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MORPHOMETRIC PARAMETERS AND LEAF ASH CONTENT OF TREE PLANTS: INDICATION OF TECHNOGENIC LOAD IN THE CONDITIONS OF AN INDUSTRIAL REGION

This article is dedicated to studying the influence of ash element distribution in the tissues of woody plants` foliar organs on the fluctuating asymmetry of leaf blades in industrial areas. The research goal is a comprehensive study of the trends in the relationship between ash content and fluctuation of morphometric parameters of leaf blades under conditions of increased anthropogenic impact, using Pavlodar as an example. The research hypothesis states that the increase in ash element content in the tissues of leaf blades is directly proportional to significant variations in morphometric parameters within the sample and serves as an indicator of environmental pollution. The research objects are leaves of *Populus balsamifera*, *Betula pendula*, *Acer negundo*. According to the location of industrial emission sources, they were divided into three zones: northern, eastern, and central. The leaves were collected at the end of the 2023 growing season, with subsequent measurements of the length and width of the leaf blade and calculation of the standard deviation. The significance of differences between samples was assessed based on the results of variance analysis. Ash content determination was carried out by the dry ashing method of leaves in a muffle furnace. It was found that the maximum concentration of ash elements is characteristic of *Populus balsamifera* and *Acer negundo*, with the highest degree of atmospheric air pollution identified for the Alumina Plant, consistent with the significant results of the range of variation in morphometric indicators within the sample. An increase in mineral accumulation in leaf blades from southeast to northwest within the central and eastern industrial zones (excluding the Alumina plant) was noted. The obtained results confirm a direct proportional relationship between significant fluctuations in morphometric parameters as ash content increases, which can be used as an indicative method of anthropogenic pollution in industrial regions.

Key words: bioindication, fluctuating asymmetry, technogenic pollution, industrial zone.

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Ағаш өсімдіктері жапырақтарының морфометриялық параметрлері мен күлділігі: өнеркәсіптік аймақтағы техногендік жүктеменің индикациясы

Бұл мақала ағаш өсімдіктерінің жапырақ мүшелерінің тіндеріндегі күл элементтерінің таралуының өнеркәсіптік аймақтардағы жапырақ алақандарының тербелмелі асимметриясына әсерін зерттеуге арналған. Зерттеудің мақсаты – Павлодар қаласының мысалында техногендік әсердің жоғарылауы жағдайында күл шамасының жапырақ алақандарының морфометриялық параметрлерінің ауытқуымен өзара байланысының тенденцияларын кешенді зерттеу. Зерттеу гипотезасы – жапырақ алақандарының тіндеріндегі күл элементтерінің көбеюі үлгі шегіндегі морфометриялық параметрлердің айтарлықтай өзгеруіне тікелей пропорционалды және қоршаған ортаның техногендік ластануының көрсеткіші болып табылады. Зерттеу нысандары – *Populus balsamifera*, *Betula pendula*, *Acer negundo* жапырақтары. Өнеркәсіптік шығарындылар көздерінің аумақтық орналасуына сәйкес олар үш аймаққа бөлінді: солтүстік, шығыс және орталық. Жапырақтары 2023 жылдың вегетациялық кезеңінің соңында жиналды, содан кейін жапырақ алақанының ұзындығы мен ені өлшенді және орташа квадраттық ауытқуы есептелді. Үлгілер арасындағы айырмашылықтардың маңыздылығын бағалау дисперсиялық талдау нәтижелері бойынша анықталды. Күлдің құрамын анықтау муфель пешіндегі жапырақтарды құрғақ күлдендіру

әдісімен жүзеге асырылды. Күл элементтерінің максималды концентрациясы *Populus balsamifera* және *Acer negundo*-ға тән екені анықталды, соған сәйкес Алюминий зауыты үшін атмосфералық ауаның ластануының ең жоғары дәрежесі анықталды, бұл үлгі ішіндегі морфометриялық көрсеткіштердің өзгеру диапазонының маңызды нәтижелеріне сәйкес келеді. Орталық және шығыс өнеркәсіп аймағы (Алюминий зауытын қоспағанда) шегінде қаланың оңтүстік-шығысынан солтүстік-батысына қарай жапырақ алақандарында минералдардың жинақталуының өсуі байқалды. Алынған нәтижелер күл көрсеткіштері өскен сайын морфометриялық параметрлердің айтарлықтай ауытқуының тікелей пропорционалды байланысын растайды, оны өнеркәсіптік аймақ жағдайында техногендік ластанудың индикациялық әдісі ретінде пайдалануға болады.

Түйін сөздер: биоиндикация, тербелмелі асимметрия, техногендік ластану, өндірістік аймақ.

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Морфометрические параметры и зольность листьев древесных растений: индикация техногенной нагрузки в условиях промышленного региона

Данная статья посвящена изучению влияния распределения зольных элементов в тканях фолиарных органах древесных растений на флуктуационную асимметрию листовых пластин в условиях промышленных зон. Цель исследования – комплексное изучение тенденций взаимосвязи величины зольности с флуктуацией морфометрических параметров листовых пластинок в условиях повышенного техногенного воздействия на примере города Павлодар. Гипотеза исследования – рост содержания зольных элементов в тканях листовых пластин прямо пропорционален значительной вариации морфометрических параметров в пределах выборки и является индикатором техногенного загрязнения окружающей среды. Объекты исследования – листья *Populus balsamifera, Betula pendula, Acer negundo*. Согласно территориальному расположению промышленных источников выбросов, они были разделены на три зоны: северная, восточная и центральная. Листья отобраны в конце вегетационного периода 2023 года с последующим измерением длины и ширины листовой пластинки и расчетом среднеквадратического отклонения. Оценка значимости различий между выборками определена по результатам дисперсионного анализа. Определение содержания золы осуществляли методом сухого озоления листьев в муфельной печи. Выявлено, что максимальная концентрация зольных элементов характерна для *Populus balsamifera* и *Acer negundo*, в соответствии с чем наибольшая степень загрязнения атмосферного воздуха выявлена для Алюминиевого завода, что согласуется со значимыми результатами диапазона варьирования морфометрических показателей внутри выборки. Отмечен рост накопления минеральных веществ в листовых пластинках в направлении с юго-востока на северо-запад города в пределах центральной и восточной промзоны (за исключением Алюминиевого завода). Полученные результаты подтверждают прямо пропорциональную взаимосвязь значительной флуктуации морфометрических параметров по мере роста показателей зольности, что может использоваться в качестве индикационного метода техногенного загрязнения в условиях промышленного региона.

Ключевые слова: биоиндикация, флуктуационная асимметрия, техногенное загрязнение, промышленная зона.

Introduction

One of the most promising indicators of plant susceptibility to changes in the environment, particularly the composition of atmospheric air, is the accumulation of ash-forming elements by plants, which form a mineral residue. The content of these elements is reflected in the ash residue that remains after the removal of organic substances.

The concentration of ash-forming elements in the tissues of leaf blades of woody plants is determined by several factors, among which the most characteristic ones are the quality of the environment and genotypic features of plant predisposition. Equally important in forming the ash composition of plants are environmental conditions such as temperature, acidity, and soil salinity, as well as moisture levels and shading [1, 2]. Leaf ash content indicators can reflect the degree of technogenic load on atmospheric air within a region, characterising the assimilation capacity of plant organisms and serving as a phytosignaling indicator of air pollution levels, although the relationship between these indicators is not always confirmed in practice [3]. The study

of ash content indicators plays an important role not only in terms of their importance for plant organisms but also from the perspective of the migration of these elements into other components of the ecosystem. Equally important is the aspect related to the influence of ash-forming elements on plant vitality, where excessive accumulation of such elements affects plant growth retardation, disrupts nutrient balance [4], cell structure, damages proteins and lipids, stimulates the accumulation of active oxygen forms [5], inhibits enzyme activity, disrupts respiratory and photosynthetic processes, damages stomatal function and structure [6, 7], and inhibits vital processes [8, 9].

It is important to note that one of the directions in the field of phytoindication today is studying the variation of morphometric parameters of plants or their organs [3]. Methods for phytoindication of technogenic pollution [10] based on assessing the asymmetry of leaf blade parameters (length and width) are being widely implemented, which is particularly relevant for industrial centres in the country [11, 12].

Currently, many regions of the Republic of Kazakhstan face the issue of air pollution from various emission sources [1]. Pavlodar is a city of regional significance and one of the significant industrial centres of the Republic of Kazakhstan. This role subjects the city to a substantial level of negative impact due to emissions of pollutants into the atmosphere by industrial enterprises. The seriousness of this problem is further compounded by mobile sources of pollution (transport). Materials collected near factories were studied as part of the research since these infrastructure objects constitute a significant portion of pollution sources.

According to the national report on the environment state in the Republic of Kazakhstan, 26% of all emissions into the atmosphere are attributed to the city of Pavlodar. The main contribution to the city's pollution comes from fuel and energy complexes, which account for 66.2% of emissions. Just under a quarter (23.5%) of emissions come from enterprises engaged in metallurgical activities [13].

According to the data from the Department of Ecology of the Pavlodar Region of the Committee for Environmental Regulation and Control of the Ministry of Ecology, Geology, and Natural Resources of the Republic of Kazakhstan, emissions from first category industrial enterprises in 2023 amounted to 182.932 thousand tons, while emissions from stationary sources of the second and third categories totaled 9.851 thousand tons. In comparison, similar figures in 2022 comprised 199.145 thousand tons and 1.2 thousand tons (including the fourth category), respectively. The decrease in emissions from industrial sources of the first category is compensated by an increase in the share of emissions from sources belonging to categories II and III. The main proportion of pollutants released into the atmosphere is attributed to carbon monoxide (exceeding MPC in 783 cases), hydrogen sulfide (exceeding MPC in 640 cases), and nitrogen dioxide (exceeding MPC in 566 cases). Nitrogen oxide concentrations (exceeding MPC 32 times) and suspended particles (exceeding MPC 36 times) also play a significant role. The share of airborne particles in the form of dust was 1.8 MPC. The study of air quality using the Air quality index (AQI) equal to 4 characterised it as a low level; Standard Index (SI=7.6) indicated a high level of pollution; and the assessment based on Maximum Repeatability (MR=9%) demonstrated an elevated level [14, 15]. Despite various measures aimed at reducing industrial emissions, the overall quality of air according to different evaluated parameters does not show a consistently low level. This emphasises the relevance of the research based on the selected parameters and research methods.

In accordance with this, the research goal is defined as a comprehensive study of the relationship between ash content and fluctuation of morphometric parameters of woody plants` leaf blades under conditions of increased anthropogenic impact in the city of Pavlodar (one of the industrial centers of regional and national importance). According to the stated goal, the research hypothesis is determined: the increase in ash content in leaf tissue of woody plants is directly proportional to significant variation in morphometric parameters within the sample and serves as an indicator of environmental pollution.

Materials and methods

The objects of the study were leaves of some trees, which are most common near industrial facilities: *Populus balsamifera*, *Betula pendula*, *Acer negundo*. Leaf selection was carried out on the territory of seven industrial enterprises in the northern, eastern, and central industrial zones of Pavlodar (according to varying levels of technogenic load).

Considering the locations of industrial facilities, they were divided into three zones: northern (Pavlodar Oil Chemistry Refinery LLP (POCR), CHP-3), eastern (CHP-1, Pavlodar Alumina Plant (Aluminium of Kazakhstan JSC), Kazakhstan Electrolysis Plant JSC) and central (Pavlodar Machine-Building Plant JSC and Pavlodar Plant of Pipeline Fittings LLP).

Leaves were collected at the end of the growing season (from October 1 to October 7, 2023) from individual trees (at least five for each point, at a height of 1.5-2 metres) approximately of the same age. Twenty maximally healthy, well-developed, and undamaged leaves were selected from each tree. The length and width of the leaf blade were measured for each selected leaf sample, as well as the standard deviation for each parameter, reflecting the degree of dispersion of random variable values relative to their mean. To assess the significance of differences between samples, the obtained data underwent analysis of variance.

The ash content was determined by the method of dry ashing of leaves in the muffle furnace. The experiment was conducted in three replicates for each sample. Ash content was calculated using the formula [16]:

$$\text{Ash content (\%)} = \frac{m_{\text{ash (g)}} * 100}{m_{\text{dry sample(g)}}} \quad (1)$$

where:

m_{ash} – mass of ash;

$m_{dry\ sample}$ – mass of dry sample.

The mathematical processing of the obtained data was carried out in Microsoft Excel 2019.

Results and discussion

The most sensitive organisms constantly exposed to pollutants in the atmosphere are plants, where woody plants are of particular interest. The leaves of woody plants are the assimilation organs that come into contact with the atmospheric air, accumulating various pollutants (which enter from the atmosphere) on the surface and in their tissues. The influence of these pollutants begins after interacting with plant organs and often being absorbed by leaf blades [17]. Toxic substances can accumulate in photosynthetic organs during the process of performing their assimilation role by absorbing toxicants from the surrounding environment [18].

Different levels of technogenic impact affect the development of foliar organs, which is reflected in the formation of their morphometric parameters [19, 20]. Table 1 presents the main morphometric parameters of leaf blades of woody plants under industrial conditions in Pavlodar city.

Table 1 – Main morphometric parameters of woody plants` leaf blades under industrial conditions in Pavlodar city

Type of tree	Morphometric parameter	Pavlodar Oil Chemistry Refinery LLP (POCR), CHP-3	Kazakhstan Electrolysis Plant JSC	Pavlodar Machine-Building Plant JSC, Pavlodar Plant of Pipeline Fittings LLP	CHP-1	Pavlodar Alumina Plant (Aluminium of Kazakhstan JSC)
Populus balsamifera	length, cm	8,20±1,91	7,38±1,92	7,78±0,91	7,74±0,63	8,40±1,24
	width, cm	8,12±0,76	4,34±0,9	6,74±1,56	5,64±0,48	7,78±1,20
	standard deviation, σ					
Betula pendula	length, cm	5,36±0,55	5,38±0,28	6,20±0,64	5,36±0,87	6,62±0,66
	width, cm	4,38±0,65	4,60±0,63	4,80±0,63	4,56±0,66	5,66±0,41
	standard deviation, σ					
Acer negundo	length, cm	7,60±0,53	7,82±1,63	8,76±0,72	7,48±0,72	6,42±1,12
	width, cm	4,6±0,56	3,68±0,60	5,00±1,28	3,86±0,57	3,38±0,35
	standard deviation, σ					
Note: standard deviation parameters of length are represented in the numerator, and width – in the denominator						

The data presented in Table 1 indicates that the length parameters of poplar leaf blades exhibit dominant values in samples collected in the northern and eastern parts of the industrial zone (near the Pavlodar Alumina Plant). The central industrial zone and CHP-1 show slightly lower values for leaf blade parameters, which may be attributed to the emissions from these facilities and the cumulative impact of neighbouring stationary sources due to air mass migration. The reduction in leaf parameters of trees

growing near the Kazakhstan Electrolysis Plant is explained by the mass emissions of pollutants from this facility, as well as the proximity to the Pavlodar Alumina Plant and CHP-1.

Morphometric parameters of birch and maple in the central industrial zone and areas furthest from the city's stationary sources (Pavlodar Oil Chemistry Refinery, CHP-3 and Kazakhstan Electrolysis Plant) exhibited similar variability. Overall, parameters within the same species fluctuated insignificantly, but more developed foliar organs were found within the boundaries of the Pavlodar Machine-Building Plant and Pavlodar Plant of Pipeline Fittings, which may be due to lower environmental impact from these facilities and smaller production volumes compared to the industrial giants in Pavlodar (Pavlodar Oil Chemistry Refinery and Kazakhstan Electrolysis Plant). Similar trends were observed for leaf width parameters in the studied areas, except for maple growing near the Electrolysis Plant (average leaf width was 20% smaller compared to samples from the Pavlodar Oil Chemistry Refinery, CHP-3, and more than 25% smaller than those from the central industrial zone), which can be attributed to weaker leaf blade development influenced by abiotic conditions and significant atmospheric pollution.

The length and width parameters of birch and maple samples from CHP-1 and Pavlodar Alumina Plant showed an inversely proportional relationship. The difference between similar leaf blade parameters of birch samples collected near the Pavlodar Alumina Plant and CHP-1 was 20% in favour of the former. The investigated parameters of maple in these territories prevailed by approximately 15% in samples from CHP-1 compared to those from the Pavlodar Alumina Plant.

The analysis of the standard deviation of length and width for assimilation organs demonstrated significant fluctuations in length within the sample of *Populus balsamifera* from territories of the Pavlodar Oil Chemistry Refinery, CHP-3, Kazakhstan Electrolysis Plant, and Pavlodar Alumina Plant (ranging from 1.00 to 1.55). Considerable variation in width was observed for Alumina Plant, Machine-Building Plant and Plant of Pipeline Fittings samples (ranging from 0.97 to 1.26). This indicates a substantial dependence of leaf blade parameters on the degree of technogenic load. Moreover, a difference in standard deviation of 0.03 was observed between leaf blade parameters of samples from the Alumina Plant, indicating relatively unstable morphometric indicators within the obtained samples. This suggests that the emissions from this plant manifest in a more significant variation of these two main parameters within the sample. Significant fluctuations with a similar tendency are characteristic of *Acer negundo* samples collected near the Electrolysis and Alumina Plants (length parameters) and in the central industrial zone (width parameters). The variation in these parameters indicates that emissions from the Electrolysis and Alumina Plants primarily affect the length of *Acer negundo* leaf blades, while pollutants released into the atmosphere by facilities in the central industrial zone impact the width parameters of this plant species. *Betula pendula* showed a minor range of variations in morphometric parameters compared to each other, which may be related to the physiological characteristics of leaf blades and a low susceptibility to pollutants.

Therefore, the results of morphometric analysis indicate that the main fluctuations in parameters are characteristic of *Populus balsamifera*, which may be a result of strong technogenic impact, as well as the predisposition of this tree species to accumulate chemical elements. In other cases, significant roles may also be played by some other abiotic factors.

The assessment of the reliability of differences between morphometric parameters of woody plants` leaf blades near sources of anthropogenic emissions in industrial zones was carried out based on the results of dispersion analysis presented in Table 2 and Figure 1. To ensure the objectivity of the relationship between indicators and location of plants, the results are territorially distributed by zones.

The obtained results of analysis of dispersion complexes, including the length and width of leaf organs, demonstrate an excess of the F-criterion value for the length parameter of *Betula pendula* in three industrial zones compared to the F-critical. A similar situation was observed for the F-criterion of the leaf blade`s width of *Populus balsamifera* in the northern and eastern industrial zones. The degree of technogenic load is clearly reflected within the eastern industrial zone for all parameters and tree species, except for the length of the leaf blade of *Populus balsamifera*. The overall assessment of indicators across all industrial enterprises demonstrated a statistically significant difference in parameters of the studied assimilation organs under the influence of technogenic pollutants in various magnitudes. This confirms that this criterion objectively determines the influence of atmospheric pollution on the formation of morphometric characteristics of leaf blades, which can be used in practice as an objective method of indication.

The average indicators for leaf blade ash content are presented in Table 3 and in Figure 2 (the distribution of indicators is indicated from Pavlodar Oil Chemistry Refinery to Pavlodar Oil Chemistry Refinery according to the sequence in Table 3).

Table 2 – Results of dispersion analysis of averaged parameters of foliar organs` length and width (three industrial zones of Pavlodar)

Plant species under study	Fisher–Snedecor test		
	Length	Width	$F_{crit.}$ ($p \leq 0,05$)
Northern industrial zone			
Populus balsamifera	0,77	4,76	$f_{crit.}$ (1;18)=4,41
Betula pendula	7,47	0,21	$f_{crit.}$ (1;26)=4,22
Acer negundo	0,32	2,39	$f_{crit.}$ (1;26)=4,22
Eastern industrial zone			
Populus balsamifera	2,26	61,57	$f_{crit.}$ (2;27)=3,35
Betula pendula	25,55	21,59	$f_{crit.}$ (2;24)=3,40
Acer negundo	5,67	3,60	$f_{crit.}$ (2;33)=3,27
Central industrial zone			
Populus balsamifera	0,06	0,23	$f_{crit.}$ (1;20)=4,35
Betula pendula	6	0,72	$f_{crit.}$ (1;18)=4,41
Acer negundo	3,97	0,16	$f_{crit.}$ (1;18)=4,41
General indicators for three industrial zones			
Populus balsamifera	0,61	16,88	$f_{crit.}$=2,87
Betula pendula	7,15	5,29	
Acer negundo	5,15	5,86	

Note: when $f_{exp} < f_{critical}$, group mean values of the sample differ insignificantly (marked in green); when $f_{exp} > f_{critical}$ – they differ significantly (marked in blue).

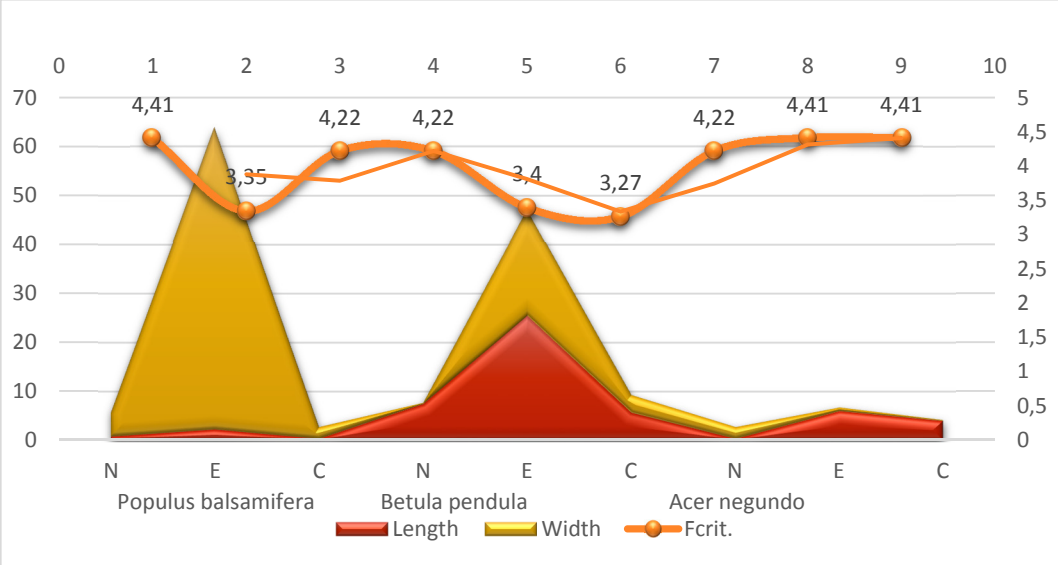

Figure 1 – Distribution of Fisher's criterion values for morphometric parameters of foliar organs of woody plants in three industrial zones of Pavlodar city (N – Northern industrial zone, E – Eastern industrial zone, C – Central industrial zone)

Table 3 – Average ash content indicators of leaf blades of trees in industrial zones of Pavlodar (average results for three replicates), %

Type of tree	Industrial plants					Average by type of woody plant
	Pavlodar Oil Chemistry Refinery LLP (POCR), CHP-3	Kazakhstan Electrolysis Plant JSC	Pavlodar Machine-Building Plant JSC, Pavlodar Plant of Pipeline Fittings LLP	CHP-1	Pavlodar Alumina Plant (Aluminium of Kazakhstan JSC)	
Populus balsamifera	10,01	13,80	16,09	14,85	16,00	14,1
Betula pendula	7,32	6,74	9,48	6,47	10,90	8,2
Acer negundo	14,45	15,78	12,62	15,69	19,10	15,5
Enterprise average	10,6	12,1	12,7	12,3	15,3	12,6

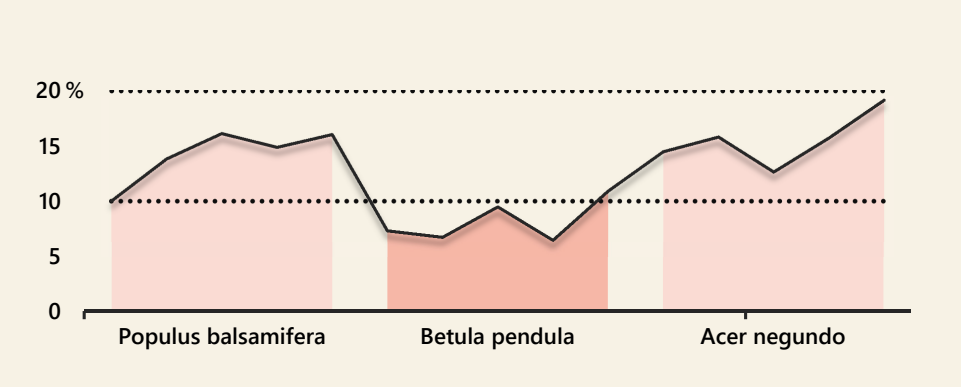

Figure 2 – Average ash content of trees` leaf blades in industrial zones of Pavlodar (in 3 replicates), %

According to the obtained data, it has been revealed that the ash content of *Populus balsamifera* and *Acer negundo* is higher compared to *Betula pendula* in all selected samples, regardless of the industrial plant`s location, which is confirmed by the research of other scientists [2, 21-22]. Meanwhile, the ash content of birch in all territories was below 10%, except for the Pavlodar Alumina Plant area (10.90%). The ash content of poplar and maple samples did not decrease below 10%. The maximum level of mineral residue was observed in leaf samples of trees growing within the Alumina Plant area. High levels of mineral accumulation are also characteristic of poplar and birch growing near the central industrial zone plants. Other ash content indicators varied depending on the sampling point and the species of the studied tree.

The study of average ash content by tree species and industrial plants allowed us to establish that the maximum level of ash content is characteristic of maple (15.5%), while the mineral residue of birch samples was almost half as much (8.2%) compared to poplar. At the same time, the ash content of poplar did not vary significantly compared to maple and was 1.4% lower. The highest indicators of technogenic load were characteristic of the Alumina Plant, with an average ash content value for all studied tree samples of 15.3%. The minimum average indicators were associated with Pavlodar Oil Chemistry Refinery and CHP-3 (10.6%). The results obtained for the central industrial zone plants and the eastern industrial zone (excluding the Pavlodar Alumina Plant) ranged from 12.1% to 12.7% from southeast to northwest of the city. Overall, the total average ash content for all samples of the studied trees and all industrial plants was 12.6%.

It should be noted that the increase in ash content indicators correlates positively with a wide range of variation in morphometric parameters, manifested in the predominance of the Fisher's criterion value over the F-critical value. This demonstrates the reliability of the determined ash content indicators and their direct relationship with the parameters of the studied phytocomplex (in the course of investigating atmospheric pollution), as well as the possibility of using these indicators in assessing the degree of technogenic pollution.

Conclusion

Modern conditions of man-made loads, particularly in an industrial region of the country, require diverse approaches to assessing the degree of air pollution and the environment as a whole. One of the most obvious factors showing the consequences of industrial load on the environment can be the indicators of growth and development of woody plants, where the objective result of a specific vegetation period is the parameters of foliar organs` development.

A study of the morphometric parameters of leaf blades of three woody plant species and the proportion of mineral content (ash content) in them revealed that a significant level of influence from man-made emissions leads to fluctuations in the length and width of leaves over a wide range, sometimes with suppression of the development of these parameters. It was found that the highest degree of air pollution is characteristic of the Pavlodar Alumina Plant, which is reflected in a significant range of variation in morphometric indicators within the sample and relatively small differences in the case of each individual sample. The average ash content indicators for the central and eastern industrial zone factories (excluding the Alumina Plant) varied between 12.1% and 12.7% from the southeast to the northwest of the city. The minimum average indicators were recorded in samples taken from the Pavlodar Oil Chemistry Refinery, CHP-3 (10.6%). The highest level of deposition of mineral substances in tissues is characteristic of *Populus balsamifera* and *Acer negundo* (all zones). The results demonstrate a positive correlation between a wide range of fluctuations in morphometric parameters and an increase in ash content in the corresponding samples, which may be a manifestation of further consequences inhibiting the development of the entire woody plant as a whole.

Conflict of interest

The author declares no conflict of interest.

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References

1. Есенжолова А.Ж., Панин М.С. Листья древесных и кустарниковых растений как биоиндикаторы загрязнения города Темиртау свинцом и цинком // Материалы VII международной научной конференции молодых ученых «наука и образование – 2011» II часть. Астана, Евразийский национальный университет им. Л.Н. Гумилева. – 2011. – С. 208-210.

2. Ишимова А.Е. Зольность листьев, хвои и коры древесных растений как индикаторный признак загрязнения воздушного бассейна г. Семей // Труды XVI Международного симпозиума имени академика М.А. Усова студентов и молодых ученых, посвященного 110-летию со дня основания горно-геологического образования в Сибири. – 2012. – С. 547-549.

3. Fedorova D.G., Ukenov B.S. Fluctuating asymmetry of leaves of mountain ash (Sorbus aucuparia l.) as a bioindicator of aerotechnogenic pollution of the city of Orenburg // Vestnik of Immanuel Kant Baltic Federal University Series Natural and Medical Sciences. –2023. – No 4. – P. 103–114. https://doi.org/10.5922/gikbfu-2023-4-8

4. Islam F., Yasmeen T., Ali Q., Ali S., Arif M.S., Hussain S., et al. Influence of Pseudomonas aeruginosa as PGPR on oxidative stress tolerance in wheat under Zn stress // Ecotoxicol Environ. Saf. – 2014. – No 104. – C. 285-293. https://doi.org/10.1016/j.ecoenv.2014.03.008

5. Ahammed G.J., Wu M.-J., Wang Y.-Q., Yan Y.-R., Mao Q. Ren J.-J., et al. Melatonin alleviates iron stress by improving iron homeostasis, antioxidant defense and secondary metabolism in cucumber // Sci. Hortic. – 2020. – No 265. – P. 109–205. https://doi.org/10.1016/j.scienta.2020.109205

6. Genchi G., Sinicropi M.S., Lauria G., Carocci A., Catalano A. The effects of cadmium toxicity // International Journal of Environmental Research and Public Health. – 2020. – No 17 (11). – P. 3782. https://doi.org/10.3390/ijerph17113782

7. Guo Z.-L., Gao Y.-H., Yuan X.-Q., Yuan M.-X., Huang L., Wang S.-C., et al. Effects of heavy metals on stomata in plants: A review // Int. J. Mol. Sci. – 2023. – No 24 (11). – P. 9302. https://doi.org/10.3390/ijms24119302

8. Rahman S.U., Nawaz M.F., Gul S., Yasin G., Hussain B., Li Y.-L., et al. State-of-the-art OMICS strategies against toxic effects of heavy metals in plants: A review // Ecotoxicol Environ. Saf. – 2022. – No 242. – P. 113952. https://doi.org/10.1016/j.ecoenv.2022.113952

9. Clemens S. Toxic metal accumulation, responses to exposure and mechanisms of tolerance in plants // Biochimie. – 2006. https://doi.org/10.1016/j.biochi.2006.07.003

10. Nowak D.J., Crane D.E., Stevens J.C. Air pollution removal by urban trees and shrubs in the United States // Urban Forestry and Urban Greening. – 2006. – No 4(3-4). – P. 115–123. https://doi.org/10.1016/j.ufug.2006.01.007

11. Zakharov V.M., Trofimov I.E. Fluctuating asymmetry as an indicator of stress // Emerg. Top. Life Sci. – 2022. – No 6 (3). –P. 295 – 301. https://doi.org/10.1042/ETLS20210274

12. Mendes G., Boaventura M.G., Cornelissen T. Fluctuating Asymmetry as a Bioindicator of Environmental Stress Caused by Pollution in a Pioneer Plant Species. // Environ Entomol. – 2018. – No 47 (6). – P. 1479 – 1484. https://doi.org/10.1093/ee/nvy147

13. Национальный доклад о состоянии окружающей среды и об использовании природных ресурсов Республики Казахстан за 2022 год [Электронный ресурс]. – Режим доступа: https://ecogosfond.kz/wp-content/uploads/2023/12/NDSOS-2022-RUS-gotov1-1.pdf

14. Информационный бюллетень о состоянии окружающей среды по Павлодарской области. 2023 год [Электронный ресурс]. – Режим доступа: https://www.kazhydromet.kz/ru/ecology/ezhemesyachnyy-informacionnyy-byulleten-o-sostoyanii-okruzhayuschey-sredy/2023

15. Информационный бюллетень о состоянии окружающей среды по Павлодарской области. 2022 год [Электронный ресурс]. – Режим доступа: https://www.kazhydromet.kz/ru/ecology/ezhemesyachnyy-informacionnyy-byulleten-o-sostoyanii-okruzhayuschey-sredy/2022

16. Федорова А.И. Практикум по экологии и охране окружающей среды. – М.: Гуманит. Изд. Центр ВЛАДОС, 2001. – 288 с.

17. Fuhrer J., Bungener P. Effects of air pollutants on plants // Analusis. John Wiley and Sons Inc. – 1999. – No ¬ 27(4). – P. 355–362. https://doi.org/10.1051/analusis:1999270355

18. Hrygorchuk I., Optasyuk O., Lyubinska L., Plakhtiy P. Analysis of phytoindication properties of Robinia pseudoacacia l. in the conditions of kamyanets-podilsky // Biology & ecology. – 2022. – №7. – P. 68–75. https://doi.org/10.33989/2021.7.2.261550

19. Neposhyvailenko N., Hrytsan Y., Petryk Y., Huba O. Application of fluctuating asymmetry methods for environmental monitoring in Kamianske // Collection of Scholarly Papers of Dniprovsk State Technical University (Technical Sciences). – 2023. – No 2(43). – P. 155–169. https://doi.org/10.31319/2519-2884.43.2023.17

20. Salt D.E., Blaylock M., Kumar N.P.B.A., Dushenkov V., Ensley B.D., Chet I., Raskin I. Phytoremediation: A novel strategy for the removal of toxic metals from the environment using plants // Nature Biotechnology. – 1995. – No 13(5). – P. 468–474. https://doi.org/10.1038/nbt0595-468

21. Terekhina N.V., Ufimtseva M.D. Leaves of trees and shrubs as bioindicators of air pollution by particulate matter in Saint Petersburg // Geography, Environment, Sustainability. – 2020. – No 13(1). – P. 224–232. https://doi.org/10.24057/2071-9388-2019-65

22. Hrotkó K., Gyeviki M., Sütöriné D.M., Magyar L., Mészáros R., Honfi P., Kardos L. Foliar dust and heavy metal deposit on leaves of urban trees in Budapest (Hungary) // Environmental Geochemistry and Health. – 2021. – No 43(5). – P. 1927–1940. https://doi.org/10.1007/s10653-020-00769-y

23. Tsagaan B., Ganbaatar O., Darizav T., Byambaa, K. Content and distribution of some chemical elements in the poplar leaves (Populus laurifolia) in Ulaanbaatar // Proceedings of the Mongolian Academy of Sciences. – 2020. – P. 18–27. https://doi.org/10.5564/pmas.v60i4.1502

24. Hrdlička P., Kula E. Changes in element content of birch leaves (Betula Pendula Roth) in polluted air // Polish Journal of Environmental Studies. – 2011. – No 20(3). – P. 661–670.

25. Gololobova A., Legostaeva Y. An Assessment of the Impact of the Mining Industry on Soil and Plant Contamination by Potentially Toxic Elements in Boreal Forests // Forests. – 2023. – No 14(8). https://doi.org/10.3390/f14081641

References

1. Ahammed G.J., Wu M.-J., Wang Y.-Q., Yan Y.-R., Mao Q. Ren J.-J., et al. (2020) Melatonin alleviates iron stress by improving iron homeostasis, antioxidant defense and secondary metabolism in cucumber. Sci. Hortic., no. 265, pp. 109205. https://doi.org/10.1016/j.scienta.2020.109205

2. Clemens S. (2006) Toxic metal accumulation, responses to exposure and mechanisms of tolerance in plants. Biochimie. https://doi.org/10.1016/j.biochi.2006.07.003

3. Esenzholova A.Zh., Panin M.S. (2011) List'ya drevesnykh i kustarnikovykh rasteniy kak bioindikatory zagryazneniya goroda Temirtau svintsom i tsinkom [Leaves of trees and shrubs as bioindicators of lead and zinc pollution in the city of Temirtau]. Materialy VII mezhdunarodnoy nauchnoy konferentsii molodykh uchenykh «nauka i obrazovaniye – 2011» II chast'. Astana, Eurasian National University. L.N. Gumilyov, pp. 208-210.

4. Fedorova A.I., Nikol'skaya A.N. (2001) Praktikum po ekologii i okhrane okruzhayushchey sredy [Workshop on ecology and environmental protection]. M., Humanit. Ed. VLADOS Center, 288 p.

5. Fedorova D.G., Ukenov B.S. (2014) Fluctuating asymmetry of leaves of mountain ash (sorbus aucuparia l.) as a bioindicator of aerotechnogenic pollution of the city of Orenburg. Vestnik of Immanuel Kant Baltic Federal University Series Natural and Medical Sciences, no. 4, pp. 103-114. https://doi.org/10.5922/gikbfu-2023-4-8

6. Fuhrer J., Bungener P. (1999) Effects of air pollutants on plants. Analusis. John Wiley and Sons Inc., no. 27(4), pp. 355–362. https://doi.org/10.1051/analusis:1999270355

7. Genchi G., Sinicropi M.S., Lauria G., Carocci A., Catalano A. (2020) The effects of cadmium toxicity. International Journal of Environmental Research and Public Health, no. 17(11), pp. 3782. https://doi.org/10.3390/ijerph17113782

8. Gololobova A., Legostaeva Y. (2023). An Assessment of the Impact of the Mining Industry on Soil and Plant Contamination by Potentially Toxic Elements in Boreal Forests. Forests, pp. 14(8). https://doi.org/10.3390/f14081641

9. Guo Z.-L., Gao Y.-H., Yuan X.-Q., Yuan M.-X., Huang L., Wang S.-C., et al. (2023) Effects of heavy metals on stomata in plants: A review. Int. J. Mol. Sci., no. 24 (11), pp. 9302. https://doi.org/10.3390/ijms24119302

10. Hrdlička P., Kula E. (2011). Changes in element content of birch leaves (Betula Pendula Roth) in polluted air. Polish Journal of Environmental Studies, no. 20(3), pp. 661–670.

11. Hrotkó K., Gyeviki M., Sütöriné D.M., Magyar L., Mészáros R., Honfi P., Kardos L. (2021) Foliar dust and heavy metal deposit on leaves of urban trees in Budapest (Hungary). Environmental Geochemistry and Health, no. 43(5), pp. 1927–1940. https://doi.org/10.1007/s10653-020-00769-y

12. Hrygorchuk I., Optasyuk O., Lyubinska L., Plakhtiy P. (2022). Analysis of phytoindication properties of Robinia pseudoacacia l. in the conditions of kamyanets-podilsky. Biology & ecology, no. 7, pp. 68–75. https://doi.org/10.33989/2021.7.2.261550

13. Informatsionnyy byulleten' o sostoyanii okruzhayushchey sredy po Pavlodarskoy oblasti. 2023 god [Information bulletin on the state of the environment in the Pavlodar region. 2023] [Electronic resource]. URL: https://www.kazhydromet.kz/ru/ecology/ezhemesyachnyy-informacionnyy-byulleten-o-sostoyanii-okruzhayuschey-sredy/2023

14. Informatsionnyy byulleten' o sostoyanii okruzhayushchey sredy po Pavlodarskoy oblasti. 2022 god [Information bulletin on the state of the environment in the Pavlodar region. 2022] [Electronic resource]. URL: https://www.kazhydromet.kz/ru/ecology/ezhemesyachnyy-informacionnyy-byulleten-o-sostoyanii-okruzhayuschey-sredy/2022

15. Ishimova A.E. (2012) Zol'nost' list'yev, khvoi i kory drevesnykh rasteniy kak indikatornyy priznak zagryazneniya vozdushnogo basseyna g. Semey [Ash content of leaves, needles and bark of woody plants as an indicator of air pollution in Semey]. Trudy XVI Mezhdunarodnogo simpoziuma imeni akademika M.A. Usova studentov i molodykh uchenykh, posvyashchennogo 110-letiyu so dnya osnovaniya gorno-geologicheskogo obrazovaniya v Sibiri, pp. 547-549.

16. Islam F., Yasmeen T., Ali Q., Ali S., Arif M. S., Hussain S., et al. (2014) Influence of Pseudomonas aeruginosa as PGPR on oxidative stress tolerance in wheat under Zn stress. Ecotoxicol Environ. Saf., no. 104, pp. 285-293. https://doi.org/10.1016/j.ecoenv.2014.03.008

17. Mendes G., Boaventura M.G., Cornelissen T. (2018) Fluctuating Asymmetry as a Bioindicator of Environmental Stress Caused by Pollution in a Pioneer Plant Species. Environ Entomol., no. 47 (6), pp. 1479–1484. https://doi.org/10.1093/ee/nvy147

18. Natsional'nyy doklad o sostoyanii okruzhayushchey sredy i ob ispol'zovanii prirodnykh resursov Respubliki Kazakhstan za 2022 god [National report on the state of the environment and the use of natural resources of the Republic of Kazakhstan for 2022] [Electronic resource]. URL: https://ecogosfond.kz/wp-content/uploads/2023/12/NDSOS-2022-RUS-gotov1-1.pdf

19. Neposhyvailenko N., Hrytsan Y., Petryk Y., Huba O. (2023) Application of fluctuating asymmetry methods for environmental monitoring in Kamianske. Collection of Scholarly Papers of Dniprovsk State Technical University (Technical Sciences), no. 2(43), pp. 155–169. https://doi.org/10.31319/2519-2884.43.2023.17

20. Nowak D.J., Crane D.E., Stevens J.C. (2006) Air pollution removal by urban trees and shrubs in the United States. Urban Forestry and Urban Greening, no. 4(3-4), pp. 115–123. https://doi.org/10.1016/j.ufug.2006.01.007

21. Rahman S.U., Nawaz M.F., Gul S., Yasin G., Hussain B., Li Y.-L., et al. (2022) State-of-the-art OMICS strategies against toxic effects of heavy metals in plants: A review. Ecotoxicol Environ. Saf., no. 242, pp. 113952. https://doi.org/10.1016/j.ecoenv.2022.113952

22. Salt D.E., Blaylock M., Kumar N.P.B.A., Dushenkov V., Ensley B.D., Chet I., Raskin I. (1995) Phytoremediation: A novel strategy for the removal of toxic metals from the environment using plants. Nature Biotechnology, no. 13(5), pp. 468–474. https://doi.org/10.1038/nbt0595-468

23. Terekhina N.V., Ufimtseva M.D. (2020) Leaves of trees and shrubs as bioindicators of air pollution by particulate matter in Saint Petersburg. Geography, Environment, Sustainability, no. 13(1), pp. 224–232. https://doi.org/10.24057/2071-9388-2019-65

24. Tsagaan B., Ganbaatar O., Darizav T., Byambaa K. (2020). Content and distribution of some chemical elements in the poplar leaves (Populus laurifolia) in Ulaanbaatar. Proceedings of the Mongolian Academy of Sciences, pp. 18–27. https://doi.org/10.5564/pmas.v60i4.1502

25. Zakharov V.M., Trofimov I.E. (2022) Fluctuating asymmetry as an indicator of stress // Emerg. Top. Life Sci., no. 6 (3), pp. 295–301. https://doi.org/10.1042/ETLS20210274

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