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Age periods of development of protective forest stands in the restoration of eroded ravine-gully lands

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Abstract. Currently, great attention is paid to the role, importance, optimal use of soils, their protection, and combating degradation. By adopting the Sustainable Development Goals at the national level, Ukraine is obliged to implement new programmes and projects that will guarantee macroeconomic stability, environmental balance, and social cohesion in practice. In the course of the studies of the multifunctional role of protective forest stands, which at one time were created in eroded territories, which include ravine-gully lands, to revive the properties of soils, a study was conducted to justify their restoration function. 90 soil and lysotypological points were laid in anti-erosion plantings of different periods of plant growth and development with the selection of 270 soil samples to fulfil this goal. Their water-physical and agrochemical properties were investigated with the processing of the obtained data by statistical methods. Based on the analysis of scientific literature sources, the examination of successful production experience and the conducted research of anti-erosion plantings to determine their impact on soil properties and the environment, qualitative stages of ecological restoration of eroded soils were developed. Changes in the age periods of growth and development of woody plants in protective forest stands created on ravine-gully lands lead to a gradual ecological restoration of eroded soils. A clear correlation between the age periods of growth and development of woody plants with qualitative stages of ecological restoration of eroded soils was obtained. The selection of research objects provided for considering the same technology for creating anti-erosion plantings, growth, and development in the same conditions, which would correspond to five age periods of growth and development of woody plants. In each age period, qualitative changes occur during the growth and development of vegetation cover, and quantitative changes in indicators that characterise the properties of the soil are presented in comparison with the control that was selected to be a pasture. The main functions of these plantings are given. All age periods of growth and development of anti-erosion plantings in terms of conducting forestry measures for the successful cultivation of anti-erosion plantings and their effective action were considered. The stages of ecological restoration of eroded territories are clearly coordinated with the selected age periods. Prospects for understanding the process of restoring protective vegetation cover, in particular, forest stands, and their direct impact on the properties of eroded soils open up

Keywords: erosion processes, eroded soils, anti-erosion role, development periods, qualitative stages, soil properties, hydraulic roughness

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Introduction

Currently, the role, importance, and optimal use of soils, their protection, and control of degradation are given great attention (Pdivinen et al., 1994; Manual on methods and criteria, 1994; Lund, 1998; ISO/TR 14061, 1998; Mayer, 2003; Johnson, 2004; Duran Zuazo & Pleguezuelo, 2008; Prescott, Katsensteiner & Weston, 2021). According to experts from international organisations, 47.5% of the Earth's land is degraded land. As of 2015, Ukraine had a total area of degraded land of 148.14 km² (25.57%). At the 2015 UN Summit on Sustainable Development, a common vision of new guidelines for the development of a planetary society until 2030 (Let's save the soil) was presented. Ukraine must implement new programmes and projects that in practice guarantee macroeconomic stability, environmental balance (On the National programme, 2000), and social cohesion to achieve Sustainable Development Goals at the national level. Thus, ensuring the rational use, protection, and improvement of the natural environment, in particular, the properties of eroded soils, is relevant.

Grandiose work on the creation of anti-erosion plantings in Ukraine was conducted in the 60s of the 20th century. A comprehensive study of their impact on the restoration of the properties of eroded ravine-gully lands began in 1980. According to the results of research work of the Department of Forests Restoration and Melioration of the National University of Life and Environmental Sciences of Ukraine, qualitative stages of ecological restoration of eroded territories were proposed to establish the sequence of elimination of the consequences of water erosion processes on ravine-gully lands (Maliuha, 1987, 2008). The ecological restoration was conducted through the use of anti-erosion forest stands.

The entire life cycle of forests consists of a consistent combination of certain phases of growth and development. Therewith, the temporary state of the forest is reflected in the corresponding stages. Thus, the phase of growth and development of forest crops is a certain qualitative and quantitative state during a certain period of life. N.P. Kobranov is rightly considered the founder of the theory of growth and development phases, and subsequent research in this area was continued by V.V. Ogievsky, A.A. Khiron, P.R. Talman, M.E. Tkachenko, P.V. Voroponov, L.N. Hribanov, V.G. Atrokhin, A.A. Kairukshtis, A.I. Yuodvalkis, and others (Merzlenko & Babich, 2020). Various interpretations were obtained, but the goal of all was to promote the implementation of economic measures necessary to optimise the growth of plantings (reafforestation): the addition and evaluation of crops, the regulation of living conditions through the use of treatment logging, etc.

M.A. Lokhmatov (1985) considers such periods of development of protective forest stands on ravine-gully lands: 1 – formation, 2 – active development and interaction of tiers, 3 – relatively stable structure and mutual influence of storeys, 4 – weakening of vital activity of plantings, their ageing, degradation, and decay of stands in the context of assessing their condition (Lokhmatov, 1999). A similar distribution by stage of development is provided by (Johnson, 2004).

Recently, various researchers have paid a lot of attention to this issue (Duran Zuazo & Pleguezuelo, 2008; Prescott, Katsensteiner & Weston, 2021; Johnson, 2004; Yukhnovsky, Dudarets, Maliuha & Khryk, 2013). A study of certain aspects of land reclamation properties of the park stands in difficult terrain conditions was conducted (Minder, Maliuha & Yukhnovsky, 2019). Unfortunately, the studies of ravine-gully lands are insufficient.

The purpose of this study is to investigate the anti-erosion role of forest stands by their age periods of development in the conditions of ravine-gully lands. The eroded land consists of 4.5 million hectares with medium and heavily washed-out soils, in particular, 68 thousand hectares have completely lost the humus horizon. Prospects for understanding the process of restoring protective vegetation cover, in particular, forest stands, and their direct impact on the properties of eroded soils open up.

Materials and Methods

The main volume of research work has been conducted in the forest-steppe zone for ten years. The study was conducted on the territory of two former hydromeliorative forest stations – Kanivska (1958) and Rzhyshevskivska (1964), created to eliminate the consequences of water erosion by hydraulic and forest reclamation methods in the protective zone of the Dnipro river. Protective forest stands on eroded ravine-gully lands were chosen as the objects of research.

The objects that had the same creation technology, grew and developed under the same conditions, and corresponded to five age periods of growth and development of woody plants were selected. The pasture was selected as the control.

90 soil lysotypological sites were laid with the selection of 270 soil samples by the selector (Maliuha, Dudarets, Yukhnovsky & Harkava, 2006; Maliuha et al., 2014).

Since the destruction of the soil occurs by concentrated surface runoff, indicators that characterise its structure, hardness, and water permeability were selected to assess changes in the anti-erosion properties. Structural analysis of the soil was determined by the Savvinov method

(Astapov, 1958) by dry sieving of a soil sample weighing up to 1.0 kg on a sieve column from 10 to 0.25 mm. The soil hardness was determined by the Golubev device in 30-fold repetition. The soil hardness M.A. Kaczynski scale was used (Berezhniak, 2013; Zrazhevsky & Lohvynenko, 1971). Determination of soil water permeability was conducted using steel cylinders with a diameter of 80 mm and a height of 100 mm, which are sharpened in the lower part for easy installation in the soil. The study was performed from the surface of a 10-centimetre layer of soil. The lower cylinders were half buried in the soil, and the upper 50 mm were filled with water. A column of water with a height of 50 mm conventionally corresponds to the water level during the passage of a heavy downpour. The stopwatch determined the time of water absorption in a 10-time repetition.

The assessment of changes in the fertility of eroded soils was conducted by agrochemical indicators of

the 1 metre of soil. The content of agrochemical indicators was obtained by the following methods: easily hydrolysed nitrogen, mg/kg of soil – Tiurin-Kononova (Workshop on agrochemistry, 2001); mobile phosphorus and exchange potassium, mg/kg of soil – Kirsanov (Workshop on agrochemistry, 2001); humus, % – Tiurin (Workshop on agrochemistry, 2001). Based on the results obtained, considering the density of soil composition, nutrient reserves of a 1-meter thickness were calculated.

Statistical data processing was conducted using graphoanalytical, correlation, and regression analysis using the Excel and Statistica programmes.

Results and Discussion

Changes in the age periods of growth and development of woody plants in protective forest stands created on ravine-gully lands lead to a gradual ecological restoration of eroded soils, which is reflected in Table 1.

Table 1. Correlation of age periods of growth and development of woody plants with qualitative stages of ecological restoration of eroded soils

Age periods, years	Content of age periods of growth and development of woody plants of protective forest stands	Stages restoration	Content of qualitative stages ecological restoration eroded soils
up to 7	Engraftment and closure of forest crops	I	Beginning of impact on eroded soils, slowing down and sharply reducing erosion processes
8-15	Forming a forest tent of plantings	II	Stopping soil erosion, strengthening their biological processes
16-30	Intensive differentiation of woody plant species	III	Substantial improvement of the physical and chemical properties of soils, complete cessation of erosion processes
31-60	Formation of the forest biogeocenosis	IV	Ecological restoration of eroded growing conditions and creation of prerequisites for the return of such lands to economic circulation
Over 60	Effective action of the first generation of forest stands	V	Full return of land after rehabilitation to full-fledged economic circulation

In the first age period of life (up to 7 years of age), forest crops that are created on eroded lands take root. Success in the field of protective afforestation depends on the quality of implementation of the technology for creating forest reclamation stands.

In the first age period, protective forest stands do not show a statistically substantial effect on soil properties compared to the control (Table 2). During this period of growth and development of woody plants of anti-erosion plantings, there are representatives of living grass

aboveground cover, mainly steppe or meadow species. On the one hand, herbaceous plants serve as important components of the natural protective vegetation cover, which counteract the intensive development of erosion

processes, on the other hand, they create quite powerful competitive conditions for the engraftment of protective forest stands. Their number during this period is 100-300 pcs.*m².

Table 2. Indicators of restoration of properties of the upper 10-centimetre soil layer under the influence of forest stands and invertebrates

Plantings of up to 7 years of age	Hardness, kg*cm ⁻²	Water permeability, mm*min ⁻¹	Structural particles >1 mm, %
	$\chi \pm m$		
Pure oak trees	19.3 ± 0.4	6.5 ± 0.4	27.8 ± 1.0
Control	20.4 ± 0.3	6.0 ± 0.5	24.5 ± 0.7
Mixed oak trees	19.1 ± 1.0	7.0 ± 0.7	32.1 ± 1.2
Control	20.1 ± 0.4	3.9 ± 0.4	28.6 ± 1.1
Pure pine trees	18.7 ± 1.2	6.5 ± 1.9	34.4 ± 3.6
Control	19.0 ± 0.6	6.3 ± 0.3	26.6 ± 0.6
Mixed pine trees	19.0 ± 0.4	5.6 ± 0.9	31.0 ± 1.3
Control	20.5 ± 0.5	4.3 ± 0.4	25.8 ± 0.8

Among the representatives of grass vegetation that is intensively developing, it is necessary to name: field bindweed, narrow-leaved peas, noble yarrow, common sainfoin, chickweed, field clover, autumn hawkbit, woolly burdock, cypress spurge, common thistle, etc.

The conducted studies established that there is a certain improvement, and sometimes deterioration of some

indicators that determine the properties of the soil, in particular, its hardness, structure, and water permeability. Indicators that characterise agrochemical properties, in particular, the content and reserves of nutrients, also do not have a statistically substantial difference, since their values differ slightly from the control ones. Nutrient reserves of a metre-deep soil layer are shown in Table 3.

Table 3. Nutrient reserves of a metre-deep soil layer

Plantings of up to 7 years of age	Nutrient reserves			
	organic matter, t*ha ⁻¹	easily hydrolysed nitrogen	mobile phosphorus	exchange rate potassium
		kg*ha ⁻¹		
	$\chi \pm m$			
Pure oak trees	75 ± 4.2	274 ± 22.0	354 ± 14.6	266 ± 16.0

Table 3. Continued

Plantings of up to 7 years of age	Nutrient reserves			
	organic matter, t*ha ⁻¹	easily hydrolysed nitrogen	mobile phosphorus	exchange rate potassium
		kg*ha ⁻¹		
$\chi \pm m$				
Control	57 ± 3.5	201 ± 2.3	200 ± 17.0	239 ± 14.3
Mixed oak trees	77 ± 4.4	282 ± 13.8	348 ± 13.4	276 ± 15.5
Control	60 ± 8.8	213 ± 4.0	212 ± 4.6	238 ± 20.2
Pure pine trees	61 ± 6.1	204 ± 9.2	428 ± 13.6	585 ± 33.6
Control	68 ± 2.1	202 ± 7.5	418 ± 13.5	508 ± 19.7
Mixed pine trees	74 ± 4.2	224 ± 9.4	458 ± 24.4	564 ± 20.5
Control	75 ± 3.1	197 ± 3.0	400 ± 10.4	507 ± 23.9

The relatively weak influence of forest stands on soil properties is explained by the fact that it is extremely difficult for them to adapt to uncharacteristic and harsh growing conditions, so they face high energy costs and a substantial indicator of the intensity of living space (Maliuha & Minder, 2020). The intensity of falling off depends mainly on compliance with the technology of creating plantings, and on how well it is possible to create conditions for the engraftment of plants that are sensitive at a young age and simultaneously plastic in terms of attachment.

Plantings need help in the form of timely agrotechnical care, which gives them the opportunity to get rid of excessive competition of grass vegetation, and it is easier to overcome "stressful" situations during engraftment. A characteristic feature of the first age period in anti-erosion terms is the fact that there is no unified layer of the forest floor. Optimal density of artificially created plantings can be adjusted for the duration of their rising period.

During the second age period of growth and development of woody plants (from 8 to 15 years), a forest tent is formed. There is a complete closure of branches in rows and aisles, the soil is covered with a unified layer of litter. Grassy vegetation from plantings of dense woody plant species, when the soil illumination is up to 10% compared to an open place on sunny days, is substantially limited or does not

exist at all. It occurs only in places of a sparse wooden tent and on the edges in the amount of 0-15 pcs.*m², and in the plantings, there are only a few shade-tolerant representatives: meadow geranium, wood bluegrass, hairy sedge, narrow-leaved lungwort, hazelwort, ground elder, yellow archangel, etc.

Thus, as woody plants of protective forest stands grow and develop, due to the growth of crowns and shading of the soil, the grass cover changes. Light-demanding types of grass vegetation thin out and gradually disappear, being replaced by more adapted shade-tolerant ones.

The formation of a unified layer of litter, which limits the conditions for the intensive development of meadow grass vegetation, increases its hydraulic roughness, promotes the transfer of surface meltwater and stormwater to ground water, and preserves soil moisture. The moisture capacity of the undisturbed state of the forest floor, depending on the species composition of plantings, can reach 150-200%. Disruption of the litter condition due to the possible manifestation of surface runoff or herding of livestock substantially reduces its moisture capacity by 1.4-1.9 times. During this period, the interpenetration of root systems continues, and the development of deep soil horizons depending on the density and composition of plantings (Pasternak, Shinkarenko & Kravcova, 1974;

Orlovsky, Podzharov & Vorob'ev 1980; Maliuha, 1987; Minder, Maliuha & Yukhnovsky, 2019).

This age period is characterised by an increase in the number of soil invertebrates: worms, springtails, nematodes, and mites (Zonn, 1955; Zrazhevsky, 1957; Zrazhevsky & Lohvynenko, 1971; Gordienko, Nagornaya & Kisten', 1986), which, in addition to their main function, increase the water permeability of the soil. After litter transformation, their excrement accelerates bacterial activity (Kachinskij, 1975; Prescott, Katsensteiner & Weston, 2021). Earthworms play a special role in mixing and crushing litter with clay soil particles (Zrazhevskij, 1957; Zrazhevskiy & Lohvynenko, 1971; Kachinskij, 1975). Their excrement is much richer in phosphorus than soil:

they contain 300% more lactate-soluble phosphoric acid and 40% more nitrogen. Earthworms need well-filled air and moist soil with *pH* 5.8-8.3. Due to the tunnels dug by worms, the soil loosens. Ants also substantially affect soil loosening and mixing (Zonn, 1955; Pogrebnyak, 1955; Zrazhevsky, 1957; Zrazhevsky & Lohvynenko, 1971).

The activity of invertebrates and other shrews has a positive effect on the physical and water-physical properties of the soil, which in turn causes changes in physico-chemical characteristics, helping to slow down the development of erosion. The properties of the soil, the main ones of which are determined by hardness, water permeability and structure, are peculiar markers of its anti-erosion capabilities (Table 4).

Table 4. Indicators of restoration of properties of the upper 10-centimeter soil layer under the influence of forest stands and invertebrates

Plantings aged 8-15 years	Hardness, $\text{kg}\cdot\text{cm}^{-2}$	Water permeability, $\text{mm}\cdot\text{min}^{-1}$	Structural particles >1 mm, %
	$\chi \pm m$		
Pure oak trees	16.7 \pm 0.5	8.2 \pm 0.4	32.9 \pm 3.0
Control	19.8 \pm 0.6	6.5 \pm 0.6	25.1 \pm 1.7
Mixed oak trees	17.2 \pm 0.4	8.5 \pm 0.2	38.4 \pm 1.2
Control	19.5 \pm 1.0	4.2 \pm 0.7	29.0 \pm 1.3
Pure pine trees	16.6 \pm 0.6	7.3 \pm 0.5	32.4 \pm 2.6
Control	18.4 \pm 0.9	6.5 \pm 0.2	27.2 \pm 0.9
Mixed pine trees	15.9 \pm 0.7	8.3 \pm 0.8	37.0 \pm 2.1
Control	19.3 \pm 0.8	5.0 \pm 0.5	26.7 \pm 1.1

In the second age period of growth and development of woody plants of forest reclamation plantings, the soil hardness decreases markedly by 10-18% compared to the control areas, which contributes to increased growth of root systems. Water permeability, having an inverse relationship with soil hardness, on the contrary, increases from 26 to almost 123%. The soil acquires structural features, in particular, the number of structural particles with a diameter of more than 1 mm increases by 19-38%.

Admittedly, all these changes occur depending on the species composition of plantings.

Improvements in physical and water-physical properties, in turn, cause changes in the agrochemical characteristics of the soil. Freshly formed humus, holding soil lumps together and forming a water-resistant structure, not only slows down the development of erosion but also stops its manifestation. Reserves of the main agrochemical indicators of the metre-deep soil layer are shown in Table 5.

Table 5. Nutrient reserves of a metre-deep soil layer

Plantings aged 8-15 years	Nutrient reserves			
	organic matter, t*ha ⁻¹	easily hydrolysed nitrogen	mobile phosphorus	exchange rate potassium
		kg*ha ⁻¹		
	$\chi \pm m$			
Pure oak trees	90 ± 6.2	339 ± 28.9	460 ± 25.5	356 ± 27.8
Control	60 ± 6.4	207 ± 2.0	205 ± 12.2	241 ± 10.9
Mixed oak trees	103 ± 7.3	362 ± 23.8	456 ± 14.0	362 ± 12.5
Control	65 ± 7.0	218 ± 3.6	217 ± 10.3	245 ± 15.7
Pure pine trees	76 ± 2.0	235 ± 2.3	473 ± 5.6	645 ± 12.2
Control	70 ± 5.5	206 ± 7.0	400 ± 14.0	506 ± 16.1
Mixed pine trees	80 ± 2.6	246 ± 10.2	487 ± 15.2	624 ± 12.8
Control	74 ± 4.3	200 ± 4.1	407 ± 11.3	508 ± 20.2

Studies showed that in the second age period of growth and development of woody plants of forest reclamation stands, their influence increases. Reserves of organic matter increase by 8-58%, easily hydrolysed nitrogen – by 14-64%, mobile phosphorus – by 18-124%, exchange potassium – by 23-48%, depending on the type of plants and the composition of plantings.

The period of individual plant growth gradually turns into direct interaction and mutual influence. Plants begin to crowd each other in space, competing for light, water, soil nutrients, etc. The struggle for living space (Maliuha & Minder, 2020) is intensifying towards the end of the second age period in both the aboveground and underground parts of plantings. The tent of the stand becomes denser and more powerful along the entire height of the crown placement. Relations between woody plants become strained, which leads to the inevitable differentiation of primarily relatively fast-growing woody plant species.

Treatment logging in anti-erosion plantings should be aimed at improving the growth conditions of plantings (primarily the main types of woody plants), strengthening their reclamation functions, and increasing

the level of biological resistance. Felling residues should be crushed and used as mulch to increase the anti-erosion role of plantings, (Lokhmatov, 1999).

Strengthening the reclamation functions of anti-erosion plantings is achieved by forming a well-developed shrub undergrowth and a tree tent; solid, sufficiently powerful, loose litter, which together increases the hydraulic roughness (Orlovsky, Podzharov & Vorob'ev, 1980; Teleshek, Cherneckij, Ivashko, 1985). Inspection logging, as noted by P.S. Pasternak, I.B. Shinkarenko, P.S. Kravcova, has a positive effect on improving soil development, increasing the volume of soil permeated with roots (Pasternak, Shinkarenko & Kravcova, 1974). Typical under such conditions is the cessation of the development of erosion processes in the territory occupied by the plantation and the suspension in the adjacent area. The threat of restoration of planar erosion remains in cases of transit surface runoff through micro-cavities.

In the third age period, there is an intensive differentiation of woody plants of artificial forest stands (16-30 years), and the formation of a forest environment in them in harsh conditions of competition for existence. Plants grow

and develop due to the action of their active surface, which requires space, which is necessary to increase the size of the aboveground part of trunks and crowns, and spread root systems. Therefore, solving the spatial problem for individual trees and plantings, in general, is vital (Maliuha & Minder, 2020). During this age period, all trees cannot continue to grow and develop under the same conditions. The differentiation of trees, which manifests itself through intense competition for living space, becomes inevitable. There are processes of intensive thinning out of plantings, which negatively affect the anti-erosion properties, in particular, hydraulic roughness, which is partially compensated by the restoration of the activity of living subsurface cover. Grassy vegetation is 15-35 pcs.*m².

Among the representatives of the living ground cover during this age period of plantings, the following predominate: common bracken, unspotted lungwort, sweet woodruff, lanceolate star, Solomon's seal, wood avens, etc. that are common in fresh conditions of oak forests. In other forest-growing conditions, appropriate indicators are formed from representatives of the living subsurface cover.

During the third age period of ecological restoration of eroded land, plantings have a more intense impact on the environment and, especially, on the soil. Due to their forest reclamation properties, the following processes occur: the development of deep horizons by root systems, the

death and restoration of active roots, accompanied by an increase in the content of organic matter in the soil; the accumulation of organic sediment on the surface, which, due to mineralisation, replenishes the soil with nutrients that are easily accessible to plants, and the manifestation of colmative ability by plantings. During this period, soil invertebrates become especially active, which, together with other representatives of flora and fauna, act as direct participants in soil-forming processes.

Indicators of physical, water-physical, physico-chemical, agrochemical, and biological properties of soils of this age period acquire specific statistical importance, which indicates their active soil-forming role. Improving the water-physical properties of the soil, primarily water permeability, contributes to the most complete transfer of meltwater and rainwater to intra-soil (Table 6). The soil hardness under pure and mixed plantings is 14.0-15.7 kg*cm⁻². Compared to the control, the decrease occurred by 13-26%. These are small values for the mentioned age period, which have substantially decreased compared to previous periods. Water permeability increased by 36-115%, and the content of structural particles increased by 64-102%.

Consequently, a substantial change in the water-physical properties of the soil causes the complete cessation of the development of erosion processes in the areas under forest reclamation plantings.

Table 6. Indicators of restoration of properties of the upper 10-centimeter soil layer under the influence of forest stands and invertebrates

Plantings aged 16-30 years	Hardness, kg*cm ⁻²	Water permeability, mm*min ⁻¹	Structural particles >1 mm, %
	$\chi \pm m$		
Pure oak trees	14.0 ± 2.3	12.8 ± 0.9	52.6 ± 5.2
Control	19.0 ± 1.1	7.0 ± 0.8	26.0 ± 1.2
Mixed oak trees	14.9 ± 0.7	11.4 ± 0.3	53.9 ± 6.1
Control	18.9 ± 1.3	5.3 ± 1.0	30.1 ± 1.4
Pure pine trees	15.7 ± 0.6	9.4 ± 0.8	46.2 ± 2.5
Control	18.0 ± 0.7	6.9 ± 0.9	29.3 ± 1.7
Mixed pine trees	14.0 ± 0.5	10.3 ± 0.4	46.8 ± 1.8
Control	18.8 ± 0.8	5.8 ± 1.2	28.4 ± 1.3

Plantings begin to enter the fruiting phase, which has a positive result in the formation of self-seeding on open ravine slopes devoid of woody vegetation, which is important in anti-erosion terms. A comparison of the nutrient reserves of the specified age period is given in Table 7.

Reserves of organic matter increase by 22-51%, easily hydrolysed nitrogen – by 31-135%, mobile phosphorus –

by 5-136%, exchange potassium – by 42-68%, depending on the type of plants and the composition of plantings.

During this age period, it is necessary to conduct treatment logging, which has an exclusively differentiated approach to each individual forest stand, depending on the characteristics of the growth and development of woody plants.

Table 7. Nutrient reserves of a metre-deep soil layer

Plantings of age 16-30 years old	Nutrient reserves			
	organic matter, t*ha ⁻¹	easily hydrolysed nitrogen	mobile phosphorus	exchange rate potassium
		kg*ha ⁻¹		
	$\chi \pm m$			
Pure oak trees	103 ± 4.9	416 ± 31.6	502 ± 19.4	421 ± 12.4
Control	68 ± 3.3	209 ± 3.0	213 ± 8.9	250 ± 17.1
mixed oak trees	104 ± 13.0	519 ± 35.3	430 ± 15.2	411 ± 67.8
Control	70 ± 9.2	221 ± 6.2	230 ± 10.7	249 ± 18.0
Pure pine trees	93 ± 3.5	272 ± 9.0	440 ± 42.0	727 ± 31.9
Control	75 ± 5.1	208 ± 7.3	420 ± 13.7	512 ± 20.7
Mixed pine trees	98 ± 8.9	352 ± 46.4	578 ± 35.3	765 ± 25.3
Control	80 ± 5.8	204 ± 5.6	414 ± 12.4	514 ± 21.4

Notably, in protective anti-erosion plantings (especially under the age of 30), treatment logging should be performed with less intensity than in operational forests. It is advisable to chop the felled plant mass and spread it evenly over the territory. This measure aims to increase the hydraulic roughness of the surface, prevent possible wash-outs and erosion of the soil due to heavy rains and transit flow of surface runoff through micro-cavities.

Fourth age period, the life interval of which covers from 31 to 60 years is primarily characterised by the completion of the formation of the forest environment in forest stands involving fast-growing plant species and

the manifestation of the effective action of their first generation. Scots pine and Scots oak, as representatives of long-lasting main plant species, have time to identify these functions only at the end of the mentioned period of development of forest stands. Successfully created protective forest stands of the first generation using fast-growing plant species in the presence of vital energy resources do not limit their existence at the age of 60 years. The formation of the forest environment radically changes the forest conditions in comparison with areas that are not covered with forest vegetation.

Anti-erosion plantings of this age period are

characterised by the beginning of thinning out of the tent by reducing the number of leaves and needles per unit length of the shoot, and by conducting treatment cuts, removing stunted and dry trees. Care for such plantings is planned by the forester.

Because of this, the amount of organic precipitation decreases, the illumination of the soil increases, which together leads to intensive growth of grass vegetation (35-50 pcs.*m²). The consequence of this is the appearance under the tent of oak stands, in addition to the wood bluegrass and hairy sedge, also hazelwort, sweet woodruff, ground elder; in robiniaceae – greater celandine; in pine – stoloniferous pussytoes, rare spring sedge, sheep fescue, etc. The root system of plants of this period develops the upper soil horizons more intensively, which has a positive

effect on water permeability, and therefore contributes to the transfer of surface runoff to soil.

In this age period, the intensive influence of plantings on the properties of the soil and its soil formation continues. In terms of its properties, the soil becomes forest type and has substantial differences from agricultural soil.

Relative to the average indicators of physical, water-physical, physico-chemical, and biological properties of the soil, there is a statistically substantial difference not only in comparison with the control area, but also with previous age periods of growth and development of woody plants of forest reclamation stands. There is no surface runoff in forest areas. The investigated indicators of restoration of the properties of the active surface layer of the soil are given in Table 8.

Table 8. Indicators of restoration of properties of the upper 10-centimeter soil layer under the influence of forest stands and invertebrates

Plantings aged 31-60 years	Hardness, kg*cm ⁻²	Water permeability, mm*min ⁻¹	Structural particles >1 mm, %
	$\chi \pm m$		
Pure oak trees	14.5 ± 0.6	20.0 ± 2.9	66.2 ± 1.6
Control	18.7 ± 0.9	7.4 ± 0.7	26.9 ± 1.7
Mixed oak trees	13.5 ± 1.0	14.2 ± 1.1	63.4 ± 3.2
Control	18.5 ± 0.8	6.8 ± 0.5	30.7 ± 2.0
Pure pine trees	15.4 ± 0.2	12.8 ± 0.4	56.2 ± 5.4
Control	17.6 ± 0.7	7.1 ± 0.8	31.3 ± 1.9
Mixed pine trees	13.3 ± 0.6	15.1 ± 0.2	58.6 ± 3.3
Control	18.2 ± 1.1	6.2 ± 0.9	29.8 ± 2.1

Soil hardness decreases by 12-27%, water permeability increases by 80-170%, the number of structural particles in the soil increases by 79-146% compared to the control indicators, depending on the plant species and the composition of stands.

Plantings continue to bear fruit en masse, which serves as the basis for the spread of seeds and the appearance of self-seeding. Its viability has features of manifestation not

only in the areas of ravine slopes that remained uninhabited, but also under the tent or on the edge of anti-erosion plantings that continued to thin out due to the differentiation of stands.

Agrochemical properties, in particular, those presented here on the example of soil nutrient reserves, also have convincing statistical importance in comparison with the control (Table 9).

Table 9. Nutrient reserves of a metre-deep soil layer

Plantings of age 31-60 years old	Nutrient reserves			
	organic matter, t*ha ⁻¹	easily hydrolysed nitrogen	mobile phosphorus	exchange rate potassium
		kg*ha ⁻¹		
	$\chi \pm m$			
Pure oak trees	105 ± 1.8	330 ± 7.9	603 ± 25.1	884 ± 40.0
Control	69 ± 4.5	217 ± 7.8	422 ± 14.7	518 ± 18.6
Mixed oak trees	106 ± 2.9	438 ± 45.7	619 ± 43.0	908 ± 27.0
Control	78 ± 8.1	219 ± 5.0	430 ± 11.3	520 ± 22.4
Pure pine trees	97 ± 10.6	426 ± 38.3	439 ± 10.9	401 ± 65.5
Control	67 ± 5.4	220 ± 6.3	217 ± 15.0	257 ± 19.3
Mixed pine trees	113 ± 3.2	499 ± 29.7	527 ± 16.4	452 ± 55.0
Control	65 ± 8.6	215 ± 8.2	221 ± 13.6	268 ± 23.2

Reserves of organic matter increase by 36-74%, easily hydrolysed nitrogen – by 52-132%, mobile phosphorus – by 43-138%, exchange potassium – by 56-75%, depending on the type of plants and the composition of plantings.

Therefore, the fourth age period can be characterised as the period of the beginning of the age of protective ripeness of anti-erosion forest stands on eroded lands (Pavlovsky, 1973). During this age period, natural reforestation extends to nearby agricultural land.

During this period of growth and development of woody plants of anti-erosion plantings, forest floor reserves range from 2.5 to 8.5 t/ha⁻¹ (Yukhnovskiy, Dudarets, Maliuha & Khryk, 2013; Maliuha et al., 2021). Features of the influence of forest litter are as follows: reducing the physical evaporation of moisture from the soil, its compaction and freezing; promoting the accumulation of moisture due to meltwater and precipitation, which seep into the

soil, and increasing the level of moisture capacity of the litter, which can reach 300-400%. There is an increase in the anti-erosion effect of protective forest stands not only on the territories that they actually cover but also on adjacent ones.

The fifth age period of effective operation of the first generation, characterised by the entry of middle-aged plantings into the self-regulation phase, is associated with an age interval of more than 60 years for woody plant species of a long life cycle. Forest stands involving Scots pine and Scots Oak during this period of their growth and development have a well-formed effective forest environment, in which forest conditions radically change in comparison with eroded territories that are not covered with forest vegetation.

The main indicators of restoration of physical and water-physical properties of the active soil layer of anti-erosion plantings are given in Table 10.

Table 10. Indicators of restoration of properties of the upper 10-centimetre soil layer under the influence of forest stands and invertebrates

Plantings older than 60 years	Hardness, kg*cm ⁻²	Water permeability, mm*min ⁻¹	Structural particles >1 mm, %
	$\chi \pm m$		
Pure oak trees	13.9 ± 0.4	26.2 ± 0.7	65.3 ± 4.1
Control	18.9 ± 1.3	7.7 ± 1.1	28.7 ± 2.5
Mixed oak trees	13.2 ± 1.1	27.5 ± 0.3	77.1 ± 2.0
Control	18.6 ± 1.2	7.4 ± 0.7	32.5 ± 1.8
Pure pine trees	13.8 ± 0.5	21.7 ± 0.9	62.6 ± 1.0
Control	17.9 ± 1.0	6.9 ± 0.6	33.0 ± 2.4
Mixed pine trees	14.2 ± 0.3	26.0 ± 0.5	68.3 ± 1.5
Control	18.0 ± 1.4	6.5 ± 0.8	33.7 ± 1.7

The soil hardness in mixed oak stands is the lowest – 13.2 kg*cm⁻². The overall soil hardness index of oak and pine stands decreased by 21-29% compared to the control. The value of the water permeability indicator increased by 214-300%. Mixed oak stands have the highest water permeability index – 27.5 mm*min⁻¹.

Such results correspond, according to the assessment by N.A. Kachinskij, to water permeability (Kachinskij, 1975; Berezhniak, 2013) for the first hour of seeping, which will be equal to more than 1000 mm. This is explained by the action of soil animals: moles, worms, and many other smaller ones, and the influence of root systems. Soil with such indicators is able to absorb even the transit part of surface runoff, which can enter plantings from the catchment area. It is important to consider positive changes regarding the increase in the share of structural aggregates by 90-137%.

The processes of soil formation in anti-erosion plantings continue to acquire intense manifestation, and the average values of the considered indicators of soil properties, as in the previous age period, have a statistically

substantial difference not only in comparison with the control area but also with plantings of other age periods of growth and development of woody plants.

Under the tent of thinning out plantings, a sufficient amount of organic precipitation and optimal illumination determines the development of grass vegetation (50-150 pcs.*m²). Its composition includes both shade-tolerant species – hazelwort, lanceolate star, male fern, hazelwort, unspotted lungwort, Solomon's seal, and relatively light-demanding – wood anemone, viola mirabilis, ribwort plantain, common dandelion, white clover, danewort, brown knapweed, red dead-nettle. Not only do self-seeding plants appear, but also undergrowth develops, increasing hydraulic roughness.

The properties of the forest soil continue to improve. Therewith, during this period (at least until the age of 70-80 years), the first generation does not manage to fully reach the level of properties of zonal soils that are formed under natural forest stands. A comparison of nutrient reserves of a metre-deep soil thickness under forest stands is given in Table 11.

Table 11. Nutrient reserves of a metre-deep soil layer

Plantings older than 60 years	Nutrient reserves			
	organic matter, t*ha ⁻¹	easily hydrolysed nitrogen	mobile phosphorus	exchange rate potassium
		kg*ha ⁻¹		
	χ ± m			
Pure oak trees	121 ± 14.3	440 ± 15.7	798 ± 34.1	1007 ± 18.8
Control	71 ± 7.2	224 ± 6.3	423 ± 17.2	523 ± 17.9
Mixed oak trees	146 ± 3.8	417 ± 4.0	908 ± 23.6	1092 ± 30.7
Control	78 ± 5.2	230 ± 6.5	437 ± 16.2	527 ± 21.9
Pure pine trees	115 ± 2.7	494 ± 26.6	545 ± 12.0	497 ± 53.8
Control	83 ± 6.0	228 ± 9.2	237 ± 13.8	261 ± 24.3
Mixed pine trees	128 ± 4.6	612 ± 18.4	732 ± 20.7	632 ± 42.9
Control	85 ± 9.0	240 ± 8.7	260 ± 14.3	268 ± 20.6

Reserves of organic matter increase by 38-87%, easily hydrolysed nitrogen – by 81-155%, mobile phosphorus – by 89-182%, exchange potassium – by 90-136%, depending on the type of plants and the composition of plantings.

Plantings continue to bear fruit, and the viability of self-seeding plants and their biological stability increase. Thus, after 60 years, protective anti-erosion plantings are defined as self-regulating ecological systems, that is, there is an ecological restoration of former eroded lands, and their transformation into productive, important territories for economic use.

This age period is characterised by the maximum manifestation of all functions of protective forest stands: energy, water-regulating, water-absorbing, soil-protecting, colmatative, soil-forming, restorative, recreational, sanitary-hygienic, aesthetic, educational, climate-regulating, environmental-stabilising. These functions work simultaneously and provide a multifunctional role for forest stands (Yukhnovsky, Dudarets, Maluha & Khryk, 2013).

The maximum manifestation of all the above functions takes place only during the life of the forest or

anti-erosion plantings as a powerful and well-established organism that acts clearly.

Conclusions

A clear correlation between the age periods of growth and development of woody plants with qualitative stages of ecological restoration of eroded soils was obtained. In each age period, qualitative changes occur during the growth and development of vegetation cover, and quantitative changes in indicators that characterise the properties of the soil, compared to the control (pasture).

In the first age period, protective forest stands do not show a statistically substantial effect on soil properties compared to the control. They need help in the form of timely agricultural treatment. If the plantings are successfully created, they do not need forestry care.

The second period is characterised by an improvement in physical and water-physical properties, which cause changes in the agrochemical characteristics of the soil. Forestry care is used if there were miscalculations in the selection of woody plant species or for non-compliance with the technology. For this purpose, lighting is conducted to improve growth conditions, strengthen land reclamation

functions, and increase the stability of plantings. Felling residues should be crushed and used as mulch to enhance the anti-erosion role of plantings.

In the third period, there is a substantial change in the water-physical properties of the soil, which causes the complete cessation of the development of erosion processes in the areas under forest reclamation plantings. Treatment logging has an exceptionally differentiated approach, and it is advisable to grind the felled plant mass and spread it evenly over the territory to increase hydraulic roughness in regulating surface runoff.

The fourth period is characterised by the beginning

of the age of protective ripeness of anti-erosion forest stands. There is an increase in their influence on the processes of soil formation. The average indicators of physical, water-physical, physico-chemical, agrochemical, and biological properties of the soil have a statistically substantial difference not only in comparison with the control area but also with plantings of other age periods of growth and development of woody plants.

After 60 years, as for the fifth age period, protective anti-erosion plantings are defined as self-regulating ecological systems that are characterised by the manifestation of basic functions.

References

- [1] Astapov, S. V. (1958). *Meliorative soil science (workshop)*. Moscow: Sel'hozgiz, 367 [in Russian].
- [2] Berezhniak, M. F. (2013). *Pedology*. Kyiv: TOV "NVP "Interservis", 304 [in Ukrainian].
- [3] Duran Zuazo, V. H., & Pleguezuelo C. R. R. (2008). Soil-erosion and runoff prevention by plant covers. A review. *Agronomy for Sustainable Development, Springer Verlag*, 28 (1), 65–86. <http://dx.doi.org/10.1051/agro:2007062>
- [4] Gordienko, M. I., Nagornaya, R. V., & Kisten', A. V. (1986). Impact of clearing of felling areas on soil properties. *Forest Journal*, 1, 8–13 [in Russian].
- [5] ISO/TR 14061. Information to assist forestry organizations in the use of the Environmental Management System standards ISO 14001 and ISO 14004. International Organization for Standardization. (1998). 11. <https://www.sis.se/api/document/preview/612099/>.
- [6] Johnson, P. S. (2004). Thinking about oak forests as responsive ecosystems. Gen. Tech. Rep. SRS-73. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station, 13–18. <https://www.srs.fs.usda.gov/pubs/6486>
- [7] Kachinskij, N. A. (1975). *Soil, its properties and life*. Moscow: Nauka, 294 [in Russian].
- [8] Let's save the soil – let's save our well-being. Available at <https://www.ua.undp.org/content/ukraine/uk/home/ourperspective/ourperspectivearticles/2018/01/02/desertification-un-convention-ukraine.html>.
- [9] Lokhmatov, N. A. (1999). *Development and restoration of the steppe forest plantings*. Balakleya: SIM [in Russian].
- [10] Lund, H. Gyde. (1998). IUFRO Guidelines for Designing Multipurpose Resource Inventory. *IUFRO World Series*, 8, 216. Available at <https://www.iufro.org/uploads/media/ws8.pdf>.
- [11] Maliuha, V. M., Dudarets, S. M., Yukhnovskiy, V. Yu., & Harkava, O. M. (2006). Soil sampler. Patent of Ukraine for useful model. G01N 1/04. № 22065; declared 27.11.2006; published 10.04.2007, № 4 [in Ukrainian].
- [12] Maliuha, V. M., Yukhnovskiy, V. Yu., Dudarets, S. M., Minder, V. V., Protsenko, I. A., & Krylov, Ya. I. (2014). Device for soil sampling. Patent of Ukraine for useful model. G01N 1/04. № 88990; declared 10.10.2013; published 10.04.2014, № 7 [in Ukrainian].
- [13] Maliuha, V., Khryk, V., Minder, V., Kimeichuk, I., Raduchych, M., Rasenchuk, A., Brovko, F., & Yukhnovskiy, V. (2021). Fractional composition and formation of forest litter in scots pine plantations on ravine-gully systems and the plain of the Central part of Ukraine. *Forestry ideas*, 27, 1 (61), 89–100.
- [14] Maliuha, V. M. (1987). *The experience of creating protective plantations on the eroded lands of the Kanev dislocations*. Kyiv [in Russian].
- [15] Maliuha, V. M. (2008). Stages of restoring the fertility of eroded soils under the influence of protective forest plantations. *Forestry and agroforestry*, 112, 118–124 [in Ukrainian].
- [16] Maliuha, V. M., & Minder V. V. (2020). Indicator of tension in the living space of protective forest plantations. *Ukrainian Journal of Forest and Wood Science*, 11 (4), 47–59 [in Ukrainian]. <http://dx.doi.org/10.31548/forest2020.04.005>
- [17] Manual on methods and criteria for harmonized sampling, assessment, monitoring and analysis of the effects of air pollution on forests/3rd edition. (1994). Federal Research Centre for Forestry and Forest Products (BFH), 177.
- [18] Mayer, P. (2003). Impulses for Research. *Living Forest Summit in Vienna*, 11 (1–2), 10–11.
- [19] Merzlenko, M. D., & Babich, N. A. (2020). *Artificial reforestation*. Moscow: Izd-vo Yurajt [in Russian].
- [20] Minder, V., Maliuha, V., & Yukhnovskiy, V. (2019). *Meliorate properties of park stands in the conditions of complex relief*. Kyiv: Kondor [in Ukrainian].

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- [21] On the National Program for the Formation of the National Ecological Network of Ukraine for 2000–2015: Law of Ukraine (2000). Newspaper “Guide”, 3–16 [in Ukrainian].
- [22] Orlovskij, V. B., Podzharov, V. K., & Vorob’ev, V. N. (1980). *Protective afforestation in Belarus*. Minsk: Urozhaj [in Russian].
- [23] Pasternak, P. S., Shinkarenko, I. B., & Kravcova, P. S. (1974). Scots pine root system development at different planting density and thinning intensity. *Forestry and agroforestry*, 38, 16–20 [in Russian].
- [24] Pavlovskij, E. S. (1973). *Arrangement of agroforestry plantations*. Moskow: Lesnaya prom-st [in Russian].
- [25] Pdivinen, R., Lund, H. Gyde, Poso, S., & Zawila-Niedzwiecki, T. (Eds.). (1994). IUFRO International Guidelines for Forest Monitoring. *IUFRO World Series*, 5, 42. Available at <https://www.iufro.org/uploads/media/ws5-en.pdf>
- [26] Pogrebnyak, P. S. (1955). *Basics of forest typology*. Kyiv: Akademiya Nauk USSR [in Russian].
- [27] Prescott, C. E., Katzensteiner, K., & Weston, C. (2021). Soils and restoration of forested landscapes. *Soils and landscape restoration*, 299–331. <https://doi.org/10.1016/B978-0-12-813193-0.00011-4>
- [28] Teleshek, Yu. K., Cherneckij, A. I., & Ivashchenko, S. S. (1985). *The owner’s use of ravine and ravine lands*. Kyiv: Urozhaj [in Russian].
- [29] Workshop on agrochemistry. Tutorial. (2001). Moskow: Moskovskij Gosudarstvennyj Universitet [in Russian].
- [30] Yukhnovskiy, V. Yu., Dudarets, S. M., Maliuha, V. M., & Khryk, V. M. (2013). *Anti-erosion forest plantations of ravine-gully systems*. Kyiv: Kondor [in Ukrainian].
- [31] Zonn, S. V. (1955). Biogeocenotic method and its significance for studying the role of biological factors in soil formation. *Pedology*, 6, 5–13 [in Russian].
- [32] Zrazhevskij, A. I. (1957). *Earthworms as a factor of forest soil fertility*. Kyiv: AN USSR [in Russian].
- [33] Zrazhevskiy, A. I., & Lohvynenko, I. I. (1971). About biological activity of soil and decomposition of forest waste. Collection of scientific works of the Ukrainian Agricultural Academy. *Biological bases of increasing crop yields*, 40, 121–124 [in Ukrainian].

Вікові періоди розвитку захисних лісових насаджень у відновленні еродованих яружно-балкових земель

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Анотація. На теперішній час питанням ролі, значущості, оптимального використання ґрунтів, їхньої охорони та боротьби з деградацією приділяють величезну увагу. Ухвалюючи Цілі Сталого Розвитку на національному рівні, Україна зобов'язана впроваджувати нові програми та проекти, які на практиці гарантуватимуть макроекономічну стабільність, екологічний баланс і соціальну згуртованість. Під час наукових досліджень багатофункціональної ролі захисних лісових насаджень, які свого часу створювали на еродованих територіях, до складу яких входять яружно-балкові землі, для відродження властивостей ґрунтів проведено дослідження з обґрунтування їхньої відновлювальної функції. Для виконання поставленої мети закладено 90 ґрунтолісотипологічних пунктів у протиерозійних насадженнях різних періодів росту і розвитку рослин із відбором 270 зразків ґрунту. Здійснено дослідження їхніх водно-фізичних і агрохімічних властивостей із обробленням отриманих даних статистичними методами. На підставі аналізу наукових літературних джерел, вивчення успішного виробничого досвіду та власних досліджень протиерозійних насаджень із визначення їхнього впливу на властивості ґрунту і навколишнє середовище, розроблено якісні етапи екологічного відновлення еродованих ґрунтів. Зміна вікових періодів росту і розвитку деревних рослин у захисних лісових насадженнях, створених на яружно-балкових землях, призводить до поступового поетапного екологічного відновлення еродованих ґрунтів. Отримано чітке співвідношення вікових періодів росту і розвитку деревних рослин з якісними етапами екологічного відновлення еродованих ґрунтів. Добір об'єктів досліджень передбачав урахування однакової технології створення протиерозійних насаджень, зростання і розвиток в однакових умовах, які б відповідали п'ятьом віковим періодам росту і розвитку деревних рослин. У кожному віковому періоді відбуваються якісні зміни під час росту і розвитку рослинного покриву, а також кількісні зміни показників, що характеризують властивості ґрунту, які представлені порівняно з контролем, яким обрано вигін. Надано основні функції цих насаджень. Приділено увагу всім віковим періодам росту і розвитку протиерозійних насаджень у частині проведення лісівничих заходів для успішного вирощування протиерозійних насаджень та їхньої ефективної дії. З виділеними віковими періодами чітко узгоджуються етапи екологічного відновлення еродованих територій. Відкриваються перспективи розуміння процесу відновлення захисного рослинного покриву, зокрема лісових насаджень і їхнього безпосереднього впливу на властивості еродованих ґрунтів

Ключові слова: ерозійні процеси, еродовані ґрунти, протиерозійна роль, періоди розвитку, якісні етапи, властивості ґрунту, гідравлічна шорсткість

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Phytodecoration of interiors of the government house of Ukraine: analysis and suggestions

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Abstract. The study presents the results of studies of bioaesthetic characteristics of decorative elements of phytodesign of office interiors. It is established that the phytodecoration of interiors is an important component of creating a comfortable environment for employees of various institutions. Modernisation of phytodesign elements was conducted for the premises of the Government House of Ukraine, based on the results of surveys and analysis of the species composition of tropical and subtropical plants cultivated in the premises of this institution. The collection and primary processing of information were conducted using the route survey method. Visualisations of model phytocompositions were formed based on specialised Real Time Landscaping Architect software. During the research, the existing range of tropical and subtropical plants that were used for phytodecoration of the interiors of the Government House of Ukraine was investigated, and its expansion was proposed. Groups of plants for functional and aesthetic purposes in the premises are analysed and project proposals are developed on their basis to improve the decorative nature of the interiors of the Government House of Ukraine. It is established that the decoration of premises involving phytocompositions on the territory of the object under study appeared only in 2003, while compositions of live plants replaced the use of artificial flowers. It was determined that the range of decorative deciduous and beautifully flowering plants that were attracted for phytodecoration of the interiors of the Government House of Ukraine includes 22 species. Considering the specific features of the internal layout of the building, seven project proposals of phytocompositions were developed for decorating recreation rooms, entrance and transit zones, meeting rooms, press and journalism halls, and the Small Hall of the Government House of Ukraine. It is proposed to expand the range of decorative deciduous and beautifully flowering plants into seven species, namely representatives of the *Araliaceae* Juss., *Araceae* Juss., *Arecaceae* Bercht. & J. Presl., *Begoniaceae* C. Agardh, *Campanulaceae* Juss., *Nephrolepisaceae* Pic. Serm. families, considering their aesthetic and utilitarian functions, and optimal options for placing phytocompositions, model phytocompositions for decorating the interiors of the Government House of Ukraine were developed on their basis

Keywords: enclosed space, public buildings, project proposals, phytodesign, phytoergonomics, phytocomposition

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Introduction

Phytodecoration is a new area in the formation of the architectural environment through a harmonious combination of vegetation with the object world. Currently, the use of plants for arranging the interiors of various premises is explained by the need for humans to be closer to nature due to the large-scale urbanisation of cities and local technogenic environmental pollution. Successful solution of these problems requires a comprehensive approach to the wide possibilities of applying the beneficial properties of plants: phytoncidotherapy, colour therapy, aesthetic therapy, aromatherapy, and many other functions.

A person spends most of their life in a closed environment, so isolation from nature should be compensated by creating elements of flora and phytodesign in the premises, which help to increase the artistic expressiveness of the internal space, improve its functional organisation, and contribute to improving the sanitary and hygienic parameters of the air.

The level of comfort of a closed environment is created by the optimal combination for a person of a complex of important indicators that ensure the performance of two main functions: aesthetic – harmony, integrity, compliance with the environment, style, trends, and utilitarian – temperature, cleanliness, humidity, and air speed, sound and noise insulation. Phytodecoration ensures the fulfilment of these parameters and solves several issues related to the performance of these functions.

The scientific approach to indoor landscaping involves combining the aesthetic perception of colour, texture, and shape of flowers and leaves of plants with another important feature – phytoncidal properties, which is relevant, because individual elements of the interior and decor with paintwork, plastic products can emit poisons and toxins. In addition, the air in any room of the building contains fungal spores, pathogenic microorganisms, pollen, soot microparticles, and various chemical compounds. Therefore, the rational selection of the range of plants for the phytodesign of a closed environment solves a number of tasks related to both a complex aesthetic nature and a phytosanitary plan.

The use of the principles of functional and decorative gardening in the organisation of interiors of administrative buildings contributes to the visual harmonisation of the environment, optimisation of its functional organisation and improvement of environmental indicators. This, in turn, will reduce the fatigue of a person in this environment, increase their performance and have a positive effect on their physical and psychological state.

Phytodecoration of administrative building interiors – a specific area of phytodesign, so now it is relevant to use elements of nature in the design of closed architectural

compositions of interiors of the Government House of Ukraine.

One of the most important issues of our time is the environmental safety and protection of humans, the environment of their life, and existence in the conditions of rapid development of urbanised territories and the expansion of industrial complexes. The issue of indoor landscaping interested scientists back in the late 1970s. In 1981, D. Grodzinsky defined phytodesign and outlined the theoretical basis for the use of plants in closed systems, and developed technological aspects of the formation of phytocompositions (Grodzinsky, 1986).

The practical application of the principles of phytodesign in interiors and the study of their aesthetic and functional substantiality was conducted by V. Sniezhko, V. Pushkar, N. Kryzhanivska, N. Chhartishvili, N. Mkhitarian, M. Hunter, and D. Khesayon. Features of phytodesign of premises were investigated by L. Mashinsky, O. Stepanenko. Many papers were devoted to determining the decorative role of plants and investigating their artistic and aesthetic aspects in phytodesign (Kryvonos, 2019; Kuznetsova & Stepanyuk, 2013; Hnatyuk & Shepelyuk, 2019), the use of ornamental plants and current trends in phytodesign of interiors (Kosenko, Hrabovyi, Opalko, Muzyka & Opalko, 2020; Cetti, 2014).

The purpose of the study is to analyse the available phytocomposition solutions for interiors in the premises of the Government House of Ukraine and, based on them, provide proposals for the selection of an assortment of plants for creating new compositions intended for decorating the spaces of administrative buildings.

Materials and Methods

During the study, the following methods and techniques were used: route survey – collection and primary processing of material; assessment of plant decorative properties. The specialised Real Time Landscaping Architect Software was used to create visualisations of project proposals.

Results and Discussion

In the interior design of public administrative buildings, ideas of rationalism and functionality prevail over aesthetic appearance, because, considering the specific features of working in such types of premises, first of all, attention is paid to the problems of air conditioning, insulation, and noise absorption. It is established that in the 2000s, the first phytocompositions in the interiors of the Government House of Ukraine were formed from artificial flowers (Saakov, 1983), which only partially ensured the performance of aesthetic functions. Only in 2003 did fresh flowers appear, decorating the general appearance of the premises (Fig. 1).



Figure 1. General view of the meeting room of the Government House of Ukraine before reconstruction (<http://inpress.ua/ru/economics/14281-zasedanie-kabmina-kommunalnye-tarify-ponizit-chislo-turistov-povysit-osoboe-vnimanie-gorlovke>)

In 2004, the reconstruction of the halls of the Government House of Ukraine was completed, and specialists from the Department of landscaping and phytodecoration formed the

first phytocompositions (Fig. 2). The first phytocompositions of the great hall of the Club of the Cabinet of Ministers of Ukraine were formed from *Spathiphyllum wallisii* Regel plants (Fig. 3).



Figure 2. Official meeting hall of the Government House of Ukraine after reconstruction (<http://www.center.net.ua/news/396>)



Figure 3. General view of the great hall of the Club of the Cabinet of Ministers of Ukraine (<http://www.center.net.ua/news/396>)

The main focus of phytodecoration of the interior of the Club of the Cabinet of Ministers of Ukraine hall before

the reconstruction was the composition of *S. wallisii* and *Hedera helix* L. plants (Fig. 4).



Figure 4. General view of the Club of the Cabinet of Ministers of Ukraine hall before the reconstruction (<http://www.center.net.ua/news/396>)

Modern phytocompositions of the premises of the Government House of Ukraine present a diverse range of sub-tropical and tropical plants – *Aglaonema commutatum* Schott, *Asparagus aethiopicus* L., *Epipremnum aureum* (Linden & André) G. S. Bunting, *Dracaena deremensis* Engl., *H. helix*, *Crassula arborescens* (Mill.) Willd., *Clivia nobilis* Lindl., *Monstera deliciosa* Liebm., *S. wallisii*, *Schlumbergera truncata* (Haw.)

Moran, *Zamioculcas zamiifolia* (Lodd.) Engl., *Saintpaulia grandifolia* B. L. Burt, *Yucca gigantea* Lem., *Ficus benjamina* L., *Oxalis acetosella* L., *Oxalis hedysaroides* Kunth., *Nolina longifolia* (Karw. ExSchult. &Schult.f.)Hemsl., *Hibiscus rosa-sinensis* L., *Codiaeum variegatum* (L.) Rumph. ex A. Juss., *Chlorophytum comosum* (Thunb.) Jacques, *Dieffenbachia seguine* (Jacq.) Schott and species of the genus *Phalaenopsis* Blume (Fig. 5).



Figure 5. General view of the Club Cabinet of Ministers of Ukraine hall after Reconstruction (<http://rian.com.ua/columnist/20151024/375735012.html>)

The aesthetic design of free space in the premises is created through phytodesign of a closed environment, which allows for achieving maximum comfort and cosiness.

Modern phytocompositions, techniques, and means of landscaping for the organisation and visual harmonisation of the interiors of the Government House of Ukraine were proposed, which will increase aesthetics and improve the sanitary and hygienic indicators of the environment by introducing natural outlines and properties. The species composition of plants that were used for phytodecoration of the premises of the Government House of Ukraine is analysed, and it is established that it includes 22 species of decorative deciduous and flowering plants. It was proposed to expand it by involving some representatives of *Araliaceae*, *Araceae*, *Arecaceae*, *Begoniaceae*, *Campanulaceae*, *Nephrolepisaceae* families, and on their basis, project proposals for phytodecoration of individual premises of the Government House of Ukraine were developed.

Modern methods of phytodesign consist in the fact that the use of plants in residential premises and offices helps to form conditions close to the natural environment, which will positively affect both the nature of human perception of each composition individually and in general on the surrounding space (Kniazeva, 2013). Plants that are used for indoor gardening should be resistant to

environmental conditions and be harmoniously combined with the overall style of interior design.

Notably, for fragmentary phytodecoration of interior interiors, it is advisable to use solitary plants or groups of them. Since plants attract special attention, it is necessary to choose a place for them, considering the lighting, temperature, and humidity of the air, its contamination with harmful substances (Popova, 2012). In addition, plants must meet the conditions of the room in terms of size, structure, silhouette, pattern, and colour of leaves. For this, big plants with large leaves are used (representatives of the *Arecaceae* family and *Monstera* Adans., *Aralia* L., *Philodendron* Schott, *Ficus* L., *Cordyline* Comm. Ex R. Br., *Agave* L., *Sansevieria* Thunb.) genera, supplemented with smaller species (*Aspidistra* Ker Gawl., *Aglaonema* Schott, *Pilea* Lindl., *Chlorophytum* Ker Gawl., *Oxalis* L., *Begonia* L. *Hedera* L. et al.) (Porubynovskaia, 1974). Planters and containers in which plants are grown should be in harmony with the architecture of a particular room in shape, size, color, material, and it is advisable to decorate the top layer of soil with moss, pebbles, expanded clay, sand, or ground cover plants (Artiushyn, 1982; Orlova, 2011).

A phytocomposition in the Government House of Ukraine in the Small hall (Fig. 6) was designed. The range consists of plants *C. comosum* that is distinguished by its

decorative and phytoergonomics function, and is arranged according to habit with all other plants. *A. commutatum* creates a vertical axis of the future phytocomposition, is quite undemanding to the level of lighting and does not require frequent watering. *Nephrolepis cordifolia* (L.) C. Presl. will adorn the compositions with its splendour, due to the shape of openwork leaves. In the future, this composition

will be located in the centre of the Small Hall of the Government House of Ukraine. This room has a low level of lighting, so an assortment of plants that are undemanding to the level of insolation were selected (Rak, 2009). It is believed that such a highly decorative phytocomposition will complement the design of the Small Hall of the Government House of Ukraine.



Figure 6. Project proposal for phytodecoration of the Small Hall of the Government House of Ukraine:
1 – *A. commutatum*, 2 – *C. Comosum*, 3 – *N. cordifolia*

Phytocomposition for the design of the meeting room in the club premises of the Government House of Ukraine (Fig. 7) is simple in its assortment, undemanding to light, watering, decorative, and does not require careful maintenance (Smyrnova, 2015). The phytocomposition

will be formed in rectangular modules in a regular style. The range includes the following species: *S. wallisii* and *N. cordifolia*. Plants have phytoncidal properties, and different shades of green will have a positive effect on the emotional state of employees.



Figure 7. Project proposal for phytodecoration of the Club of the Government House of Ukraine meeting room:
1 – *S. wallisii*, 2 – *N. sordifolia*

Phytocompositions for the entrance areas of the Government House of Ukraine were also designed (Fig. 8). Undemanding plants that grow well in conditions of limited insolation were offered to create a phytocomposition (Fomyna, 2015): *N. sordifolia* and *Araceae* Juss. family

representatives – *Anthurium andraeanum* Linden ex Andre, which, due to its unusual red bract bedspreads, will act as the main accents. These plants were determined to increase productivity, have a good impact on the environment, and are well adapted to indoor environments.



Figure 8. Phytodecoration project proposal of the entrance area of the Government House of Ukraine:
1 – *A. andraeanum*, 2 – *N. sordifolia*

A project proposal for the design of the press and journalism hall was developed (Fig. 9). It was formed based on gravel pallets, and the range is selected so that the agricultural equipment of phytocomposition care does not involve complex and frequent operations.

Undemanding plants that have phytoncidal properties and can positively affect the microclimate of the environment were selected to create it (Tsvetkova, 2015), – *Chamaedorea elegans* Mart., *S. wallisi*, *N. sordifolia* and *Begonia semperflorens* Link & Otto.



Figure 9. Project proposal for phytodecoration of the press and journalism hall of the Government House of Ukraine:
1 – *C. elegans*, 2 – *N. cordifolia*, 3 – *S. wallisii*, 4 – *B. semperflorens*

For well-lit rooms of the Government House of Ukraine, phytocompositions that are combined with *Schefflera actinophylla* (Endl.) Harms, which has an approximate columnar crown shape, and *B. semperflorens* were offered (Fig. 10). *Araliaceae* Juss. family representatives look

spectacular in indoor areas, their wide range and variety of structures, shapes, and colours of leaf blades emphasise and give uniqueness to the interior. *B. semperflorens* is distinguished by the red colours of flowers and bright green leaves (Shakhov, 2006).



Figure 10. Project proposal for phytodecoration of the recreation room of the Government House of Ukraine:
1 – *S. actinophylla*, 2 – *B. semperflorens*

Project proposals for transit premises were developed using another representative of the *Araliaceae* family – *H. helix* (Fig. 11). Evergreen woody vine in nature can reach 30 m in length and has a large number of cultivars with various decorative features (atypical shape and colour of leaves, the nature of the edge of the leaf blade) (Volkova, 2012). Flexible, branched ivy stems and numerous aerial roots-suckers are able, attaching to foreign objects, to lift and hold the plant at a height. The plant is shade-tolerant, so it will grow well in partial shade, near the window of

the northern part of the room, but cannot withstand direct sunlight (Hriunvald, 2006; Tsvetkova, 2011).

For the design of the entrance area of the Government House of Ukraine, monospecies compositions using lianas of the *Araliaceae* family (Fig. 11), and decorative deciduous and flowering plant species combined with it are proposed (Fig. 12). When creating such phytocompositions, *H. helix* plant shoots must be fixed on installed supports or frame structures, so that the desired shape and volume of the composition can be achieved.



Figure 11. Project proposals for phytodecoration of the premises of the Government House of Ukraine using *H. helix* plants

Rich, bright green leaves of *H. helix* have a refreshing colour and soothing character, capture, and absorb a substantial proportion of dust from the air. Scientists at the University of Dresden in 2009 reported on the high

efficiency of this plant in absorbing toluene, octane, formaldehyde, trichloroethylene, and benzene from the air, which helps to improve its quality characteristics in the room (Mayrand, Clergeau & Vergnes, 2018).

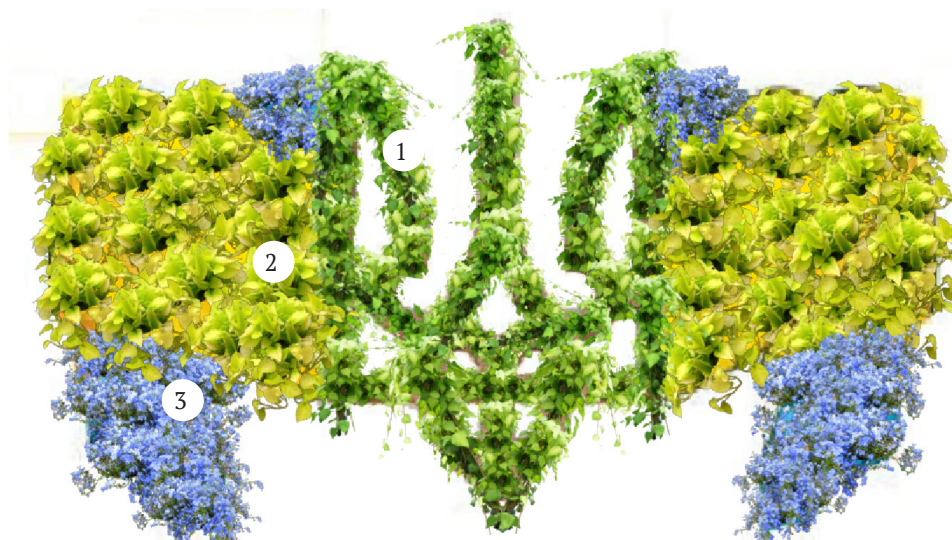


Figure 12. Project proposals for the stylisation of state symbols of Ukraine using ornamental plants:
1 – *H. helix*, 2 – *E. aureum* ‘Neon’, 3 – *Campanula isophylla* ‘Blue Bali’

Phytodesign of interiors involves aesthetic, artistic, and functional design of the overall appearance of the space, where ornamental plants play a substantial role, which, in turn, have a certain psychoemotional load, which can positively affect the mood and performance of a person. Thus, when choosing an assortment for harmonious phytocompositions, it is necessary to consider such components of their bioaesthetic characteristics as colour, contrast, dynamics, rhythm, proportion, scale, symmetry.

Conclusions

According to the results of the study, it was established that the first phytocompositions from live plants in the interiors of the Government House of Ukraine appeared in 2003,

which indicated the need for the formation of functional and decorative greenery.

The species composition of tropical and subtropical plants that are part of the phytocompositions of the interiors of the Government House of Ukraine includes 22 species of decorative deciduous and flowering plants. It was proposed to expand this range of highly decorative plants by attracting seven species of representatives of *Araliaceae*, *Araceae*, *Arecaceae*, *Begoniaceae*, *Campanulaceae*, *Nephrolepisaceae* families.

Considering the need to form a complete picture of interior decoration, seven model phytocompositions for decorating the entrance and transit zones, meeting rooms, press and journalism halls, Small hall, and separate rooms of the Government House of Ukraine were developed.

References

- [1] Artiushyn, L. F. (1982). *Floriculture*. Moscow: Knyga [in Russian].
- [2] Cetti, L. (2014). *Exquisite Book of Paper Flower Transformations: Playing with Size, Shape, and Color to Create Spectacular Paper Arrangements*. New York: Abrams.
- [3] Fomyina, Y. A. (2012). *Flowers in the house. Fitodesign for your health*. Moscow: Eksmo [in Russian].
- [4] Grodzinskiy, A. M. (1986). *Phytoncide in ergonomics*. Kyiv: Navukova dumka Publ. [in Russian].
- [5] Hnatyuk, L. R., & Shepelyuk, K. S. (2019). Use of phytodesign in the interior of office space. *Theory and practice of design*, 17, 31–39. <https://doi.org/10.18372/2415-8151.17.14344>
- [6] Hriunvald, G. (2006). *Houseplants: Features of growth in at home and in nature*. Saint Petersburg: Krystall [in Russian].
- [7] Kniazeva, T. P., & Kniazeva, D. V. (2013). *Houseplants*. Moscow: Olma Medya Hrupp [in Russian].
- [8] Kolesnykova, E. N. (2014). *Simple floriculture. Unpretentious houseplants*. Moscow: Fenyks [in Russian].

- [9] Kosenko, I. S., Hrabovyi, V. M., Opalko, O. A., Muzyka, H. I., & Opalko, A. I. (2020). Current trends in Green Urbanism and peculiarities of multifunctional complexes, hotels and offices greening. *Ukrainian Journal of Ecology*, 10 (1), 226–236. https://doi.org/10.15421/2020_36
- [10] Kostyna-Kassanelly, N. N. (2013). *Palm trees, cacti, ferns and other exotic houseplants*. Kharkiv: Klub semeinoho dosuha [in Russian].
- [11] Kryvonos, V. H. (2019). Formation of an aesthetic comfortable environment for public interiors by means of phytodesign. *Cultural heritage of Siberia*, 1 (27), 40–46 [in Russian].
- [12] Kutas, E. N. (1984). *Ecological and biological features of the life of plants in the conditions of interiors*. Minsk: Nauka i tekhnika [in Russian].
- [13] Kuznetsova, I. O., & Stepanyuk, T. O. (2013). Influence of main artistic means of composition on use of phytodesign in the interior. *Scientific Bulletin of NFTU of Ukraine*, 23 (18), 316–320 [in Ukrainian].
- [14] Mayrand, F., Clergeau, P., Vergnes, A., & Madre, F. (2018). Vertical Greening Systems as Habitat for Biodiversity. In *Nature Based Strategies for Urban and Building Sustainability* (pp. 227–237). Elsevier. <https://doi.org/10.1016/C2016-0-03181-9>
- [15] Official website Club CMU. Available at <http://www.center.net.ua/news/396>.
- [16] Official website CMU. Available at. <http://rian.com.ua/columnist/20151024/375735012.html>.
- [17] Official website of the Cabinet of Ministers of Ukraine. Available at <http://inpress.ua/ru/economics/14281-zasedanie-kabmina-kommunalnye-tarify-ponizit-chislo-turistov-povysit-osoboe-vnimanie-gorlovke>.
- [18] Orlova, T. F. (2011). *Floriculture*. Volgograd: NAA [in Russian].
- [19] Popova, G. R. (2012). *Your houseplants plants*. Moscow: Kladez-buks, Astrel [in Russian].
- [20] Porubynovskaia, G. V. (1974). *Decorative houseplants*. Moscow: Planeta [in Russian].
- [21] Rak, Y. (2009). *Encyclopedia of houseplants*. Moscow: Nyolla-Press [in Russian].
- [22] Saakov, S. G. (1983). *Greenhouse and houseplants and their care*. Lviv: Nauka [in Ukrainian].
- [23] Shakhov, V. V. (2006). *Begonias*. Moscow: Kladez-buks [in Russian].
- [24] Smyrnova, T. V. (2015). *Houseplants: monthly care calendar*. Moscow: Eksmo [in Russian].
- [25] Tsvetkova, M. V. (2005). *Floriculture: professional advice*. Moscow: Knyzhkyn Dom; Moscow: Eksmo [in Russian].
- [26] Tsvetkova, M. V. (2011). *1000 species of indoor plants. Floriculture from A to Z*. Kharkiv: Klub semeinoho dosuha [in Russian].

Фітодекорування інтер'єрів будинку уряду України: аналіз та пропозиції

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Анотація. У статті наведено результати досліджень біоестетичних характеристик декоративних елементів фітодизайну інтер'єрів офісних приміщень. Встановлено, що фітодекорування інтер'єрів є важливою компонентою формування комфортного середовища для працівників різних установ. Осучаснення елементів фітодизайну здійснювали для приміщень Будинку Уряду України, базуючись на результатах обстежень та аналізу видового складу тропічних і субтропічних рослин, що культивуються у приміщеннях цієї установи. Збирання та первинне оброблення інформації проводили за допомогою методу маршрутного обстеження. Візуалізації модельних фітокомпозицій формували на основі спеціалізованого програмного забезпечення Real Time Landscaping Architect. Під час досліджень вивчено наявний асортимент тропічних і субтропічних рослин, які були використані для фітодекорування інтер'єрів Будинку Уряду України, та запропоновано його розширення. Проаналізовано групи рослин за функціональним та естетичним призначенням у приміщеннях і розроблено на їх основі проектні пропозиції щодо підвищення декоративності інтер'єрів Будинку Уряду України. Встановлено, що декорування приміщень за участю фітокомпозицій на території досліджуваного об'єкту з'явилося лише у 2003 р., при цьому композиції із живих рослин замінили використання штучних квітів. Виявлено, що асортимент декоративно-листяних і красивооквітучих рослин, які були залучені для фітодекорування інтер'єрів Будинку Уряду України, налічує 22 види. Зважаючи на специфіку внутрішнього планування будівлі, розроблено сім проектних пропозицій фітокомпозицій для декорування кімнат відпочинку, вхідної та транзитної зон, зали засідань, зали преси та журналістики і Малої зали Будинку Уряду України. Запропоновано розширення асортименту декоративно-листяних і красивооквітучих рослин на сім видів, а саме представників родин *Araliaceae* Juss., *Araceae* Juss., *Arecaceae* Bercht. & J. Presl., *Begoniaceae* C. Agardh, *Campanulaceae* Juss., *Nephrolepisaceae* Pic. Serm., з урахуванням їхніх естетичних та утилітарних функцій, а також оптимальні варіанти розміщення фітокомпозицій і розроблено на їх основі модельні фітокомпозиції для декорування інтер'єрів Будинку Уряду України

Ключові слова: закритий простір, громадські будівлі, проектні пропозиції, фітодизайн, фітоергономіка, фітокомпозиція

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Regarding some mechanical properties of decking made of wood-polymer composites with different fillers

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Abstract. One of the areas of wood waste processing is their use in the production of wood-polymer composites (WPC). The relevance of wood-polymer products is due to the wide range of applications and qualities of this material. WPC does not rot, is not damaged by insects and fungi, and does not contain harmful binders. WPC products do not crack or warp and are water-resistant, which makes them a good material for manufacturing decking. Therewith, the decking board must have certain mechanical qualities, which will allow it to be used in fairly harsh conditions – under the influence of moisture, UV radiation, and with a certain load. The purpose of this study was to determine the main physical and mechanical characteristics (density, flexural strength, elastic modulus, water absorption, hardness, abrasion resistance, changes in linear dimensions when the atmospheric environment changes) of decking samples made of WPC with various fillers. For the study, samples were taken from hollow decking, in which polyethylene (PE) and polyvinyl chloride (PVC) were used as a filler. Based on the conducted experimental studies, it was identified that the density of both samples is quite high, close to the maximum; the difference is insubstantial, but when examining micro-cuts under a microscope in samples in which PE is used as a binder, a larger number of cavities are observed, which indicates the presence of excess moisture or a lack of mineral fillers. It can also be a sign of polymer destruction. It was determined that a number of other important indicators, such as flexural strength, elastic modulus, water absorption, and abrasion resistance, were the best in samples with polyvinyl chloride filler. The greatest difference was in the flexural strength index – 35%. It was also identified that both samples were equivalent in hardness. However, the elastic modulus of the sample with a PE filler exceeded the values of the sample with a PVC filler by almost 2.5 times. Thus, based on the conducted studies, it is possible to identify a number of clear dependencies that indicate that the use of polyvinyl chloride as a binder substantially improves the physical and mechanical performance of decking based on a wood-polymer composite. The results of the conducted research will allow solving the problems of improving the strength characteristics of wood-composite material to expand the range of goods based on wood waste

Keywords: density, hardness, modulus of elasticity, water absorption, abrasion resistance

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Introduction

One of the areas of wood waste processing is their use in the production of wood-polymer composites (WPC). The relevance of wood-polymer products is determined by a wide range of applications, ranging from interior decoration of houses, offices, construction of gazebos, and terraces, to details of automotive products. The disadvantages of existing similar products include the high cost associated with using only primary raw materials (Galiyev, 2015).

Given that the main share of WPC products falls on decking, the task of developing flooring in the form of boards based on wood waste and secondary polymers, produced by conventional methods of processing polymer composites, is relevant. Wood-polymer composite is a modern material containing wood filler (50-80%), polymers, and special chemical impurities (additives). The rapid development of WPC is due to a number of advantages noted in the papers (Klesov, 2010; Safin et al., 2014). The properties of WPC depend on the properties of the polymer matrix, wood particles, the nature of the bond, and the interaction between them. WPC does not rot, is not damaged by insects and fungi, and does not contain harmful binders. WPC products do not crack, do not warp, and are water-resistant. A number of authors note that moisture resistance is more affected by the type of binder, rather than the percentage of wood filler (Khasanshin et al., 2011). A functional relationship describing changes in water absorption and WPC density as a function of polymer content has also been established (Safin et al., 2014).

Since WPC is often used as a structural element, its physical and mechanical qualities become important. In the literature, there is very limited information about the dependence of the physical and mechanical properties of WPC on their composition. Some authors have noted that rigidity and strength are satisfactory only if an expensive

binder is added to the material: this is necessary to increase the compatibility between wood flour and polymer, which would otherwise have no similarity in the course of the corresponding chemical reactions (Lu et al., 2005; Yang et al., 2012), and to create efficient load transfer between wood fibres and the surrounding polymer (Mazzanti et al., 2012).

Since WPC is brittle, it often contains impurities that increase impact strength (Mazzanti et al., 2019, 2019, 2020).

Matseyevich & Askadskiy (2017) noticed that WPC based on matrix polymer PVC has much better properties than WPC based on matrix polymers such as polyethylene and polypropylene. This applies to such important indicators as flexural strength and elastic modulus.

Based on the analysis of these literature sources, it was identified that wood-polymer composite is a modern material that is becoming increasingly popular due to its qualities. The main area of the study is the examination of the polymer component of the material and its impact on physical and mechanical parameters.

The purpose of the study is to determine the main physical and mechanical characteristics (density, flexural strength, elastic modulus, water absorption, hardness, abrasion resistance, changes in linear dimensions in the event of changes in the atmospheric environment) of WPC samples with different fillers.

Materials and Methods

For the study, samples of hollow decking made of wood-polymer composite with a cross-section of 23×128 mm of dark brown colour were selected, the layer on the back side is smooth, profiled on the front side with different fillers. In sample 1, the filler was polyethylene (PE), and in sample 2 – polyvinyl chloride (PVC) (Fig. 1, a, b).

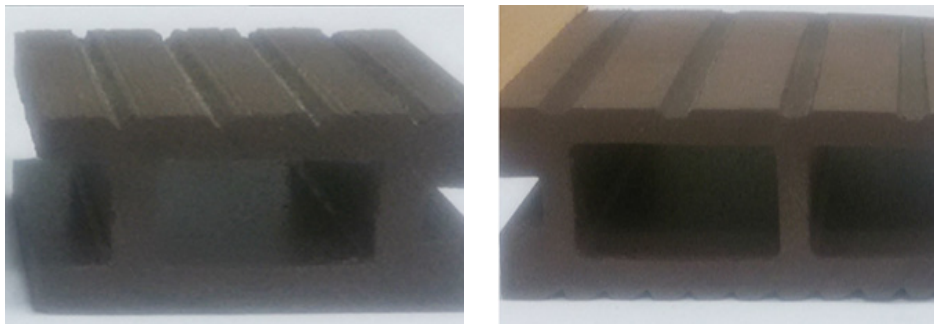


Figure 1. Prototypes of decking: a – with PE filler, b – with PVC filler

Since WPC is a fairly new material, there is no state regulatory framework for testing mechanical properties. The density was determined according to the international standard ISO 1183-1. Density for WPC is a reference indicator and gives an indirect assessment of strength indicators, characterises the presence of mineral fillers in the WPC, and depends on the type of polymer and the composite. Notably, the reduced density accelerates the process of WPC oxidation and is the result of increased porosity (the presence of cavities) of boards due to the presence of moisture in the initial components of WPC (primarily wood fibres) and the destruction of the polymer during processing (in case of overheating, excessive shear and/or lack of additives).

Excessive porosity allows oxygen to enter the WPC material from the inside, substantially increasing the available surface area along with the oxidation rate. Moisture is an effective catalyst for polymer oxidation.

A very important indicator for decking is hardness, which characterises the contact strength of the product, allows assessing the indentation resistance and scratch resistance. The value of the indicator depends on the type of polymer matrix, the amount of filler, and the density of the finished composite. Hardness was determined using a Shore hardness tester. The method described in GOST 24621-91 was applied. For the study, an indenter for a durometer of type D (from 20 to 90) was used in the form of a steel rod with a diameter of 1.10-1.40 mm.

Flexural strength is one of the main indicators of the mechanical properties of a material. It characterises the correctness of the selected composition and technological modes of production and the efficiency of the binder in the composition. The value of this indicator characterises the balance of the formula and the correctness of the technological process. The flexural strength was determined according to the methods given in EN 310 and GOST 10635.

The modulus of elasticity during bending is directly related to the deflection of the board placed on the supports under a certain load. In contrast to the flexural strength of composite boards, which usually substantially exceeds the requirements of building codes for the usually accepted step of laying logs (approximately 40 centimetres (16 inches) from the centre), the modulus of elasticity when bending composite boards on a polymer basis often imposes certain restrictions on their installation: the step of laying logs should not exceed 1/360 of the section. This indicator is not normalised, but at this density, it should be more than 1300 MPA.

Water absorption characterises the geometric stability and hygroscopicity of the WPC profile. Water is the

main aggressive factor of atmospheric influences, as it causes swelling of the material and accumulation of defects, especially when the temperature changes from (-) to (+). The research method given in EN 1087-1 and GOST 32399 was used to determine water absorption.

The value of the water absorption index depends on the formulation and homogenisation of the composition, indicates the distribution and combination of the components of the wood filler.

Water absorption of WPC materials can lead to: the deformation of boards, swelling, and mould spread. In addition, the saturation of WPC boards with water sometimes reduces the modulus of elasticity when bending boards, therefore, causing greater deflection under load. Water absorption also leads to faster destruction of boards, oxidation (water is a catalyst for polymer oxidation), and other negative consequences. WPC materials absorb water due to their porosity (cavities).

WPC decking samples were first conditioned to a constant mass, then kept in water (pH 7±1) at a temperature of 20±1°C for 72 hours. In water, the samples were placed on the edge so that the distance to the walls and bottom of the container was at least 15 mm. After that, the samples were removed and wiped with filter paper. Dried samples were placed in a freezer with a temperature of minus 12°C for 24 hours. The samples were then removed and placed in a drying chamber for 70 hours at a temperature of 70°C. After drying and cooling the samples for 4 hours, the cycle was repeated. A total of three test cycles were performed.

Important indicators for decking are the rate of wear (abrasion) and the change in linear dimensions when the atmospheric environment changes (high humidity/low humidity), mm/100 mm in length. The study was conducted according to the method given in GOST 9590. Wear was determined on a Taber 5155 Rotary abrasimeter. The samples were pre-weighed with an accuracy of 0.001 g and fixed on the device. When reaching 500 rpm, the test was stopped and the samples were weighed again with an accuracy of 0.001 g. The wear rate was calculated by the formula.

Before determining the change in linear dimensions when the atmospheric environment changed, the length of the samples was measured with an accuracy of 0.02 mm. Three samples were placed in a drying cabinet and kept at a temperature of 70±2°C for 24 hours, and three samples were in a chamber with a relative humidity of 92±3% and a temperature of 40±2°C for 96 hours.

Results and Discussion

The density of both samples is quite high, close to the maximum; the difference is insubstantial, but when examining

micro-sections under a microscope at 600x magnification, a larger number of cavities are observed in sample No. 1 (Fig. 2a), which indicates the presence of excess moisture in the board or a lack of mineral fillers, and the destruction

of the polymer. In sample No. 2, which has a higher density of 1.91% and a lower porosity (Fig. 2b), the presence of metal is observed, which can accelerate the oxidation process of the board at high temperatures.

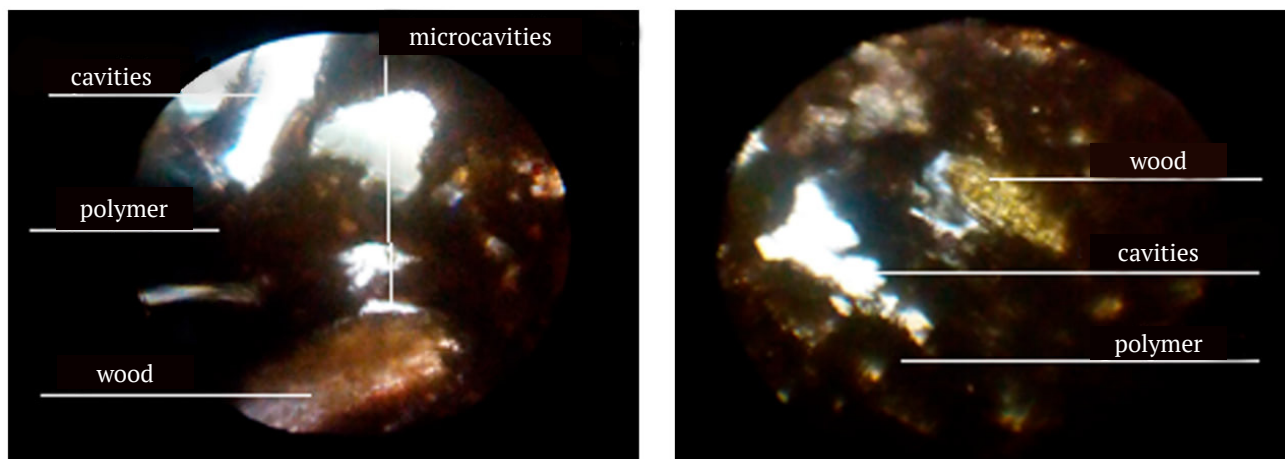


Figure 2. Images of WPC board sections under a microscope at 600x magnification: a – sample No.1, board with larger cavities; b – sample No.2, board with smaller cavities

Table 1 shows the results of determining the physical and mechanical parameters of boards made of WPC. The hardness of sample No.1 slightly exceeds the hardness

of sample No.2 – by 5.8%. Therefore, with this parameter in the complex, samples can be considered equally substantial.

Table 1. Results of experimental determination of physical and mechanical parameters of WPC decking

Indicator	Parameter values	
	Sample No.1 WPC (PE)	Sample No.2 WPC (PVC)
Density, g*cm ⁻³ (kg*m ⁻³)	1,258 (1258)	1,282 (1282)
Shore hardness (units of Shore by D durometer from 20 to 90)	62.1	58.5
Flexural strength, MPa (kgf*cm ⁻²)	17.1 (174.42)	26 (265.2)
Modulus of elasticity (hardness), MPa	2646	1053

Table 1. Continued

Indicator	Parameter values	
	Sample No.1 WPC (PE)	Sample No.2 WPC (PVC)
Water absorption, %	2.63	2.02
Abrasion resistance (wear rate, mg/100 rpm)	0.08	0.05
Change in linear dimensions when the atmospheric environment changes (high humidity/low humidity), mm/100 mm length	0.72/1.6	0.5/0.3

When examining the flexural strength, it was identified that sample No.2 substantially exceeds the strength of sample No.1, meets regulatory requirements (25 MPa) and has advantages in a substantial margin of flexural strength during board exploitation.

The study of the elastic modulus showed a substantial excess of this indicator in sample No.1 compared to sample No.2. The elastic modulus value of sample No.2 can be considered satisfactory, but insufficient for the available density.

During the experiment to determine water absorption, intense discolouration of board samples No.1 was observed, in contrast to the integrity of samples No.2. In addition, during an increase in humidity and temperature and during mechanical damage, a persistent unpleasant specific smell was observed from the samples of board No.1. According to this indicator, sample No.1 substantially exceeds sample No.2 (by 30.2%), which indicates that in conditions of high humidity and atmospheric influence, board No.2 will provide the best water absorption indicators.

Table 1 shows that the wear of sample No.1 substantially exceeds the wear of sample No.2, which indicates greater resistance to abrasion of board No.2. This is also due to reinforcement with metal elements.

The study of such an important indicator for decking as the change in linear dimensions under changing operating conditions showed that the elongation of 100 mm of WPC board No.1 was 0.72 mm and 1.6 mm, and sample No.2 – 0.5 mm and 0.3 mm. Consequently, sample No. 2 was more resistant to changes in linear dimensions under conditions of high humidity (92±3%) with the environment temperature of (40±2°C) and high temperatures (70±2°C) with low humidity. Notably, in general, this indicator of

WPC boards is largely unpredictable. An increase in temperature for every 10°F (≈3.6°C) accelerates the oxidative degradation of WPC by about three times. On a hot sunny day, at an air temperature of 90°F (32°C), the surface of WPC flooring heats up to approximately 130-140°F (54-60°C). At 110°F (43°C), the flooring surface temperature reaches 160°F (70°C), and the thermal oxidation of the polymer in WPC is accelerated by a factor of 240. Two powerful stabilising factors contribute to extending the service life of composite decking boards – the density of WPC and the introduction of antioxidants.

Conclusions

The obtained results of experimental studies allow the evaluation of the physical and mechanical parameters of WPC decking with various fillers. According to the results of the study, it was identified that the quality indicators of decking made of wood-polymer composite have a fairly high level and generally meet the established standards. Therewith, it is noted that WPC decking with a PE-based binder has worse performance, which can be explained to some extent by the presence of a large number of cavities. The presence of cavities indicates excessive moisture in the board or a lack of mineral fillers, and the destruction of the polymer. Thus, based on the conducted studies, it is possible to identify a number of clear dependencies that indicate that the use of polyvinyl chloride as a binder substantially improves the physical and mechanical performance of decking based on a wood-polymer composite.

The results of the conducted study will help solve the problems of improving the strength characteristics of wood-composite material to expand the range of goods based on wood waste.

References

- [1] Galiyev, I. M. (2015). *Creation of multilayer flooring based on wood-polymer composites*. Kazan [in Russian].
- [2] Khasanshin, R. R., Lashkov, V. A., Safin, R. R., & Valiyev, F. G. (2011). Heat treatment of wood filler in the production of composite materials. *Technological University Bulletin*, 20, 150–154 [in Russian].
- [3] Klesov, A. A. (2010). *Wood-polymer composites*. Sankt-Peterburg: Nauchnyye osnovy i tekhnologii [in Russian].
- [4] Lu, J. Z., Wu, Q., & Negulescu, I. I. (2005). Wood-fiber/high-density-polyethylene composites: Coupling agent performance. *J. Appl. Polym. Sci*, 96, 93–102. <https://doi.org/10.1002/app.21410>
- [5] Mazzanti, V., Pariante, R., Bonanno, A., Ruiz de Ballesteros, O., Mollica, F., & Filippone, G. (2019). Reinforcing mechanisms of natural fibers in green composites: Role of fibers morphology in a PLA/hemp model system. *Compos. Sci. Technol*, 180, 51–59. <https://doi.org/10.1016/j.compscitech.2019.05.015>
- [6] Mazzanti, V., Malagutti, L., Santoni, A., Sbardella, F., Calzolari, A., Sarasini, F., & Mollica, F. (2020). Correlation between mechanical properties and processing conditions in rubber-toughened wood polymer composites. *Polymers*, 12, 278. <https://doi.org/10.3390/polym12051170>
- [7] Mazzanti, V., Malagutti, L., Blanchard, M., Yi S., & Mollica, F. (2019). In-line rheological properties of rubber toughened Wood Polymer Composites. *IOP Conf. Ser. Mater. Sci.*, 634:012043. <https://doi.org/10.1088/1757-899X/634/1/012043>
- [8] Mazzanti, V., Cavalcoli, V., Balbo, A., & Mollica, F. (2019). Hygrothermal degradation effects on a rubber toughened WPC. *Mater. Today*. <https://doi.org/10.1016/j.matpr.2019.11.062>
- [9] Matseyevich, T. A., & Askadskiy A. A. (2017). Mechanical properties of a terrace board on the basis of polyethylene, polypropylene and polyvinylchloride. *Construction: science and education*, 3 (24), 48–49. <https://doi.org/10.22227/2305-5502.2017.3.4>
- [10] Safin, R. R., Galiyev, I. M., & Akhmadiyev, M. G. (2014). Modeling the properties of highly filled wood-polymer composite materials obtained by extrusion. *Kazan Technological University Bulletin*, 20, 150–154 [in Russian].
- [11] Yang, T. H., Leu, S. Y., Yang, T. H., & Lo, S. F. (2012). Optimized material composition to improve the physical and mechanical properties of extruded wood-plastic composites (WPCs). *Constr. Build. Mater*, 29, 120–127.

Щодо деяких механічних властивостей терасної дошки з деревинно-полімерних композитів із різним наповнювачем

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Анотація. Одним із напрямів перероблення деревинних відходів є їх використання у виробництві деревинно-полімерних композитів (ДПК). Актуальність деревинно-полімерних виробів зумовлено широким спектром застосування та якість цього матеріалу. ДПК не гниє, не ушкоджується комахами та грибами, не містить шкідливих в'язучих. Вироби з ДПК не розтріскуються, не жолобляться, водостійкі, що робить їх гарним матеріалом для виготовлення терасної дошки. Разом з тим, у терасної дошки мають бути певні механічні якості, що дасть змогу використовувати її в досить жорстких умовах – під дією вологи, УФ-випромінювання та з певним навантаженням. Це дослідження мало на меті визначення основних фізико-механічних характеристик (щільності, міцності на згин, модуля пружності, водопоглинання, твердості, стійкості на стирання, зміни лінійних розмірів при зміні атмосферного середовища) зразків терасної дошки, виготовленої з ДПК з різними наповнювачами. Для дослідження було відібрано зразки з пустотілої терасної дошки, у яких як наповнювач застосовано поліетилен (ПЕ) та полівінілхлорид (ПВХ). На основі проведених експериментальних досліджень було встановлено, що щільність обох зразків є достатньо високою, близькою до максимальної; різниця є несуттєвою, однак при дослідженні мікрорізів під мікроскопом у зразках, у яких як в'язуче застосовано ПЕ, спостерігається більша кількість порожнин, що свідчить про наявність зайвої вологи або нестачу мінеральних наповнювачів. Також це може бути ознакою деструкції полімеру. Визначено, що низка інших важливих показників, як-от міцність на згин, модуль пружності, водопоглинання, стійкість до стирання, найкращими виявилися у зразках із наповнювачем із полівінілхлориду. Найбільша різниця була у показника міцності на згин – 35 %. Також встановлено, що за твердістю обидва зразки виявилися рівнозначними. Проте модуль пружності у зразка з наповнювачем з ПЕ перевищив показники зразка з наповнювачем із ПВХ майже у 2,5 разу. Отже, на основі проведених досліджень можливо виявити низку чітких залежностей, які свідчать, що застосування полівінілхлориду як в'язучого значно покращує фізико-механічні показники терасної дошки на основі деревинно-полімерного композиту. Результати проведених досліджень дадуть змогу вирішувати проблеми покращення міцнісних характеристик деревинно-композиційного матеріалу для розширення асортименту на основі деревинних відходів

Ключові слова: щільність, твердість, модуль пружності, водопоглинання, стійкість до стирання

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Pulse drying of red oak wood workpieces

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Abstract. The reasons for reducing the cost of lamella made of oak wood – the front covering of floorboards – are determined. It is established that when drying oak wood at low temperatures, moisture accumulates in the area near the surface – the so-called conditional source of moisture. This leads to the development of light spots inside the lumber, which were stored for a long time in conditions of increased air humidity and had a low rate of moisture removal. It is proposed to intensify the drying process by using pulse modes, which consist of periods of heating and cooling of wood to avoid this defect. During the heating period, the temperature of the material gradually increases, the wood receives a thermal shock and accumulates heat, and drying occurs only due to the humidity gradient. During cooling, the temperature of the medium decreases, the degree of saturation increases and, accordingly, the equilibrium humidity increases. As a result, the surface layers of the material are moistened, moisture is levelled along the thickness of the wood, and drying stresses are relaxed. Experimental studies of pulse drying of workpieces made of red oak wood with a thickness of 30 mm and 50 mm were conducted in laboratory conditions. The amplitude of the temperature fluctuation – 30°C and the expediency of cyclic heating are determined only until the average humidity of the material reaches 20%, after which the wood must be dried to the required final humidity at a constant heating temperature. A method for calculating the duration of pulse drying is proposed, which considers the kinetics of heating and cooling periods of red oak lumber products with a thickness of 30 mm and 50 mm. It is recommended to consider the process of temperature change kinetics as the sum of the processes of cyclic heating, which occurs according to the polynomial dependence, and cyclic cooling, which occurs according to the exponential dependence. It is determined that the ratio of the duration of cyclic heating to the duration of cyclic cooling is 1/3. Using heat and mass transfer criteria and the experimentally determined moisture conductivity coefficient of red oak wood, an adequate model for calculating wood temperature and relative humidity during wood heating and cooling cycles was developed. Based on the results of theoretical and experimental studies, pulsed drying modes of red oak workpieces of various thicknesses are proposed, which prevent the development of white spots inside the material. There was a reduction in the process duration by 1.5-2.4 times and a reduction in energy consumption by 1.53 times. The indicators of residual stresses, the values of the stress difference in the workpieces after drying, and the values of the static flexural strength determined experimentally showed that their drying quality corresponds to the first quality category according to DSTU 4921:2008. Comparison of the obtained values with the maximum permissible values of the tensile strength across the fibres in the tangential direction $\sigma_m = 6.5$ MPa showed a safety margin of 25%, which indicates the possibility of using pulse drying modes for high-quality drying of workpieces made of red oak wood

Keywords: Red Oak (*Quercus rubra*), coefficient of moisture conductivity, pulse modes, drying quality, drying time

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Introduction

Among manufacturers of floor coverings, the fast-growing introduction of red oak (*Quercus rubra*) is gaining popularity today. Red oak covers an area of 2251 hectares in the forests of the State Forestry fund of Kyiv Polesia (Poliakova, 1999).

Parquet billet, made of solid wood and coatings in the form of parquet boards, consisting of several layers and having a front coating in the form of slats made of solid hardwood are considered floor coverings. In the technology of manufacturing lamella, the following methods are used: pre-cutting of lumber to slats and its subsequent drying, accompanied by substantial labour costs for the formation of drying sets, and pre-drying of lumber with subsequent production of lamella.

Today, convection chambers heated with hot water are used for drying lumber. When drying oak wood at low temperatures, moisture accumulates in the area near the surface – the so-called conditional source of moisture (Pinchevska, Spirochkin, Sedliacik & Oliynyk, 2016). This leads to the development of light spots inside the lumber, which were stored for a long time in conditions of increased air humidity and had a low rate of moisture removal. The development of stains reduces the cost of the lamella. It is possible to get rid of this defect by intensifying the drying process by increasing the temperature of the drying agent. However, prolonged exposure to high temperatures $t_{heat} > 60^{\circ}\text{C}$ for wood with a humidity greater than $W > 30\%$ contributes to a sharp decrease in its strength. Because of this, it became necessary to develop rational modes for the drying process of lumber made from red oak wood.

The removal of moisture from hard hardwoods is characterised by certain features: a substantial duration of the process; fastidiousness to the drying regime parameters due to temperature and humidity limits; the risk of defects or discolouration during the drying process, etc. (Pinchevska, Koval & Marchenko, 2012; Wegener & Fengel, 1987). This is primarily due to the anatomical structure of wood – substances that form the microstructure of these species (Vintoniv & Uholiev, 2007).

One of the ways to intensify the drying process of lumber is the use of pulse modes, the essence of which is to alternate periods of heating and cooling (Miliü & Kolin, 2008; Remond & Perre, 2008). During pulsed drying, the heating and cooling cycles play different roles in heat and mass transfer processes (Lykov, 1956). During the heating period, the temperature of the material gradually increases, the wood receives a thermal shock and accumulates heat, and drying occurs only due to the humidity gradient. During cooling, the temperature of the medium decreases, the degree of saturation increases and, accordingly, the

equilibrium humidity increases. The temperature inside the wood exceeds the temperature of the surface layers. Due to this difference, a positive temperature gradient occurs in the wood, which leads to the migration of moisture from more heated layers to less heated ones. As a result, the surface layers of the material are moistened, moisture is levelled along the thickness of the wood, and drying stresses are relaxed (Pleschberger, Hansmann, Mueller & Teischinger, 2013). Since no energy is consumed during the cooling period of wood, this leads to a substantial reduction in its usage (Kosarin, 2012; Miliü & Kolin, 2008) and a 24% reduction in the prime cost of the process (Kosarin, 2012). Mixed opinions are expressed about the effect of periodic heating on the drying time, in particular, the reduction of the process duration by 1.5-2 times for beech and oak wood is indicated in (Lubovitsly, 1986), the opposite opinion is highlighted in the papers (Bond & Espinoza, 2016; Salin, 2003). However, all researchers note an improvement in the quality of drying.

It is necessary to consider the temperature and humidity of the drying agent during heating, determine the safe amplitude of temperature fluctuations for the drying quality, and the influence of the heating temperature level on the mechanical properties of the material to determine the quantitative values of the parameters of pulsed drying modes of lumber. The frequency of heating-cooling cycles during drying should be conducted only during the period when the wood contains Free Moisture. Further application of such cycles does not affect the rate of removal of bound moisture (Pleschberger, Hansmann, Mueller & Teischinger, 2013; Miliü & Kolin, 2008). After the wood reaches humidity $W = 20\%$ the temperature of the drying agent should be maintained at a constant level until the lumber reaches the specified final humidity (Welling, Riehl & Zerhau, 2004; Folvik & Magnar, 2004).

The creation of pulsed modes is based on the principle of intermittent processes observed during atmospheric drying or drying using solar energy in solar dryers (Tepnadse, 1986; Hasan & Langrish, 2016), when the wood is heated during the day and cooled at night. The use of pulse modes, in contrast to drying in solar dryers, allows adjusting the parameters of the drying agent depending on the characteristics of the dried material. The difficulty lies in determining rational modes since the known analytically calculated parameters differ both in the level of temperature and the amplitude of its fluctuations, the level of relative humidity, the duration of the “heating – cooling” cycles, even for lumber of the same species and thickness (Kosarin, 2012; Shyshkina, 2006). Thus, today, there are no theoretically confirmed and experimentally verified modes

of intensive drying of red oak wood that would not cause the formation of a so-called conditional source of moisture, which causes the appearance of light spots in the inner layers of lumber.

The purpose of the study is to determine the parameters of a rational drying mode for lumber made of red oak wood in the process of pulse drying, which will ensure high-quality drying of wood with the preservation of mechanical properties.

Materials and Methods

Red oak workpieces without visible defects with a thickness of 30 mm and 50 mm were selected, which corresponds to the thickness of industrial lumber, which is most often used in lamella manufacturing technology to analyse the main operating parameters. The width of the experimental samples was 85-90 mm, and the average initial humidity ranged between 45-50%. The samples were dried to a humidity of 7-8%. Drying was conducted in a laboratory drying device with a loading volume of 0.12 m³ of dense material equipped with an automatic process control system

that maintains the drying agent circulation rate at 1.2 m/s. The temperature inside the samples was measured using thermocouples. Saturated steam was supplied to the chamber to avoid rapid removal of moisture and, accordingly, cracking of the material during heating.

The DSTU 4921:2008 and ENV 14464:2002 methods were used to calculate the internal stress index of dried workpieces based on the relative deformation of the teeth of power sections. The values of the elastic modulus and elastic deformations were determined according to the method presented in a paper (Uholiev, 2007).

Determination of the mechanical properties of dried wood (tensile strength and elastic modulus under static bending) was performed in accordance with the instructions of the standard method (EN 408:2010) using the P-5 testing machine. The tests were conducted indoors at an air humidity of 65±5% and an environment temperature of 20±2°C.

The hypothesis of oscillatory drying kinetics is proposed to calculate the rational parameters of the drying mode, which consists in representing the temperature change of the material according to the sinusoidal law:

$$t_{surf} = t_{mid} + A_t \cdot \sin\left(\frac{2\pi}{\tau_{per}} \cdot \tau_{dr}\right) + \frac{1}{2}(t_a - t_{in})Ki \cdot \varepsilon \cdot Ko \cdot Ly, \quad (1)$$

where t_{surf} – wood surface temperature, °C; t_{mid} – arithmetic mean of the heating and cooling temperature values, °C; A_t – oscillation amplitude, °C; τ_{per} – duration of one cycle (heating–cooling), h; τ_{dr} – duration of the drying process, h; t_a – environment temperature, °C; t_{in} – initial wood temperature, °C; Ki – Kirpichev criterion (Lykov, 1956); ε – coefficient of phase transformation of moisture (Horokhovskiy, 2008); Ko – the Kosovich criterion (Lykov, 1956); Ly – Lykov criterion (Lykov, 1956).

It is necessary to have quantitative values of the moisture conductivity coefficients of oak wood, which are determined experimentally to determine the quantitative values of the Lykov criterion Ly and the Kirpichev criterion Ki . The contact humidification method was used (Serhovskiy & Rasev, 1987; Alpatkina, 1970) to determine the coefficients of moisture conductivity. For this purpose, samples of red oak wood originating from the Polesia zone – the largest area of oak forests in Ukraine were selected. The total number of experiments considering the obtained (Alpatkina, 1970) coefficient of variation $V_{a'} = 7.7\%$ was 32 pcs. Other components of the above-mentioned criteria and the coefficient of phase transformation of moisture were determined by known dependencies (Vintoniv,

Sopushynskiy & Teischinger, 2007; Horokhovskiy, 2008; Kosarin, 2012; Shubin, 1990; Ozarkiv & Kopynets, 2006).

Results and Discussion

The parameters of the pulse drying mode were determined empirically. The parameters of the drying agent during heating were as follows: temperature $t = 100^\circ\text{C}$, relative humidity – $\varphi = 90\text{-}100\%$. The heating duration is determined by reaching the temperature of the centre of the workpieces $t_{cen} = 85^\circ\text{C}$. A study of the duration of the process was conducted in the case of reaching different cooling temperature levels ($t_{cool1} = 25^\circ\text{C}$, $t_{cool2} = 55^\circ\text{C}$, and $t_{cool3} = 70^\circ\text{C}$) to determine the rational amplitude of temperature fluctuations. It is determined that the highest rate of moisture removal from samples is characteristic of the amplitude of fluctuations in the sample temperature period equal to 30°C , similar to the results obtained in the studies (Zakharzhevskiy, 1948; Minhazov & Kachalin, 1976).

The hypothesis of temperature change according to the sinusoidal law does not correspond to experimental data, while the duration of heating the material is almost 3 times shorter during cooling (Fig. 1).

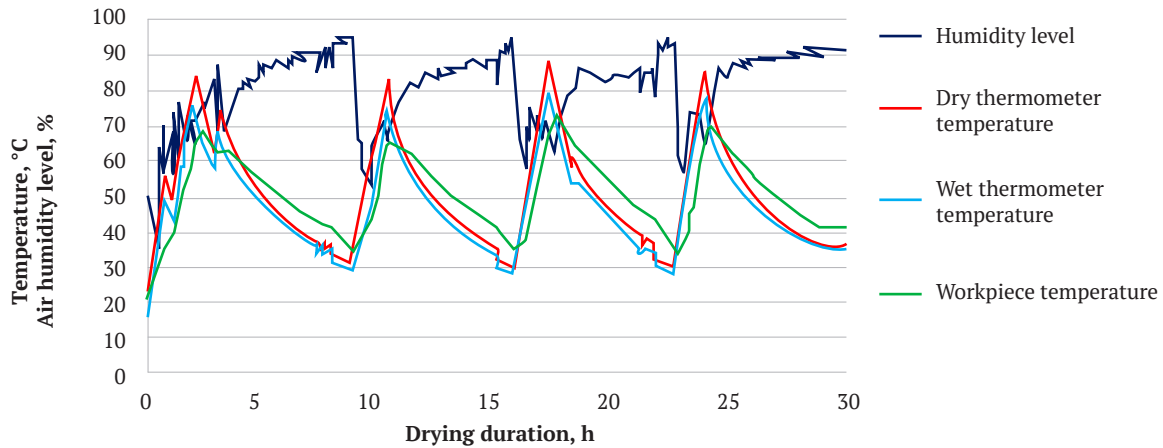


Figure 1. Factual values of the parameters of the drying mode of red oak with a thickness of 50 mm at the initial stage

Experimental data on the kinetics of temperature changes (Fig. 2) showed that the heating period is polynomial dependent, and the cooling period is exponential. According to the differences in the kinetics of changes in the surface temperature of samples corresponding to the temperature of a wet piece during the heating period $t_{sur.heat}$, h, and cooling $t_{sur.cool}$, h, the hypothesis of the sinusoidal law of its change was adjusted. It is proposed to consider separate periods of heating and cooling:

$$\begin{cases} t_{surf.heat} = t_{cen.heat} + \frac{1}{2} \cdot (t_c - t_{cen.cool}) \cdot K i_m \varepsilon K o L u, \\ t_{surf.cool} = t_{cen.cool} + \frac{1}{2} \cdot (t_c - t_{cen.heat}) \cdot K i_m \varepsilon K o L u, \end{cases} \quad (2)$$

where $t_{cen.heat}$, $t_{cen.cool}$ – temperature of the central part of the workpieces during the heating and cooling period, respectively, °C.

Total drying time τ_{dry} , h, according to the proposed mode, is advisable to be determined by the total number of cycles consisting of the sum of heating periods τ_{heat} , h, cooling τ_{cool} , h, and continuous heating period τ_{cont} , h (from humidity $W = 20\%$ to final humidity $W_f = 6-10\%$):

$$\tau_{cyw} = n \cdot (\tau_{heat} + \tau_{cool}) + \tau_{cont}, \quad (3)$$

where n – number of cycles of the oscillating drying process, pcs.; τ_{heat} – heating duration, h; τ_{cool} – duration of the

cooling process, h; τ_{cont} – duration of drying with continuous heating to the operational humidity of the material from humidity $W = 20\%$, h.

The following equation was used (Serhovskiy & Rasev, 1987) to determine the last drying period at constant temperature:

$$\tau_{cont} = \frac{3600 \cdot S^2}{\pi^2 \cdot a'} \ln\left(\frac{W_{in} - W_{eq}}{W_f - W_{eq}}\right), \quad (4)$$

where a' – coefficient of moisture conductivity, cm^2/s ; W_{in} , W_f , W_{eq} – initial, final, and equilibrium humidity, respectively, %; S – material thickness, cm.

An empirical equation is proposed to determine the number of heating-cooling cycles depending on the thickness of the material and the initial humidity:

$$n = (14 \cdot W_{in} - 85) \cdot S + 0,033 \cdot W_{in} - 5,623. \quad (5)$$

Checking the obtained equation for the substantiated level of 5% confirmed the adequacy of the model (according to the Student's criterion $t_{calc} = 0.01 < t_{table} = 2.05$; according to the Fischer criterion $F_{calc} = 1.10 < F_{table} = 2.98$).

Considering the specific features of the kinetics of heating and cooling cycles, the regression equation of the drying duration of the material during pulsed heating is presented as:

$$\begin{cases} \tau_{heat} = ((0,005 \cdot S - 0,0012) \cdot W_k + 0,65 \cdot S + 0,05) \cdot t_{heat} + \\ + (0,14 - 2,00 \cdot S) \cdot W_k + 75,05 \cdot S - 6,54; \\ \tau_{cool} = ((1,65 \cdot S - 0,069) \cdot \ln(W_k) - 10,17 \cdot S + 0,264) \cdot t_{cool} + \\ + (4,08 - 86,48 \cdot S) \cdot \ln(W_k) + 474,92 \cdot S - 10,09, \end{cases} \quad (6)$$

where W_f – final moisture content of the material, %; t_{heat} , t_{cool} – heating and cooling temperatures, respectively (according to Table 1), °C.

Verification of theoretical equations for the duration of heating and cooling cycles (Fig. 2) confirmed the adequacy of the models (Table 1).

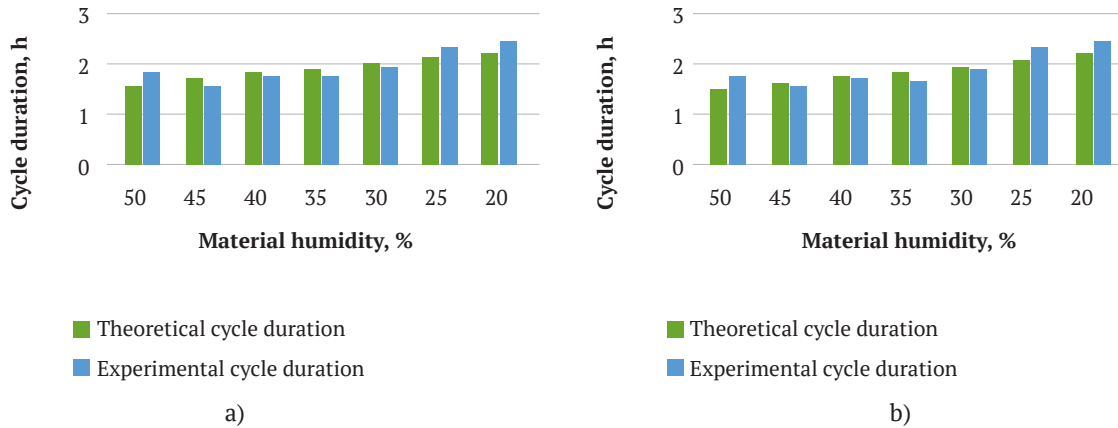


Figure 2. Comparison of experimental and calculated duration of drying cycles of 50 mm thick red oak workpieces: a – heating; b – cooling

Table 1. Results of checking the adequacy of models for duration values for different drying periods

Species	Drying period	Student's <i>t</i> -criterion		<i>F</i> -Fischer criterion	
		t_{calc}	t_{crit}	F_{calc}	F_{table}
Red oak heating	cooling	0.41	2.07	1.31	2.82
	heating	0.41	2.07	1.31	2.82

The following equation of the treatment in different periods of pulsed drying to determine the degree of saturation ϕ agent is proposed:

$$\begin{cases} \phi_{heat} = 100^{1-(0,006+10^{-5}(120-t_c)^{1,46}) \cdot (t_c-n \cdot t_{cen_{heat}} + \frac{1}{2}(t_c-t_0) \cdot Ki_m \varepsilon KOLu)^{1,074+10^{-17}(146-t_c)^{7,77}}} \\ \phi_{cool} = 100^{1-(0,006+10^{-5}(120-t_c)^{1,46}) \cdot (t_c-n \cdot t_{cen_{cool}} + \frac{1}{2}(t_c-t_0) \cdot Ki_m \varepsilon KOLu)^{1,074+10^{-17}(146-t_c)^{7,77}}} \end{cases}, \quad (7)$$

where t_{env} – environment temperature of the drying chamber, °C.

The values of medium base density of red oak wood – $\rho_b = 570 \text{ kg/m}^3$, and also dependences of moisture conductivity coefficients on the temperature in the tangential and radial directions obtained experimentally are used to calculate the corresponding criteria in equations (2) and (7):

- for the radial direction:

$$a' = (0,1491 \cdot t - 3,4210) \cdot 10^{-6}, \quad (8)$$

- for the tangent direction:

$$a' = (0,1203 \cdot t - 2,9170) \cdot 10^{-6}. \quad (9)$$

In accordance with the obtained results of theoretical and experimental studies, pulsed drying modes of workpieces made of red oak wood are proposed (Table 2).

Table 2. Recommended pulse drying modes for red oak wood

Average humidity, %	Mode parameters	Lumber thickness, mm	
		30	50
1%	Environment temperature t_{env} , °C	100	80
	Workpiece temperature t_{heat} , °C	85	65
	Cooling temperature t_{cool} , °C	55	35
	Degree of air humidity ϕ , %	95	95
30-25	Environment temperature t_{env} , °C	100	80
	Workpiece temperature t_{heat} , °C	85	65
	Cooling temperature t_{cool} , °C	55	35
	Degree of air humidity ϕ , %	50	79

Table 2. Continued

Average humidity, %	Mode parameters	Lumber thickness, mm	
		30	50
25-20	Environment temperature t_{env} , °C	100	80
	Workpiece temperature t_{heat} , °C	85	65
	Cooling temperature t_{cool} , °C	55	35
	Degree of air humidity φ , %	38	55
20-15	Environment temperature t_{env} , °C	100	80
	Degree of air humidity φ , %	35	40
<15	Environment temperature t_{env} , °C	100	80
	Degree of air humidity φ , %	35	38

According to the results of drying by the proposed modes, it was identified that no unacceptable defects were observed in the workpieces of thicknesses, the wood colour

became darker, and the texture was more clearly manifested. After cutting the lumber, no white spots were identified on the lamella (Fig. 3).



Figure 3. The surface of lamella made of oak wood, dried in various modes: a) low-temperature with the presence of white spots; b) cyclic – with a uniform colour

Comparison of the obtained results of the drying duration according to the proposed pulse modes with the calculated values of the drying duration according to conventional continuous modes (Serhovskiy & Rasev, 1987) showed a reduction in the process duration by 1.5-2.4 times, depending on the thickness of the workpieces.

According to the relative deformation of the power sections, it was determined that dried workpieces correspond to the first category of drying quality according to

DSTU 4921: 2008 in terms of the assessment of internal stresses. The stress plots were visualised (Fig. 4) and the values of the voltage drop after drying are determined by the mode given in Table 2 to quantify the stress state of red oak samples with a thickness of 50 mm. Comparison of the obtained values with the maximum permissible values of the tensile strength across the fibres in the tangential direction $\sigma_m = 6.5$ MPa showed a safety margin of 25%, that is, dried workpieces should not deform during further processing.



Figure 4. Diagram of residual stresses of sample No.2

When testing dried workpieces for static bending, it was identified that after reaching the maximum load, the samples retained their shape for a certain time before final destruction. The maximum fracture load at the factual humidity of the sample dried in the classical continuous mode and the developed pulse mode was 3.1 kH and 3.8 kH, respectively. Consequently, short-term exposure to elevated temperatures of the drying agent did not affect the mechanical properties of 50 mm thick red oak samples.

Conclusions

Based on the conducted theoretical and experimental studies of pulse drying of workpieces made of red oak wood, rational modes are proposed that allow for avoiding

the appearance of white spots inside the workpieces. It is determined that the values of the ultimate strength for static bending of dried workpieces made of red oak wood are 15.0% higher than the values of the ultimate strength for wood that was dried according to the classical low-temperature regime.

It is advisable to implement the developed oscillatory modes in non-heater drying units, the advantage of which is low inertia in temperature, that is, the dryer heats up and cools down quickly. The use of the developed modes of oscillatory drying in such chambers, tested in industrial conditions, provides economic efficiency by reducing the drying time and reducing energy costs by up to 40%.

References

- [1] Alpatkina, R. P. (1970). *Investigation of the moisture conductivity of wood of the main native species*. Moscow [in Russian].
- [2] Bond, B. H., & Espinoza, O. (2016). A Decade of Improved Lumber Drying Technology. *Current Forestry Reports*, 2 (2), 106–118. <https://doi.org/10.1007/s40725-016-0034-z>
- [3] EN 408:2010 - Timber structures - Structural timber and glued laminated timber - Determination of some physical and mechanical properties. iTeh Standards Store. (n.d.). <https://standards.iteh.ai/catalog/standards/cen/5adc63d2-e164-4b6e-9c2d-64dd8a9d6f19/en-408-2010>.
- [4] Folvik, K., & Magnar, S. K. (2004). *Various wood properties influencing the development of checks in knots during drying*. Advances in drying of wood. NTI-papers from COST-E15 seminars 2000-2004. 99 p.
- [5] Hasan, M., & Langrish, T. A. (2016). Development of a sustainable methodology for life-cycle performance evaluation of solar dryers. *Solar Energy*, 135, 1–13. <https://doi.org/10.1016/j.solener.2016.05.036>
- [6] Hasan, M., & Langrish, T. A. (2016). Time-valued net energy analysis of solar kilns for wood drying: A solar thermal application. *Energy*, 96, 415–426. <https://doi.org/10.1016/j.energy.2015.11.081>
- [7] Horokhovskiy, A. H. (2008). *Lumber drying technology based on modeling and optimization of heat and mass transfer processes in wood*. Ekaterinburh [in Russian].
- [8] Kosarin, A. A. (2012). *Impulse drying technology for sawn timber*. Moscow [in Russian].
- [9] Lubovitsky, P. V. (1986). *Drying of wood with cyclic heating (experience of enterprises)*. Moscow [in Russian].
- [10] Lykov, A. V. (1956). *Heat and mass transfer during drying*. Moscow: Hosenerhoizdat [in Russian].
- [11] Miliü, G., & Kolin, B. (2008). Oscillation drying of beech timber – initial experiments. End user’s needs for wood material and products. *The Netherlands*, 115–124.
- [12] Minhazov, M. H., & Kachalin, N. V. (1976). *Oscillating schedules of sawn timber drying*. Moscow [in Russian].
- [13] Ozarkiv, I. M., Kopynets, Z. P., & Atsberher, Y. L. (2006). Methods of research of Kirpichov’s criterion as the main criterion of formation of cracks during the process of wood convective drying. *Nauovyy Visnyk NLTU Ukraine*, 16.2, 81–85 p. [in Ukrainian].
- [14] Pinchevska, O., Spirochkin, A., Sedliačik, J., & Oliynyk, R. (2016). Quality assessment of lumber after low temperature drying from the view of stochastic process characteristics. *Wood Research*, 61 (6), 871–883.
- [15] Pleschberger, H., Hansmann, C., Müller, U., & Teischinger, A. (2013). Fracture energy approach for the identification of changes in the wood caused by the drying processes. *Wood Science and Technology*, 47 (6), 1323–1334. <https://doi.org/10.1007/s00226-013-0578-z>
- [16] Poliakov, O. H. (1999). *Biotechnological features of red oak (Quercus rubra L) in artificial plantations of Kyiv Polissya*. Kyiv [in Ukrainian].
- [17] Remond, R., & Perre, P. (2008). Drying strategies capable of reducing the stress level of a stack of boards as defined by a comprehensive dual scale model. *Maderas Ciencia y Tecnología*, 10, 3–18.
- [18] Salin, J.-G. (2003). A Theoretical Analysis of Timber Drying in Oscillating Climates. *Holzforchung*, 57 (4), 427–432. <https://doi.org/10.1515/hf.2003.063>
- [19] Serhovskiy, P. S., & Rasev, A. I. (1987). *Hydrothermal treatment and wood preservation*. Moscow: Lesnaya promyshlennost [in Russian].
- [20] Shubin, G. S. (1990). *Drying and heat treatment of wood*. Moscow: Lesnaya promyshlennost [in Russian].
- [21] Shyshkina, E. E. (2006). *Drying of lumber in low capacity chambers with natural air circulation*. Ekaterinburh [in Russian].
- [22] Tepnadze, M. U. (1986). *Schedules and technology of lumber drying in solar dryers*. Moscow [in Russian].
- [23] Ugolev, B. N. (2007). *Wood science and forestry commodity science: Textbook*. Moscow: HOU VPO MHUL [in Russian].
- [24] Vintoniv, I. S., Sopushynsky, I. M., & Teishinger, A. (2007). *Wood science*. Lviv: Apriori [in Ukrainian].
- [25] Wegener, G., & Fengel, D. (1987). Investigation on colour changes resulting from drying of European oakwood. *Fourth International Symposium on Wood and Pulp Chemistry*, 27 (30), 121–123.
- [26] Welling, J., Reihel, T., & Zerhau, W. (2004). *Oscillating Drying Conditions*. Technical report.
- [27] Zakharzhevskiy, V. H. (1948). *High-speed wood drying*. Moscow: Timber industry [in Russian].

Імпульсне сушіння заготовок із деревини дуба червоного

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Анотація. Визначено причини здешевлення виготовленої з деревини дуба ламелі – лицьового покриття дошок для підлоги. Встановлено, що під час сушіння деревини дуба за низьких температур виникає накопичення вологи у зоні біля поверхні – так зване умовне джерело вологи. Це призводить до утворення світлих плям усередині пиломатеріалів, які довгий час зберігались в умовах підвищеного ступеня насичення повітря та мали низьку швидкість видалення вологи. Для уникнення цього дефекту запропоновано інтенсифікувати процес сушіння шляхом використання імпульсних режимів, які складаються з періодів нагрівання та охолодження деревини. У період нагрівання температура матеріалу поступово підвищується, деревина отримує тепловий удар і накопичує тепло, сушіння відбувається лише за рахунок градієнта вологості. Під час охолодження температура середовища знижується, ступінь насичення зростає і, відповідно, підвищується рівноважна вологість. У результаті поверхневі шари матеріалу звожуються, волога по товщині деревини вирівнюється, відбувається релаксація сушильних напружень. У лабораторних умовах проведено експериментальні дослідження імпульсного сушіння заготовок із деревини дуба червоного товщиною 30 мм і 50 мм. Визначено амплітуду коливання температури – 30 °C та доцільність проведення циклічного нагрівання лише до досягнення середньої вологості матеріалу 20 %, після чого деревину потрібно висушувати до необхідної кінцевої вологості за сталої температури нагрівання. Запропоновано метод розрахунку тривалості імпульсного сушіння, який враховує особливості кінетики періодів нагрівання і охолодження пилопродукції з деревини дуба червоного товщиною 30 мм і 50 мм. Рекомендовано розглядати процес кінетики зміни температури як суму процесів циклічного нагрівання, що відбувається за поліноміальною залежністю, та циклічного охолодження, що відбувається за експоненціальною залежністю. Визначено, що співвідношення тривалості циклічного нагрівання до тривалості циклічного охолодження становить 1/3. З використанням тепломасообмінних критеріїв та визначеного експериментальним шляхом коефіцієнта вологопровідності деревини дуба червоного розроблено адекватну модель розрахунку температури деревини та відносної вологості повітря протягом циклів нагрівання та охолодження деревини. На основі отриманих результатів теоретичних і експериментальних досліджень запропоновано імпульсні режими сушіння заготовок дуба червоного різної товщини, які запобігають утворенню білих плям усередині матеріалу. Зауважено скорочення процесу у 1,5-2,4 рази та зменшення енерговитрат у 1,53 рази. Визначені експериментальним шляхом показники залишкових напружень, величини перепаду напружень у заготовках після сушіння та величини межі міцності на статичний згин показали, що якість сушіння їх відповідає I категорії якості згідно з ДСТУ 4921:2008. Порівняння отриманих значень із максимально допустимими значеннями межі міцності на розтяг поперек волокон у тангенціальному напрямку $\sigma_m = 6,5$ МПа показало запас міцності 25 %, що свідчить про можливість застосування імпульсних режимів сушіння для якісного сушіння заготовок із деревини дуба червоного

Ключові слова: дуб червоний (*Quercus rubra*), коефіцієнт вологопровідності, імпульсні режими, якість сушіння, термін сушіння

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Influence of growing conditions on changes in the species composition of mycobiota of scots pine seeds

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Abstract. The species composition of Scots pine seeds collected from plantings growing in different forest conditions and selected from trees of different age groups is investigated. It is identified that the seeds most often encountered micromycete species – *Alternaria alternata*, *Cladosporium cladosporioides*, *Fusarium oxysporum*, *Mycelia sterilia*. Dominant micromycete species are identified, in particular, *Penicillium cyclopium*, *Alternaria alternata*, *Cladosporium cladosporioides*, *Fusarium sambucinum*, which are most dangerous for the development of healthy planting material. The largest number of micromycetes from seeds of plantings growing in wet (A_3) – 189 species and fresh pine barrens (A_2) – 103 micromycetes, and the smallest – fresh (B_2) and wet su-barrens (B_3), respectively 92 and 93 isolates. *Micromycetes Penicillium cyclopium*, *Alternaria alternata*, *Trichothecium roseum* had the highest occurrence frequency on experimental samples of Scots pine seeds selected from fresh barren plantations, and the lowest – *Mortierella alpine*, *P. canescens*, *P. lanosum*, *P. variabile*, *Fusarium sporotrichioides*. Notably, *Mycelia sterilia* (9.2%) and *Fusarium sporotrichioides* (9.6%) were most often identified on seeds selected from trees of different age groups, while the least often ones were *Alternaria alternata*, *A. tenuissima*, *Fusarium verticillioides*, *Trichothecium roseum* – 1.9%. The similarity of the species composition of mycobiota seeds selected from young and medium-aged plantings (similarity indicator – 84.2%) and medium-aged and mature ones (similarity indicator – 89.4%) was investigated. Less similarity was observed between the species composition of fungi identified on seeds selected from young and mature plantings (the similarity rate is 73.6%). The seeds of middle-aged and mature plantings were the most similar, and the seeds of young and mature ones were the least similar. Therewith, seeds selected from different age groups are different in the species composition of micromycetes (the similarity varied in the range of 73.6-89.4%)

Keywords: age groups of trees, mycobiota, type of forest conditions, micromycetes, Scots pine

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Introduction

Scots pine, like many other coniferous tree species, is naturally restored only by seed. Phytopathogenic fungi that cause seed diseases are given special attention in forestry production, since their presence on seeds, even in hundredths of a per cent of the total number of microorganisms, poses a real threat during its germination. Therefore, the study of mycobiota seeds is relevant, and its quality class is the key to the formation of stable and productive pine plantations (Bojko & Bashta, 2015). The seed quality class may decrease if the seeds are infected with pathogens (Bilaj, 1984; Bilaj, 1998). On growing trees, the seeds are protected by cone scales and, with timely harvesting, are almost not affected by pathogens from the outside. Seeds of unopened cones are 100% healthy, but have their own microflora, including pathogenic (Rozenfeld, 2005).

The wide ecological plasticity of fungi according to the method of nutrition and substantial biodiversity allows them to occupy almost all niches of the forest phytocenosis, to ensure the circulation of substances in the biocenosis. It is known that the oldest form of existence of fungi is a saprotrophic way of life, and the transition to parasitism in them occurred in the process of long-term evolutionary development (Patyka, 2007). According to the degree of parasitic activity and lifestyle, groups of fungi are distinguished, which are located at different stages of the evolutionary ladder (Bilokin, 1995).

Evidently, even in natural conditions, the species and form diversity of mycological and microbiological groups of Scots pine is directly related to the diet (all other conditions being equal). It is known that the plant selects its own myco- and micro-complex, and it is quite likely that this is due to the nutrition of the plant. Myco- and micro-organisms are characterised by selectivity to certain organic and mineral compounds, and their ratio substantially affects mycobiota (Pidoplichko, 1977; Pidoplichko, 1991).

According to the study by Sandul (2010), crops created from dark seeds in barren conditions are characterised by more intensive growth, are better adapted to growth in them, and are much more promising for reforestation and afforestation. According to Bojko & Puzrina (2015), forest conditions substantially affect the quality indicators of the seed quality class. Seeds collected in fresh su-barren plantings (B_2) had the highest germination rate ($91.0 \pm 2.1\%$). Its germination energy was also higher ($81.3 \pm 1.5\%$). Seeds collected from fresh and wet pine barren plantings had germination rate and germination energy indicators on average 4-15% lower than seeds, which in studies represent the conditions of fresh and wet soil. Seeds selected from plantings in wet su-barren conditions (B_3), were characterised

by high germination energy ($83.1 \pm 1.1\%$) and germination rate ($89.2 \pm 1.5\%$). Seeds obtained from trees that grew in wet forest A_3 conditions, achieved a germination rate of $85.0 \pm 1.8\%$ and had germination energy of $78.4 \pm 1.7\%$. Therewith, there was no substantial difference in seed germination rate from trees of different age groups. In particular, the germination energy of seeds selected from young plantings was $76.5 \pm 2.1\%$, medium-aged – $76.0 \pm 1.3\%$, mature – $79.3 \pm 2.1\%$, its germination rate – $85.0 \pm 1.8\%$, $85.0 \pm 1.5\%$, $87.5 \pm 1.8\%$ accordingly.

Some authors, in particular, Antonova (1990), note that seeds from young trees are not inferior to seeds from older plantings. This is confirmed by the study by Reshetnik (2010), which noted that at least at a young age (up to 25 years) there is such a hereditary property. According to the results obtained by the researcher, the germination rate, germination energy, and seed mass from young Scots pine trees were higher compared to the same indicators of seeds of 100–120-year-old trees.

Naturally, the conditions from which seeds are selected substantially affect the qualitative and quantitative indicators (Bojko & Puzrina, 2015). Considering this, the studies were conducted to identify micromycetes of different forest conditions and age groups, which, according to the data, have different species composition.

The purpose of the study is to analyse the species composition of mycobiota seeds collected from plantings growing in different forest conditions and from trees of different ages.

The object of research – mycobiota of Scots pine seeds selected from seeds of different forest conditions and age groups of trees.

The subject of research – species composition of mycobiota of Scots pine seeds.

The study objectives – determine the species composition of automycobiota of Scots pine seed batches from different forest-growing conditions (fresh barren – A_2 , wet barren – A_3 , fresh su-barren – B_2 , wet su-barren – B_3) and from trees of different ages (young, middle-aged, mature).

Materials and Methods

During the study, special scientific methods were used: mycological and phytopathological – to isolate myco- and microorganisms from seeds and further examine pathogenic, cultural, antagonistic properties.

The research material was Scots pine seeds (*Pinus sylvestris* L.), collected in plantings of different ages (young, middle-aged, mature) and different types of forest-growing conditions (FGC) (wet barren (A_3), fresh barren (A_2), fresh su-barren (B_2), wet su-barren (B_3)).

The study was conducted in the problem laboratory “Phytopathology and Mycology” of the V.F. Peresykin Department of Phytopathology of the National University of Life and Environmental Sciences of Ukraine.

For the study, agarised differential diagnostic nutrient media optimal for the growth and development of individual physiological groups of microorganisms were used: meat-peptone agar (MPA) – for bacteria; Czapek medium – for mycelial fungi; potato-glucose agar (PGA) – for mycelial fungi and yeast.

Scots pine seeds were disinfected with a 0.5% solution of Potassium permanganate enzyme for 20 minutes, washed with sterile tap water, after which the test material

was sown on agarised nutrient media or laid out on filter paper under sterile conditions to isolate mycobiota. The crops were incubated in triple repetition at a temperature of 26-28°C for 5-7 days. Counting of colonies began 3-4 days after seeding of the test sample and performed 2-3 accounts with an interval of 1-2 days.

Results and Discussion

The largest number of micromycetes was identified on seeds collected in wet (A_3) – 189 species and fresh pine barrens (A_2) – 103 micromycetes, while the smallest was from the fresh (B_2) – 92 types and wet su-barrens (B_3) – 93 isolates (Table 1).

Table 1. Mycobiota of Scots pine seeds harvested from trees in various types of forest conditions, %

Types of micromycetes		FGC				occupancy rate, %
		fresh barren – A_2	wet barren – A_3	fresh su-barren – B_2	wet su-barren – B_3	
		occurrence frequency, %				
1	<i>Mortierella alpina</i>	3.45	–	–	–	25.0
2	<i>Mucor globosus</i>	–	5.56	3.70	–	50.0
3	<i>M. hiemalis</i>	–	5.56	–	–	25.0
4	<i>Rhizopus nigricans</i>	–	–	–	6.25	25.0
5	<i>Chaetomium botrychodes</i>	–	–	–	6.25	25.0
6	<i>Aspergillus niger</i>	–	–	7.41	–	25.0
7	<i>A. versicolor</i>	10.3	–	–	–	25.0
8	<i>Paecilomyces varioti</i>	–	11.1	–	6.25	50.0
9	<i>Penicillium canescens</i>	3.45	–	–	6.25	25.0
10	<i>P. cyclopium</i>	27.6	11.1	7.41	–	75.0
11	<i>P. expansum</i>	3.45	–	–	12.5	50.0
12	<i>P. funiculosum</i>	6.89	5.56	–	–	50.0
13	<i>P. lanosum</i>	3.45	–	–	–	25.0
14	<i>P. variable</i>	3.45	–	3.70	–	50.0
15	<i>P. wortmannii</i>	–	–	–	6.25	25.0

Table 1. Continued

Types of micromycetes		FGC				occupancy rate, %
		fresh barren – A ₂	wet barren – A ₃	fresh su-barren – B ₂	wet su-barren – B ₃	
16	<i>Alternaria alternata</i>	10.3	–	22.2	18.7	75.0
17	<i>A. tenuissima</i>	3.45	–	–	6.25	50.0
18	<i>Cladosporium cladosporioides</i>	3.45	–	3.70	12.5	75.0
19	<i>C. herbarum</i>	–	–	3.70	–	25.0
20	<i>Fusarium graminearum</i>	–	–	3.70	–	25.0
21	<i>F. moniliforme</i>	–	5.56	3.70	–	50.0
22	<i>F. oxysporum</i>	–	–	14.8	–	25.0
23	<i>F. sambucinum</i>	3.45	5.56	7.41	–	75.0
24	<i>F. sporotrichioides</i>	3.45	–	–	–	25.0
25	<i>Trithothecium roseum</i>	10.3	27.8	–	–	50.0
26	<i>Gliocladium roseum</i>	–	16.7	7.41	–	50.0
27	<i>Acremonium strictum</i>	–	5.56	–	–	25.0
28	<i>Epicoccum nigrum</i>	–	–	11.1	–	25.0
29	<i>Mycelia sterilia</i>	6.89	–	–	12.5	50
Total number of isolates, pcs.		103	189	92	93	–

This indicator is slightly lower in fresh barren seeds (A₂) – 103 isolates, almost the same number of species was inherent in seeds selected in fresh (B₂) and wet (B₃) su-barrens.

This factor can be explained by the presence of moisture, since micromycetes choose the most favourable conditions for their development, with a sufficient amount of moisture necessary for their vital activity. The type of forest conditions (A₂) substantially differs in its quantitative and specific composition of micromycetes.

Most often, micromycete species were identified on seeds collected from different forest conditions. These are *Alternaria alternata* (occurrence frequency (OF) – 7.4-10.0%, occupancy rate (OR) – 10.0-83.3%); *Cladosporium*

cladosporioides (OF – 1.7-12.5%, OR – 53.3-79.2%); *Fusarium oxysporum* (OF – 2.5-6.7%, OR – 46.7-66.7%); *Mycelia sterilia* (OF – 3.0-40.0%, OR – 33.3-83.3%).

Micromycetes had the highest occurrence frequency on experimental samples of Scots pine seeds selected from fresh barren plantations *Penicillium cyclopium* – 26.7%, *Alternaria alternata*, *Trithothecium roseum* – 10.3%, and the smallest *Mortierella alpine*, *P. canescens*, *P. lanosum*, *P. variable*, *Fusarium sporotrichioides* – 3.45%.

For wet barren (A₃) the highest occurrence frequency was in *Trithothecium roseum* – 27.8%, *Gliocladium roseum* – 16.7%, the lowest – *Mucor globosus*, *M. hiemalis*, *Acremonium strictum*, *Penicillium funiculosum*, *Fusarium moniliforme* – 5.56%.

In the conditions of fresh su-barren the most often were *Alternaria alternata* (22.2%), *Fusarium oxysporum* (14.8%), *Aspergillus niger*, *P. cyclopium*, *F. sambucinum*, *Gliocladium roseum* (7.41%), the least *Cladosporium cladosporioides*, *C. herbarum*, *Fusarium graminearum*, *F. moniliforme* (3.70%).

Micromycetes had the highest occurrence frequency on experimental samples of Scots pine seeds selected from fresh barren plantations *Penicillium cyclopium* – 26.7%, *Alternaria alternata*, *Trithothecium roseum* – 10.3%, and the smallest *Mortierella alpina*, *P. canescens*, *P. lanosum*, *P. variabile*, *Fusarium sporotrichioides* – 3.45%.

In the conditions of wet su-barren (B₃) the following species were characterised by the maximum occurrence frequency: *Alternaria alternata* (18.7%), *Cladosporium cladosporioides*, *Penicillium expansum* (12.5%). The species with minimum frequency indicators were: *Rhizopus nigricans*, *Chaetomium botrychodes*, *Paecilomyces varioti*, *Penicillium canescens* (6.25%).

As for the micromycete population coefficient, the dominant species were *Penicillium cyclopium*, *Alternaria alternata*, *Cladosporium cladosporioides*, *Fusarium sambucinum* (75% settlement rate), which are most dangerous for the development of healthy planting material.

Also very dangerous were the following species: *Trithothecium roseum*, *Gliocladium roseum*, *Fusarium*

moniliforme, *Penicillium expansum*, *P. funiculosum*, *Paecilomyces varioti*, *Mucor globosus* (OR – 50%).

Consequently, forest conditions to a certain extent affect the species diversity of mycobiota components.

In all experimental versions, *Mortierella alpina* were isolated (OF varied between 1.5-13.3%, OR – 6.6-10%); *Mucor globosus* (OF – 1.5-16.7%, OR – 13.3-50.0%); *M. hiemalis* (OF was 1.3-12.5%, OR – 12.5-25%); *Rhizopus nigricans* (OF – 1.7-6.25%, OR – 6.7-25%); *Paecilomyces varioti* (OF – within 0.8-11.1%, OR – 10.0-25.0%); *P. lanosum* (OF – 3.45%, OR – 13.3-25.0%); *P. variabile* (OF – 2.1-3.45%, OR – 12.5-50.0%); *P. wortmannii* (OF – 0.8-6.25%, OR – 13.3-25%); *Alternaria alternata* (OF – 7.4-10.0%, OR – 10.0-83.3%); *A. tenuissima* (OF – 1.9-16.7%, OR – 33.3-50.0%); *Cladosporium cladosporioides* (OF – 1.7-12.5%, OR – 53.3-79.2%); *F. oxysporum* (OF – 2.5-6.7%, OR – 46.7-66.7%); *F. sambucinum* (OF – 4.0-6.7%, OR – 30.0-50.0%); *F. sporotrichioides* (OF – 6.2-16.7%, OR – 16.7-60.0%); *Mycelia sterilia* (OF – 3.0-40.0%, OR – 33.3-83.3%).

In the course of the study, such an important factor as the influence of the age of plantings on the species diversity of the microbiota of Scots pine seeds was investigated. Seeds were harvested on the farm in stands of different ages of I-II classes of bonitets, which grew in conditions of fresh su-barren (Table 2). Seeds selected from different age groups are different in the species composition of micromycetes (similarity varied in the range of 73.6-89.4%).

Table 2. Occurrence frequency (OF) and occupancy rate (OR) of mycobiota Scots pine seeds from trees of different age groups, %

Types of fungi		Scots pine seeds from trees of different age groups					
		young		middle-aged		mature	
		OF, %	OR, %	OF, %	OR, %	OF, %	OR, %
1	<i>Mortierella alpina</i>	3.7	13.3	1.6	6.7	2.5	10.0
2	<i>Absidia glauca</i>	1.9	6.7	0.8	3.3	1.7	6.7
3	<i>Mucor globosus</i>	4.6	16.7	4.0	16.7	3.4	13.3
4	<i>M. hiemalis</i>	1.9	6.7	0.8	3.3	1.7	6.7
5	<i>Rhizopus nigricans</i>	1.9	6.7	2.4	10.0	1.7	6.7
6	<i>Chaetomium globosum</i>	–	–	1.6	6.7	–	–
7	<i>Aspergillus. flavus</i>	7.4	26.7	4.0	16.7	5.2	20.0
8	<i>A. fumigatus</i>	3.7	13.3	3.2	13.3	4.3	20.8
9	<i>A. nidulans</i>	1.6	13.3	4.0	16.7	4.3	20.8
10	<i>A. niger</i>	3.7	30.0	6.4	16.7	7.7	37.5
11	<i>A. oryzae</i>	8.3	20.0	3.2	13.3	4.3	20.8

Table 2. Continued

Types of fungi		Scots pine seeds from trees of different age groups					
		young		middle-aged		mature	
		OF, %	OR, %	OF, %	OR, %	OF, %	OR, %
12	<i>A. terreus</i>	5.6	13.3	2.4	10.0	5.2	25.0
13	<i>Paecilomyces varioti</i>	3.7	6.7	3.2	13.3	–	12.5
14	<i>Penicillium canescens</i>	1.9	6.7	4.0	16.7	2.5	10.0
15	<i>P. chrysogenum</i>	1.9	6.7	1.6	6.7	0.8	3.3
16	<i>P. cyclopium</i>	4.6	13.3	1.6	6.7	2.5	3.3
17	<i>P. expansum</i>	1.9	6.7	2.4	10.0	2.5	10.0
18	<i>P. funiculosum</i>	2.7	10.0	4.8	20.0	5.2	20.0
19	<i>P. lanosum</i>	3.7	13.3	4.8	20.0	5.2	20.0
20	<i>P. variable</i>	1.9	6.7	–	–	–	–
21	<i>P. wortmannii</i>	1.9	6.7	10.0	12.5	5.2	13.3
22	<i>Trichoderma viride</i>	–	–	16.7	95.8	2.5	20.0
23	<i>Alternaria alternata</i>	1.9	6.7	10.0	83.3	3.4	10.0
24	<i>A. tenuissima</i>	1.9	6.7	16.7	50.0	3.4	13.3
25	<i>Cladosporium cladosporioides</i>	–	–	10.0	79.2	1.7	6.7
26	<i>C. herbarum</i>	–	–	–	–	1.7	6.7
27	<i>Fusarium verticillioides</i>	1.9	6.7	–	–	1.7	37.5
28	<i>F. oxysporum</i>	3.7	13.3	13.3	66.7	2.5	6.7
29	<i>F. sambucinum</i>	2.7	10.0	6.7	50.0	1.7	10.0
30	<i>F. sporotrichioides</i>	9.6	16.7	16.7	66.7	2.5	10.0
31	<i>Mycelia sterilia</i>	9.2	33.3	40.0	83.3	5.0	23.3
32	<i>Trichothecium roseum</i>	1.9	6.7	20.0	–	3.4	13.3
33	<i>Epicocum nigrum</i>	3.7	13.3	16.7	–	2.5	10.0
Total quantity isolates, pcs.		108	–	124	–	116	–

Mycelia sterilia (9.2%), *Fusarium sporotrichioides* (9.6%), were the most frequent, while the least frequent were *Alternaria alternata*, *A. tenuissima*, *Fusarium verticillioides*, *Trichothecium roseum* – 1.9%.

Seeds selected from middle-aged plantings were most populated with the spores of *Trichoderma viride* – 95.8%, *Alternaria alternata*, *Mycelia sterilia* – 83.3%, *Cladosporium cladosporioides* – 79.2%, *Fusarium oxysporum*,

F. sporotrichioides – 66.7%. The lowest population rate was observed for micromycetes of *Absidia glauca* – 3.3%, *Mortierella alpina*, *Penicillium chrysogenum*, *P. cyclopium* – 6.7%. Highest occurrence frequency (seeds selected from middle-aged plantings) – *Mycelia sterilia* – 40.0%, *Trichothecium roseum* – 20.0%, lowest – *Mucor globosus*, *M. hiemalis* – 0.8%, *Penicillium chrysogenum*, *P. cyclopium* – 1.6%, *Absidia glauca* – 4.0%.

Seeds collected from a mature plantation were the most polluted with *Aspergillus niger*, *Fusarium verticillioides* (37.5%), *Aspergillus terreus* (25.0%), *Mycelia sterilia* (23.3%). The lowest population coefficient is observed in the species of *Penicillium chrysogenum*, *P. cyclopium* (3.3%), *Mucor hiemalis*, *Rhizopus nigricans*, *Cladosporium cladosporioides*, *C. herbarum* – 6.7%.

The maximum occurrence frequency is in *Aspergillus niger* (7.7%), *Penicillium funiculosum*, *P. lanosum* (5.2%), *Mycelia sterilia* (5.0%), minimum frequency – *P. chrysogenum* (0.8%), *Absidia glauca*, *M. hiemalis*, *Rhizopus nigricans*, *Cladosporium cladosporioides*, *C. herbarum*, *Fusarium verticillioides*, *F. sambucinum* – 1.7%.

Dominant among all age groups were the following species: *Trichoderma viride* (20.0-95.8%), *Mycelia sterilia* (33.0-83.3%), *Alternaria alternata* (6.7-83.3%), *Cladosporium cladosporioides* (6.7-69.2%).

The similarity of the species composition of mycobiota seeds selected from young and medium-aged plantings (similarity indicator – 84.2%) and medium-aged and mature ones (similarity indicator – 89.4%) was established. Less similarity was observed between the species composition of fungi identified on seeds selected from young and mature plantings (the similarity rate is 3.6%). The most similar seeds were middle-aged and mature plantings, the least similar – young and mature ones.

Conclusions

As the analysis of the similarity of micromycetes of Scots pine seeds selected in plantings showed, the largest

number of micromycetes was identified in seeds from wet (A_3) – 189 species and fresh barrens (A_2) – 103 micromycetes, while the smallest was from the fresh (B_2) – 92 types and wet su-barrens (B_3) – 93 isolates; the largest number of micromycete species was observed on Scots pine seeds selected from middle-aged plantings (124 strains). Seeds selected from young stands of Scots pine have the highest occupancy rate.

The dominant species in all types of forest conditions were *Penicillium cyclopium*, *Alternaria alternata*, *Cladosporium cladosporioides*, *Fusarium sambucinum* micromycetes (75% settlement rate), which are most dangerous for the development of healthy planting material.

Mycobiota of Scots pine seeds collected in fresh su-barren (B_2) and wet su-barren conditions (B_3), were the most similar (1.6%). Mycobiota of seeds from fresh barren (A_2) and wet barren (A_3) in the species composition is similar.

The highest occurrence frequency and the occupation rate on seeds selected from different conditions were observed in *Alternaria alternata* (OF – 7.4-10.0%, OR – 10.0-83.3%); *Cladosporium cladosporioides* (OF – 1.7-12.5%, OR – 53.3-79.2%); *Fusarium oxysporum* (OF – 2.5-6.7%, OR – 46.7-66.7%); *Mycelia sterilia* (OF – 3.0-40.0%, OR – 33.3-83.3%).

It was identified that the largest number of micromycete species is observed on Scots pine seeds selected from middle-aged plantings (124 strains). The highest seed occupancy rate selected from young Scots pine stands is inherent in *Mycelia sterilia* (13.3%), *Epicocum nigrum* (16.7%), *Aspergillus niger* (30.0%), the smallest – *Paecilomyces varioti*, *Penicillium chrysogenum* – 6.7%.

References

- [1] Antonov, N. M. (1990). *Influence of the age of the parent stand on the quality of seeds*. Moskva: Lesnaja prom-st [in Russian].
- [2] Bilaj, V. I. (1998). *Biologically active substances of microscopic fungi and their application*. Kyiv: Naukova dumka [in Ukrainian].
- [3] Bilaj, V. I. (1984). *Soil micromycetes*. Kyiv: Naukova dumka [in Ukrainian].
- [4] Bilokin, I. P. (1995). *Plant growth and development*. Kyiv: High school [in Ukrainian].
- [5] Bojko, G. O., & Bashta, O. V. (2015). Mycobiota seeds of Scots pine (*Pinus sylvestris* L.). *Scientific Bulletin of the NULES of Ukraine*, 10, 34–40 [in Ukrainian].
- [6] Bojko, G. O., & Puzrina, N. V. (2015). Germination and germination energy of Scots pine (*Pinus sylvestris* L.) seeds of different colors. *Scientific Bulletin of the NULES of Ukraine*, 198 (2), 209–114 [in Ukrainian].
- [7] Patyka, V. P. (2007). *Ecology of microorganisms*. Kyiv: Basis [in Ukrainian].
- [8] Pidoplichko, N. M. (1977). *Atlas of mushroom mushrooms*. Kyiv: Naukova dumka [in Ukrainian].
- [9] Pidoplichko, N. M. (1991). *Mushroom flora of roughage Publishing House of the Academy of Sciences of the Ukrainian SSR*. Kyiv: Naukova dumka [in Ukrainian].
- [10] Pidoplichko, N. M. (1978). *Phytotoxicity of fungi of the genus Fusarium - the causative agent of root rot of winter wheat*. *Microbiology*. Kyiv: Naukova dumka [in Ukrainian].
- [11] Reshetnik, L. L. (2010). *Seed productivity of Scots pine*. Zhytomyr: Polissya [in Ukrainian].
- [12] Rozenfeld, V. V. (2005). *Phytopathogenic properties of strains isolated from pine seeds*. Zhytomyr: Polissya [in Ukrainian].
- [13] Sandul, T. R. (2010). *Influence of the color of Scots pine seeds on the growth of its plantations in the conditions of fresh pine in the southern part*. Kyiv: Polissya [in Ukrainian].

Вплив умов місцезростання на зміну видового складу мікобіоти насіння сосни звичайної

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Анотація. Досліджено видовий склад мікроміцетів насіння сосни звичайної, зібраного з насаджень, що зростають у різних лісорослинних умовах, та відібраного з дерев різних вікових груп. Встановлено, що на насінні найчастіше траплялися види мікроміцетів – *Alternaria alternata*, *Cladosporium cladosporioides*, *Fusarium oxysporum*, *Mycelia sterilia*. Визначено домінуючі види мікроміцетів, зокрема *Penicillium cyclopium*, *Alternaria alternata*, *Cladosporium cladosporioides*, *Fusarium sambucinum*, які найбільш небезпечні для розвитку здорового садивного матеріалу. Ідентифіковано найбільшу кількість мікроміцетів із насіння насаджень, що зростають в умовах вологого (A_2) – 189 видів та свіжого бору (A_2) – 103 мікроміцети, а найменшу – свіжого (B_2) та сирого субору (B_2), відповідно 92 і 93 ізоляти. Найбільшу частоту трапляння на дослідних зразках насіння сосни звичайної, відібраного з насаджень свіжого бору, мали мікроміцети *Penicillium cyclopium*, *Alternaria alternata*, *Trithothecium roseum*, а найменшу – *Mortierella alpine*, *P. canescens*, *P. lanosum*, *P. variable*, *Fusarium sporotrichioides*. Зазначено, що найчастіше на насінні, яке відібране з дерев різних вікових груп, траплялися *Mycelia sterilia* (9,2%), *Fusarium sporotrichioides* (9,6%), тоді як найменшу частоту трапляння мали – *Alternaria alternata*, *A. tenuissima*, *Fusarium verticillioides*, *Trithothecium roseum* – 1,9%. Досліджено подібність видового складу мікобіоти насіння, відібраного з молодих та середньовікових насаджень (показник подібності – 84,2%) та середньовікових і стиглих (показник подібності – 89,4%). Меншу подібність спостерігали між видовим складом грибів, ідентифікованих на насінні, відібраному з молодих та стиглих насаджень (показник подібності становить 73,6%). Найбільш подібним було насіння середньовікових і стиглих насаджень, найменш подібним – молодняків і стиглих. При цьому насіння, відібране із різних вікових груп, є різним за видовим складом мікроміцетів (подібність варіювала у межах 73,6-89,4%)

Ключові слова: вікові групи дерев, мікобіота, тип лісорослинних умов, мікроміцети, сосна звичайна

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Content of the main components of essential oil in the needles of scots pine growing in geographic cultures

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Abstract. The aim of the research is to analyze the content of terpenes in the needles of trees of climatic ecotypes of Scots pine growing in geographic forest crops and to reveal the differences in the level of essential oils. The object of the research is 17 Scots pine climatotypes growing in geographical plantations on the territory of the Negorelsk Educational and Experimental Forestry Enterprise of the Minsk region in Belarus. Qualitative and quantitative analysis of Scots pine needles essential oil was carried out by gas-liquid chromatography without preliminary fractionation on chromatograph "Kristall 5000.1". In the studied climatotypes of Scots pine, different levels of essential oil content among monoterpenes, sesquiterpenes and oxygen-containing groups were determined, as well as significant differences in the content of a number of components within the studied groups were revealed. The highest yield of essential oil is observed in the subspecies of the European Western Scots pine – 1.9%, slightly lower than this indicator in the forest-steppe subspecies (1.7%). This indicator was significantly lower in the European Eastern pine variety – 1.1% and the Siberian subspecies – 1.0%. The obtained data on the composition of essential oil and the ratio of a number of components among subspecies and varieties of Scots pine (subspecies: Lapland, Siberian, forest-steppe, European; varieties: European western and eastern) will further select the most promising climatic ecotypes and subspecies for selection resistance to biotic and abiotic environmental factors, taking into account the growth and productivity of stands. Information on the content of essential oil components in the needles of climatotypes and subspecies of Scots pine makes it possible to expand knowledge in the field of plant resistance, their safety and growth, especially in the context of the outlined climate change

Keywords: component composition, extractives, monoterpenes, sesquiterpenes, diterpenes, geographical plantations, climatic ecotype

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Introduction

The integrated and rational use of plant resources involves the inclusion of the entire biomass of the plant in the production process. In particular, one of the main directions of the chemical processing of plant raw materials is the production of extractive substances. Among the extractives, it is customary to distinguish compounds that are directly involved in plant growth and compounds that are not involved in growth and development (Krasilnikova, 2004). The primary metabolites are carbohydrates, amino acids, fatty acids, chlorophylls, cytochromes, nucleotides, as well as compounds that act as intermediates in various metabolic reactions. In addition, plants contain a huge amount of substances that are not involved in the main metabolism. Such substances are usually called secondary metabolites or substances of secondary origin. Unlike primary metabolites present in all plant cells, secondary metabolites can be specific for one or several plant species (Kretovich, 1986; Crozier, 2006). Secondary metabolites include mainly low-molecular substances that are not part of the plant cell, contained in the intercellular space. This group of substances is extremely diverse in chemical composition. By their chemical nature, these substances are represented by terpenes and their derivatives, resin acids, lipids, fatty acids, phytosterols, polyphenols and tannins. Despite the assignment of these compounds to secondary metabolites, this is rather arbitrary, since many of these substances are the most important physiologically active compounds that play a primary role in the processes of respiration and photosynthesis. To date, about 20-30 thousand plant species have been studied for the presence of secondary metabolites, which make up only a little more than 10% of the entire flora of the Earth (Cheldt, 2011).

The variety of secondary metabolites also determines the variety of functions they perform (Kivanç & Akgül, 1986; Teissedre & Waterhouse, 2000; Mardarowicz, Wianowska, Dawidowicz & Sawicki, 2004). But in general, we can say that secondary metabolites in plants perform primarily ecological functions. They protect plants from various pests and pathogens, participate in plant reproduction (determining the color and smell of flowers, fruits), and ensure the interaction of plants with each other and with other organisms in the ecosystem. In addition, this class of substances contributes to the formation of plant resistance to unfavorable factors (Babkin, 2017; Schmidt, 2005). Almost all of these substances also have biological activity, which makes them indispensable sources of raw materials in the production of pharmaceuticals, food, and perfumery products (Babkin, 2011; Plemenkov & Tevs, 2014; Ponomoreva, Molochova & Chochlov, 2015). Plant secondary compounds can be divided into three groups based on different biosynthetic pathways of their origin: alkaloids, phenolic compounds, and terpenoids (Plemenkov, 2001; Lovkova, 1981; Britton, 1986).

Terpenes are hydrocarbons formed from varying amounts of isoprene (C₅H₈). Without the participation of isoprenoids, processes such as the growth and development of plants and animals are impossible, since many plant hormones (gibberellins, abscisic acid, brassinosteroids) belong to this class of compounds. However, most of the isoprenoids known to date are substances of specialized (secondary) plant metabolism, which are involved in signaling processes and protection against phytopathogens. Obviously, the main role of isoprenoids specific for certain families, genera and species of plants (these are mainly mono-, sesqui-, di-, sesqui- and triterpenoids) is reduced to protecting plants from various adverse environmental influences, including macro- and micro-pests. For example, resinous substances, rubber and gutta, heal wounds in the bark and wood of plants, protecting them from pests. Resins prevent animals from eating plants. Essential oils also help to attract pollinators. Many components of essential oils and other isoprenoids act as allelopathic agents. It should be noted that the reason for the formation of a huge number of various isoprenoids in plants still remains a mystery, the functions of many of them remain unclear. The process is carried out by absorbing the energy of sunlight, which is converted into the energy of chemical bonds, and is accompanied by the release of free oxygen. The resulting monosaccharides are converted in plants into cellulose, hemicelluloses, starch, lignin, fatty alcohols, acids, their esters, fats, amino acids, waxes, vitamins, essential oils, alkaloids.

In the literary sources the information is also given, which will be indicated in detail below that depending on the content of the components of the essential oil, the resistance of plants to abiotic and biotic environmental factors is determined.

In this regard, it is relevant to determine the content of essential oils in the needles of various climatic ecotypes of Scots pine growing in geographic forest cultures.

Numerous articles are devoted to the determination of the content of the components of Scots pine essential oil. In some of the works (Maksimov, 2004), the composition of the monoterpene fraction of the essential oil isolated from the needles of various subspecies of Scots pine in their habitat was studied.

According to Russian scientists from Forest Institute named after V.N. Sukachev (Kuzmin, 2019), more resistant climatypes of Scots pine are those with a higher ratio of α -pinene to 3-carene.

Finland researchers found out that northern climatypes have a higher content of α -pinene in comparison with 3-carene, and these climatypes are more stable in Finland (Manninen, Tarhanen, Vuorinen & Kainulainen, 2002). Various specialized terpenoidogenic structures were found not only in needles, but also in the primary bark,

secondary phloem and wood of the stem, roots and reproductive organs (Vasiliev, 1977).

Determination of the content of the share of essential oil in different parts of the tree indicates unequal concentration in the covered by needles shoots and trunk (Stepen, 1999).

A study of the seasonal dynamics of the release of essential oil in spruce (Esyakova & Stepen, 2008), pine (Stepen, 1995; Petrenko, 1967) and fir (Lobanov & Stepen, 2004) shows that there are two peaks in the oil content in needles: spring – in May and autumn – in September.

During the transition to the dormant state of trees in the plantation, the essential oil is enriched with oxygen-containing compounds and sesquiterpenes and reaches a maximum in the month of December. The specificity was also noted in the study of pine forests in Ukraine (Poltavchenko & Rudakov, 1973).

The aim of the research is to analyze the content of terpenes in the needles of trees of climatic ecotypes of Scots pine growing in geographic forest cultures and to reveal the differences in the level of essential oils.

Materials and Methods

The object of the research is 17 Scots pine climatotypes growing in geographical plantations on the territory of the Negorelsk Educational and Experimental Forestry Enterprise of the Minsk region in Belarus. Scots pine geographic plantations were created in 1959 by V. Mishnev and E. Mantsevich in collaboration with the Central Control Station of Forest Seeds and the Belarusian Control Station of Forest Seeds on an area of 8.7 hectares. The seeds were obtained from 200 locations in the former Soviet Union. However, most of them were excluded due to typological heterogeneity. As a result, 65 seed samples were selected from the plantations of the group of forest types of the green moss forest, which were sown in April 1958 in the nursery of the Negorelsk Experimental Forestry. The soil on the nursery is coherent sand in terms of texture. To obtain the same seedling density in one row, the same number of viable seeds per 1 long m was sown. After sowing, the ridges were covered with moss. Until mid-July, seedlings were shaded with sieve shields. The seedlings were taken care of, which consisted of weeding and loosening the soil three times.

The area for geographic plantations was set aside in the quarter 15 the forest cultivation area was a clear-cut of 1958, with the correct configuration, stretched from north to south. In the fall, the cutting area was grubbed and leveled with a bulldozer, then plowed to a depth of 25 cm. In April 1959, the area was re-leveled with a bulldozer and harrowed with disc harrows in two tracks.

The final leveling of the area was carried out manually with gathering and burning of the roots before

planting. The spatial distribution of plantations was made according to the principle of allocation of large climatic regions. These areas are located on the site in the direction from north to south, and they are grouped according to the greatest geographic difference from west to east. Each administrative region is represented by a plot of planting with an area of 0.1 hectares. These sections are bounded on all sides by a 2-meter road and poles are set. On the western side, a 4-meter road adjoins the site. The work Kruk et al. (2019) provides information that this object as geographic forest plantations was the source material for obtaining the Scots pine Negorelskaya variety for the first time in Belarus, which is characterized by intensive growth in height and resistance to fusarium.

For a more convenient analysis of the content of essential oil components in needles, all studied climatotypes of Scots pine in geographical plantations are divided into subspecies (races, varieties) in accordance with the classification by Pravdin (1964) (subspecies Lapland, European, Siberian, steppe, hooked) with some modification. The hooked subspecies that grows in the Crimea and the Caucasus is not represented in our experience. Since the steppe subspecies in geographical plantations completely disappeared at the age of 5 (Kustanai, Kokchetav, Akmola, Pavlodar climatotypes of Kazakhstan), we additionally introduced the forest-steppe group of climatotypes: Belgorod, Kursk, Volgograd, Khmel'nitsky, Poltava, Rostov. We also subdivided the European subspecies into two varieties – European western (Vologda, Estonian, Latvian, Vitebsk, Minsk and Grodno) and European eastern (Ulyanovsk and Bashkir).

Method of selection of woody greenery. The woody greenery of Scots pine climatotypes in geographic plantations were selected from 17 plots with 20-25 trees in each of them, taken by the randomization method, in the crown of which branches were cut evenly from four sides. Woody greens were taken in the month of February. According to the literature, the release of essential oil reaches its maximum value and its composition stabilizes in the winter months (Stepen, 1995).

Method of selection of middle sample. The needles were separated from the cut branches of woody greens trees without dividing them by age, and an initial sample of the material under study was obtained. The formation of the middle sample from the original was carried out by quartering. The original sample was poured onto a smooth surface and leveled in the form of a square, and then simultaneously from two opposite sides it was poured into the middle so that a roller was obtained. After that, we grabbed the needles from the ends of the roller and also poured them into the middle. The needles were again smoothed over the area of the square and again poured into the middle. Stirring was repeated in this manner three times. After

mixing, the original sample was again smoothed with a thin layer and divided into four triangles. Two opposite triangles of the needles were removed, and the two remaining ones were connected, mixed and again divided in the indicated manner until the mass of one triangle was approximately five times the weight of the sample. From one triangle, a weighed portion was taken for chemical analysis (isolation of essential oil), and from the opposite triangle, a weighed portion was taken to determine the moisture content of the sample (Deruma, 1983).

Method for the extraction of essential oil from needles. Most of the components of essential oils have a boiling point of 150 to 300°C and higher, however, all the substances that make up their composition are distilled with water vapor. The hydro distillation method is based on the ability of oils to be distilled with water vapor and on the determination of the amount of oil that is released from a plant sample (Pleshkov, 1985). The 150-250 g of raw material crushed to a size of 4-7 mm with known moisture content was placed in a flask with a capacity of 500 cm³, and it was poured with distilled water so that the water surface covered the plant material. The flask was placed in a heating mantle, and then a nozzle for collecting essential oils and

a reflux condenser were attached. After the beginning of boiling, the resulting vapor, carrying with it the essential oil, entered the refrigerator, where it condensed into a liquid consisting of water and small drops of essential oil. The condensed mixture passed into the receiver to collect the essential oil. The intensity of boiling was selected in such a way that 2-3 drops per second flowed out of the refrigerator. Otherwise, the refrigerator could be “flooded” and ejection. Water, as a heavier liquid, settled to the bottom of the receiver and poured back into the flask, and the essential oil floated to the surface, where it slowly accumulated. The process of hydrodistillation in the boiling stage lasted at least 4 hours. During this time, about 80% of the essential oil contained in the plant was distilled off. After the end of the distillation process, the flask was cooled and the device was disassembled (Figure 1).

The essential oil was located in the collector in the form of a thin layer (yellowish) above the water surface. The selection of essential oil was carried out using a syringe with a long needle. The essential oil was carefully poured using a syringe into a pre-weighed small tightly closing bottle, the name of the essential oil and the date of extraction were signed.

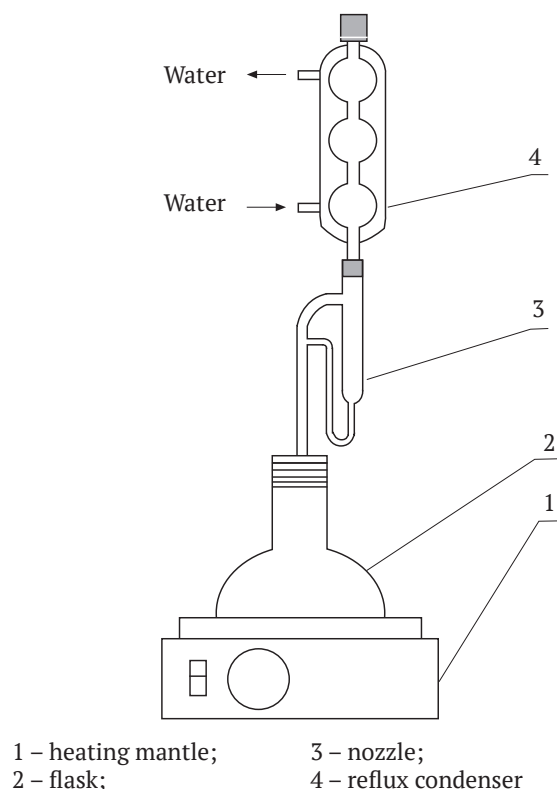


Figure 1. Installation for the extraction of essential oil

The calculation of the essential oil content in the needles was carried out on an absolutely dry weight of plant material. The calculation of the results in mass percent was carried out according to the formula 1:

$$C = \frac{m}{G} \cdot 100\%, \quad (1)$$

where: C – essential oil content, % (mass); m – the mass of the essential oil after distillation, g; G – the mass of an absolutely dry sample of needles, g.

The resulting essential oil was dried with anhydrous sodium sulfate and then used to determine its physical, physicochemical parameters, as well as for chemical research.

Qualitative and quantitative analysis of Scots pine needles essential oil was carried out by gas-liquid chromatography without preliminary fractionation on chromatograph “Kristall 5000.1”. To separate the components, a capillary column 0.25 mm in diameter and 60 m long with a deposited phase of 100% dimethylsiloxane was used. Nitrogen was used as a carrier gas. The air: nitrogen: hydrogen flow rate ratio was 10:1:1. The nitrogen flow rate through the column was 20 ml/min.

The conditions for chromatographic analysis are as follows: isothermal mode at 70°C for 20 min, then a programmed temperature rise at a rate of 2°C/min to 150°C with holding at the final temperature for 40 min. Evaporator temperature – 250°C. The analyzed sample with a volume of 0.2 µL was introduced with a microsyringe into the dispenser-evaporator.

The identification of individual components was carried out using reference compounds, as well as on the basis of the known literature data on the retention indices of individual compounds (Cheftman, 1986). The quantitative

content of the components was calculated by the method of internal normalization according to the peak areas. Statistical analysis was performed in accordance with the methods described in Ostakin et al. (1989), Pen (1982) and Kolesnikov (2003). To determine the required sample size when performing the research, the admissible error value Δx was taken equal to 5% of the average value of the indicator at a confidence level of $\alpha = 95\%$. After the experiment, the variance S^2 and the standard deviation S were calculated. Next, the ratio $\Delta x/S$ was found, and the sample size was determined from the corresponding table (Pen & Mencher, 1973). The results of each series of parallel experiments were subjected to statistical processing in order to find gross errors (“blunders”) using the Student’s test (Ostakin et al., 1989). In this case, the dubious result was excluded from the sample, and the remaining data were used to calculate the arithmetic mean and the estimate of the reproducibility variance.

Results and Discussion

The obtained data on the physicochemical parameters of Scots pine essential oil of various geographical origin indicate that among the studied climatypes, grouped into subspecies, there are differences in the mass fraction of essential oil in terms of absolutely dry weight, relative density and refractive index at $t = 20^\circ\text{C}$ (Table 1).

The highest yield of essential oil is observed in the subspecies of the European Western Scots pine – 1.9%, slightly lower than this indicator in the forest-steppe subspecies (1.7%). This indicator was significantly lower in the European Eastern pine variety – 1.1% and the Siberian subspecies – 1.0%. It is noted that an essential oil content of 1% is typical for pines growing in extreme conditions of an urbanized environment (Lamotkin, Hil, Romanyuk & Skakovskiy, 2019).

Table 1. Changes in the physicochemical parameters of Scots pine essential oil of various geographical origin

Name of the climatype (subspecies, varieties) of Scots pine	Physicochemical parameters of essential oil of Scots pine climatypes		
	mass fraction of essential oil, in terms of absolutely dry weight, %	relative density, g/cm ³	refractive index at $t = 20^\circ\text{C}$
Scots pine subspecies Lapland			
Leningrad, Arkhangelsk	1.7±0.1	0.8639±0.005	1.4841±0.001
	1.9±0.1	0.8632±0.005	1.4836±0.001
By subspecies Lapland	1.8±0.1	0.8635±0.005	1.4838±0.001

Table 1. Continued

Name of the climatype (subspecies, varieties) of Scots pine	Physicochemical parameters of essential oil of Scots pine climatYPES		
	mass fraction of essential oil, in terms of absolutely dry weight, %	relative density, g/cm ³	refractive index at t = 20°C
Scots pine variety European western			
Vologda,	1.4±0.1	0.8639±0.005	1.4840±0.001
Estonian,	1.8±0.1	0.8638±0.005	1.4844±0.001
Latvian,	1.9±0.1	0.8639±0.005	1.4850±0.001
Vitebsk,	2.0±0.1	0.8632±0.005	1.4849±0.001
Minsk,	2.0±0.1	0.8633±0.005	1.4850±0.001
Grodno	2.1±0.1	0.8628±0.005	1.4849±0.001
By variety European Western	1.9±0.1	0.8635±0.005	1.4847±0.001
Scots pine variety European oriental			
Ulyanovsk,	1.0±0.1	0.8638±0.005	1.4840±0.001
Bashkir	1.1±0.1	0.8639±0.005	1.4842±0.001
By variety, European oriental	1.1±0.1	0.8639±0.005	1.4841±0.001
By subspecies European	1.7±0.1	0.8636±0.005	1.4846±0.001
Scots pine subspecies forest-steppe			
Belgorodsky,	1.6±0.1	0.8634±0.005	1.4838±0.001
Kursk,	1.8±0.1	0.8633±0.005	1.4840±0.001
Volgograd,	1.6±0.1	0.8628±0.005	1.4846±0.001
Khmelnitsky,	1.7±0.1	0.8639±0.005	1.4846±0.001
Poltava,	1.8±0.1	0.8635±0.005	1.4840±0.001
Rostov	1.7±0.1	0.8633±0.005	1.4840±0.001
By subspecies forest-steppe	1.7±0.1	0.8634±0.005	1.4842±0.001
Scots pine Siberian subspecies			
Tomsk	1.0±0.1	0.8639±0.005	1.4838±0.001
By subspecies Siberian	1.0±0.1	0.8639±0.005	1.4838±0.001

The relative density of the essential oil of the studied subspecies of Scots pine varies within insignificant limits – from 0.8634 to 0.8639 g/cm³ (minimum – in Grodno and Volgograd climatYPES – 0.8628 g/cm³ each and maximum – in Leningrad, Vologda, Latvian, Khmelnitsky, Bashkir and Tomsk climatYPES – 0.8639 g/cm³ each). In terms of the refractive index, the variation ranges from 1.4838 (subspecies

Lapland and Siberian) to 1.4847 (European Western Scots pine).

The results of determining the content of the main components of essential oil in the needles of various climatYPES of Scots pine are presented in Table 2, the group composition of monoterpenes – in Table 3, the group composition of sesquiterpenes – in Table 4.

Table 2. The content of the main components in the essential oil of various climatypes of Scots pine growing in 61-year-old geographical plantations

Name of the climatype (subspecies, varieties) of Scots pine	The main components of the essential oil, %										
	α -pinene	camphene	3-carene	limonene	terpinolene	caryophyllene	α -muurelene	γ -cadinene	δ -cadinene	bornyl acetate	total
Scots pine subspecies Lapland											
Leningrad, Arkhangelsk	30.2 43.3	3.6 3.2	17.2 5.9	2.4 0.9	3.0 0.6	1.8 5.0	4.6 4.5	2.4 5.1	6.4 8.1	2.2 3.7	74.0 80.2
By subspecies Lapland	36.8	3.4	11.6	1.7	1.8	3.4	4.5	3.8	7.2	2.9	77.1
Scots pine variety European western											
Vologda,	39.0	5.1	13.7	2.0	1.5	6.0	3.0	1.3	3.1	0.8	75.6
Estonian,	31.2	2.8	13.5	1.5	1.6	3.0	4.1	4.6	7.9	1.5	71.6
Latvian,	17.1	2.8	24.2	1.1	2.6	6.2	6.5	3.2	7.3	1.9	72.8
Vitebsk,	18.0	2.6	23.2	2.1	2.1	6.7	5.5	4.7	8.2	1.8	75.0
Minsk,	20.6	3.2	24.0	2.1	2.6	7.3	4.3	4.2	6.9	1.2	76.4
Grodno	17.9	3.5	24.1	2.4	4.0	5.2	4.4	3.6	7.4	2.0	74.5
By variety European Western	24.0	3.3	20.5	1.9	2.4	5.7	4.6	3.6	6.8	1.5	74.3
Scots pine variety European oriental											
Ulyanovsk, Bashkir	20.3 16.8	1.9 2.2	8.8 9.3	2.5 3.0	1.5 1.1	3.7 6.8	8.2 5.4	5.7 4.8	5.9 10.7	0.8 1.0	59.3 61.1
By variety, European oriental	18.6	2.1	9.1	2.8	1.3	5.3	6.8	5.3	8.3	0.9	60.2
By subspecies European	22.6	3.0	17.6	2.1	2.1	5.6	5.2	4.0	7.2	1.4	70.8
Scots pine subspecies forest-steppe											
Belgorodsky, Kursk,	21.9 21.2	1.8 1.9	8.2 9.3	1.1 1.4	1.3 1.3	5.3 4.5	5.1 3.1	7.0 7.1	12.6 13.1	1.3 0.8	65.7 63.8
Volgograd,	25.5	3.8	16.9	1.2	2.5	13.4	2.0	1.9	5.0	2.3	74.4
Khmelnitsky,	15.2	2.3	13.7	1.7	1.9	8.8	9.7	6.9	10.9	1.7	72.7
Poltava,	16.9	1.5	4.8	1.1	0.7	6.6	7.6	8.1	17.4	1.5	66.1
Rostov	27.0	2.4	14.5	2.4	2.1	5.7	3.7	4.9	9.1	1.6	73.2
By subspecies forest-steppe	21.3	2.3	11.2	1.5	1.6	7.4	5.2	6.0	11.4	1.5	69.3

Table 2. Continued

Name of the climatype (subspecies, varieties) of Scots pine	The main components of the essential oil, %										
	α -pinene	camphene	3-carene	limonene	terpinolene	caryophyllene	α -muurelene	γ -cadinene	δ -cadinene	bornyl acetate	total
Scots pine Siberian subspecies											
Tomsk	21.0	2.5	8.7	2.2	1.5	3.6	5.0	5.9	9.6	1.5	61.5
By subspecies Siberian	21.0	2.5	8.7	2.2	1.5	3.6	5.0	5.9	9.6	1.5	61.5

It should be mentioned that the lowest content among the group of monoterpenes, sesquiterpenes and the oxygen-containing group was noted in the latter, while the proportion of bornyl acetate in the essential oil does not exceed 3% – from 0.9% in the European oriental variety to 2.9% in the Lapland pine.

It was found that the largest share of the identified components of essential oil was in the variant of Scots pine of the Lapland subspecies – 77.1%. In the variety of Western European Scots pine, the share of recognized components was slightly lower and amounted to 74.3%, in the forest-steppe subspecies – 69.3%. This indicator turned out to be significantly lower in the variants of the Siberian subspecies and the variety of the European Eastern – 61.5% and 60.2%, respectively.

In terms of the content of α -pinene, a component of monoterpenes, the subspecies of Lapland pine has the highest share – 36.8%. This indicator is at the level of 21.0-24.0% in other variants of subspecies and varieties.

In terms of the content of 3-carene, an inverse relationship is observed – the least of this component is in the Siberian, forest-steppe and Lapland pine – 8.7%, 11.2% and 11.6%, respectively. The maximum is observed in the European western variety – 20.5%. In the Lapland pine, the ratio of these components reaches more than 3:1. This ratio is achieved in the Siberian pine and the European eastern variety at the level of 2-3:1. A slightly lower ratio of 2:1 was noted in the forest-steppe subspecies and the European western variety.

A more detailed analysis of the component composition of monoterpenes is presented in table 3. The proportion of monoterpenes in the total amount of essential oils ranges from 44.1% (subspecies Siberian and forest-steppe) to 62.3% (subspecies Lapland). Moreover, in the Lapland subspecies, more than half (59.9%) in this group is occupied by α -pinene, and 3-carene is 3 times less (18.1%). In the Siberian subspecies, this ratio is 2.4: 1 (47.6% versus 19.7%), in the forest-steppe subspecies – 2.0:1 (49.5% versus 24.7%).

Table 3. Composition of essential oil monoterpenes in various subspecies of Scots pine in 61-year-old geographical forest plantations

Name of the climatype (subspecies, varieties) of Scots pine	Geographical coordinates		Essential oil group – monoterpenes					
	northern latitude	eastern longitude	α -pinene	camphene	3-carene	limonene	terpinolene	total
Scots pine subspecies Lapland								
Leningrad,	61	34	45.8	5.5	26.1	3.7	4.5	66.0
Arkhangelsk	62	43	74.0	5.4	10.1	1.5	1.0	58.5

Table 3. Continued

Name of the climatype (subspecies, varieties) of Scots pine	Geographical coordinates		Essential oil group – monoterpenes					
	northern latitude	eastern longitude	α -pinene	camphene	β -carene	limonene	terpinolene	total
By subspecies Lapland	61-62	34-43	59.9	5.5	18.1	2.6	2.8	62.3
Scots pine variety European western								
Vologda,	59	40	53.4	7.0	18.8	2.7	2.1	73.1
Estonian,	58	27	51.6	4.6	22.3	2.5	2.7	60.4
Latvian,	57	22	30.9	5.1	43.6	1.9	4.6	55.5
Vitebsk,	55	29	31.1	4.5	40.0	3.6	3.6	58.0
Minsk,	54	27	33.0	5.1	38.4	3.3	4.2	62.5
Grodno	53	24	29.5	5.7	39.7	4.0	6.5	60.8
By variety European Western	53-59	22-40	38.3	5.3	33.8	3.0	4.0	61.7
Scots pine variety European oriental								
Ulyanovsk,	54	48	46.3	4.4	20.1	5.6	3.4	43.8
Bashkir	54	58	37.7	5.0	21.0	6.7	2.4	44.5
By variety, European oriental	54	48-58	42.0	4.7	20.6	6.2	2.9	44.2
By subspecies European	53-59	22-58	39.2	5.2	30.5	3.8	3.7	57.3
Scots pine subspecies forest-steppe								
Belgorodsky,	51	38	57.4	4.8	21.6	2.8	3.3	38.1
Kursk,	51	34	52.3	4.7	22.9	3.5	3.1	40.6
Volgograd,	51	42	42.5	6.3	28.1	2.0	4.2	60.0
Khmelnitsky,	50	27	36.1	5.4	32.4	4.0	4.4	42.2
Poltava,	49	33	60.4	5.2	17.1	3.9	2.5	27.9
Rostov	47	40	48.5	4.4	26.0	4.3	3.8	55.6
By subspecies forest-steppe	47-51	27-40	49.5	5.1	24.7	3.4	3.6	44.1
Scots pine Siberian subspecies								
Tomsk	57	85	47.6	5.7	19.7	4.9	3.3	44.1
By subspecies Siberian	57	85	47.6	5.7	19.7	4.9	3.3	44.1

Table 4. Composition of essential oil sesquiterpenes in various subspecies of Scots pine in 61-year-old geographical forest plantations

Name of the climatype (subspecies, varieties) of Scots pine	Geographical coordinates		Essential oil group – sesquiterpenes				
	northern latitude	eastern longitude	caryophyllene	α -muurelene	γ -cadinene	δ -cadinene	total
Scots pine subspecies Lapland							
Leningrad, Arkhangelsk	61 62	34 43	5.9 13.6	15.6 12.3	8.2 13.9	21.6 22.1	29.8 36.6
By subspecies Lapland	61-62	34-43	9.8	13.9	11.1	21.9	33.2
Scots pine variety European western							
Vologda,	59	40	24.2	12.2	5.1	12.6	24.7
Estonian,	58	27	8.5	11.8	13.3	22.6	34.8
Latvian,	57	22	15.2	15.9	7.9	18.1	40.6
Vitebsk,	55	29	17.7	14.5	12.5	21.6	37.9
Minsk,	54	27	21.5	12.7	12.3	20.1	34.1
Grodno	53	24	14.6	12.4	10.1	20.8	35.4
By variety European Western	53–59	22–40	17.0	13.3	10.2	19.3	34.6
Scots pine variety European oriental							
Ulyanovsk,	54	48	6.9	15.2	10.6	10.8	54.2
Bashkir	54	58	12.8	10.2	9.0	20.2	53.1
By variety, European oriental	54	48-58	9.9	12.7	9.8	15.5	53.7
By subspecies European	53-59	22-58	15.2	13.1	10.1	18.4	39.4
Scots pine subspecies forest-steppe							
Belgorodsky,	51	38	9.0	8.6	11.9	21.4	59.1
Kursk,	51	34	8.0	5.5	12.5	23.1	56.8
Volgograd,	51	42	37.4	5.6	5.3	13.9	35.8
Khmelnitsky,	50	27	16.1	17.7	12.5	19.9	54.8
Poltava,	49	33	9.5	10.9	11.7	25.1	69.4
Rostov	47	40	13.9	9.0	12.1	22.3	40.7

Table 4. Continued

Name of the climatype (subspecies, varieties) of Scots pine	Geographical coordinates		Essential oil group – sesquiterpenes				
	northern latitude	eastern longitude	caryophyllene	α -muurelene	γ -cadinene	δ -cadinene	total
By subspecies forest-steppe	47-51	27-40	15.7	9.6	11.0	21.0	52.8
Scots pine Siberian subspecies							
Tomsk	57	85	8.4	11.6	13.7	22.1	43.4
By subspecies Siberian	57	85	8.4	11.6	13.7	22.1	43.4

Sesquiterpenes are also widely represented in Scots pine needles of various geographic origins. It should be noted that in the pine needles of the European Eastern variety, their content exceeds the proportion of monoterpenes (53.7% versus 44.2%). An excess of sesquiterpenes (52.8% versus 44.1%) over monoterpenes was also noted in the forest-steppe subspecies. This ratio is practically at the same level (43.4% versus 44.1%) in the Siberian subspecies of Scots pine. In other variants, there is a noticeable excess of monoterpenes over sesquiterpenes – 62.3% versus 33.2% in the Lapland pine and 61.7% versus 34.6% in the European western variety. In general, for the European subspecies, the content of monoterpenes exceeds that of sesquiterpenes (57.3% versus 39.4%).

It is also important that the noted fact that in various subspecies and varieties of Scots pine in the group composition of sesquiterpenes, there is an excess of one component in the composition δ -cadinene – from 15.5%

in the variety of European Scots pine to 22.1% in the Siberian subspecies.

Conclusions

As a result of the work done, the composition of the main components of the essential oil from the group of monoterpenes, sesquiterpenes and the oxygen-containing group was revealed, inhomogeneous in content, among various subspecies and climatypes of Scots pine growing in geographical forest cultures on the territory of the Negorelsk educational and experimental forestry enterprise (Minsk region, Republic of Belarus). The data obtained on the composition of the essential oil and the ratio of a number of components within or from different groups in it will make it possible in the future to select the most promising climatic ecotypes for breeding for resistance to biotic and abiotic environmental factors, taking into account the productivity indicators of climatic stands, quality of trunks, assessment of the vital state of trees in the plantation and their safety.

References

- [1] Babkyn, V. A., et al. (2011). *Biomass larch: the chemical composition to innovative products*. Novosibirsk: SO RAN [in Russian].
- [2] Babkyn, V. A. (2017). *Extractive substances of larch wood: chemical composition, biological activity, prospects for practical use*. Innovation and expertise, 2 (20), 210–223 [in Russian].
- [3] Brytton, H. (1986). *Biochemistry of natural pigments*. Moscow: Myr, 42 [in Russian].
- [4] Vasylev, A. E. (1977). *Functional morphology of plant secretory cells*. Leningrad [in Russian].
- [5] Deruma, V. Ya. (1983). *Basic principles of selection and preparation of samples of greenery for the study of its chemical composition. Study of the chemical composition of woody greenery. Methodical bases*. Ryha: Zynatne [in Russian].
- [6] Esiakova, O. A., & Stepen, R. A. (2008). *Indication of air pollution in Krasnoyarsk by morphometric and chemical parameters of Siberian spruce needles*. Chemistry of plant raw materials, 1, 143–148 [in Russian].
- [7] Kolesnykov, V. L. (2003). *Mathematical foundations of computer modeling of chemical-technological systems: textbook manual for university students*. Minsk: BHTU [in Russian].

- [8] Krasylnykova, L. A., et al. (2004). *Plant biochemistry*. Kharkov: Torsynh [in Russian].
- [9] Kretovych, V. (1986). *Plant biochemistry*. Moscow: Vysh. shk. [in Russian].
- [10] Kruk, N. K., Nosnykov, V. V., & Rabko, S. V. (2019). Current state, problems and prospects for reforestation in Belarus. In *Forest restoration and forest melioration in Ukraine: beginning, current state, challenges of the present and prospects in the conditions of the Anthropocene* (pp. 417–446). Kyiv: Kondor [in Russian].
- [11] Kuzmyn, S. R. (2019). Scots pine needles and wood with varying degrees of resistance to fungal pathogens. In *Materials of the 6th International Conference-Meeting “Conservation of Forest Genetic Resources”. Shchuchynsk, Respublyka Kazakhstan 16–20 September, 2019* (pp. 131–132). Kokshetau: Myr Pechaty [in Russian].
- [12] Lamotkyn, S. A., Hyl, E. V., Romaniuk, L. Y., & Skakovskiy, E. D. (2019). Seasonal dynamics of *Picea glauca* essential oil terpenoids in urban settings. *Plantresources*, 55 (2), 259–267 [in Russian].
- [13] Leshkov, B. P. (1985). *Workshop on plant biochemistry*. Moscow: Ahropromyzdat [in Russian].
- [14] Lobanov, V. V., & Stepen, R. A. (2004). Influence of biocenotic factors on the content and composition of fir oil. *Coniferous boreal zones*, 2, 148–156 [in Russian].
- [15] Lovkova, M. Ya. (1981). *Biosynthesis and metabolism of alkaloids in plants*. Moscow: Nauka, 169 [in Russian].
- [16] Maksymov, V. M. (2004). *Population structure Pinus sylvestris (Pinaceae) by the composition of monoterpenes in the Central Russian forest-steppe*. Abstract of Dr. dissertation for Agricultural Science, 06.03.01 – Forest Inventory and Forest Measurement. Voronezh [in Russian].
- [17] Ostakyn, A. Y. (1989). *Application of methods in computers. Planning and processing of experiment results*. Minsk: Vysh. Shk. [in Russian].
- [18] Pen, R. Z. (1982). *Statistical methods for modeling and optimization of pulp and paper production processes*. Krasnoarsk: Krasnoarsk State Univ. [in Russian].
- [19] Pen, R. Z., & Mencher, E. M. (1973). *Statistical methods in the pulp and paper industry*. Moscow: Lesnai prom-st [in Russian].
- [20] Petrenko, E. S. (1967). Variability of the number of resin channels in the needles of Scots pine. *Forestry*, 6, 76–83 [in Russian].
- [21] Plemenkov, V. V. (2001). *Introduction to the chemistry of natural compounds*. Kazan: Kazan [in Russian].
- [22] Plemenkov, V. V., & Tevs, O. A. (2014). Biomedical properties and prospects of terpenoids (isoprenoids). *Chemistry of plant raw materials*, 4, 5–20 [in Russian].
- [23] Poltavchenko, Yu. A., & Rudakov, H. A. (1973). Evolution of biosynthesis of monoterpenes in the pine family. *Plant resources*, 9 (4), 481–493 [in Russian].
- [24] Ponomareva, E. Y., Molokhova, E. Y., & Kholov, A. K. (2015). The use of essential oils in pharmacy. *Modern problems of science and education*, 4, 37–45 [in Russian].
- [25] Pravdin, L. F. (1964). *Scots pine: Variability, intraspecific taxonomy and selection*. Moscow: Nauka [in Russian].
- [26] Stepen, R. A. (1995). The composition of the essential oil and volatile terpenoids of the shoots *Pinus sylvestris* L. in Central Siberia. *Plant resources*, 4, 63–70 [in Russian].
- [27] Stepen, R. A. (1999). Ecological and resource significance of volatile terpenoids from pine forests in Central Siberia. *Chemistry of plant raw materials*, 2, 125–129 [in Russian].
- [28] Kheldt, H. V. (2011). *Biochemistry of plants*. Moscow: BINOM. Knowledge laboratory [in Russian].
- [29] Kheftman, E. (1986). *Chromatography. Practical application of the method. Part 1*. Moscow: Myr [in Russian].
- [30] Crozier, A., et al. (2006). *Plant secondary metabolites: occurrence, structure and role in the human diet*. Oxford: Blackwell Publishing Ltd.
- [31] Kivanç, A., & Akgül, A. (1986). Antibacterial activities essential oils from Turkish spices and citrus. *Flavour and fragrans Journal*, 1 (4–5), 175–179. <http://doi.org/10.1002/ffj.2730010409>
- [32] Mardarowicz, M., Wianowska, D., Dawidowicz, A. I., & Sawicki, R. (2004). Comparison of terpen composition in Engelmann spruce (*Picea Engelmann*) using hydridistillation. *SPME and PLE. Zeitschriftfür Natur forschung*, 59 (9–10), 641–648. <http://doi.org/10.1515/znc-2004-9-1006>
- [33] Schmidt, A., et al. (2005). Induced chemical defenses in conifers: Biochemical and molecular approaches to studying their function. Amsterdam. *Elsevier*, 39, 1–28.
- [34] Teissedre, P. L., & Waterhouse, A. L. (2000). Inhibition of oxidation of human low-density lipoproteins by phenolic substances in different essential oils varieties. *J. Agric. Food Chem*, 48 (9), 3801–3805. <http://doi.org/10.1021/jf.990921x>

Вміст основних компонентів ефірної олії у хвої сосни звичайної, яка росте у географічних культурах

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Анотація. Метою досліджень стало проведення аналізу складу терпенів і встановлення відмінностей за рівнем вмісту ефірних масел у хвої сосни звичайної різних кліматичних екотипів, які ростуть у географічних лісових культурах. Об'єкт дослідження представлений 17 кліматипами сосни звичайної, які ростуть у географічних культурах на території Негорільського навчально-дослідного лісгоспу Мінської області Білорусі. Якісний і кількісний аналіз ефірного масла хвої сосни звичайної здійснювали методом газорідинної хроматографії без попереднього фракціонування на хроматографі «Кристал 5000.1». У досліджуваних кліматипів сосни звичайної встановлено різний рівень за складом ефірного масла серед монотерпенів, сесквітерпенів і кисеньвмістної групи, а також виявлено істотні відмінності за вмістом низки компонентів усередині досліджуваних груп. Найбільший вихід ефірної олії спостерігається у підвиді сосни звичайної різновиду європейська західна – 1,9 %, трохи нижче цей показник у підвиді лісостепова – 1,7 %). Істотно нижчий показник виходу ефірної олії виявився у сосни звичайної різновиду європейська східна та підвиді сибірська, який становить 1,1 % і 1,0 % відповідно. Отримані дані щодо складу ефірної олії і співвідношення в ній низки компонентів серед підвидів і різновидів сосни звичайної (підвиди: лапландська, сибірська, лісостепова, європейська; різновиди: європейська західна і східна) дадуть змогу в подальшому проводити відбір найбільш перспективних кліматичних екотипів і підвидів для селекції на стійкість до біотичних і абіотичних факторів середовища з урахуванням показників росту і продуктивності деревостанів. Відомості про склад компонентів ефірної олії у хвої кліматипів і підвидів сосни звичайної допоможуть розширити знання щодо стійкості рослин, їх збереження і росту, особливо в умовах зміни клімату в напрямі аридизації

Ключові слова: компонентний склад, екстрактивні речовини, монотерпени, сесквітерпени, дітерпени, географічні культури, кліматичний екотип

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Conservation of representatives of the *Drosera* L. genus using biotechnological methods

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Abstract. The paper examines the features of obtaining planting material of rare representatives of *Drosera spatulate* L. and *Drosera aliciae* L. using microclonal propagation for their preservation and subsequent cultivation in ex vitro conditions. The method of sterilisation of *D. spatulate* and *D. aliciae* explants was developed with 80-90% production of aseptic material. The influence of various sterilisation options on the development of microshoots was investigated. The two best solutions for sterilisation are: 0.1% AgNO₃ solution and 12.5% H₂O₂ solution. The features of organogenesis and regeneration of the whole organism from cultured tissues and organs of representatives of *Drosera* L. are investigated. The optimal nutrient medium was selected at the stage of introduction *D. spatulate* and *D. aliciae* into the in vitro culture (MS with added PVP 2 mg·l⁻¹). Optimal conditions for direct morphogenesis of *Drosera spatulate* L. and *Drosera aliciae* L. tissues were determined, which allowed mass production of improved, genetically homogeneous planting material. The effect of exogenous growth regulators at various stages of plant morphogenesis under in vitro conditions is shown. In vitro rhizogenesis conditions were improved. In particular, according to the results of the study, the highest coefficient of reproduction (1:8) and root system formation was obtained on a hormone-free medium with a halved content of macronutrients and a nutrient medium with the addition of 0.5 mg·l⁻¹ IBA. Under such conditions, active morphogenesis and the formation of a developed root system were observed in all propagated plants. Based on the results of the conducted research, a method of microclonal reproduction was developed, which allowed for obtaining genetically stable, disease-free regenerative *D. spatulate* and *D. aliciae* plants with an optimally formed root system and vegetative mass. The resulting homogeneous planting material can be used in floriculture, creating terrariums, for pharmacological purposes, and for the purpose of introduction

Keywords: *Drosera* L., microclonal reproduction, morphogenesis

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Introduction

In Ukraine, due to the land reclamation works conducted in the last century, the territories of wetlands and swamps have substantially decreased. In addition, climate change also causes swamps to dry up, causing swamp plants to suffer. On the territory of wetland complexes, the area of localities of red book plant species has substantially decreased (Andrienko & Protopopova, 2010; Umanets & Moisienko, 2012; Chornobrov et al., 2019).

Biodiversity conservation is a major challenge in the face of rapid environmental changes. The problem of preserving extremely vulnerable stenotopic flora species is

particularly acute. Exactly the species of the *Drosera* genus are indicators of climate change and are sensitive to fluctuations in the water level, etc. All members of the *Drosera* genus are endangered species, except for species of the *Drosera rotundifolia* genus, however, according to researchers (Rak & Kachula, 2017), they are listed in the new edition of the Red book of Ukraine in the category “vulnerable”.

On the territory of Ukraine, there are three types of sundew: round-leaved (*Drosera rotundifolia* L.), English (*Drosera anglica* Huds.) and oblong-leaved sundew (*Drosera intermedia* Hayne) (Fig. 1).

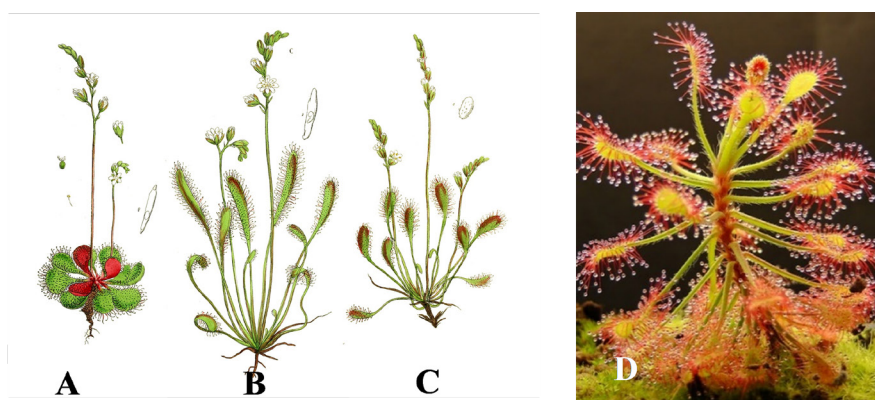


Figure 1. Representatives of *Drosera* L.: a – *Drosera rotundifolia* L.; b – *Drosera anglica* Huds.; c – *Drosera intermedia* Naupe; d – sundew appearance

D. rotundifolia is distributed in the arctic and temperate zones of Eurasia and North America (GBIF Secretariat, 2014). In Europe, it occurs almost all over the territory, but very unevenly. It is quite abundant in North and Atlantic Europe, occasionally in the middle and very rarely in the South (except for the South-East) (Melzig & Krenn, 2011).

In Ukraine quite recently *D. rotundifolia* was quite common in the forest zone and in the north of the forest-steppe, occasionally in the south of the forest-steppe and in the Carpathians, and very rarely in the north of the left-bank steppe (Andrienko, 2009; Chorna, 2006; Kiraly, 2009). However, according to recent observations, today there are a large number of locations of *D. rotundifolia* lost due to anthropogenic impact and drainage of swamps (Andrienko, 2009; Umanets, 2012).

The use of biotechnological methods for obtaining plant raw materials of *Drosera* L. is extremely relevant in both landscaping and pharmacology (Egan & map der Kooy, 2013), as they provide healthy, sterile plant material in large quantities, regardless of the season.

The optimal area for developing conservation strategies for endangered species is an integrated scientific approach that combines the use of biotechnological techniques for *in vitro* culture, rational collection management for efficient recovery of endangered populations and species (Chornobrov & Bilous, 2021), the use of molecular genetic techniques to document and maintain collections (Chung et al., 2013), assessment of the parameters of genetic diversity of natural and artificially created populations, replenishment of collections, and their exchange.

Using the *in vitro* culture method is an optimal modern solution that provides an opportunity of:

- restoration and reproduction of valuable, rare, and endangered species of flowering plants that are difficult to reproduce *in situ* and *ex situ*;
- creating a collection of genetically homogeneous plants *in vitro* culture;
- getting healthy planting material;
- mass production of valuable plant genotypes from the collections of botanical gardens.

The originality of this area is the creation of a genetic bank of samples of plant raw materials, which is an indispensable resource for characterising the conservation and sustainable use of biodiversity of the plant world, identifying the most productive genotypes of economic crops and crops with the increased adaptive potential to external environmental factors, quantifying the parameters of genetic diversity of natural and artificially created crops *ex situ* populations, and collections of individual taxa (Matthews, 1994; Chorna, 2006).

The purpose of the study – determination of the features of direct plant regeneration of *Drosera spatulate* L. and *Drosera aliciae* L. at different stages of microclonal reproduction.

Until now, such representatives of species of the *Drosera* genus were successfully cultivated *in vitro*: *D. binata* La Billardier, *D. natalensis* Diels (Anthony, 1992; Caniato et al., 1989), *D. capensis* L. (Curkovic & Berljak, 1996), *Drosera-regia* Stephens (Janssens, 1986), *D. rotundifolia* L. (Anthony, 1992; Bonnet et al., 1984; Kukulczanka & Czastka, 1987; Simola, 1978) and *D. spatulata* Labill. (Blehova et al., 1990, 1992). However, protocols for microclonal reproduction and composition of nutrient media (NM) have not yet been developed for *D. spatulata* (sundew), in particular, in Ukraine. Because of this, the most common method of propagation currently is the seed one (Fernández-Pascual, 2016), due to the ease of sterilisation to create primary crops.

Given the substantial demand for carnivorous plants (Baskin & Baskin, 2014) and the lack of developed methods of microclonal reproduction, the conservation and reproduction of rare and endangered species of this group of plants *ex situ*, as the creation of a genetic bank *in vitro* is becoming increasingly relevant.

Materials and Methods

The original explants were parts of the generative complex that are formed from buds restored in a single visible growth cycle, which contain a stem, leaves, buds, and a flower or inflorescence.

Methods and approaches generally accepted in biotechnology were followed, modifying them individually for each genotype to decontaminate the original explants (Chornobrov & Bilous, 2021).

Cultivation of meristem sites was conducted on modified Murashige and Skoog media (MS) (Murashige & Skoog, 1962) by adding phytohormones of various concentrations to their composition (Araújo et al., 2014; Baranyai & Joosten, 2016; Clapa et al., 2010).

In addition, activated carbon ($1 \text{ g} \cdot \text{l}^{-1}$) was added to the medium (once), as a hydrocarbon food – sucrose

($30 \text{ g} \cdot \text{l}^{-1}$), mesoinositol ($100 \text{ mg} \cdot \text{l}^{-1}$), agar (0.7%), and two chelate forms of iron: ethylenediamine-di-2-hydroxyphenylacetic acid (Fe-EDDHA) and ethylenediaminetetraacetic acid (Fe-EDTA), medium pH 5.6-5.7.

Explants were cultured at a temperature of $25 \pm 2^\circ\text{C}$, with a 16-hour photoperiod, for illumination with an intensity of 2000-3000 lx.

The main indicator of the effectiveness of the sterilising agent was the number of explants that developed normally.

Representatives of *Drosera spatulate* L. and *Drosera aliciae* L. were used as donor plants in the study, taken from container culture.

Results and Discussion

At the initial stage of introduction to *in vitro* culture Murashige and Skoog (MS) nutrient media with full or half-reduced mineral element content were used for regeneration.

During experimental work, a sterilising solution was selected, which was easily washed out of the tissues with distilled water to less harm the explant tissues. For this purpose, generally accepted methods were used to obtain sterile starting material. A solution of 70% ethyl alcohol ($\text{C}_2\text{H}_5\text{OH}$), 1.7 per cent and 1.25 per cent sodium hypochlorite NaClO solutions, hydrogen peroxide solutions (H_2O_2) of various concentrations – 12.5% and 25%, and 0.1% silver nitrate solution (AgNO_3). The reagents were used both separately and in combination with different exposures and washing modes to achieve this goal.

Each of the sterilising solutions and exposure time had a different effect on *Drosera* L. explants. Method of sterilisation using a 70% ethanol solution (30 seconds), then holding in a 1.25% NaClO solution with an exposure of 20 minutes and three times washing in sterile water did not damage tissues and did not inhibit plant development and ensured the sterility of explants by 60%. Notably, the sequence and exposure of the use of various sterilising reagents were determined empirically during operation, depending on the type of explant and the degree of its infection.

Sterilisation mode using 70% ethanol and holding for 30 seconds and in 0.1% AgNO_3 solution for 5-7-10 minutes and three times washing in sterile water for 10 minutes each time affected the plants in different ways. Sterilisation with a 10-minute exposure resulted in a complete loss of plant material, resulting in all plants being sterile but not viable.

In turn, the exposure is 7 minutes in 0.1% AgNO_3 solution allowed getting 50% of viable explants, and the exposure of 5 minutes was the most optimal. Under such conditions, the number of aseptic and regenerative plants was 80%.

In parallel with the two previous schemes, a 50% solution of hydrogen peroxide (H_2O_2) in two ratio options, 1:1 and 1:2, with different exposure times, was used to determine the most optimal method of sterilisation.

When using a 50% hydrogen peroxide solution in a ratio of 1:2, the yield of aseptic explants on the third day after administration was 80-90%. Therewith, washing the explants from the remains of the sterilising solution one time is enough. This method is the least toxic and effective for non-woody shoots.

Induction of organogenesis from *Drosera* L. meristem culture was conducted by culturing the obtained primary microshoots from aseptic explants obtained after their preliminary sterilisation.

On the sixth day of cultivation, induction of axillary buds was observed, which on day 10-14 had a size of 0.2-0.3 cm.

The yield of aseptic viable explants was 90-100%. After 2-3 days, active release of phenolic compounds was observed, which negatively affected the growth and development of explants. Polyvinylpyrrolidone (PVP) ($1-2\text{ g}^*l^{-1}$) was added to the MS nutrient medium to avoid this, the adsorption properties of which contribute to the uniform distribution of nutrients in the medium and reduce the negative impact of secondary metabolic products.

The shoots were divided into segments and transferred to nutrient media containing different compositions and concentrations of phytohormones to induce morphogenesis (Table 1).

Table 1. Composition of components of the nutrient medium for induction of organogenesis

No.	NM components	Concentration by medium variants, mg^*l^{-1}				
		1	2	3	4	5
1	Macronutrients of MS	100	100	30	100	100
2	Microelements of MS	1.0	1.0	1.0	1.0	1.0
3	vitamins of MS	1.0	1.0	1.0	1.0	1.0
4	Fe chelate	10	5	5	10	5
5	BAP	1.0	-	-	1.0	-
6	Glucocorticoids	0.1	-	-	-	-
7	Glycine	-	-	-	1.0	-
8	Kinetin	-	0.25	-	-	0.25
9	IAA	0.5	-	-	-	-
10	Mesoinosite, g^*l^{-1}	0.1	0.1	0.1	0.1	0.1
11	Sucrose, g^*l^{-1}	30	20	20	30	20
12	Agar, g^*l^{-1}	6.7	6.7	6.7	6.7	6.7
13	PVP, g^*l^{-1}	1	-	-	2	2
14	IBA	-	-	0.1	0.2	-
pH 5.6-5.7						

Induction of morphogenesis largely depended on the composition of NM and at the initial stages of reproduction

took place mainly on basic MS media. Cultivation was conducted for 21 days (Fig. 2).



Figure 2. Regenerative plants *D. spatulate* on morphogenic medium on day 21 of cultivation

Analysing the data, it was concluded that morphogenesis of *D. spatulate* and *D. aliciae* most intensively passed on a medium with the addition of kinetin 0.25 mg*l⁻¹ and PVP 2 g*l⁻¹ explants had dimensions of 2.5-2.8 cm and typically rich green colour, formed roots

of 2-3 pcs. on an explant, 3.5-4.9 cm long (Fig. 3). In turn, the release of phenols in the basal part and near the roots was observed on a medium of ½ MS without the addition of PVP. The accounting results are shown in Table 2.

Table 2. Features of explant development on different media variants (day 21 of cultivation)

No.	Composition of NM (PGR)	Hormone concentration, mg*l ⁻¹	Number of explants, pcs.	Formation of shoots		Formation of roots	
				pcs.	cm	pcs.	cm
1	BAP Glucocorticoids IAA	1.0 0.1 0.5	2	2.7±0.9	0.5±1.3	-	-
2	Kinetin	0.25	2	3.3±0.56	2.3±1.1	2.5±4.3	1.6±3.2
3	IBA	0.1	2	2.8±3.6	0.62±0.8	3.8±3.1	1.3±2.4
4	IBA BAP	0.2 1.0	2	3.4±3.3	0.26±0.5	-	-
5	Kinetin AA	0.25 5.0	2	4.9±1.5	2.6±1.5	2.5±1.5	2.8±1.2

Note: AA– ascorbic acid; PGR – plant growth regulators; NM – nutrient medium



Figure 3. Regenerative plants *D. spatulate* and *D. aliciae* on morphogenic medium on day 21 of cultivation

When added to the medium BAP 1.0 mg^*1^{-1} + GC 0.5 mg^*1^{-1} the attenuation of explants was determined ($0.4\text{-}0.6 \text{ cm}$), which were characterised by the formation of weakened, deformed leaves that had a light colour. On a medium with the addition of 0.1 mg^*1^{-1} IBA explants were also thin, weak – $0.4\text{-}0.7 \text{ cm}$, but simultaneously retained the ability to form roots (on one explant – up to 3-5 pcs.).

On NM supplemented with 0.2 mg^*1^{-1} IBA + 1.0 mg^*1^{-1} BAP did not observe a substantial difference in the size of explants, and the roots were formed much smaller in size. The most optimal environment was the use of 0.25 mg^*1^{-1} kinetin and the addition of PVP 2 g^*1^{-1} , and hormone-free NM MS with a halved composition of

macronutrients. Active growth and induction of rhizogenesis were observed in this medium.

On 21-28 days of cultivation, formed regenerative plants were obtained, the total size of which reached 8 cm with a well-formed root system. The resulting regenerative plants were used for further mass multiplication *in vitro*.

After the successful production of sterile viable regenerative plants *D. spatulate* and *D. aliciae*, the components of the nutrient medium for induction of rhizogenesis *in vitro* of *Drosera* L. were selected. For this purpose, sterile plants were divided into separate microparticles and planted on NM, different in composition: MS+IAA (0.5 mg^*1^{-1}); MS+IBA 0.5 mg^*1^{-1} + IAA 0.5 mg^*1^{-1} ; MS+IBA 4 mg^*1^{-1} + 0.5 mg^*1^{-1} BAP; h/f MS and $\frac{1}{2}$ MS (Table 3).

Table 3. Influence of plant growth regulators on morphogenesis of *D. spatulate* and *D. aliciae*

Medium	Viable microshoots		Coefficient reproduction	Presence of a root system
	pcs.	%		
Hormone-free MS	10	100	9	available
$\frac{1}{2}$ MS	10	100	8	available
MS + BAP 0.5 mg^*1^{-1}	2	20	8	absent
MS + BAP 1.0 mg^*1^{-1}	3	30	3	absent
MS + BAP 1.5 mg^*1^{-1}	1	10	4	absent
MS + kinetin 1 mg^*1^{-1}	3	25	4	absent
MS + kinetin 2 mg^*1^{-1}	3	30	3	absent

Table 3. Continued

Medium	Viable microshoots		Coefficient reproduction	Presence of a root system
	pcs.	%		
MS + kinetin 3 mg*l ⁻¹	8	80	4	absent
MS + IBA + 0.5 mg*l ⁻¹	10	100	5	absent

As can be seen from the table, the addition of low concentrations of cytokinins BAP and kinetin to NM had a positive effect on the growth of regenerative plants and contributed to the formation of the root system in 50% of plants. The addition of auxin IBA at a concentration of 0.5 mg*l⁻¹ also had a positive effect on the induction of explant tissue rhizogenesis. Within two weeks, explants

formed a developed root system and doubled their growth. As a result of research, the highest coefficient of reproduction (1:8) and root system formation was obtained on a hormone-free medium with a halved content of macro-nutrients and on NM with the addition of 0.5 mg*l⁻¹ IBA. All plants showed active morphogenesis and formed roots (Fig. 4).

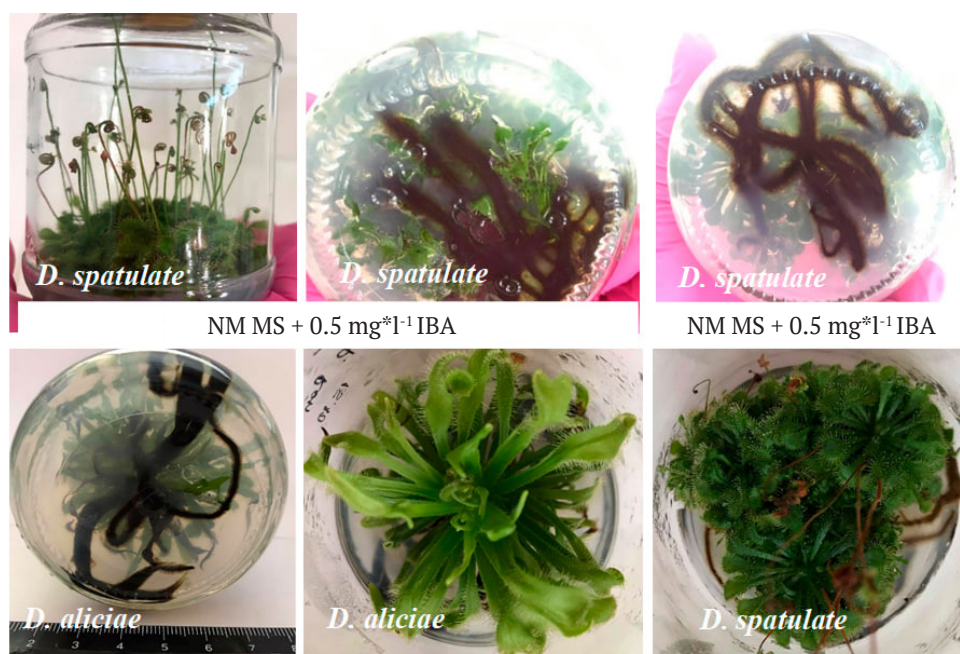


Figure 4. Formation of a developed root system and induction of microshoot growth on NM ½ MS

Summarising the results obtained, the most effective can be considered NM ½ MS, which can be used both for plant cultivation and root formation, with the only exception being forced induction. If rapid root formation to transfer plants to the soil is necessary, it is best to use NM with the addition of 0.5 mg*l⁻¹ IBA.

Conclusions

Based on the results of the conducted research, a method of microclonal reproduction was developed, which allowed for obtaining genetically stable, disease-free regenerative plants *D. spatulate* and *D. aliciae* with an optimally formed root system and vegetative mass. The resulting

homogeneous planting material can be used in floriculture, creating terrariums, for pharmacological purposes, and for the purpose of introduction. The method of explant sterilisation of *D. spatulate* and *D. aliciae* with 80–90% production of the aseptic culture of plant tissues was developed. The influence of various sterilisation options on the development of microshoots was investigated. It was identified that sterilisation using a 0.1% AgNO₃ (5 min) solution is the most effective and three times washing in dH₂O, and sterilisation with explants kept for 30 seconds in a solution of 70% ethanol and 12.5% solution H₂O₂ with a single wash 10 min in dH₂O. It was experimentally established that NM MS with the addition of 2 g^{*l}⁻¹ PVP is optimal at

the stage of introduction of *D. spatulate* and *D. aliciae* *in vitro*. Microshoot regeneration of *D. spatulate* and *D. aliciae* were investigated depending on the type of explant and the composition of the NM. Morphogenesis was most effective on NM with the addition of 0.25 mg^{*l}⁻¹ kinetin and on h/f MS. Such cultivation conditions provided 100% regeneration of regenerative plants with a reproduction rate of 1:8. After investigating the effect of cytokinins on microclonal reproduction of *D. spatulate* and *D. aliciae*, it was identified that the development and induction of multiple shoot formation *in vitro* works best in a h/f MS environment. It is necessary to add NM 0.5 mg^{*l}⁻¹ IBA to induce the formation of the root system.

References

- [1] Andrienko, T., & Protopopova, V. (2010). *Insectivorous plants of Ukraine*. Kyiv: Alterpress [in Ukrainian].
- [2] Anthony, J. L. (1992). *In vitro* propagation of *Drosera* spp. *HortScience*, 27, 850.
- [3] Araújo, P. V., Porto, M., Silva, A., Almeida, J. D., Lourenço, J., Schwarzer, U., Silveira, P., & Peixoto, M. (2014). *Drosera rotundifolia* L. – mapa de distribuição (*Drosera rotundifolia* L. – distribution map). Flora-On: Flora de Portugal Interactiva, Sociedade Portuguesa de Botânica. Available at <http://www.flora-on.pt/wDrosera>.
- [4] Baranyai, B., & Joosten, H. (2016). Biology, ecology, use, conservation and cultivation of round-leaved sundew (*Drosera rotundifolia* L.): a review. *Mires and Peat*, 18, 1–28. Available at <http://www.mires-and-peat.net/>.
- [5] Baskin, C. C., & Baskin, J. M. (2014). *Seeds: Ecology, Biogeography, and Evolution of Dormancy and Germination*. Academic Press, London.
- [6] Blehova, A., Erdelsky, K., & Bobak, M. Cultivation of organ and callus culture of *Drosera spatulata* Labill. in *in vitro* conditions. *Acta Facultatis Rerum Naturalium Universitas Comenianae Physiol. Plant*, 28, 93–102.
- [7] Chorna, H. (2006). *Flora of reservoirs and swamps of the Forest-Steppe of Ukraine*. *Vascular plants*. Kyiv: Phytosocial center [in Ukrainian].
- [8] Chornobrov, O. Yu., & Bilous, S. Yu. (2021). *In vitro* plant regeneration of Christmas cactus (*Schlumbergera truncata* (Haw.) Moran) by indirect morphogenesis *Folia Forestalia Polonica, Series A – Forestry*, 63 (1), 68–73. <https://doi.org/10.2478/ffp-2021-0007>
- [9] Chornobrov, O., Bilous, S., Chornobrov, O., & Manko, M. (2019). Peculiarities of morphogenesis of the endangered species of willow (*Salix* spp.) *in vitro*. *BIOLOGIJA*, 65 (1), 48–55.
- [10] Chung, M. Y., Lopez-Pujol, J. & Chung, M. G. (2013). Population history of the two carnivorous plants *Drosera peltata* var. *nipponica* and *Drosera rotundifolia* (*Droseraceae*) in Korea. *American Journal of Botany*, 100 (11), 2231–2239. <http://dx.doi.org/10.3732>
- [11] Clapa, D., Alexandru, F. & Pacurar, I. (2010). *In vitro* multiplication, conservation and *ex vitro* acclimation of *Drosera rotundifolia*. *Bulletin of University of Agricultural Sciences and Veterinary Medicine Cluj-Napoca, UASVM Horticulture*, 66 (1)/2009, 34–39.
- [12] Curkovic Perica, M., & Berljak, J. (1996). *In Vitro* Growth and Regeneration of *Drosera spatulata* Labill. on Various Media. *HortScience*, 31 (6). <https://doi.org/10.21273/HORTSCI.31.6.1033>
- [13] Egan, P. A., & Van der Kooy, F. (2013). Phytochemistry of the carnivorous sundew genus *Drosera* (*Droseraceae*) – Future perspectives and ethnopharmacological relevance. *Chemistry & Biodiversity*, 10 (10), 1774–1790. <http://dx.doi.org/10.1002>
- [14] Fernández-Pascual, E. (2016). Comparative seed germination traits in bog and fen mire wetlands. *Aquatic Botany*, 130, 21–26. <http://dx.doi.org/10.1016/j.aquabot.2016.01.001>
- [15] GBIF Secretariat. (2014). *Drosera rotundifolia* L. species in GBIF backbone taxonomy. Available at <http://www.gbif.org/species/3191030>.
- [16] Janssens, J. (1986). *In vitro* propagation of Sundew *Drosera-regia* Stephens. *Meded Fac Landbouwwet. Rijksuniv. Gent*, 51, 61–66.

- [17] Konvaliuk, I., Kravets, N., & Drobik, N. (2010). Direct organogenesis of in vitro yellow gentian (*Gentiana Lutea* L.). *Journal of Biotechnology*, 3 (5), 66–73.
- [18] Kiraly, G. (Ed.). (2009). *Új magyar fűvészkönyv. Magyarország hajtásos növényei*. Határozókulcsok. – Jászvafi: ANP Igazgatóság.
- [19] Kukulczanka, K. & Czastka, B. (1987). Propagation of *Drosera* L. in vitro. *Wiad Bot.*, 31, 61–64.
- [20] Matthews, R. F. (1994). *Drosera rotundifolia*. Fire Effects Information System, US Department of Agriculture Forest Service, Rocky Mountain Research Station, Fort Collins. Available at <http://www.fs.fed.us/database/feis/plants/forb/drorot/all.html>.
- [21] Melzig, M. F., Pertz, H. H., & Krenn, L. (2011). Anti-inflammatory and spasmolytic activity of extracts from *Droserae* Herba. *Phytomedicine*, 8, 225–229. <http://dx.doi.org/10.1078/0944-7113-00031>
- [22] Murashige, T., & Skoog, F. (1962). A revised medium for rapid growth and bioassay with tobacco tissue cultures. *Physiol. Plant*, 15, 473–497.
- [23] Rak, O., & Kachula, I. (2017). Cancer OO NATURA 2000 network as an innovative system of protection of rare species and settlements in Ukraine. *Proceedings of the scientific-practical seminar (Kyiv, February 15, 2017) / Series: "Conservation Biology in Ukraine" 1*, 131–132.
- [24] Simola, L. K. (1978). Dipeptides as nitrogen sources for *Drosera rotundifolia* in aseptic culture. *Physiol. Plant*, 44, 315–318.
- [25] Umanets, O., & Moisienko, I. (2012). The most southern find of *Drosera rotundifolia* in Ukraine. *Black Sea Botanical Journal*, 8 (3), 342–346.

Збереження представників роду *Drosera* L. з використанням біотехнологічних методів

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Анотація. У роботі проведено дослідження особливостей отримання садивного матеріалу рідкісних представників *Drosera spatulate* L. та *Drosera aliciae* L. з використанням мікроклонального розмноження з метою їх збереження й подальшого культивування в умовах *ex vitro*. Відпрацьовано методику стерилізації експлантатів *D. spatulate* та *D. aliciae* з 80-90 % отриманням асептичного матеріалу. Вивчено вплив різних варіантів стерилізації на розвиток мікропагонів. Найкращими розчинами для стерилізації визначено два: 0,1-відсотковий розчин AgNO_3 та 12,5-відсотковий розчин H_2O_2 . Досліджено особливості органогенезу та регенерації цілого організму з культивованих тканин та органів представників *Drosera* L. Підбрано оптимальне живильне середовище на етапі введення у культуру *in vitro* *D. spatulate* та *D. aliciae* (МС із додаванням PVP 2 мг·л⁻¹). Визначено оптимальні умови прямого морфогенезу тканин *Drosera spatulate* L. та *Drosera aliciae* L., що дало змогу масового отримання оздоровленого, генетично однорідного садивного матеріалу. Показано дію екзогенних регуляторів росту на різних етапах морфогенезу рослин в умовах *in vitro*. Удосконалено умови ризогенезу *in vitro*. Зокрема за результатами досліджень найвищий коефіцієнт розмноження (1:8) та формування кореневої системи було отримано на безгормональному середовищі з удвічі зменшеним вмістом макроелементів і живильному середовищі з додаванням 0,5 мг·л⁻¹ ІМК. За таких умов у всіх розмножуваних рослин спостерігали активний морфогенез і формування розвиненої кореневої системи. За результатами проведених досліджень було розроблено методику мікроклонального розмноження, яка дала можливість отримати генетично-стабільні, вільні від хвороб рослини-регенеранти *D. spatulate* та *D. aliciae* з оптимально сформованою кореневою системою та вегетативною масою. Отриманий однорідний садивний матеріал можна використовувати у квітникарстві, створенні тераріумів, для фармакологічних цілей та з метою інтродукції

Ключові слова: *Drosera* L., мікроклональне розмноження, морфогенез

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Myco- and microorganisms in the tuberculosis pathology of the common ash in Ukraine and interaction between them

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Abstract. Attention is focused on the fact that in recent years there has been epiphytotic dieback out of many species of forest woody plants both in Ukraine and in other countries of the world, which has a dynamic character and a tendency to grow. In the deep pathology of this phenomenon, phytopathogenic bacteria, which have high reproduction energy and can penetrate the plant both from the outside and cause a pathological process as vital obligates, were left without attention. It has been established that the most common and harmful disease of common ash in Ukraine is tuberculosis. The causative agent of the disease is the phytopathogenic bacterium *Pseudomonas syringae* pv. *savastanoi* Gard. affects both trunks, branches and shoots, and inflorescences of common ash. Bacteria *Pseudomonas* sp., *Pseudomonas fluorescens* Mig., *Pseudomonas syringae* Van., *Erwinia herbicola* Eh., *Xanthomonas* sp. were isolated from tuberculous pathology as a concomitant myco- and microbiota and micromycetes *Cladosporium cladosporioides* Fres., *Ulocladium botrytis* Preus., *Mycelia sterilia* (dark), *Mycelia sterilia* (orange), *Fusarium heterosporum* Lin., *Fusarium* sp., W., *Cylindrocarpon didymium* Har., etc. The mechanism of systemic relationships of the components of myco- and microbiota of tuberculous pathology of common ash in the regulation (self-regulation) of pathogenicity and aggressiveness of vital obligates has been investigated. Attention is focused on the prospects and expediency of using the antagonistic properties of myco- and microorganisms and biological products based on them for the prevention and protection of tree plantations from bacterial pathogens. It is shown that the pathology of common ash is a multifaceted phenomenon with interrelated processes of an infectious and non-infectious nature. The need to distinguish between the etiology and pathogenesis of this negative phenomenon is indicated, that is, not to mix the factors that lead to the weakening of ordinary ash (factors catalyzing the disease) and the factors that cause its epiphytotic dieback

Keywords: bacteria, fungi, common ash, antagonism, *Pseudomonas syringae* pv. *savastanoi*

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Introduction

Mico- and microorganisms are an integral part of the forest biocenosis, which determines its depth, which is directly involved in all stages of growth and development of woody plants and the utilization of mortmass and detritus. Among the systematic and functional groups of myco- and microbiota, a special place is occupied by phytopathogenic endophytes of various trophic specializations, capable of causing significant ecological, economic and social damage under certain conditions, which is confirmed by deep pathology with massive (epiphytotic) dieback out of many species of woody plants (Scots pine, spruce European, silver birch, common ash, in somewhat smaller volumes common oak, white fir, aspen, common hornbeam) both in Ukraine and abroad.

In particular, the degradation and mass dieback out of tree plantations has reached a global level and has been noted practically throughout the entire range of many ash species, including common ash, both in European countries and in the USA and Asian countries (EPPO, 2020).

The pathology was first discovered in Northern and Central Europe in the 1990s (Kowalski & Holdenrieder, 2009), and then was discovered in Germany and Sweden (Langer, 2017), Norway (Talgø, 2009), the Czech Republic, Slovakia and Finland (Jankovský & Holdenrieder, 2009), Austria (Halmschlager & Kirisits, 2008) and Hungary (Kirisits et al., 2009). In 2008, the disease spread to France (Husson, 2011), in 2009 it was Italy and Greece (Ogris, 2010), which caused the trees to dieback. The latest reports of noted pathology of *Fraxinus excelsior* L. were received from Belgium (Chandelier, 2009), Netherlands, England and Ireland (COST, 2011). In Ukraine, pathological dieback of ash has been reported since 2014 (Davydenko et al., 2013; Goychuk & Kulbanska, 2014; Matsiakh & Kramarets, 2014). Ash is currently dieback in 30 European countries (COST, 2011).

From different parts of the planet, there are reports of similar and different etiology and symptoms of tuberculous pathology. Based on scientific research, many possible pathogens – fungi have been put forward (Kowalski & Holdenrieder, 2009; Lygis et al., 2005; Przybył, 2002; Langer, 2017) (in particular, *Hymenoscyphus fraxineus* Bar.,

which was identified in Ukraine (Davydenko et al., 2013), bacteria (Cherpakov, 2012; Goychuk et al., 2019), nematodes (John, 1967; Ryss & Polyana, 2018), mycoplasmas (Bricker & Stutz, 2004), representatives of harmful entomofauna (Korda et al., 2019), as well as the influence of climatic and soil-hydrological indicators (Goberville et al., 2016), however, no consensus has been reached yet.

Materials and Methods

Material for the study of the peculiarities of tuberculous pathology of common ash was collected in fresh oak forests of Western Podillia of Ukraine, which, as you know, are optimal for the growth of highly productive deciduous forests with the participation of *Fraxinus excelsior*, in particular, in natural conditions on the territories of state forestry enterprises (Chortkivske forestry enterprise, Ternopilske forestry enterprise, Buchatske forestry enterprise). In the study area, *Fraxinus excelsior* usually grows in mixed stands with *Acer pseudoplatanus* L., *Acer platanoides* L., *Quercus robur* L., *Tilia cordata* Mill., *Alnus glutinosa* (L.) Gaerth., *Prunus avium* L., *Carpinus avium* L. and *Ulmus campestris* L., *U. glabra* Mill. However, there are also mono-cultures of ash, which are also characterized by high productivity. The vast majority of stands with *Fraxinus excelsior* have a stand density of 0.7-0.8. The age groups are dominated by middle-age and pre-matured stands, which account for about 58% of the area of stands.

Affected samples were taken according to pathology of varying intensity, from trees of different age groups (young, by middle-age and matured stands) and from different parts of the trunk in transverse and longitudinal sections – from the bark, from the affected bast part, on the border of healthy and affected wood and visually healthy tissue.

During the research, reconnaissance and detailed methods of forest pathological examinations were used, as well as methods of phytopathological, microbiological and mycological studies according to generally accepted methods (Patyka, 2017), due to which studies of the pathogenic, anatomical-morphological, cultural and antagonistic properties of *Pseudomonas syringae* pv. *savastanoi* and

associated bacteria and micromycetes in the tuberculous pathology of ash (Goychuk, 2020a).

In the laboratory of the D. K. Zabolotny Institute of Microbiology and Virology of the NASU homogenized and plated on potato agar (PA) pieces of affected tissues. Bacterial cultures were grown in a thermostat at a temperature of 26°C. The number of microorganisms depending on functional and other traits was tested for their growth on special nutrient media (potato agar, meat-peptone agar, meat-peptone broth, malt extract of agar, a medium of Chapek, etc.). The pathogenic properties of the isolates were manifested in laboratory and field conditions by artificial infection of vegetative and generative organs of common ash and indicator plants (*Phaseolus vulgaris* L., *Nicotiana tabacum* L., *Kalanchoe laciniata* L.) with a bacterial suspension with a titer of 10⁸-10⁹ cells×ml⁻¹ (according to turbidity standard). Control – sterile tap water. The placement and size of bacterial cells, Gram staining, the morphology of colonies of microorganisms, their biological, biochemical and cultural properties were studied using special methods (Patyka, 2017).

To determine the ability of bacterial isolates to ferment various sources of hydrocarbons, the mineral medium of Omelyansky was used. The following organic compounds were used as sources of carbohydrates: lactose, xylose, rhamnose, trehalose, raffinose, L-arabinose, maltose, sorbitol, salicin, sucrose, galactose, fructose, glycerin, mannitol, citrate. The enzymatic or oxidative pathway of glucose uptake was determined by the growth of microorganisms on Omelyansky's medium under anaerobic conditions under a 1 cm layer of vaseline oil. The indicator was an aqueous solution of bromothymol blue. Milk and gelatin were used to detect proteolytic enzymes in bacteria. Interactions between microorganisms were investigated by the method of delayed antagonism. The test cultures were a standard set of bacterial strains from the collection of the Department of Phytopathogenic Bacteria of the D.K. Zabolotny Institute of Microbiology and Virology of the NASU, as well as isolated by us from vegetative and generative organs of common ash.

The antibacterial activity of biopesticides based on *Bacillus* sp. was investigated by titration and on ash in vivo.

To assess the typicality of the species of micromycetes and to determine their position in the structure of dominance in the biocenosis, we applied the criterion of a spacious frequency of occurrence. To study the typical diversity of fungi in the biogeocenosis, we used the concept of the seasonal frequency of occurrence of the species. To characterize the species composition of fungi in the wood samples under study, the Sorensen-Chekanovsky similarity coefficient was used.

Results and Discussion

Nowadays, practically all systematic groups of myco- and microorganisms (as causative agents of diseases) are known on ordinary ash – fungi, bacteria, mycoplasma-like organisms (MPO), viruses, viroids, as well as algae, lichens, higher flowering plants, etc. Our research is aimed directly at establishing the species composition and mechanism of systemic relationships of the components of the myco- and microbiota of tuberculous pathology of common ash to regulate (self-regulate) the pathogenicity and aggressiveness of vital obligate as a permanent (inalienable, obligatory) presentation in a part of the plant organism.

The symptomatology of tuberculous pathology of common ash in the study region is typically infectious and manifests itself on the branches, trunks, and generative organs of ash. At the same time, instead of a smooth greenish-grey bark, small elliptical soft tumors are formed due to local swelling of the bark and filling the voids with an odorless gray sticky bacterial mass.

Over time, the affected areas of the trunk become flattered, crack, the cambium and bast in the middle part die off and collapse. In the center of tuberculous formations, a crack forms, which over time heals. However, complete overgrowth does not occur. From year to year, new tumors form, which spread both along the length and the perimeter of the trunk (branch). As a result, specific long-term lesions are formed, which outwardly resemble a “scab” (Fig. 1).

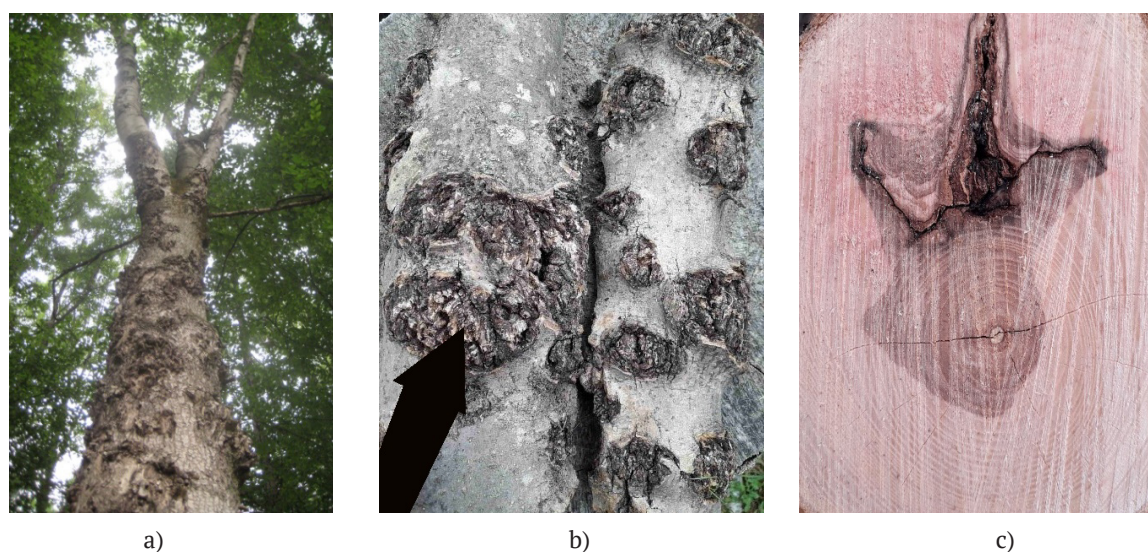


Figure 1. Symptoms of tuberculous pathology of common ash:
 a – general view of the affected *Pseudomonas syringae* pv. *savastanoi* tree;
 b – tuberculous formations on the trunk;
 c – the consequences of joint colonization of the ash trunk with the causative agent of tuberculosis, nectriosis and wood-coloring fungi

The number of wounds on a tree depends on the degree of injury and the age of the tree, but generally, on one affected tree, dozens and even hundreds of foci of tuberculosis can be counted. The presence of lesions deep in the trunk, which is overgrown with wood, usually spread along with the annual rings. Rotten areas on the trunk of an ash tree are formed exclusively during mixed infection with the formation of open ulcers with the participation of wood-destroying and wood-coloring fungi, in particular from the *Ascomycota* and *Basidiomycota* divisions. In the formation of open wounds (ulcers), usually the causative agents of common or stepped cancer, mainly *Nectria galligena* Bres., are involved or *Endoxylina stellulata* Rom. (anamorph – *Libertella fraxini* Ogan.). And then the disease proceeds with symptoms characteristic of these pathogens (stepped open ulcers are formed).

To establish the etiology of this phenomenon, we conducted special myco- and microbiological analyzes, the result of which is the identification of the pathogen and the

species composition of concomitant myco- and microbiota of tuberculosis pathology.

As a result of determining the species composition of the pathogenic microflora of tuberculous pathology of common ash, 7 species of bacteria were identified. The analysis of the obtained results showed the similarity of the studied samples with the following species: *Pseudomonas syringae* pv. *savastanoi*, *P. fluorescens*, *P. syringae*, *Pseudomonas* sp., *Erwinia herbicola*, *Xanthomonas* sp, *Bacillus subtilis* Eh. and *Bacillus pumilus* Eh. According to the results of artificial infection, the isolates showed pathogenicity both on ash-key, young ash trunks (branches), and on indicator plants. At the same time, they were non-pathogenic to the leaves of common ash (only minor damage to the leaf blade remained at the sites of the introduction of the bacterial inoculum). The average values of bacteria isolated from the vegetative and generative organs of *Fraxinus excelsior* ranged from 1 to 168 CFU (Fig. 2). The largest number (116, 168 CFU) of bacteria was obtained by isolating *Pseudomonas syringae* pv. *savastanoi*.

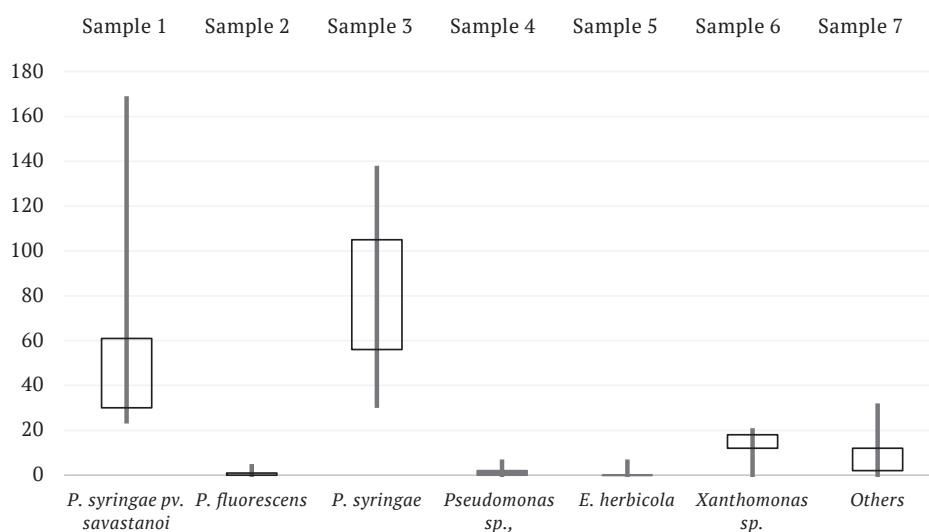


Figure 2. Number of colony-forming units (CFU) bacteria isolated from vegetative and generative organs *Fraxinus excelsior*

Also, thanks to the results of artificial infection of common ash by injection into the trunks of a suspension of a daily culture of microorganisms (8.6-9.97 CFU×ml⁻¹) and by introducing a pure bacterial culture under the bark (14.1-21.27 CFU×ml⁻¹) (both in vivo and in vitro), we confirmed the

bacterial etiology of tuberculous pathology (Fig. 3) and isolated the pathogen – the phytopathogenic bacterium *Pseudomonas syringae* pv. *savastanoi*. When carrying out the above-mentioned works, circadian rhythms of plant resistance (Gvozdyak, 2005) to bacteriosis pathogens were taken into account.



Figure 3. The result of artificial infection of the organs of common ash *Pseudomonas syringae* pv. *savastanoi*

The agent isolated by us has typical features for the genus *Pseudomonas*. These are non-spore-bearing mobile rods 0.4-0.8×1.3-3.0 microns in size, gram-negative, placed singly, in pairs or in short chains, sometimes in groups, lophotrichs, with 1-6 polar flagella. The ends of the sticks are smoothly rounded. On the potato agar, colonies are grey-white, smooth, round, transparent, with a denser center, with an equal or slightly wavy, sometimes with a blue tint, edge. Colonies on meat-peptone agar are small, 2-3 mm in diameter, grow slowly, gray-white, round, flat, or convex, with a notch in the center, transparent, with an equal or wavy edge. On meat-peptone broth, the growth is moderate, bacteria form uniform cloudiness. No growth was found on the Czapek and Omelyansky medium.

The strains are not homogeneous according to physiological characteristics. The aerobic, not fermenting glucose under vaseline oil. Bacteria assimilate sucrose, galactose, fructose, glycerin, mannitol, citrate; do not assimilate lactose, xylose, rhamnose, trehalose, raffinose, L-arabinose, maltose, sorbitol, salicin. They do not reduce nitrates. They cause a hypersensitivity reaction on the

leaves of *Nicotiana tabacum* and form a fluorescent pigment on the potato agar.

Growth was noted at 37°C. According to the given signs, the causative agent of tuberculous pathology is close to that described in the literature (Iacobellis & Caponero, 1998; Cherpakov; 2012; Ramos et al., 2012; Suresh & Rupert, 2016; Caballo-Ponce et al., 2017; Goychuk et al., 2019).

In particular, growth (no growth) on most nutrient media, significant variability with food sources, relationship in the production of enzymes. The main differences are the absence of fluorescence in liquid nutrient media and the slow absorption of carbohydrates and alcohols. The heterogeneity and plasticity of this species are associated with the possibility of expanding the spectrum of nutritious plants.

In the course of our analysis of mycobiota, affected by tuberculous pathology of ash branches in the region, of the study in total (including identified only to the level of the genus *Fusarium* sp. and *Phoma* sp.). Were identified 7 genera and 10 species of micromycetes. Usually, the affected tissue samples had a mixed infection (Fig. 4).



Figure 4. Colonies of micromycetes isolated from vegetative and generative organs of affected trees *Fraxinus excelsior*:
a – *Mycelia sterilia* (orange), *M. sterilia* (dark), *Cladosporium cladosporioides*, *Ulocladium botrytis*;
b – *U. botrytis*, *Phoma* sp., *C. cladosporioides*

The analysis of the obtained results showed the similarity of the studied samples with the following species: *Acremonium strictum*, *Cladosporium cladosporioides*, *C. didymum*, *Fusarium sporotrichiella* Bilaivar. (Peck) Wol., *Fusarium heterosporum*, *Fusarium* sp., *Mycelia sterilia* (dark), *M. sterilia* (orange), *Phoma* sp., *Ulocladium botrytis*.

Based on the results obtained, it is possible to differentiate the identified species into separate categories, in particular, to assert that *Ulocladium botrytis* is a typical dominant species (spatial and seasonal frequency of occurrence exceeds 60%). Typical numerous species include – *Phoma* sp., *Cladosporium cladosporioides*,

Mycelia sterilia (orange). Following the types of rare species – *Acremonium strictum*, *Cladosporium didymum*, *Fusarium sporotrichiella*, *F. heterosporum*, *Fusarium* sp. and *M. sterilia* (dark). There are no random species. *Ulocladium*

botrytis is characterized by a high occupancy rate (57.1%), while *Acremonium strictum*, *C. didymum*, and *Fusarium sporotrichiella* are characterized by a low one (14.3%). *F. heterosporum* (Fig. 5).

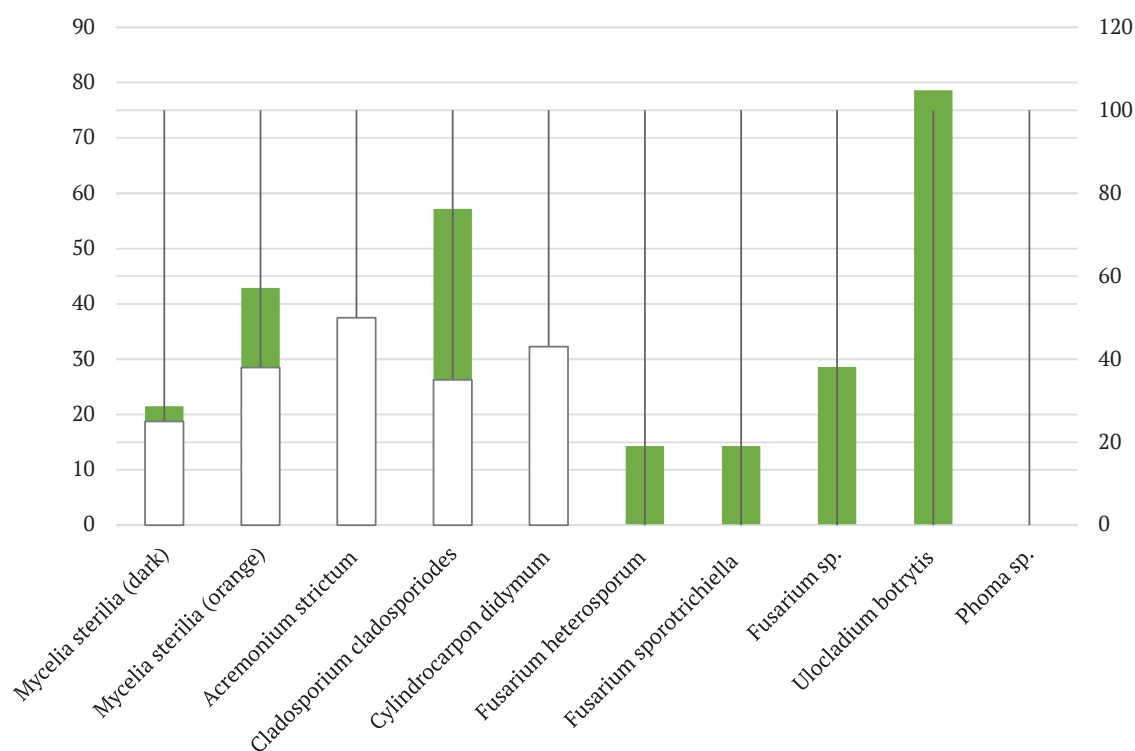


Figure 5. Spatial and seasonal frequency of occurrence of micromycetes of tuberculous pathology of common ash

Based on the calculation of the Sorensen-Chekanovsky similarity coefficient ($S > 0.5$), we see that there are significant differences between the species composition of the compared stages of the study. In general, the results of the study showed that the mycobiota of infected branches of common ash is characterized by the presence of a complex of pathogenic species, dispersedly localized over the affected area. The results obtained confirm the assumption of the presence of a complex biological complex, dieback of tree stands. We also found a disease known as “ash dieback” (“deadly disease” of ash, “peripheral dying

off”, “pathogenic dieback of ash”) in the studied stands). It should be noted that the symptoms have fundamental differences in comparison with tuberculosis. In affected plants, there is a rapid gradual (sometimes sudden) crown death due to the formation of local necrotic areas on the shoot (trunk). The leaves above the lesion site wither (starting from the top), and by the end of summer they turn black (like those burnt by fire) and do not fall off for a long time.

Studies have shown that the micromycete *Chalara fraxinea* Kow. is the causative agent of ash dieback

(Kowalski, 2006; Davydenko et al., 2013; Matsiakh & Kramarets, 2014). At the same time, attention was focused on the fact that *C. fraxinea* is an anamorph of *Hymenosyphus pseudoalbidus* (Kowalski & Holdenrieder, 2009). We have isolated several species of anamorphic fungi from the pathology of the ash dieback type (we failed to isolate *C. fraxinea*) and bacteria, in particular *Pseudomonas syringae* pv. *savastanoi*, *Erwinia horticola* and *Xanthomonas* sp. Artificial infection of ash organs with micromycetes did not lead to symptoms similar to “ash dieback”, and bacterial infections caused pathological processes similar to ash tuberculosis.

To initiate processes related to the activity of natural populations of hyperparasites, which are ecologically and trophically combined with bacterial phytopathogens, we investigated the relationship, in particular antagonistic, in the systems of “phytopathogenic bacteria-hyperparasites” of tuberculous pathology of common ash.

The study of systemic relationships, primarily antagonistic, between different types of myco- and microorganisms, including saprotrophs and pathogens, pathogens of infectious plant diseases, including bacteriosis, in the context of identifying active antagonists to pathogenic components of myco- and microbiota is extremely important and relevant. To study the antagonistic relationships in the system “bacterium-bacterium” and “bacterium-micromycete” in the laboratory, we used both isolated by us and collection strains of bacteria *Pseudomonas syringae* 8511, *Pseudomonas savastanoi* 9174, as well as micromycetes *Ulocladium botrytis*, *Phoma* sp., *Cladosporium cladosporioides*, *Acremonium strictum*, *Cladosporium didymum*, *Fusarium sporotrichiella*, *F. heterosporum*, *F. sp.*

All strains were used in cross-reactions “basic culture-test culture”. A total of 108 variants of reactions were delivered. During the research, we did not find antagonistic relationships between test cultures – pathogens of *Fraxinus excelsior* in the system “bacterium-bacterium”. In contrast to bacteria, micromycetes isolated from the vegetative and generative organs of *Fraxinus excelsior* showed some antagonistic activity against phytopathogenic bacteria. The most active were *Ulocladium botrytis* and *Cladosporium cladosporioides* with mean

sterile zones of 5.8 mm and 4.9 mm, respectively. They suppressed to varying degrees all test cultures of phytopathogenic bacteria. The activity of the other three micromycete species, *Acremonium strictum*, *Fusarium heterosporum*, and *F. sporotrichiella*, was selective. They did not inhibit the growth of *Pseudomonas* sp. (“Kr4”) and *Pseudomonas syringae* pv. *savastanoi* (“Kr4”) and weakly inhibited *Pseudomonas syringae* pv. *savastanoi* (“H1”) and the collection *Pseudomonas savastanoi* 9174. Other species of micromycetes did not show antibacterial activity. Bacteria *Pseudomonas syringae* pv. *savastanoi* (H1), *Pseudomonas syringae* 8511, *Pseudomonas savastanoi* 9174 were the most sensitive to all types of micromycetes.

Regarding the reverse effect, phytopathogenic bacteria on micromycetes, in most cases their antifungal activity was zero. Minor areas formed by the action of bacteria on micromycetes are also virtually zero. Such a result was obtained in the laboratory on an artificial nutrient medium, which differently affects the growth and activity of bacteria and micromycetes. In particular, bacteria grow intensively on the potato agar, and the growth of micromycetes is inhibited. At the same time, bacteria do not grow on Czapek medium due to the presence in these media of different nutrients for micromycetes and bacteria. Under natural conditions, the interaction in the systems “bacterium-bacterium”, “bacterium-micromycete”, “micromycete-bacterium” can and obviously should be different, because the micro- and microorganisms are influenced by various factors (woody plant at certain stages growth and development, its physiological state, the presence of a pathology, meteorological (synoptic) factors, including as catalysts of pathology, compliance of forest woody plant with forest conditions, etc.). However, experiments with coniferous forest woody plants have shown that phytopathogenic bacteria (so-called vital obligates) in natural conditions outside the pathological process do not affect the growth of micromycetes (Gvozdyak, 2005; Goychuk, 2020b). Studies of biological products (“Victant” and “P27ant”) based on aerobic spore-forming bacteria *Bacillus* sp. no high antimicrobial activity was revealed for all studied cultures of microorganisms, and their activity depended not only on the type of bacteria but also on which organs of the ash tree it was isolated from (Fig. 6).

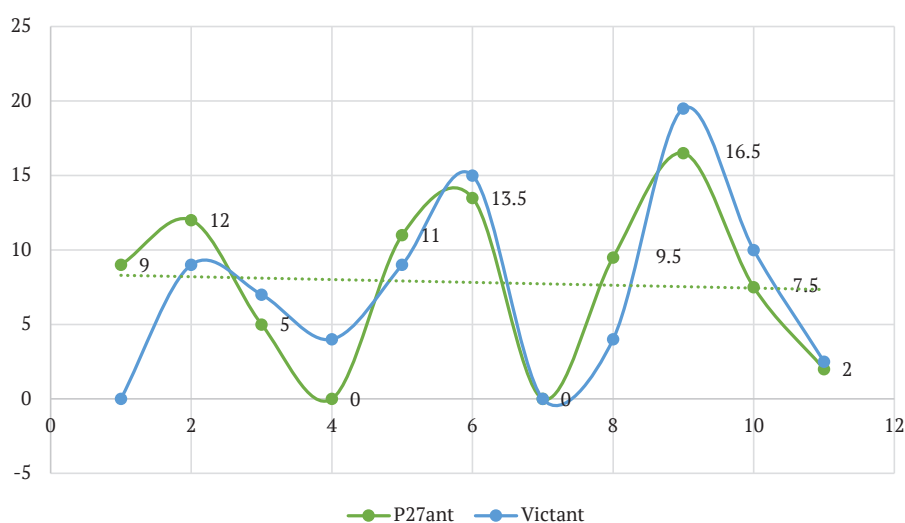


Figure 6. Antimicrobial activity of “Victant” and the strain “P27ant”

It was found that bacteria of the genus *Bacillus* sp. can suppress the adhesion and survival of phytopathogenic *P. syringae* pv. *savastanoi* on the surfaces and tissues of test plants, eliminating the pathogen population or decreasing its density with a possible attenuation of properties, the mechanism of which requires further research. Thus, our studies in combination with the results of other scientists indicate the presence of diseased trees *Fraxinus excelsior* complex biocomplex of pathogenic species, which directly involved in the dieback of ash stands. And, we found elements of antagonistic relationships between components of different systematic and functional groups of myco- and microorganisms indicate the possibility and necessity of using this phenomenon in the context of positive and negative feedback mechanisms to develop methods of biological protection of forest woody plants, including *Fraxinus excelsior*, from pathogens of infectious diseases, including bacteriosis.

Conclusions

Currently, the deterioration of phytosanitary conditions of plantations with the participation of *Fraxinus excelsior* is associated with various biotic (harmful entomofauna),

biotic parasitic (micromycetes, bacteria, nematodes, mycoplasma factors, as well as adverse climatic (synoptic, synoptic, and many), including “ash dieback” and tuberculosis, which indicates the need for comprehensive studies of pathologies of forest woody plants, including epiphytic, in particular, diseases of forest woody plants are currently associated with exogenous infection.

Isolated by us the causative agent of tuberculous pathology of common ash *Pseudomonas syringae* pv. *savastanoi* on the following grounds is close to that described in the literature: growth (no growth) on most nutrient media, significant variability in relation to nutrient sources, and so on.

Erwinia horticola, *Pseudomonas* sp., *P. fluorescens*, *P. syringae*, *P. agglomerans*, *Xanthomonas* sp., spore-bearing bacteria *Bacillus* sp., as well as micromycetes *Acremonium strictum*, *Cladosporium didymum*, *Fusarium* sp., *Fusarium sporotrichiella*, *F. heterosporum*, *Phoma* sp., *Ulocladium botrytis* and the like isolated at different stages of tuberculous pathology of *Fraxinus excelsior*. Affected plants at any age have hidden faults in the wood (blackening, cracks, rotten areas with a significant spread along the trunk), which devalues it.

It was found that both isolated phytopathogenic bacteria and concerning test cultures of bacteria did not reveal antagonistic activity. In contrast to bacteria, micromycetes isolated from the vegetative and generative organs of common ash are characterized by a large antagonistic activity concerning phytopathogenic bacteria. Thus, we found, like other researchers, elements of antagonistic relationships

between components of different systematic and functional groups of myco- and microorganisms indicate the possibility and necessity of using this phenomenon in the context of positive and negative feedback mechanisms for the development of means and methods of biological protection forest woody plants, including *Fraxinus excelsior*, from pathogens of infectious diseases, including bacteriosis.

References

- [1] Bricker, J. S., & Stutz, J. C. (2004). Phytoplasmas associated with ash decline. *J. Arboric*, *30*, 193–199.
- [2] Caballo Ponce, E., Murillo Martínez, J., Martínez Gil, M., Moreno Pérez, A., Pintado, A., & Ramos, C. (2017). *Knots untie: Molecular determinants involved in knot formation Induced by Pseudomonas savastanoi in woody hosts*. <https://doi.org/10.3389/fpls.2017.01089>.
- [3] Chandelier, A., Delhay, N., & Helson, M. (2009). First report of the ash dieback pathogen *Hymenoscyphus pseudoalbidus* (anamorph: *Chalara fraxinea*) on *Fraxinus excelsior* in Belgium. *Plant Disease*, *95*, 220–226.
- [4] Cherpakov, V. V. (2012). Bacterial diseases of forest species in pathology of forest. *Journal SPb GLTU*, *292–303* [in Russian].
- [5] COST 2011: European cooperation in science and technology. *Fraxinus dieback in Europe: elaborating guidelines and strategies for sustainable management (FRAXBACK)*. Available at http://www.cost.eu/COST_Actions/fps/FP1103.
- [6] Davydenko, K., Vasaitis, R., Stenlid, J., & Menkis, A. (2013). Fungi in foliage and shoots of *Fraxinus excelsior* in eastern Ukraine: a first report on *Hymenoscyphus pseudoalbidus*. *Forest Pathology*, *43* (6), 462–467. <https://doi.org/10.1111/efp.12055>.
- [7] EPPO. 2020. EPPO Global database. In *EPPO Global database*. Paris, France: EPPO. Available at <https://gd.eppo.int/>.
- [8] Goberville, E., Hautekèete, N.-C., Kirby, R., Piquot, Y., Luczak, C., & Beaugrand, G. (2016). Climate change and the ash dieback crisis. *Scientific Reports*, *6*, 35303. <https://doi.org/10.1038/srep35303>.
- [9] Goychuk, A., & Kulbanska, I. (2014). Etiology of Common Ash Diseases in Podolia, Ukraine. *Scientific Journal of NUBiP of Ukraine*, *24.11*, 15–19 [in Ukrainian].
- [10] Goychuk, A., Drozda, V., Kulbanska, I., & Shvets, M. (2019). Phytopathogenic bacteria in the pathology of forest trees of polyssya and forest-steppe of Ukraine. *Ukrainian Black Sea region agrarian science*, *2*, 28–33. [https://doi.org/10.31521/2313-092X/2019-2\(102\)-4](https://doi.org/10.31521/2313-092X/2019-2(102)-4).
- [11] Goychuk, A. F., Kulbanska, I. M., & Shvets, M. V. (2020a). Associated with bacteria in pathology *Fraxinus excelsior* L. *Microbiological Journal*, *82* (3), 22–34. <https://doi.org/10.15407/microbiolj82.03.022>.
- [12] Goychuk, A. F., Drozda, V. F., Shvets, M. V., & Kulbanska, I. M. (2020b). Bacterial wetwood of silver birch (*Betula pendula* roth): symptomology, etiology and pathogenesis. *Folia Forestalia Polonica*, *62* (3), 145–159. <https://doi.org/10.2478/ffp-2020-0015>.
- [13] Gvozdyak, R. I. (2005). Perspective directions of research of phytopathogenic bacteria. In *Proceedings of the International Scientific Conference “Phytopathogenic bacteria. Phytoncology. Allelopathy”* (pp. 3–8). Zhytomyr [in Ukrainian].
- [14] Halmschlager, E., & Kirisits, T. (2008). First report of the ash dieback pathogen *Chalara fraxinea* on *Fraxinus excelsior* in Austria. *Plant Pathology*, *57*, 1177.
- [15] Husson, C., Scala, B., Caël, O., Frey, P., Feau, N., Ioos, R., & Marcais, B. (2011). *Chalara fraxinea* is an invasive pathogen in France. *European Journal of Plant Pathology*, *130*, 311–324. <https://doi.org/10.1007/s10658-011-9755-9>.
- [16] Iacobellis, N. S., & Caponero, A. (1998). Evidente Characterization of *Pseudomonas syringae* ssp. *savastanoi* strains isolated from ash. *Plant Pathology*, *47*, 73–83. <https://doi.org/10.1046/j.1365-3059.1998.00202.x>.
- [17] Jankovský, L., & Holdenrieder, O. (2009). Ash and ash dieback in the Czech Republic. *Plant Protection Science*, *45*, 74–78. <https://doi.org/10.17221/45/2008-PPS>.
- [18] John, L. (1967). *Ruehle Distribution of Plant-parasitic Nematodes Associated with Forest Trees of the World*. Plant Nematologist Forestry Sciences Laboratory Athens, Georgia. <https://doi.org/10.5962/bhl.title.149734>.

- [19] Kirisits, T., Matlakova, M., Mottinger-Kroupa, S., Halmschlager, E., & Lakatos, F. (2009). Chalara fraxinea associated with dieback of narrow-leaved ash (*Fraxinus angustifolia*). *New Disease Reports*, 1–2.
- [20] Korda, M., Csóka, Gy., Szabó, Á., & Ripka, G. (2019). First occurrence and description of *Aceria fraxiniflora* (Felt, 1906) Acariformes: Eriophyoidea) from Europe, *Zootaxa*, 4568(2), zootaxa.4568.2.5. <https://doi.org/10.11646/zootaxa.4568.2.5>.
- [21] Kowalski, T., & Holdenrieder, O. (2009). The teleomorph of *Chalara fraxinea*, the causal agent of ash dieback. *Forest Pathology*, 39, 304–308. Available at <http://www.blackwell-synergy.com/loi/efp>. <https://doi.org/10.1111/j.1439-0329.2008.00589.x>.
- [22] Kowalski, T. (2006). *Chalara fraxinea* sp. nov. associated with dieback of ash (*Fraxinus excelsior*) in Poland. *Forest Pathology*, 36, 264–270.
- [23] Langer, G. (2017). Collar rots in forests of Northwest Germany affected by ash dieback. *Baltic Forestry*, 23, 4–19.
- [24] Lygis, V., Rimvydas, V., Karl-Henrik, L., & Jan, S. (2005) Wood-inhabiting fungi in stems of *Fraxinus excelsior* in declining ash stands of northern Lithuania, with particular reference to *Armillaria cepistipes*. *Scandinavian Journal of Forest Research*, 20 (4), 337–346. <https://doi.org/10.1080/02827580510036238>.
- [25] Matsiakh, I. P., & Kramarets, V. O. (2014). Declining of Common Ash (*Fraxinus excelsior* L.) in Western Ukraine. *Scientific Herald of National Forest Technical University of Ukraine*, 24.7, 67–74 [in Ukrainian].
- [26] Ogris, N., Hauptman, T., Jurc, D., Floreancig, V., Marsich, F., & Montecchio, L. (2010). First Report of *Chalara fraxinea* on Common Ash in Italy. *Plant Disease - PLANT DIS*, 94, 133–133. <https://doi.org/10.1094/PDIS-94-1-0133A>.
- [27] Patyka, V. P., Pasichnyk, L. A., Gvozdyak, R. I., Petrichenko, V. F., et al. (2017). *Phytopathogenic bacteria. Methods of research*. Vinnytsia: Windruck [in Ukrainian].
- [28] Przybył, K. (2002). Fungi associated with necrotic apical parts of *Fraxinus excelsior* shoots *Forest Pathology*, 46 (4), 387–394. <https://doi.org/10.1046/j.1439-0329.2002.00301.x>.
- [29] Ramos, C., Matas, I. M., Bardaji, L., Aragón, I. M., & Murillo, J. (2012). *Pseudomonas savastanoi* pv. *savastanoi*: Some like it knot. *Molecular Plant Pathology*, 13 (9), 998–1009. <https://doi.org/10.1111/j.1364-3703.2012.00816.x>.
- [30] Ryss, A., & Polyaniina, K. (2018). Characterization of Juvenile Stages of *Bursaphelenchus crenati* Rühm, 1956 (Nematoda: Aphelenchoidoidea). *Journal of nematology*, 50, 459–472. <https://doi.org/10.21307/jofnem-2018-042>.
- [31] Suresh, G. B., & Rupert, A. Y. (2016). *Bacterial Diseases of Forest Trees, Bacterial Diseases of Crop Plants*. CRC Press. <https://doi.org/10.1201/9781315367972>
- [32] Talgø, V., Sletten, A., Brurberg, M. B., Solheim, H., & Stensvand, A. (2009). *Chalara fraxinea* Isolated from Diseased Ash in Norway. *Plant Disease*, 93 (5), 548. <https://doi.org/10.1094/PDIS-93-5-0548A>.

Міко- і мікроорганізми туберкульозної патології ясена звичайного в Україні та взаємовідносини між ними

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Анотація. Останніми роками спостерігається епіфітотійне всихання багатьох видів лісових деревних рослин як в Україні, так і в інших країнах світу, яке має динамічний характер і тенденцію до зростання. Особливу увагу нині необхідно приділити деградації ясеневих насаджень, етиологія патології якої пов'язана із фітопатогенною бактерією – *Pseudomonas syringae* pv. *savastanoi*. Загальна схема досліджень туберкульозної патології *Fraxinus excelsior* передбачала такі етапи: рекогносцирувальні та детальні лісопатологічні обстеження за загальноприйнятими лісівничо-таксаційними та фітопатологічними методами; відбір уражених органів і тканин; ізоляція міко- і мікроорганізмів у чисту культуру; перевірка патогенних властивостей виділених ізолятів та їх ідентифікація; дослідження антагоністичних взаємовідносин у системі «бактерія-бактерія», «бактерія-мікроміцет» як можливих чинників індукції демутаційних процесів у лісовий біоценоз. Збудник туберкульозу веде до формування типових туберкульозних виразок на вегетативних та генеративних органах ясена звичайного. Характер патогенезу захворювання – хронічний, вагомо впливає на онтогенез рослини, зокрема веде до формування поліморфних типів вад деревини та деформації насіння у дерев стиглого віку. Деревя молодого віку гинуть унаслідок спільної інфекції з іншими інфекційними агентами. Деревя порослевого походження відмирають у перші роки після зараження. Дослідження механізму системних взаємин (зокрема, антагоністичних) складових міко- і мікробіоти туберкульозної патології ясена звичайного дає можливість втрутитися у процес регуляції патогенності й агресивності вітальних облігатів, шляхом застосування біопрепаратів для профілактики і захисту деревних насаджень від збудників бактеріозів. На різних стадіях туберкульозної патології *Fraxinus excelsior* L. ізолювані *Erwinia horticola*, *Pseudomonas* sp., *P. fluorescens*, *P. syringae*, *P. agglomerans*, *Xanthomonas* sp., спороносні бактерії *Bacillus* sp., а також мікроміцети *Acremonium strictum*, *Cladosporium cladosporioides*, *Cylindrocarpon didymum*, *Fusarium* sp., *F. sporotrichiella*, *F. heterosporum*, *Phoma* sp., *Ulocladium botrytis* тощо, які використані в дослідженнях як «антипод» збудника туберкульозу. Встановлено, що бактерії роду *Bacillus* sp. здатні пригнічувати адгезію і виживання фітопатогенних *P. syringae* pv. *savastanoi* на поверхнях і в тканинах тест-рослин, елімінуючи популяцію патогена або зменшуючи її щільність з імовірною атенуцією властивостей, механізм якої потребує подальших досліджень

Ключові слова: бактерії, гриби, ясен звичайний, антагонізм, *Pseudomonas syringae* pv. *savastanoi*