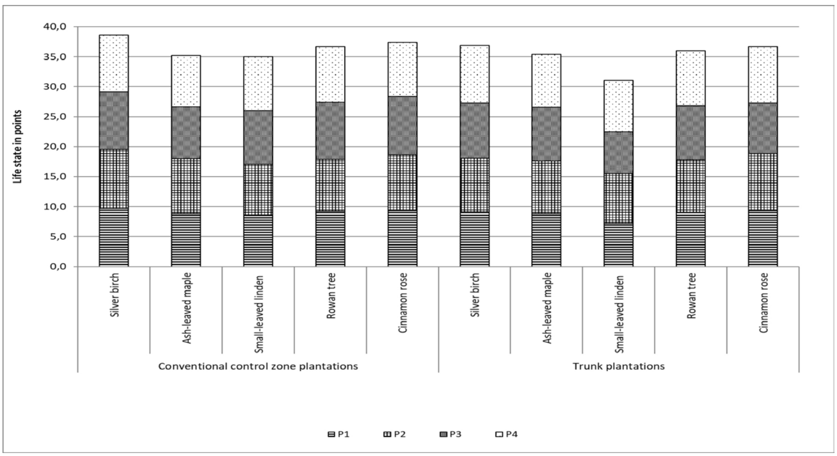

Figure 6. Life state of brushwood plants in different functional zones.
P1 – the number of live branches in tree crowns; P2 – foliage degree of crowns;
P3 – the number of live (without necrosis) leaves in crowns;
P4 – live leaf average square.

Native small-leaved linden is used in the forestry of cities in the Kama region. The life state of the studied individuals in all the studied zones is satisfactory (35 points). The foliage of trees is average and significant damages (necrosis) on the leaf blade are observed.

Rowan tree is widely used in urban forestry, especially in trunk plantations. The life state in the study areas is good (38 points). Damages of the leaf blade were almost not observed.

Silver birch is widely used in urban forestry as well, especially in trunk plantations and parks. The life state in the study areas is excellent (39-40 points). Damages of the leaf blade were not observed.

The life state of the ash-leaved maple in all the studied zones is satisfactory (34-35 points).

Cinnamon rose is used moderately in urban forestry. The life state in all the studied zones is good (38 points). Some insignificant damages (necrosis) of the leaf blades are observed. The foliage is medium.

During the study, it was found that the number of individuals with excellent and good state decreased, and the number of dried out plants increased in the areas with the intense anthropogenic load.

The lowest points of life state in urban plantations were revealed for small-leaved linden (31 points), and the highest points of life state – for silver birch (38 points). Rowan tree, cinnamon rose, and ash-leaved maple have an average life state (36-37 points).

Analysis of the study results showed that the activity of polyphenol oxidase in plant leaves was influenced by species features (significance level $P=1.93 \cdot 10^{-5}$), their growth conditions ($P=1.21 \cdot 10^{-5}$), and the interaction of species features and their growth conditions ($P=1.54 \cdot 10^{-5}$). The table 2 shows the activity of polyphenol oxidase and tannin content in plant leaves.

The maximum amount of tannins in leaves was observed in August for silver birch in the buffer zone (9.24 mg/g of dry matter) and rowan tree in the trunk plantations (9.39). In the conditions of the sanitary protection zone and main plantings in June, the quantitative content of tannins in the leaves was higher than in the control, respectively: in drooping birch by 0.69 and 0.68 mg / g dry. things, in common mountain ash by 0.18 and 0.45, in May rosehip by 0.25 and 0.47. This trend continued in July and August. The small-leaf linden had differences in the content of tannins. Thus, the content of tannins in the leaves of plants growing in a technogenic environment was lower than in plants of the control zone: in June by 1.04 and 1.13, in July in the sanitary protection zone by 0.49 and in August by 1, 57 and 0.95 mg / g dry. things.

Table 2.

Polyphenol oxidase activity and tannin content in plant leaves of various functional zones (Kama industrial region, Republic of Tatarstan, Russia)

Type of a brushwood plant	Plantation type	Polyphenol oxidase activity, activity units			Condensed tannins, mg/g of dry matter		
		June	July	August	June	July	August
Betula pendula Roth.	CCZ[1]	1.12	3.18	2.77	4.13	6.76	8.13
	BZ[2]	1.03	2.32	3.63	4.82	7.17	9.24
	TP[3]	1.18	2.42	3.31	4.81	6.83	8.84
Tilia cordata Mill.	CCZ	1.08	3.73	2.81	3.26	4.67	7.69
	BZ	1.17	3.85	3.11	2.22	4.18	6.12
	TP[3]	2.16	4.39	4.37	2.13	4.89	6.74
Sorbus aucuparia L.	CCZ	1.94	3.72	3.61	5.17	6.39	8.88
	Buffer zones	1.66	3.95	3.71	5.35	6.83	8.99
	TP	1.96	3.31	3.81	5.62	6.98	9.39
Rosa majalis Herrn.	CCZ	0.91	2.99	3.79	5.49	6.91	7.11
	Buffer zones	1.22	3.72	4.41	5.74	6.94	7.64
	TP	1.32	4.17	6.21	5.96	7.33	8.43
LSD_{05}		0.07			0.05		

Notes: CCZ[1] – conventional control zone (Alexandrovsky Park); BZ[2] – buffer zone (near the territory of the "Alabuga" SEZ enterprises); TP[3] - trunk plantations (Mira Avenue)

All the studied species showed an increase in the tannins content by the end of the growing season, and a greater increase was observed in individuals growing under technogenic stress. Activation of the synthesis of condensed tannins is a protective adaptive reaction of the studied plant species, which allows compensating for the negative impact of pollutants in the air. The accumulation of tannins in the leaves of silver birch, rowan tree, and cinnamon rose is more intense than in the plants of the control zone.

The polyphenol oxidase enzyme takes part in the synthesis of tannins, so it is important to know its activity during the growing season. In August, the enzyme activity of silver birch was higher by 0.86 and 0.56 in the buffer zones and trunk plantations, compared to the control zone. For silver birch, high activity of polyphenol oxidase was observed in July in the buffer zones, in July and August near trunk road plantations. Among the studied plants, the maximum activity was observed for cinnamon rose in August in the trunk plantations (6.21 activity units).

In the small-leaved linden in a technogenic environment, the activity of polyphenol oxidase was higher compared to the activity of this enzyme in plants of the control zone: in the sanitary protection zone: in June by 0.09 units of act., In July by 0.12 , in August by 0.30; in the main plantings: in June by 1.08, in July by 0.66, in August by 1.56. Analyzing the dynamics by months, it can be noted that the activity of polyphenol oxidase increases from June to July, regardless of the growing zone and in all studied plant species. Further, a similar trend persists for plants under conditions of technogenic stress.

Thus, it can be said that the activity of polyphenol oxidase increases in the second half of the vegetation and under the conditions of intensive technogenic load.

Conclusions

Studies show that the best life state is observed in silver birch, May rose and common mountain ash, small-leaved linden plants in a technogenic environment have a severely damaged leaf blade. The content of condensed tannins and the activity of polyphenoloxidase in plant leaves are species-specific, with a dynamic tendency to increase the content by the end of the growing season.

For urban forestry, the types of woody plants that are most resistant to gases and other pollutants should be considered, such as silver birch, cinnamon rose, and rowan tree.

Thus, the increased activity of polyphenol oxidase contributes to a decrease in the tannin content in plant leaves. This fact indicates the participation of tannins in the complex of adaptive reactions of plants, which are associated with protection from aerogenic pollutants.

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DATA ABOUT THE AUTHORS

Petr A. Kuzmin, PhD in Agricultural Sciences, Senior Researcher, Laboratory of Bioecology of Woody Plants
Federal Scientific Center for Agroecology, Complex Melioration and Protective Afforestation of the Russian Academy of Sciences
97, Universitetskiy Ave., Volgograd, 400062, Russian Federation
pa1984kuzmin@yandex.ru
ORCID: https://orcid.org/0000-0002-1303-765X

Tatyana V. Skoblikova, D.Sc. in Pedagogic, Professor of the Department of Physical Education
Southwest State University
94, 50 Let Oktyabrya Str., Kursk, 305040, Russian Federation
skoblikova-t@mail.ru
ORCID: https://orcid.org/0000-0003-0845-6179

Sergey A. Gorovoy, Candidate of Technical Sciences, Associate Professor of Department of Machine Repair and Materials Science
Kuban State Agrarian University named after I.T. Trubilin
13, Kalinina Str., Krasnodar, 350044, Russian Federation
s.a.gorovoy@inbox.ru
ORCID: https://orcid.org/0000-0003-3322-5348

Olga V. Otto, PhD in Geography, Associate Professor of the Department of Nature Management and Geoecology
Altai State University
61, Prospekt Lenina, Barnaul, 656049, Russian Federation
otto.olga@mail.ru
ORCID: https://orcid.org/0000-0002-9313-0693

ДАННЫЕ ОБ АВТОРАХ

Кузьмин Петр Анатольевич, кандидат сельскохозяйственных наук, старший научный сотрудник лаборатории биоэкологии древесных растений
Федеральный научный центр агроэкологии, комплексных мелиораций и защитного лесоразведения Российской Академии Наук (ФНЦ агроэкологии РАН)
проспект Университетский, 97, г. Волгоград, Российская Федерация
pa1984kuzmin@yandex.ru

Скобликова Татьяна Владимировна, доктор педагогических наук, профессор кафедры физического воспитания
Федеральное государственное бюджетное образовательное учреждение высшего образования «Юго-Западный государственный университет»
ул. 50 лет Октября, 94, г. Курск, 305040, Российская Федерация
skoblikova-t@mail.ru

Горовой Сергей Алексеевич, кандидат технических наук, доцент кафедры ремонта машин и материаловедения
Кубанский государственный аграрный университет имени И.Т. Трубилина
ул. Калинина, 82, г. Краснодар, 350044, Российская Федерация
s.a.gorovoy@inbox.ru

Отто Ольга Витальевна, кандидат географических наук, доцент кафедры природопользования и геоэкологии
Алтайский государственный университет
проспект Ленина, 61, г. Барнаул, 656049, Российская Федерация
otto.olga@mail.ru

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