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Practical approaches to establishing the dynamics of stand stability of breeding facilities

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Abstract. The study considers the concept of stability of tree stands and their establishment at breeding facilities considering the dynamics of the intensity of using environmental conditions. The protective properties of the forest environment, which are identified with the preservation of genetic diversity, are determined by the amount and quality of natural renewal and are associated with environmental stability (renewability), can be effectively assessed by the loss of this stability according to the above method. The study analyses approaches and areas relevant for assessing the biotic and eco-resistance of tree stands. For breeding facilities, these issues are relevant when assigning reforestation measures in forest genetic reserves, assessing the stability of stands at the time of selection of positive plantings, and evaluating selected permanent forest seed plots from the standpoint of determining the volume of planting and care. The methodology for assessing stand stability is based on determining stability indicators (stability coefficient, loss of biotic stability, loss of ecological stability), which are calculated based on a parametric (taxonomic) assessment of trees, their sanitary condition, and natural regeneration in the area under study. Using the values of the given stability indicators, plantings can be divided into three categories: stable, conditionally stable, and unstable. Appropriate forestry measures are proposed that require a separate parametric assessment of forest-forming tree species, economic groups of forest types, forest categories, target measures, or research area. During studies of the living space tension indicator, it was found that the use of forest-growing conditions occurs according to the assessment of the process of development of stands as normal, non-stressed, and stressed. To establish the indicator of normal and weakened state, a basic scale for assessing biotic stability based on state indices is proposed

Keywords: stability assessment, stress indicator, gene pool conservation, sanitary condition, area dynamics

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Introduction

In forestry science, along with the issue of increasing the productivity of stands, a great deal of attention is paid to assessing and increasing the biotic stability and eco-resistance of stands, and forest selection, accordingly, becomes more relevant in breeding and shaping sites for stability. The main factor for assigning specific economic measures, primarily in non-operational categories of forests, is the loss of stability and protective properties by plantings. Therefore, there is an obvious need to quantify the loss of biotic stability of stands by forests. These issues remain relevant for breeding facilities, especially during the appointment of reforestation measures in forest genetic reserves. It is important to assess the stability during the selection of positive plantings and permanent forest-seed plots, considering the prospect of their transfer to positive (breeding) stands or withdrawal from the registers of objects of the permanent forest-seed base.

The term “stand stability” has been widely used in the scientific literature, and relevant forestry studies have been significantly updated recently (Tretyak & Chernevyy, 2020; Maliuga, 2020; Oliynyk & Blystiv, 2019; Gilliam, 2016; Holubets, 2013; Oliynyk, 2013; Shparyk, 2012 etc.). Resistance is defined in relation to a particular component of the forest (stand) as the biotic stability of the species (ecosystem engineer), and in relation to the phytocenosis (forest environment). In forestry science, the concept of ecosystem stability (biogeocenosis) is introduced, in this case, this refers to the stability of the functioning of the forest environment (Holubets, 2008). It is noted that the concept of stability in modern forestry research has a two-way meaning depending on the area and object of study (Brang, 2001). Stability is also considered as a high resistance to external influences and as a property for maintaining a functional forest environment. First

of all, stable stands include: native stands of ecological and forestry typology (Stoiko, 2011; Parpan, 2008; Holubets, 2008, etc.), indigenous forest types in phytocenological classification (Sukachev, 1964; Holubets, 2008), nodal stages in successions and changes (Yaroshenko, 1958), stands of stable forest ecosystems (Holubets, 2013; Parpan, 2005 *et al.*). In forestry, the concepts of resistance and reproducibility (elasticity) are most often used (Brang, 2001, Oliynyk *et al.*, 2019). To assess stability, the concept of “standard” is sometimes used, which concentrates all the best signs of planting in specific growth conditions (primarily productivity), in particular, durability, biotic stability, and the ability to fully manifest its protective functions.

The qualitative characteristics of growing conditions (edatopes) are determined based on a comparison of the potential and actual productivity of plantings. It is believed that under different conditions, the stability of stands and forest tree species is not the same. Molotkov (1966) has found that in the conditions of wet hornbeam and beech forest, plantings are characterised by high productivity and stability. In general, native stands in beech forests are considered stable, this thesis is confirmed by P.S. Kaplunovskyi and V.I. Parpan. This approach is typical for the ecological and forestry typology from the standpoint of reforestation.

To evaluate individual trees in the forest, various classifications are used (Kraft, Shedelin, Zhylykin, etc.), which can be used to give a general description of stand structure, but its stability is not evaluated. The issue of loss of resistance due to damage by pests or forest diseases is considered depending on the needs of a particular area of forestry – forest protection (Meshkova *et al.*, 2018). In forestry, the assessment of the sanitary condition of each tree in six categories is used in accordance with the sanitary

regulations in the forests of Ukraine (Sanitary Forests Reg. Ukraine, 1995), and based on the results, economic measures are assigned for a specific site. To solve the problem of rapid assessment of the state and structure of forests, there is an international system for evaluating each tree in six classes, which are known as "IUFRO classes". It is also proposed to assess the life status of trees that have a biotically determined potency of the species for growth and development under certain conditions (Debrenyuk, 2017). The Guidelines on forest seed production (Los *et al.*, 2017) present a methodology for assessing the condition of trees and stands in five categories, which is based on the concept of "viability", which is informative for seeds, seedlings (self-seeding), and undergrowth. To assess the state of plantings, an indicator of living space tension is proposed (Maliuga, 2020). The substantiation of the selected indicator is carried out, in which the average height of plantings reflects the bonus (a recognised indicator of qualitative productivity), and the sum of the cross-sectional areas of trunks at a height of 1.3 m (absolute density) comprehensively characterises forest-growing conditions. Tax collectors in their production activities use tables of the sum of cross-sectional areas and stocks of plantings at density 1.0, so this approach is taken as the main one. To a certain extent, the issue of stability assessment is worked out in the studies by Blystiv (2006, 2012), Oliynyk *et al.* (2019), scientific recommendations contain the papers by Hayda *et al.* (2013), Marchuk *et al.* (2021). The issue of evaluating the efficiency of living space use by plantings is discussed by Malyuha & Minder (2020). The listed studies on the stability of forest ecosystems are important for evaluating the functionality of forest genetic reserves, which may consist of many taxation plots. The assessment of a certain designated territory (forest ecosystem, part of the population) can be based on the ratio of the state of individual

plots by area. This approach for estimating the area of reserve stands was proposed by researchers (Syrota, 2021): with the classification of the condition as "normal", which includes healthy stands, and "weakened", which includes damaged stands.

According to Oliynyk *et al.* (2019), Blystiv (2006, 2012), the concept of general forest stability can be divided into the following four main components:

1. Resistance to internal biotic factors or living organisms.
2. Resistance to anthropogenic impact.
3. Resistance to weather factors and other factors of inanimate nature.
4. Potential for the possibility of restoring and forming stable (indigenous) stands (maintaining homeostasis and protective properties).

The first two components can be combined by the concept of "biotic resistance", or resistibility (resistance). It is consonant with the concept of "natural stability", introduced on the basis of typological studies.

Forest typology is crucial for understanding and evaluating the stability of plantings. To assess the natural stability of plantings, an indicator of the typological potential (typological productivity) of a certain type of forest and modelling of the growth of ecotypes and indigenous stands as the main component of the stability of forest ecosystems are used. The term "naturalness" is also used in relation to the environment as an assessment of the inviolability of ecosystem connections or the level of its transformation. The naturalness of its individual components may correspond to the concept of biotic stability of indigenous stands, which, first of all, concerns the correspondence of the ecological optimum of a species to the growing conditions, the biology of species, and their mutual influence. For stands from the standpoint of forest selection and conservation of valuable gene pool and genetic diversity, the

concepts of autochthony and corresponding local origin, which are associated with stable stands, are used (Hayda & Yatsyk, 2013). However, the most important element in an integrated approach to determining the stability of stands remains the biotic component, which is the basis for ensuring eco-resistance.

The use of living space by artificial plantings can be normal (optimal), non-stressful, and stressful (Malyuha, 2020). Tension characterises certain processes – the loss of stability or its increase, therefore it can be used to assess processes in the stand (dynamics of stability). To make decisions on the stabilisation of processes in forest ecosystems, it is important to assess the ratio of the state of the object's territory to the areas of stable and unstable stands. The indicator "normal condition" corresponds to the set of stable stands on the site by area, "weakened" – conditionally stable and unstable. The dynamics of areas in the context of changes in these indicators by period characterises ecosystem changes and the succession process in them and is important for objects of conservation of valuable gene pool and genetic diversity.

The purpose of the study is to update the proposals for using the concept of stability in practice and express its assessment in measurable units for stands, considering the peculiarities of breeding facilities. In accordance with this goal, it was planned to achieve a comprehensive solution for assessing the state of biotic and eco-resistance by the coefficient of stability, the living space tension indicator, and the dynamics of stability by its relative loss with age.

Materials and Methods

The methodology for assessing stand stability is based on the use of taxation indicators and their sanitary condition, which are calculated based on

a parametric assessment of trees in the study plot based on test area. Basic for determination are the tree list and the scale of sanitary conditions used in production (Sanitary Forests Reg. Ukraine, 1995). Assessment of the stability of plantings is based on the method of calculating the loss of stability (LS), which is proposed for determining the stability of spruce derivatives in beech forests (Blystiv, 2006) and further for assessing the development of stability of hornbeam and beech plantings (Oliynyk & Blystiv, 2019). The calculation of the stability coefficient (SC) is based on the ratio of the average volume of a stand trunk, the average volume of a dry stand trunk, and the average volume of a healthy stand trunk. Sometimes it is sufficient to evaluate the total reserves of dry and healthy wood (Brang, 2001). This approach is effective in evaluating conditionally single-aged stands, which, as a rule, are dominated by the normal distribution of trunks by diameter. Accordingly, there is a need to adjust the formulas when evaluating complex plantings of different ages. In the case of using the scale of sanitary condition, healthy trunks for deciduous trees are assigned I–III categories of condition, and for pine trees – I and II. Normal (optimal) use of living space occurs at a relative density of 1.0 with maximum productivity of stands.

To calculate the stability coefficient (SC), the study used the ratio of trunk volumes (V) of stands for their condition and ratio coefficients ($Kv1$ – the ratio of the average volume of healthy trunks to the average volume of all trunks; $Kv2$ – the ratio of the average volume of dry trunks to the average volume of all trunks):

$$SC = Kv1 - Kv2, \quad (1)$$

at the same time: $Kv1 = V_{heal} \div V_{avg}$, $Kv2 = V_{dry} \div V_{avg}$,
 where V_{dry} – average volume of dry trunks; V_{heal} –

average volume of healthy trunks; V_{avg} – average volume of all stand trunks.

Accordingly, the loss of stability (LS) of the stand will amount to:

$$LS = 1 - SC \cdot \Sigma V_{dry} \div \Sigma V_{avg}, \quad (2)$$

where ΣV_{dry} – stock of dead wood in the stand; ΣV_{avg} – stock of stands.

In young trees, the appearance of deadwood is mainly the result of natural falling due to selection in the process of species and interspecies competition, and the total percentage of deadwood also depends on previous long-term management impacts, so the loss of stability is determined using a simplified equation:

$$LS = 1 - SC. \quad (3)$$

The same feature is distinguished by the approach for sparse and multi-age stands. Thus, the

$$LBS\ stand. = (LS\ 1s \times s.\ units.\ comp. + LS\ 2s \times s.\ units.\ comp. + \dots + LS\ dens. \times s.\ units.\ comp.) \div 0 \times \Sigma Ka1 \div n \times \Sigma Ka2 \div n \div LD, \quad (5)$$

where $LS\ 1s$, $LS\ 2s$ – loss of stability for forest-forming species in the composition ($1s$ – 1 species, $2s$ – 2 species ...); n – the number of forest-forming species in the composition for which the calculation is carried out; $s.\ units.\ comp.$ – share of units in the composition (1-9).

When determining the eco-resistance of stands (which is based on maintaining the functionality of the protective properties of the forest environment), it is advisable to consider reproducibility (regeneration) by to the presence of undergrowth, namely, calculate the coefficient of the age range of undergrowth (UarC), which is the ratio of the minimum age of undergrowth to the maximum:

formula for calculating the loss of biotic stability of plantings has the following form: weighted average sum of stand stability coefficients (SC), proportional to the average sums of the respective age coefficients and inversely proportional to the value of the loss of density, is the loss of stability. For pure stands, the equation will be as follows:

$$LS = (1 - SC) \cdot \Sigma V_{dry} \div \Sigma V_{avg} \cdot Ka1 \cdot Ka2 \div LD, \quad (4)$$

where $Ka1$ – age range coefficient (A – age) of the stand: $A_{min} \div A_{max}$; $Ka2$ – coefficient of relativity of the age of the stand: $A_{tent} \div A_{stab}$ (conditional age by forest-forming species, which correlates with biotic ripeness); LD – loss of density = $1 - D$, where D – stand density.

During the economic assessment of the stability of stands, the equation considers the stand composition and its age.

Equation for calculating the loss of biotic stability of mixed stands (*stand*) accordingly, will be as follows:

$$UarC = A_{min} \div A_{max}, \quad (6)$$

where A_{min} – minimum age of undergrowth in the stand; A_{max} – maximum age of undergrowth in the stand.

UarC partially characterises the viability of undergrowth for reforestation, so it is necessary to add the UarC value to equation 5. In practical use, this is not difficult. Undergrowth appears in stages due to the frequency of seed years, and its minimum and maximum age can be linked to this. However, in general, it is more logical to consider the protective properties of the forest environment, and therefore, not only the age parameters, but also the amount

of undergrowth, when designing measures with an appropriate assessment, determining the undergrowth availability coefficient (*UaC*) for it. The latter is calculated as the ratio of its amount per 1 ha to the optimal value for reforestation or natural conditions with the corresponding addition to equation 5:

$$UaC = N_{fact} \div N_{opt}, \quad (7)$$

where N_{fact} – amount of undergrowth, actual value; N_{opt} – amount of undergrowth, optimal value.

For *UaC*, the basic average value of 12 thousand units per 1 ha is conditionally accepted (without distribution by tree species), although it is advisable to detail the norm in calculations. Thus, the equation for calculating the loss of eco-resistance – loss of protective properties (*LPP*) of the stand, respectively, will be as follows:

$$LER = LBS \cdot UarC \cdot UaC, \quad (8)$$

where *LER* – loss of eco-resistance; *UarC* – undergrowth age range coefficient; *UaC* – undergrowth availability coefficient

The situation is similar with the density of plantings. When assessing the condition for assigning economic measures, its loss (*LD*) should also be considered when determining eco-resistance (protective properties), adding equation 8 in the denominator.

The assessment of the living space tension indicator is based on the methodology described by researchers (Malyuha, 2020; Maliuha & Minder, 2020). Indicator of living space tension (*N*) represents the ratio of the average height (H_{avg}) to absolute density (*G*) of the stand:

$$N = H_{avg} \div G, \quad (9)$$

where H_{avg} – average height, m; *G* – absolute density, m²/ha; the dimension of the living space tension indicator is m·(m²)⁻¹.

To estimate dynamic processes in space (by area) and in time (by periods), two values of the stand stability indicator are proposed, which is used to compare the state – “normal” or “weakened”. The estimate of relative loss of stability is based on the methodology described in the paper (Syrota, 2021). The normal state corresponds to a stable forest ecosystem, which is the facilities for the needs of forest seed production and the preservation of the gene pool for the duration of certification. These are normal and plus stands according to the assessment from the standpoint of forest selection. Therefore, at the time of selection, their condition is assessed as 100% normal in terms of area. Relative loss of stability (*RLS*) of the forest ecosystem of the object under study is determined by the equation:

$$RLS = Weak.S \div Nor.S \times 100, \quad (10)$$

where *Weak.S* – weakened state, ha; *Nor.S* – normal state, ha; dimension as a percentage.

Results and Discussion

Using the values of the given indicators (*SC*, *RLS*) according to the stability assessment, plantings are proposed to be divided into three categories: stable (*SC* in the range of 0.99-0.8), conditionally stable (*SC* in the range of 0.79-0.4) and unstable (*SC* is 0.39 or less).

1. Stable – without the risk of loss of stability at a specific moment (do not require economic measures). These are normal and positive stands, the cores of genetic reserves. Their functioning as objects of a permanent forest-seed base requires monitoring of stability to ensure compliance with

reproductive properties. On the other hand, it is also a promising forest fund for transferring pure stands to mixed ones for artificial monocultures, which can also take place among the selected objects of a permanent forest seed base that are not used, and this also requires monitoring of a satisfactory sanitary condition.

2. Conditionally stable (weakened stability) – objects with a risk of loss of stability that require preventive economic and selective measures, and options for implementing reformation systems and reforestation logging if it is advisable to preserve the valuable gene pool and genetic diversity at the place of origin.

3. Unstable – stands that are candidates for removal from the register of objects of permanent forest-seed base, forest fund for continuous sanitary logging. In some cases, they may be objects of preservation of a valuable gene pool by individual selection primarily for resistance outside the facility – in plantations or collections.

For such categories, appropriate forest management measures are proposed, which require separate parametric substantiation. This applies to the economic group of forest types, the category of forests, the age and spatial structure of the stand, the target measures or the line of research – in this case, the loss of stability of breeding facilities.

Studies on living space tension have established that the use of conditions occurs according to the assessment of the process as normal, non-stressful, and stressful.

1. Normal (optimal) use of conditions occurs at a relative density of 1.0 with the maximum productivity of stands. This static characteristic is inherent in the selection of positive plantings, the core of a reserve or tree stand for permanent forest-seeded areas based on an assessment of the breeding structure. Under such conditions, there is a natural

compromise between productivity and biotic stability of plantings.

2. Non-stressed – with incomplete use of the potential of forest-growing conditions by sparse stands, which is associated with varying degrees of loss of productivity, but provides optimal fruiting conditions and extends the period of functionality. By forming forest-seed plots with a density up to 0.6, the tension is reduced for a certain period, ensuring further stable growth in non-stressful forest-growing conditions.

3. Intensive use of conditions precedes the process of loosening a dense tree stand with a relative density of more than 1.0. With regard to positive stands of monocultures (in particular introducers), their subsequent development with increased productivity can be achieved by reducing biotic resistance. Further strenuous (excessive) use, teetering on the brink of destruction, and the so-called salvo falling, correspond to a loss of stability and will be assessed as unsustainable and require preventive measures. This stage is reached by artificial forests of green zones, forest parks, protected categories, and the corresponding ripe and over-mature stands that are mistakenly classified as objects of natural reserve fund.

To assess the indicator of the normal and weakened state of the site, reserve (its allocated part), a basic scale for assessing biotic stability is proposed by the sum of five basic indicators:

- damage caused by primary entomological pests;
- damage caused by secondary pests;
- exposure to phytopathological diseases;
- presence of non-viable and weakened trees;
- relative density.

Regarding the weakened state, three stages are identified to detail the planning of possible measures. After determining the absolute indicators of the first and second evaluation periods, the method

of grouping the obtained data was applied. There are five groups of dynamics of natural processes and prospects for the development of the main breed, which generalise these processes from a positive to a negative trend:

1) dynamics of natural processes is positive; the development of the main breed, if there are no negative factors, is positive;

2) dynamics of processes is almost unchanged; the development of the main breed, if there are no negative factors, is favourable;

3) dynamics of natural processes has minor negative changes; the development of the main breed in it is conditionally unfavourable;

4) dynamics of natural processes is noticeably negative; the development of the main breed is unfavourable; there is a possibility of complete loss of functions;

5) dynamics of natural processes is negative; the prospect of loss of the main breed in the composition.

The application of the proposed methodology allows assessing the dynamics of the main natural processes in stands, comparing indicators for the time of selection of breeding facilities or their inventory.

Conclusions

In forest selection, breeding and establishment of tree stands for stability require defined parameters. For this purpose, it is proposed, respectively, to use the stability coefficient of stands in a complex. Protective properties of the forest environment, in

particular, the preservation of genetic diversity, which are identified with a certain amount and quality of natural regeneration and associated with the ecological stability of stands, can be effectively evaluated by its loss according to the given methodology. Using the values of the above indicators (plantings can be divided into three categories of stability: stable, conditionally stable, and unstable, for each of which, according to forest-forming tree species, there is a need to work out the features targeted by stability criteria. Studies of the living space tension on the use of growing conditions have established that plantings with a somewhat dense three stand grow in stress. Plantations that have a density range of 0.7-1.0 develop optimally. Other plantings grow without stress, but do not fully use the living space due to the different degrees of sparsity of stands. Such medium-high plantings can be effectively used as selected and appropriately formed permanent forest-seed plots. Assessment of the condition by impact factors allows recording quantitative changes. The dynamics of areas and, accordingly, changes in basic indicators by period characterises ecosystem changes (stages of development) of the assessed forest ecosystems and is important for the objects of conservation of genetic diversity and valuable gene pool – primarily for forest genetic reserves. It is promising to use the presented results to combine the current tasks of eco-balanced forestry management with promising programmes for the conservation and formation of genetic diversity and a valuable gene pool of forest-forming species.

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Практичні підходи щодо встановлення динаміки стійкості деревостанів селекційних об'єктів

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Анотація. У статті розглянуто поняття стійкості деревостанів та їх формування для селекційних об'єктів з урахуванням динаміки напруженості використання умов середовища. Захисні властивості лісового середовища, які ототожнюють зі збереженням генетичного різноманіття, визначають за кількістю і якістю природного поновлення та асоціюють з екологічною стійкістю (відновлюваністю), можна ефективно оцінювати за втратою цієї стійкості за наведеною методикою. У статті проаналізовано підходи та напрями, які актуальні для оцінювання біотичної та екостійкості деревостанів. Для селекційних об'єктів ці питання актуальні під час призначення лісовідновних заходів у лісових генетичних резерватах, оцінювання стійкості деревостанів у момент відбору плюсових насаджень, оцінювання відібраних постійних лісонасінневих ділянок з позицій визначення обсягів формування та доглядів. Методика оцінювання стійкості деревостанів базується на визначенні показників стійкості (коефіцієнта стійкості, втрати біотичної стійкості, втрати екологічної стійкості), які розраховують на підставі параметричного (таксаційного) оцінювання дерев, їх санітарного стану та природного поновлення на досліджуваній ділянці. Використовуючи значення наведених показників стійкості, насадження можна поділити на три категорії стійкості: стійкі, умовно стійкі та нестійкі. Запропоновано відповідні лісгосподарські заходи, що потребують окремої параметричної оцінки за лісотвірними видами дерев, господарськими групами типів лісу, категоріями лісів, цільовими заходами формування чи напрямом дослідження. Під час досліджень напруженості показника життєвого простору встановлено, що використання лісорослинних умов відбувається за оцінкою процесу розвитку деревостанів, як нормальне, ненапружене і напружене. Для встановлення показника нормального й ослабленого стану запропоновано базову шкалу оцінювання біотичної стійкості за індексами стану

Ключові слова: оцінювання стійкості, показник напруженості, збереження генофонду, санітарний стан, динаміка площ

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Structural features of the forest litter of water protection pine stands in wet hygrotopes of Zhytomyr Polissya

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Abstract. The results of a study of the fractional composition, structure, and development of forest litter in water protection pine stands that grow in the prevailing wet subor and sudubrava forest conditions of Zhytomyr Polissya are presented. The age range of plantings ranges from 18-85 years. It is established that water protection pine stands in wet hygrotopes accumulate significant reserves of forest litter, which range from 33.0 t/ha in young stands to 77.0 t/ha in mature plantings. The distribution of forest litter by area in most plantings is uniform, although, in young stands, a large proportion of it accumulates in the row spacing. In terms of composition, the forest litter of pure pine stands is characterised by an average dense structure, and in pine forests with an admixture of deciduous species, the litter is usually loose, which is conditioned by the presence of annual fallen leaves in its upper horizon. The thickness of the forest litter in the row spacing of young stands varies between 2.6-2.9 cm without its clear distribution on the horizons. In middle-aged plantings, horizons are clearly distinguished in the litter profile. The total thickness of the litter reaches 4.0-4.3 cm. In ripening and ripe pine stands, the thickness of the forest litter ranges from 6.0-6.3 cm. In plantings of older age groups, the forest litter has a predominantly three-layered structure. The trend of intensive accumulation of forest litter in wet subor and sudubrava conditions up to the age of ripeness is revealed. In ripening plantings, the accumulation of litter slows down, in mature plantings, the processes of accumulation and decomposition of litter are levelled. The tendency of the predominance of the active part and, accordingly, a decrease in the inactive litter fraction in ripening and mature plantings of wet sudubrava in comparison with subor conditions is established, which indicates more active processes of litter mineralisation in wet sudubrava conditions

Keywords: stand composition, age group, forest conditions, precipitation, active and inactive litter fractions, capacity, mineralisation

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Introduction

Forest litter performs a multifaceted ecological and reclamation role in forest ecosystems. It prevents the development of erosion processes due to the accumulation of precipitation and their transformation into the ground water, reducing the physical evaporation of moisture from the soil and freezing it in winter, contributes to the accumulation of melt-water and precipitation and their transfer to ground water. Throughout the growing season, the litter serves as a kind of storage of nutrients that eventually pass into the soil, which allows maintaining a certain level of its fertility. In addition to enriching the soil with nutrients, the litter acts as mulch (Svyrydenko *et al.*, 2004).

The water protection function of floodplain forest litter is manifested in preventing siltation of water bodies, purifying water from pollutants, regulating water levels, and stabilising the hydrological regime of territories. The forest litter is also a food base and habitat for soil invertebrates and microorganisms and, as a result, improves the forest floor fertility.

Tsvetkova & Yakuba (2011) highlight the role of forest litter as a biogeochemical barrier that traps toxic metals and plays a leading role in the ability of ecosystems to self-regulate.

The forest litter performs a significant anti-erosion role, it absorbs 2-6 times more water than its mass; it perceives the kinetic energy of rain and protects the soil from destruction; the rough surface of the litter slows down the rate of runoff and facilitates soil sedimentation. With the removal of litter, runoff increases and soil water permeability decreases by 5-10 times (Gomyyo & Kuraji, 2016).

Depending on the species composition of stands, different types of forest litter are formed, which differ in the intensity and rate of mineralisation (Bogatyrev, 1990). Intensification of the processes of mineralisation of forest litter contributes to increasing the productivity of forest ecosystems, since under such conditions mineral compounds of nitrogen, phosphorus, potassium, and other elements that make up the food ration of plants are formed.

Litter plays an important role not only in the processes of substance circulation in ecosystems, but also in the processes of soil formation and reflects the zonal features of the geographical location of plantings. Especially multifaceted is the forest reclamation role of the forest litter, which determines water-regulating, water-retaining, water treatment, soil protection, anti-erosion, and other functions (Yukhnovsky *et al.*, 2013).

Fallen leaves, twigs, bark, cones, seeds, and other organic remains of forest vegetation are considered litter. The amount of litter depends on the species composition of plants, age, and form of planting (Yakuba, 2004; Solomatova, 2013).

The researchers also point to the layered structure of the forest litter. In particular, Vyshenska *et al.* (2010) distinguish the top layer of litter, which consists of fresh litter that has not yet decomposed with clearly defined elements – leaves, bark, small branches, fruits, etc. Below it is a layer that includes litter components that are already significantly damaged by the decomposition process, but their small particles still retain their morphological structure. The lower layer of litter is actually detritus, which looks like a more or less uniform organic mass of dark colour.

The fractional composition of the forest litter of pine stands was studied by Krylov (2013), Avramchuk & Bilous (2015), Kalynovsky (2017), Kamsky & Shelest (2017), Xu *et al.* (2020), Golovetskyi *et al.* (2021), Maliuha *et al.* (2021), Novák *et al.* (2020), Minder *et al.* (2019) etc. Litter in pine stands decomposes slowly, and the rate of its mineralisation decreases with age, as also shown by studies by Corter (1998), Voron *et al.* (2018), Çömez *et al.* (2020) *et al.* The reclamation and anti-erosion properties of the forest litter of pine stands on ravine-beam systems are highlighted in the monograph by Yukhnovsky *et al.* (2013). However, the issue of the structure of the forest litter of water protection stands with the main species of Scots pine, the dominant share of which grows in the wet hygrotopes of Zhytomyr Polissya, is unresolved.

Table 1, Continued

No.	Location	Stand composition	Age, years	Forest site type	Density	Growth class	Average height, m	Average diameter, cm	Reserve, m ³ /ha
4	Korolivske forestry compartment No. 33 stratum 17	5Sp4Ewb1Ba	22	C ₃	0.71	II	8.2	10.3	70
Ripening (III)									
5	Yemilchynske forestry compartment No. 60 stratum 34	10Sp	66	B ₃	0.79	I ^a	25.0	32.1	568
6	Hlumchanske forestry compartment No. 66 stratum 29	8Sp1Ewb1Ba	69	C ₃	0.81	I ^a	27.3	30.2	350
Mature and overripe (IV)									
7	Yemilchynske forestry compartment No. 69 stratum 2	9Sp1Ewb	85	B ₃	0.71	I	27.0	31.5	290
8	Barashivske forestry compartment No. 8 stratum 44	9Sp1SlI+Co	85	C ₃	0.77	I ^a	30.4	36.2	424

The age range of the stands is 18-85 years. In wet subor plantings, average heights range from 7.0-27.0 m, with an average diameter of 8.4 to 31.5 cm, and reserve – 45 to 568 m³/ha. In wet sudubrava plantings, the average height ranges between 8.1-30.4 m, the average diameter – 10.3-36.2 cm, and reserve – 65-424 m³/ha. Water protection plantings in all forest-growing conditions are growing for I^a– II growth class. All sample plots belong to the modal stands most represented in the region with a thickness of 0.70-0.81.

The study of forest litter was carried out on

discount areas, which were laid in the plantings of the studied age groups on sample plots. Discount areas were placed in the middle of the row spacing. The discount area was selected depending on the age group of plantings and the thickness of the forest litter. It was usually 1 m² (1.0×1.0 m) or 0.5 m² (0.5×1 m). The thickness of the forest litter was measured with a tape measure from the soil surface. On the discount area, the litter was cut off with a knife, carefully separating each layer, poured into numbered containers, and was disassembled into fractions in laboratory conditions (Fig. 2).



Figure 2. Distribution of forest litter samples into fractions: *a* – the process of dividing into fractions; *b* – selected fractions

Each fraction was then weighed on an electronic scale with an accuracy of 0.01 g, and to calculate the forest litter reserve, the data obtained were recalculated per 1 ha (Hordienko *et al.*, 2000).

Results and Discussion

The thickness of the litter, the rate of its decomposition and release of chemical elements depend on the type of forest, its age, stand thickness, climatic and

soil conditions, the characteristics of the edaphotope (soil conditions, water and heat regime, etc.), participation in the composition of the stand, except for coniferous, deciduous tree species, the presence or absence of grass or moss cover. Therefore,

the characteristic of morphometric indicators of the forest litter of water protection plantings, which is reflected in Table 2, were analysed with the above-mentioned forest indicators – the composition of plantings and age groups.

Table 2. Characteristics of the forest litter of water protection pine stands

No.	Age group	Stand composition	Age	Forest litter indicators					
				width, cm	total reserve, t/ha	Reserve by fractions			
						active		inactive	
						t/ha	%	t/ha	%
Wet subor stands (B_3)									
1	I	10Sp+Ewb	18	2.9	33.0	20.8	63	12.2	37
3	II	6Sp3Ewb1Co	28	4.3	42.2	22.8	54	19.4	46
5	III	10Sp	66	6.0	64.8	41.5	64	23.3	36
7	IV	9Sp1Ewb	85	6.0	77.0	55.4	72	21.6	28
Wet sudubrava stands (C_3)									
2	I	8Sp2Ewb	18	2.6	21.3	13.0	61	8.3	39
4	II	5Sp4Ewb1Ba	22	4.0	31.7	20.0	63	11.7	37
6	III	8Sp1Ewb1Ba	69	6.1	60.0	41.4	69	18.6	31
8	IV	9Sp1SlI+Co	85	6.3	82.5	60.2	73	22.3	27

Data in Table 2 indicate an intensive accumulation of forest litter in wet subor and sudubrava conditions up to the age of ripeness, where its thickness reaches 6 cm. In ripening plantings, the accumulation of litter slows down, and in mature and overripe stands it remains at the same level, that is, the processes of accumulation and decomposition of litter are equalised. This is consistent with studies by Voron *et al.* (2018), Golovetskyi *et al.* (2021).

The thickness of the forest litter in the row spacing of young stands varies between 2.6-2.9 cm. A clear distribution of litter on the horizons is not yet observed, although the half-mineralised lower layer can be traced up to 1.3 cm, and the upper layer, which consists of precipitation of the first or second years, has a thickness of 1.6-1.8 cm. Its composition is dominated by Scots pine needles with an admixture of European white birch leaves and branches.

In middle-aged water protection plantings, the profiles already clearly distinguish the litter horizons. The total litter capacity is 4.0-4.3 cm. The lower layer is represented by a semi-decomposed

organic mass up to 1.7 cm thick, and the middle layer is represented by semi-mineralised remains of pine needles, leaves, and small roots. The thickness of this horizon is 1.5-2.3 cm, and the upper layer is 1.0-1.5 cm.

In ripening and ripe pine stands, the thickness of the forest litter varies between 6.0-6.3 cm, respectively. The lower layer of litter, 1.4-2.2 cm thick, is almost completely decomposed. The middle layer of litter is represented by ungainly twigs, bark, and needles. Its width is 2.0-2.4 cm. Fresh annual precipitation from twigs, needles, and pine cones covers the surface of the forest floor with a layer of 2 cm.

The distribution of forest litter by area in most plantings is uniform, only in young stands, there is more of its accumulation in the row spacing. By composition, the forest litter of pure pine forests is characterised by an average dense structure. In pine stands with an admixture of deciduous species, the litter is usually loose, which is conditioned by the presence of annual fallen leaves in its upper layer. The ratio of active and inactive litter fractions depending on the composition of the plantation is shown in Figure 3.

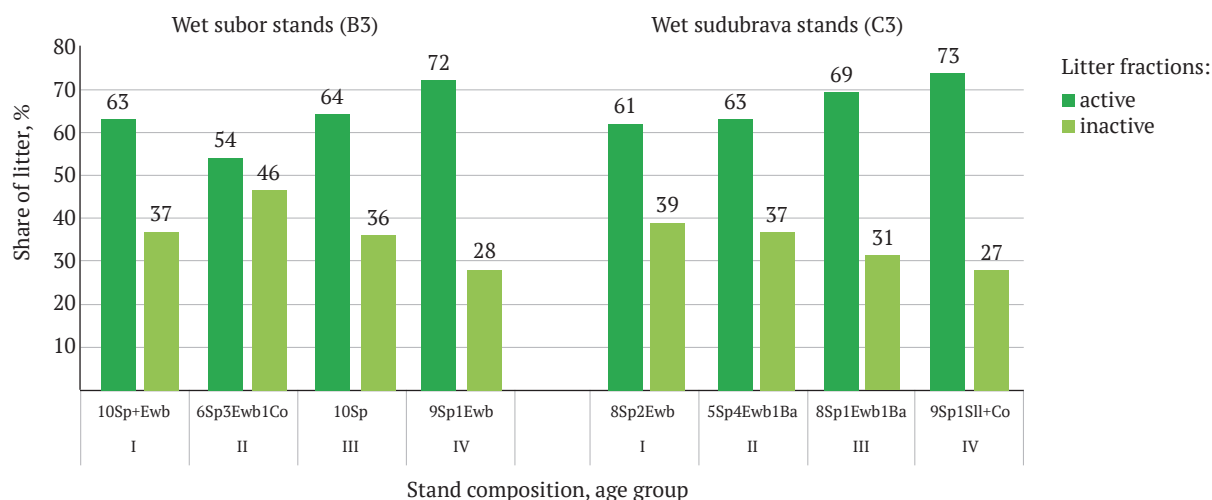


Figure 3. The ratio of active and inactive litter fractions depending on the age group and stand composition

Data analysis of Figure 3 revealed a tendency for the active part to predominate and, accordingly, a decrease in the inactive litter fraction in ripening and mature wet sudubrava stands compared to subor conditions. This indicates more active processes of litter mineralisation in wet sudubrava conditions, which is primarily associated with higher soil trophism. In general,

the active part of the fractional composition of the litter is 54-73%, and the inactive part amounts to 27-46%.

The total reserve of forest litter ranges from 33.0 t/ha in young stands to 77.0 t/ha in mature plantings, which indicates an increase in forest litter with age. Detailed summary data of reserves by litter fractions are given in Table 3.

Table 3. Generalised stock data by litter fractions

Age groups and composition, age, and SP No.	Layer of litter	Reserve of litter, t/ha	Litter fractions, t/ha				
			Inactive part			Active part	
			branches	bark	cones, needles	leaves, grass, buds	roots, dust, entomofauna
Wet subor stands (B ₃)							
Young stands: 10Sp+Ewb; A – 18; SP No. 1	1st	8.2	0.6	0.8	5.0	0.1	1.7
	2nd	24.7	0.6	0.7	4.4	0.1	19.0
	Σ	33.0	1.2	1.5	9.4	0.2	20.7
Middle-aged stands: 6Sp3Ewb1Co; A – 28; SP No. 3	1st	12.0	0.6	0.6	7.6	1.5	1.6
	2nd	30.2	2.8	1.4	6.4	0.9	18.8
	Σ	42.2	3.4	2.0	14.0	2.4	20.4
Ripening stands: 10Sp; A – 66; SP No. 5	1st	11.2	3.5	1.1	4.2	0.8	1.5
	2nd	16.8	3.0	2.3	3.7	0.5	7.4
	3rd	36.8	2.0	1.9	1.9	-	31.0
	Σ	64.8	8.5	5.3	9.8	1.3	39.9
Mature stands: 9Sp1Ewb; A – 85; SP No. 7	1st	12.3	3.5	1.3	5.0	0.5	2.0
	2nd	18.6	1.8	2.4	3.8	0.6	10.1
	3rd	46.1	1.2	0.9	2.1	-	41.8
	Σ	77.0	6.5	4.6	10.9	1.1	53.9

Age groups and composition, age, and SP No.	Layer of litter	Reserve of litter, t/ha	Litter fractions, t/ha				
			Inactive part			Active part	
			branches	bark	cones, needles	leaves, grass, buds	roots, dust, entomofauna
Wet sudubrava stands (C ₂)							
Young stands: 8Sp2Web; A – 18; SP No. 2	1st	8.5	1.2	0.9	2.4	0.9	3.1
	2nd	12.9	0.5	1.1	2.3	0.5	8.4
	Σ	21.3	1.7	2.0	4.7	1.4	11.5
Middle-aged stands: 5Sp4Ewb1Ba A – 22; SP No. 4	1st	10.9	2.2	1.0	3.2	1.8	2.6
	2nd	20.8	1.6	1.4	2.2	2.6	13.0
	Σ	31.7	3.8	2.4	5.4	4.4	15.6
Ripening stands: 8Sp1Ewb1Ba; A – 69; SP No. 6	1st	12.2	2.7	2.3	3.1	2.2	2.0
	2nd	15.1	2.0	1.6	2.7	1.0	7.6
	3rd	32.7	1.3	1.1	1.8	0.2	28.4
	Σ	60.0	6.0	5.0	7.6	3.4	38.0
Mature stands: 9Sp1Ba+Co; A – 85; SP No. 8	1st	16.6	3.0	2.1	4.8	2.5	4.2
	2nd	23.8	2.2	1.6	3.8	1.6	14.6
	3rd	42.1	1.4	1.5	1.9	0.6	36.6
	Σ	82.5	6.6	5.2	10.6	4.7	55.5

Table 3 indicates that in young and middle-aged plantings of wet subor and sudubrava, the litter has a two-layered structure. The first layer is dominated by an inactive part of branches, bark, cones, and needles, the share of which in the conditions of wet subor and sudubrava of the first age group is 6.4 t/ha (78.0%) and 4.5 t/ha (53.0%), in the middle-aged, respectively, 8.8 t/ha (73.3%) and 6.4 t/ha (58.7%). The second layer of litter of age groups 1 and 2 is already dominated by the active part with a large amount of dust, which is 3-4 times higher than the inactive part of the forest litter.

With age, the litter acquires a three-layer structure. This phenomenon is obvious in connection with the accumulation of litter and its distribution to the horizons. There is a clear trend of increasing the active litter fraction in ripening and ripe wet sudubrava plantings, which indicates more active processes of its mineralisation in contrast to the water protection pine stands of wet subor.

Conclusions

Water protection pine stands in wet subor and sudubrava conditions accumulate significant reserves of forest litter, which range from 33.0 t/ha in young stands to 77.0 t/ha in mature plantings.

The distribution of forest litter by area in most plantings is uniform, only in young stands, there is more of its accumulation in the row spacing. In terms of composition, the forest litter of pure pine stands is characterised by an average dense structure, and in pine forests with an admixture of deciduous species, the litter is usually loose, which is conditioned by the presence of annual fallen leaves in its upper horizon.

The thickness of the forest litter in the row spacing of young stands varies between 2.6-2.9 cm without its clear distribution on the horizons. In plantings of older age groups, there is a clear distribution of forest litter on the horizons. The forest litter has a predominantly three-layer structure. The top layer of litter consists of still undeveloped fresh litter of needles, leaves, bark, small branches, and fruits. A wide second semi-decomposed layer of litter is saturated with pine roots, needles, and entomofauna remains, but small particles of them still retain their morphological structure. The lower layer of litter is actually detritus, which looks like a more or less uniform organic mass of dark colour.

The trend of intensive accumulation of forest litter in wet subor and sudubrava conditions up to the age of ripeness, where its thickness reaches 6 cm of thickness, was revealed. In ripening stands, the

accumulation of litter slows down, but in mature stands it remains at the same level, that is, the processes of accumulation and decomposition of litter are levelled.

The tendency of the predominance of the active part and, accordingly, a decrease in the inactive

litter fraction in ripening and mature plantings of wet sudubrava in comparison with subor conditions is established, which indicates more active processes of litter mineralisation in wet sudubrava conditions.

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Структурні особливості лісової підстилки водоохоронних соснових насаджень у вологих гігротопах Житомирського Полісся

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Анотація. Наведено результати дослідження фракційного складу, будови і формування лісової підстилки у водоохоронних соснових насадженнях, які зростають у переважаючих вологих суборевих і сугрудових лісорослинних умовах Житомирського Полісся. Віковий діапазон насаджень коливається в межах 18-85 років. Встановлено, що водоохоронні соснові насадження у вологих гігротопах акумулюють значні запаси лісової підстилки, які коливаються від 33,0 т/га в молодняках до 77,0 т/га в стиглих насадженнях. Розподіл лісової підстилки за площею в більшості насаджень рівномірний, хоча в молодняках її більша частка нагромаджується у міжряддях. За складанням лісова підстилка чистих сосняків характеризується середньою щільною структурою, а в сосняках із домішкою листяних видів підстилка, зазвичай, пухкого складення, що зумовлено наявністю щорічного опалого листя у її верхньому горизонті. Потужність лісової підстилки у міжряддях молодняків коливається у межах 2,6-2,9 см без її чіткого розподілу на горизонти. У середньовікових насадженнях в профілі підстилки чітко виділяються горизонти. Загальна потужність підстилки становить 4,0-4,3 см. У пристигаючих і стиглих соснових насадженнях потужність профілю лісової підстилки коливається в межах 6,0-6,3 см. У насадженнях старших вікових груп лісова підстилка має переважно тришарову будову. Виявлено тренд інтенсивного нагромадження лісової підстилки в умовах вологого субору і сугрудю до віку стиглості. У пристигаючих насадженнях нагромадження підстилки уповільнюється, у стиглих насадженнях процеси нагромадження і розкладання підстилки нівелюються. Встановлено тенденцію переважання активної частини і, відповідно, зменшення неактивної фракції підстилки у пристигаючих і стиглих насадженнях вологого сугрудю порівняно із суборовими умовами, що свідчить про активніші процеси мінералізації підстилки в умовах вологого сугрудю

Ключові слова: склад насадження, вікова група, лісорослинні умови, опад, активна й неактивна фракції підстилки, потужність, мінералізація

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Specific features of the establishment of parks-monuments of landscape art in the second half of the 20th century in Ukrainian Polissya

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Abstract. The study analyses the establishment of parks-monuments of landscape art (PMLA) in the historical aspect. In the second half of the 20th century, 11 parks-monuments of landscape art were created in the Ukrainian Polissya: two of national and nine of local significance. The purpose of PMLA – protection and preservation of the most outstanding and valuable samples of park construction for their subsequent use for aesthetic, educational, scientific, environmental, and recreational purposes. The motivation for the creation of PMLAs was the preservation, reproduction, and enrichment of arboreal diversity in the conditions of the Ukrainian Polissya. Technical, fast-growing, rare, and valuable species of woody plants for forestry and gardening were planted in parks, followed by their use for scientific and economic purposes. Some of the plantings in the parks were memorable, anniversary, or dedicated to significant events (the anniversary of the October Revolution and the birthday of V.I. Lenin). The Ukrainian Polissya contains three parks created on the basis of existing oak stands (“Klevanskyi”, “Antonivka”, “Bondaretskyi”), one – on the basis of artificial plantings of *Acer platanoides* L., *Carpinus betulus* L., *Fraxinus excelsior* L., *Tilia cordata* Mill. (“Ovrutskyi”). Three parks of culture and recreation (“Horodnyanskyi”, “Vysokovskiy”, Slovyanskyi, in particular, the meadow park Slovyansky), children’s park (“Bondaretskyi”), four arboretums (“Dubrechnenskyi”, “Bayrak”, “Novostavskiy arboretum”, “Zhornivskiy”) were transformed over time or were granted the status of PMLA. According to the location in the planning structure of settlements, there are city, village, and district parks. In terms of size, PMLAs can be small, medium, large, star-shaped, axial, fan-shaped, looped, cross-shaped, and combined planning structures. In four PMLAs there are artificial and natural reservoirs, fountains. Five parks are combined (memorial park and park of culture and recreation), where memorial complexes, monuments, and obelisks are concentrated. Park plantings are represented by groups, solitaires, alleys, ordinary plantings, hedges, and sometimes groves and wooded areas. 176 species of woody plants grow on the territory of 11 PMLAs, of which 119 are listed in the IUCN Red List. Since the beginning of its creation, the number of species has increased by 75-129% in four parks, and the dendro-diversity has decreased in six parks, with 29-87% of woody plant species remaining, including 66-94% of arboretums. 11 PMLAs are valuable centres of dendro-diversity and unique plantings of Ukrainian Polissya, an example of the establishment of didactic, ethnographic, memorial, children’s, cultural, and recreational combined parks that require further protection and expansion of the area and collection. Some parks require landscaping

Keywords: history, park, species, planning structure

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Introduction

Protected areas are key to preserving biodiversity. Parks-monuments of landscape art (PMLA) are part of the natural and artificial landscape, where changes occur due to anthropogenic actions and under the influence of abiotic and biotic factors. Human activity eventually turns into history, and the landscapes created by it become a cultural heritage. Restoration and preservation of landscapes, valuable plantings, and rare woody plant species are of great importance for future generations (WWF Ukraine, 2020).

A number of studies in various areas were conducted in the Ukrainian Polissya. Savoskina & Popovych (2019) analysed the structural floral analysis of the species composition of dendrosozoexotes, in particular, century-old trees, found out the role of dendrosozoexotes in landscape phytodesign, and described the history of the park construction network. Pokotylova (2018) investigated the ecological and geographical structure of dendroflora in 25 artificial protected parks of the Rivne Oblast, some of which are located in the Ukrainian Polissya. Kotsun et al. (2010) considered the history of creation, compositional construction, and species composition of the PMLAs of the Volyn Polissya of the 19 century – “Zdorovya”, “Litynskyi”, “Lyubeshivskyi”, “Makarevychivskyi”, and the 20th century – “Dubechne”. Klimenko (2010) established the modern composition of species and cultivars of ancient Polissya PMLAs “Zdorovya”, “Ivnytskyi”, “Horodnytskyi”, distributed their green area by types of garden and park landscapes. The historical features of the establishment of the network of PMLAs of the Ukrainian Polissya during the 17th-20th centuries were considered (Savoskina, 2015). The current state of PMLA “Bayrak” (Volyn Oblast) was investigated (Kotsun, Kuzmishyna & Kotsun, 2010), and the species composition and bioecological features were summarised *Pinopsida* (Tsikhotska & Kotsun, 2011), a model ecological trail was developed (Dzyba & Pokotylova, 2016), functional zoning and the values of the “Bayrak” park were highlighted (Pokotylova & Dzyba, 2016). The study analyses the state of 14 PMLAs and their representativeness in the Volyn

Oblast, among them 8 parks located in the Ukrainian Polissya: “Bayrak”, “Dubechnenskyi”, “Zdorovya”, “Litynskyi”, “Lyubeshivskyi”, “Makarevychivskyi”, “Sadyba Lypynskoho”, “Slovianskyi” (Boiaryn, Voloshyn & Tsos, 2020). Century-old trees of the “Zhornivskyi” PMLA were studied in Kyiv Polissya (Kushnir, Sukhanova & Snihyr, 2016). In Chernihiv Polissya, a comparative analysis of the dendroflora of the botanical nature monument “Horodnyanskyi Square” and PMLA “Horodnyanskyi” was carried out (Dzyba & Shytiuk, 2015). In Volyn Polissya, the dendroflora of PMLA “Klevanskyi Park” was investigated (Dzyba, 2016) in the historical aspect of the establishment of PMLA “Novostavskyi arboretum” (Dzyba, 2020). Sherstiuk & Popovych (2018) analysed the representativeness of autochthonous dendrosozophytes in the protected areas of the Ukrainian Polissya, determined their role in the establishment of phytocompositions. Thus, in Ukrainian Polissya, no comprehensive study of PMLAs of the second half of the 20th century has been conducted. In addition, PMLAs are a component of the historical environment, which is transformed over time, which can lead to changes in their planning structure and dendro-diversity, so it is now relevant to identify the features of the establishment of the mentioned PMLAs for 70 years.

The purpose of the study is to identify the features of the establishment (history, planning structure, types of plantings, dendroflora) of parks-monuments of landscape art of the second half of the 20th century in Ukrainian Polissya based on the compartment description.

Materials and Methods

A systematic approach and comparative analysis of factual material are applied. The study was conducted in three stages. The first stage is the investigation of archival materials. The second is reconnaissance, survey of the planning structure of parks by the route method, and grouping according to the reference composition of the road and trail network (axial, cross-shaped, star-shaped, fan-shaped, loop, and combined)

(Rudenko, Elenskaia, Aleksandrov, Herasymchuk & Potaev, 1980). The third stage – detailed route, during which woody plants and their species were described (Spohn & Spohn, 2014; Kokhno *et al.*, 2001), species name – according to the International Classification (World Flora Online, 2021). Woody plant species were tested for belonging to the International Union for Conservation of Nature (IUCN) Red List of Threatened Species (the IUCN Red List, 2021). The authors of this study identified types of green spaces in the PMLA (alleys, solitaires, groups, groves, wooded areas, hedges) (Bohovaia & Fursova, 1988).

Results and Discussion

11 parks-monuments of landscape art (PMLA) of the Ukrainian Polissya, created during the last fifty years of the 20th century, were studied. PMLA is concentrated in five regions: Volyn (“Dubechnenskyi”, “Bayrak”, “Slovyanskyi”), Rivne (“Novostavskyi arboretum”, “Klevanskyi”, “Antonivka”), Zhytomyr (“Vysokovskyi”, “Bondaretskyi”, “Ovrutskyi”), Kyiv (“Zhornivskyi”), Chernihiv (“Horodnyanskyi”) (Fig. 1). Among them are PMLA “Dubechnenskyi”, “Bayrak” – of national significance, the rest of PMLAs – of local significance.

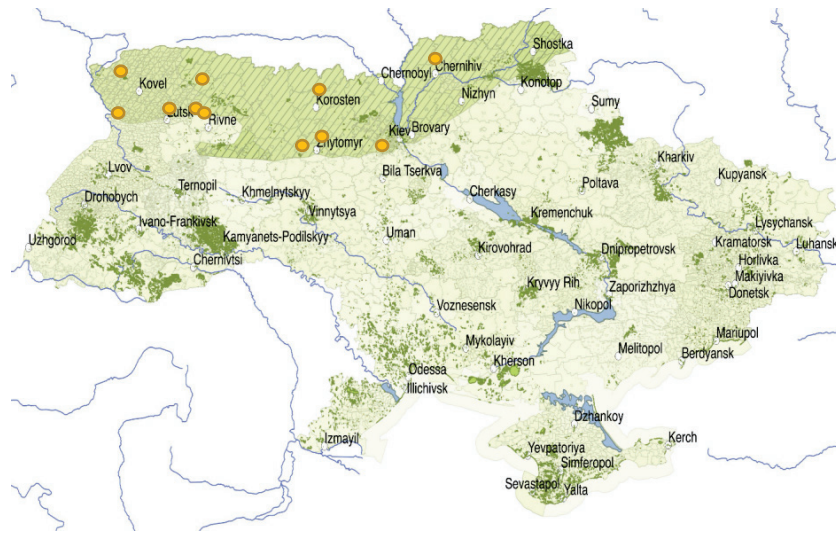


Figure 1. Parks monuments of landscape art of the second half of the 20th century in Ukrainian Polissya

By location in the planning structure of localities, these are citywide, rural, and district parks. Approaches to creating parks vary. Parks created based on existing plantings, such as parks of culture and recreation, meadow park, children’s park, arboretum, have been transformed over time or have been granted the status of PMLA. “Klevanskyi”, “Antonivka”, “Bondaretskyi” parks were created on the basis of oak forests, in order to preserve plantings of *Quercus robur* L. over 100 years old, “Ovrutskyi” – based on artificial plantings of *Acer platanoides* L., *Carpinus betulus* L., *Fraxinus excelsior* L., *Tilia cordata* Mill., which now serve as recreation areas for community residents. “Bondaretskyi” was transformed into a children’s park on the territory of a children’s

camp, it is not functioning now. “Dubechnenskyi”, “Bayrak”, “Novostavskyi”, “Zhornivskyi” – arboreta that eventually transformed into PMLA, and the area of “Novostavskyi” park decreased by 20 times. “Vysokovskyi”, “Horodnyanskyi”, Slovyanskyi – parks of culture and recreation, and part of the PMLA “Slovyanskyi” is also a meadow park.

PMLA “Dubechnenskyi” (Dubechne village, Kovel district, Volyn Oblast) was created in four years from 1956 to 1960 on the initiative of the Honoured Forester of Ukraine A.L. Dmytruk (Kotsun *et al.*, 2010). During this time, 123 species of autochthonous and introduced woody plants were planted, in particular *Chamaecyparis pisifera* Sieb. Zuss., *Catalpa bignonioides* Walter., *Platanus occidentalis* L.,

Fagus sylvatica L. and others. The status of PMLA of national significance was granted in accordance with Presidential Decree No. 715/96 of 20.08.1996 (The protection obligation No. 24, 2012). The area is 2 hectares (Dubchnivske forestry, compartment 29, stratum 24 (area 1.1 ha) and compartment 30, stratum 27 (area 0.9)) (Fig. 2, b). There is an artificial reservoir on the territory of PMLA “Dubchnenskyi” (Fig. 2, c). Combined layout structure (Fig. 2, a). The following types of

plantings were found in the park: groups, solitaires, ordinary plantings of *Picea abies* Karst., *Picea engelmannii* Parry ex Engelmann., alleys with *Thuja occidentalis* L., *Chamaecyparis pisifera* Sieb. Zuss., *Tilia cordata* Mill. Currently, the park’s dendroflora is represented by 64 species of woody plants (21 families, 45 genera). 51 species belong to the IUCN Red List (Fig. 6), among them *Juglans cinerea* L. – to disappearing categories (EN), *Aesculus hippocastanum* L. - vulnerable (VU).



Figure 2. PMLA “Dubchnenskyi”

PMLA “Bondaretskyi” (Bondartsi village, Zhytomyr district, Zhytomyr Oblast). The area of the park is 1.8 hectares (Korabelne forestry, compartment 20, stratum 4 (Fig. 3, b)). This is a former plot of forest stands of the oak grove, which was transformed into a children’s park as a place of recreation for children. The status of PMLA was provided by the decision of the Zhytomyr regional executive committee No. 149 of 31.03.1964. At the beginning of the reconstruction

of the park (1964), 21 species of woody plants were growing, including six 600-year-old specimens of *Quercus robur* L., 75 100-year-old specimens of *Quercus robur* L., 40 100-year-old specimens of *Acer platanoides* L., 50 100-year-old specimens *Carpinus betulus* L., five specimens of *Tilia cordata* Mill., and also *Aesculus hippocastanum* L, *Acer negundo* L, *Picea abies* Karst. (alley) and other species aged 15-40 years old Passport No. 36, 1970).



Figure 3. PMLA “Bondaretskyi”

Currently, 18 species of woody plants (eight families, 14 genera) aged from 50 years grow on the territory of the park in groups and as solitaires of *Quercus robur* L., *Carpinus betulus* L. (fig. 3, c), *Populus nigra* L. The oldest – 430-year-old *Quercus robur* L., 170-year-old *Carpinus betulus* L. The planning structure of the park is axial (Fig. 3, a). 17 species of woody plants belong to the IUCN Red List (Fig. 6), 14 types have least concern (LC) category.

PMLA “Ovrutskyi” (Ovruch, Korostensky district, Zhytomyr Oblast) (Fig. 4, b). Area – 1.2 ha. The status of PMLA was granted in accordance with the decision of the Zhytomyr regional executive committee No. 149

of 31.03.1964 (The protection obligation, 2010). At the beginning of the park’s creation, there were 15 species of woody plants. The park has a star-shaped planning structure (Fig. 4, a) with a fountain in the centre. Plantings are represented by groups mainly of *Acer platanoides* L., *Aesculus hippocastanum* L., *Carpinus betulus* L., *Fraxinus excelsior* L., *Tilia cordata* Mill., *Tilia platyphyllos* Scop. (Fig. 4, c), ordinary plantings of *Picea abies* Karst. Age of *Acer platanoides* L., *Carpinus betulus* L., *Fraxinus excelsior* L. and some *Tilia cordata* Mill. makes up 130-180 years old. The number of species is still unchanged – 15, all 9 families and 12 genera belong to the IUCN Red List (Fig. 6).

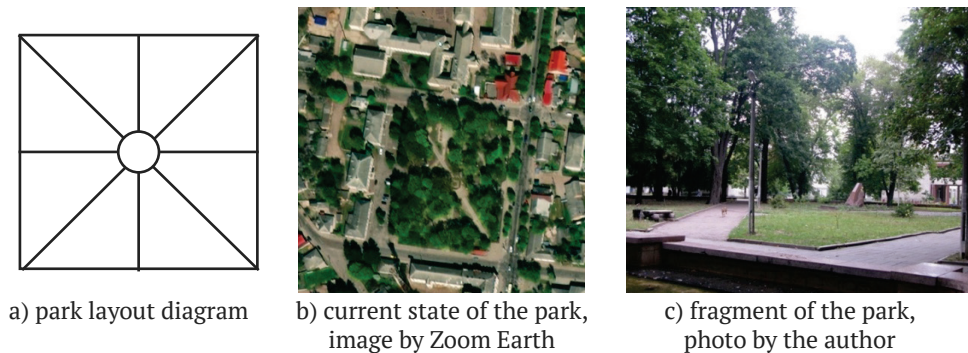


Figure 4. PMLA “Ovrutskyi”

PMLA “Park Antonivka” Antonivka village, Varaskyi district, Rivne Oblast). Area – 9.7 ha. The park is arranged on the basis of plantings of *Quercus robur* L. aged more than 100 years, for the purpose of their safety (Passport No. 2MSPM, 1995) (Fig. 5). Created in accordance with the decision of the Rivne regional council No. 33 of 28.02.1995 (Antonova *et al.*, 2008). Now the park serves as a recreation area for residents of the community. The planning structure is combined. In the southern

part of the park there is a monument to soldiers who died during the Second World War. On the territory of the park there are such types of plantings as wooded areas, groups, hedges (Table 1). At the beginning of the park’s creation, there were 23 species of woody plants. Currently, 41 species of woody plants (15 families, 29 genera) grow on the territory of the park, of which 32 species belong to the IUCN Red List (Fig. 6) (least concern category (LC) – 31 types).

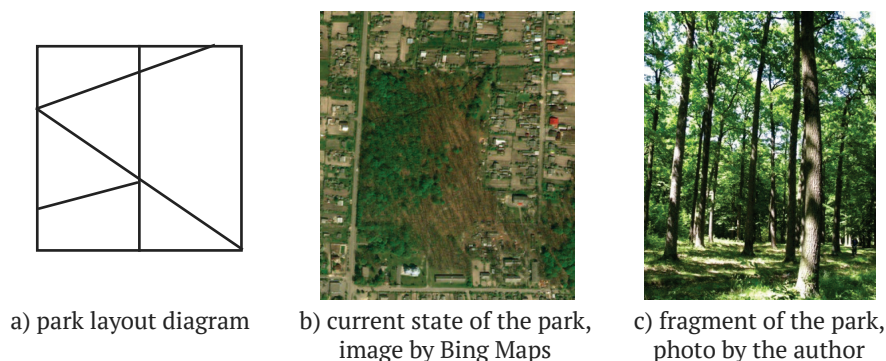


Figure 5. PMLA “Antonivka”

Table 1. Characteristics of PMLAs of the second half of the 20th century in Ukrainian Polissya

PMLA	Park area at the beginning of creation	Area, ha	Year of creation and reconstruction	Year of granting the status	Planning style	Presence of a reservoir, fountain	Availability of a memorial, monument, obelisk, or museum	Origin of the plantation	Types of plantings
Dubechnenskyi	2.0	2.0	1956-1960	1996	c	+	-	a	gr, al, sol, h
Bayrak	13.0	13.0	1975-1977	1996	c	+	+	a	gr, al, sol, h, g, row
Slovyanskyi	27.53	27.53	1988	1997	c	+	+	a	gr, al, sol, row, h
Novostavskyi	30.0	1.5	1967	1972	row	-	- (was)	a	gr, al, sol, h
Klevanskyi	7.0	7.0	1967	1967	l	-	+	n	gr, wo
Antonivka	9.7	9.7	1993	1993	l	-	+	n	gr, wo, h
Vysokivskyi	6.55	6.55	1963	1973	row	+	+	a	gr, a, sol
Bondaretskyi	1.8	1.8	1963	1963	l	-	-	n	gr
Ovrutskyi	1.2	1.2	1964	1964	row	+(f)	+	a	gr, row
Zhornivskyi	5.2	5.2	1969-1972	1972	c	-	-	a	gr, h, sol, wo
Horodnyanskyi	10.0	10.0	1959-1966	1972	row	-	-	a	gr, a, row, g

Note: layout structure – r (regular), l (landscape), c (combined); origin of plantings – a (artificial), n – (natural); types of plantings – gr (groups), al (alleys), sol (solitaires), row (row seating), h (hedges), g (grove), wo (wooded area); f – fountain.

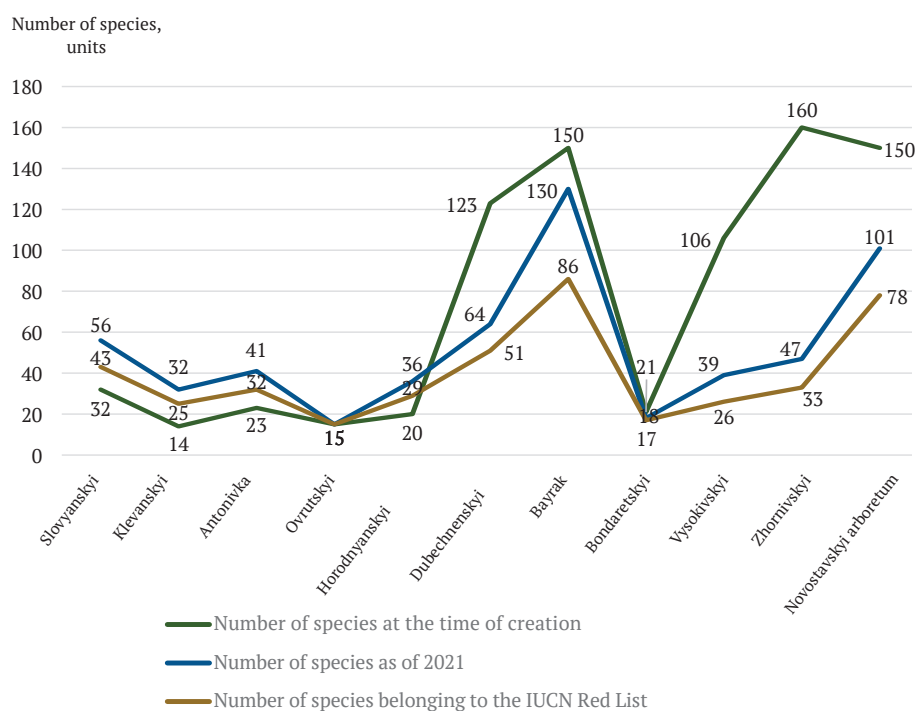


Figure 6. Dynamics of changes in the number of species in PMLAs of the second half of the 20th century

PMLA “Novostavskiy arboretum” (Novostav, Rivne district, Rivne Oblast) (Fig. 7, b). Area – 1.5 hectares. The creation of the arboretum began in 1967 (Novostavske forestry, compartment 39, stratum 22). The territory of the arboretum covered a forestry estate with buildings (0.8 ha), a greenhouse farm (0.2 ha), an arboretum (4.0 ha), a forest area with *Pinus sylvestris* L. of more than 100 years-old (25 hectares) and small architectural forms. The area of the arboretum was 30 hectares. The park was divided into sectors with plantings of *Larix* Mill., *Pinus* L., *Acer* L., *Fraxinus* L., *Juglans* L. Along the paths there are memorable alleys: “Friendship”, “Joy”, “Happiness”, “Juniors”, “Participants of the All-Union seminar” planted with *Tilia cordata* Mill., *Tilia platyphyllos* Scop., *Quercus rubra* L., *Juglans* L. and combined C *Tilia tomentosa* Moench. and *Acer platanoides* L.; *Betula pendula* Roth. and *Picea abies* Karst., *Acer platanoides* L., *Aesculus hippocastanum* L. and *Acer negundo* L., *Tilia cordata* Mill. At the intersection of paths in the

centre, a monument was erected, which was eventually removed. The status of PMLA was granted to “Novostavskiy arboretum” by the decision of the Rivne Regional Executive Committee No. 317 of 20.06.1972 and No. 343 of 22.11.1983 (Dzyba, 2020). The planning structure of the arboretum is star-shaped (Fig. 7, a). At the beginning of the creation of the park, 150 species of woody plants were planted; some of them have survived to this day (Fig. 7, c). However, over time, their number gradually decreased: in 1983 – 130 species, in 2020 – 101 species (24 families, 57 genera), of which 78 species belong to the IUCN Red List (66 species – least concern category (LC), *Aesculus hippocastanum* L. – vulnerable category (VU), *Platycladus orientalis* (L.) Franco and *Fraxinus excelsior* L. – near threatened (NT), *Fraxinus pennsylvanica* Marsh. – critically endangered (CR), *Juglans cinerea* L., *Malus niedzwetzkyana* Dieck ex Koehne. – belong to the endangered category (EN), and 6 species belong to the DD category.

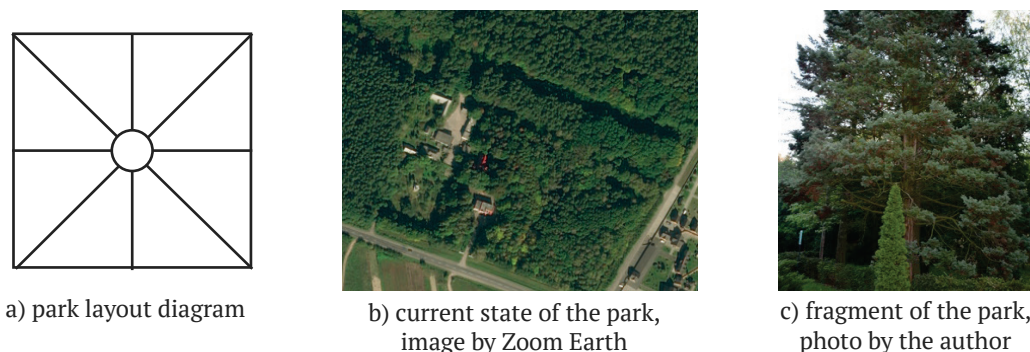


Figure 7. PMLA “Novostavskiy arboretum”

PMLA “Bayrak” (Rokyni village, Lutsk district, Volyn Oblast). The initiator of the arboretum park is P.S. Teslyuk (director of the state agricultural station). The arboretum project was developed in 1974. Volyn branch of Dipromisto (author – V.A. Tupitsa) (Kotsun, Kuzmishyna & Kotsun, 2010). During 1975–1977, the “Rokytnivskiy arboretum park” was established on the territory of the regional research and production association “Elite” on an area of 13 hectares and 250 species of woody plants were planted (Pokotylova & Dzyba, 2016). Since 1990, PMLA “Bayrak” has been protected, subordinated to the

Museum of agricultural history of Volhynia – Skansen and has become part of the open-air exhibition. The status of PMLA of national significance “Bayrak” was granted by Presidential Decree No. 715/96 (Appendix 3) of 20.08.1996. On the territory of PMLA “Bayrak” there are five garden and park landscapes: forest, meadow, park, garden and regular (Dzyba & Pokotylova, 2016). The compositional structure of the park is based on the landscape style, with elements of a regular one in the parterre (Kotsun, Kuzmishyna & Kotsun, 2010). The main plantings form areas of forest and park type, which serve as

a backdrop for groups and solitaires (Tsikhotska & Kotsun, 2011).

The planning structure of the PMLA is looped (Fig. 8, a, b). Plantings are represented by alleys, groves, solitaires, hedges, row plantings, groups (Fig. 8, c). Since the creation of the park, the number of

woody plant species has been constantly decreasing, in particular, in 2010, 143 species of woody plants grew on the territory of PMLA “Bayrak” (Pokotylova & Dzyba, 2016), and now there are 130 species of woody plants (30 families, 73 genera), of which 86 species belong to the IUCN Red List.



Figure 8. PMLA “Bayrak”

PMLA “Slovyanskyi” (Volodymyr-Volynskyi, Volodymyr-Volynskyi district, Volyn oblast). In 1988, the park “Slovyanskyi” was created (the project was developed by the Lviv design and restoration workshop for the restoration of historical and cultural monuments) on the territory of a low-lying (eutrophic) swamp on an area of 27.53 hectares, which is a floodplain of the Luha River between the Rylovytsia and Smochche rivers. In the upper part of the park, adjacent to the floodplain of the river on an area of 10.2 hectares, there is a park of culture and recreation, in the other part – a meadow park (located in its natural state). Pedestrian paths are mostly made of sand, so they do not affect the natural state and flora of this territory. In 1988, the “Prince’s alley” was built, sculptures of the princes of Kievan Rus were installed. There is also a monument to Taras Shevchenko in the park. The status of PMLA was

granted in accordance with the decision of the regional council No. 12/4 of 04.11.1997. On the territory of the park there are two “Slovyanski springs” (natural monuments of local significance, decision of the regional executive committee No. 134 of 18.03.1982) (Regulations, 1999).

The planning structure of PMLA “Slovyanskyi” is combined (axial and fan-shaped) (Fig. 9, a, b). There are the following types of plantings on the territory: alleys, groups (Fig. 9, c), row plantings, solitaires, hedges (Table 1). Now there are 56 species of woody plants growing (*Thuja occidentalis* L., *Larix decidua* Mill., *Larix kaempferi* (Lamb.) Carrière., *Fraxinus angustifolia* Vahl., *Cercidiphyllum japonicum* Siebold & Zucc. ex J.J. Hoffm. & J.H. Schult.bis., *Juglans regia* L. etc.). 43 species – belong to the IUCN Red List (Fig. 6), of which 37 species have the least concern (LC) category.



Figure 9. PMLA “Slovyanskyi”

PMLA “Klevanskyi park” (Klevan village, Rivne district, Rivne Oblast). Area – 7 hectares. Klevansky Park in 1967 was taken under protection on the basis of the decision of the executive committee of the Rivne regional council of people’s deputies No. 818 of 10.10.1967, No. 317 of 20.06.1972, No. 343 of 22.11.1983 (appendix No. 5) and granted the status of PMLA. The park is a remnant of an old oak grove, the plantings are represented mainly by *Quercus robur* L. of different ages, the oldest are 250-300 years old. On the territory there is a house of culture, a sports field, an Orthodox church, a memorial to soldiers who died in the Second World War (Dzyba,

2016) (Fig. 10, c). It is used as a place of recreation. Planning structure – fan-shaped (Fig. 10, a, b). The following types of plantings were identified in the “Klevanskyi park”: hedge (*Buxus sempervirens* L.), hedge (*Caragana arborescens* Lam.), row plantings (*Chamaecyparis pisifera* Sieb. et Zucc. and *Thuja occidentalis*), groups of *Populus simonii* Carr. and *Robinia pseudoacacia* L., *Tilia platyphyllos* Scop., *Tilia cordata* Mill. etc. In 1967, 14 species of woody plants grew. Currently, the dendroflora of PMLA “Klevanskyi park” is represented by 33 species, one hybrid of woody plants (15 families, 27 genera), of which 25 species are included in IUCN Red List (Fig. 6).

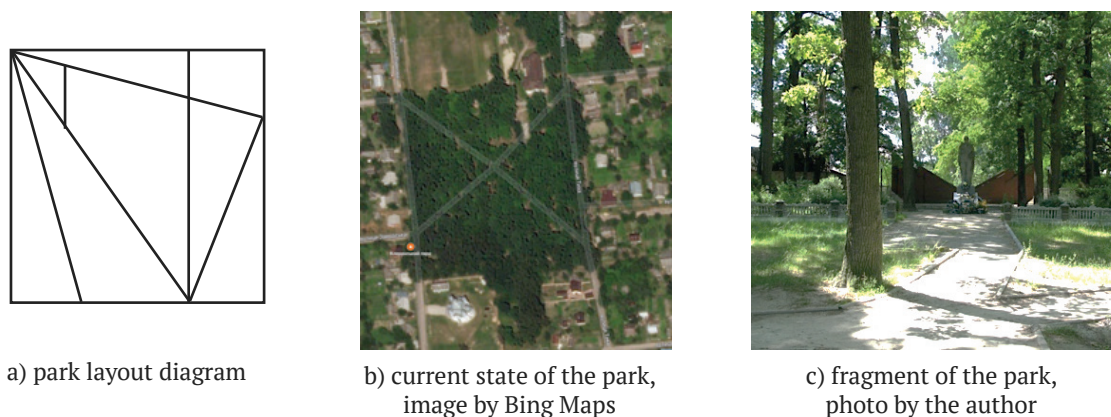


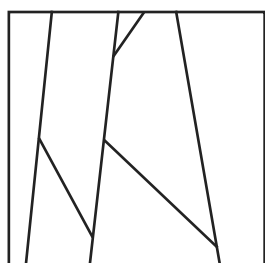
Figure 10. PMLA “Klevanskyi park”

PMLA “Zhornivski” (Zhornivka village, Fastiv district, Kyiv oblast). Area – 5.2 hectares. The “Yubileynyi” arboretum was founded during 1969-1972 by forester V.S. Galytskyi on the project of a researcher at the I.N. Hegelsky Boyarka Forest Experimental

Station (FES) in Zhornivskyi forestry of Boyarka FES (compartment 55, stratum 8, 9, compartment 56, stratum 1) (Kushnir, Sukhanova & Snihyr, 2016). Memorial cascades have been created in the park: “Kyivskyi”, “Komsomolskyi”, “Icebergs”, “Earth-Moon”

and “Love” (Sukhanova & Snihyr, 2015). The status of PMLA “Zhornivsky” is granted in accordance with decision of the Kyiv regional council of workers No. 118 of 28.02.1972 (Vasyliuk *et al.*, 2012). It has fan-shaped planning structure (Fig. 11, a, b). At the beginning of

the park, 160 species of woody plants grew, but over time their number has decreased and now amounts to 47 species (19 families, 33 genera), of which 33 species belong to the IUCN Red List (Fig. 6). Plantings are represented by arrays, groups, solitaires, hedges (Table 1).



a) park layout diagram

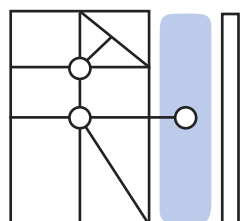


b) current state of the park, image by Google Maps

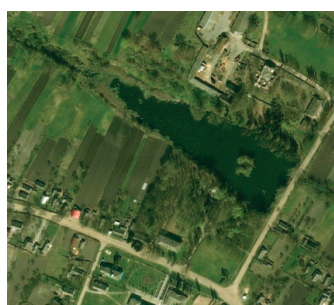
Figure 11. PMLA “Zhornivskyi”

PMLA “Vysokivskyi” (Vysoke village, Zhytomyr district, Zhytomyr Oblast). Area – 6.55 hectares (Passport No. 69, 1974). The park was established as a memorial on October 25, 1963 (now it is a place of recreation for residents of the community) according to the project of S.K. Bukata and V.M. Khapchuk. In 1963, 106 species of woody plants were planted (*Quercus robur* L., *Quercus rubra* L., *Salix babylonica* L., *Juglans regia* L., *Juglans manshurica* Maxim., *Juglans manshurica* Maxim., *Cotinus coggygria* Scop., *Populus alba* L. etc.). The park has a depression in the north-west, where a reservoir with an area of 1.55 hectares is formed (Fig. 12, c), in the centre of which is an island (Fig. 12, b). In the centre of

the park, there is an obelisk with a list of villagers who died during the Second World War. An alley of *Populus nigra* var. *italica* Münchh., the number 50 and the star from *Picea abies* Karst. were planted on the opposite side of the pond, which today are preserved only in fragments. The status of PMLA was granted by the decision of the Zhytomyr regional executive committee No. 505 of 29.12.1974 (Passport No. 69, 1974). The planning structure of the PMLA is cross-shaped (Fig. 12, a). Currently, 39 species of woody plants (18 families, 27 genera) grow in the “Vysokivskyi” PMLA, 26 of which belong to the IUCN Red List (Fig. 6). Plantings are represented by solitaires, groups, and alleys (Table 1).



a) park layout diagram



b) current state of the park, image by Bing Maps



c) fragment of the park, photo by the author

Figure 12. PMLA “Vysokivskyi”

PMLA “Horodnyanskyi” (Horodnya, Chernihiv district, Chernihiv Oblast) began to be created in 1959 on an area of 10 hectares for recreation of city residents. The initiator of the park’s creation was V.I. Konon. The development of the planning structure of the park and its implementation was carried out under the supervision of P.A. Dolsky with the participation of K.T. Chorny, the director of the boarding school I.N. Osypenko and his pupils. The park is rectangular in shape (Fig. 13, b) was divided

into eight sectors (Fig. 13, a), in the center there was a clearing with a diameter of 100 m, an area of 1.0 hectares (preserved to this day, Fig. 13, c). Within two years, alleys were planted along the sectors and a row planting of *Tilia cordata* Mill., *Tilia platyphyllos* Scop. around the clearing, along the northern and western borders of the park – an alley of *Populus nigra* L. In 1960-1961, *Pinus sylvestris* L. were planted in sectors 2 and 3, *Risea abies* (L.) Karst. – in sectors 4 and 6, and *Betula pendula* Roth. – in 5 and 8.

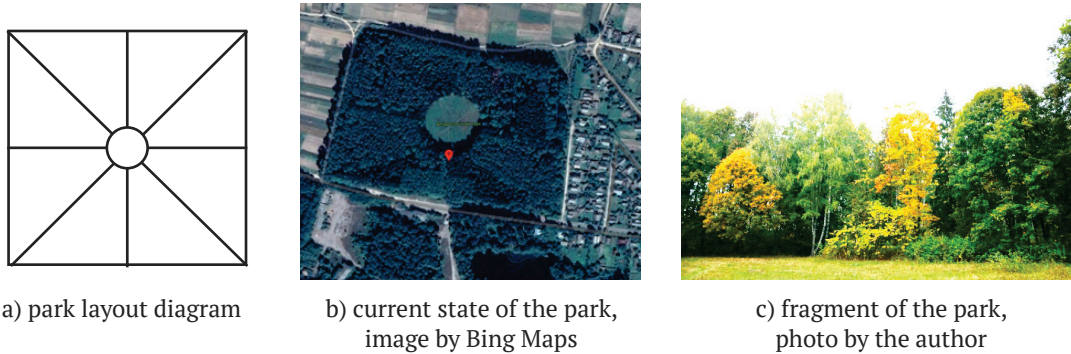


Figure 13. PMLA “Horodnyanskyi”

From 1963 to 1966, plantings were supplemented. In 1966, 20 species of woody plants grew in the park. In the future, anniversary plantings were carried out in 1967 (50 trees of *Quercus rubra* L.), 1970 (100 trees of *Acer platanoides* L.) and 1975 (30 trees of *Quercus robur* L.). In 1978, the park was granted the status of PMLA (decision of the Chernihiv regional executive committee No. 529 of 04.12.1978). In 1981, there were 37 species of woody plants in the park (Dzyba & Shytiuk, 2015). The planning structure of the park is regular and star-shaped. Plantings are represented by alleys, row plantings, groves, and groups. Currently, 36 species (28 genera, 15 families) grow on the territory of the park, conifers are sparsely distributed and are represented by *Picea abies* Karst., *Pinus sylvestris* L. and *Larix decidua* Mill. (five specimen). 29 species belong to the IUCN Red List (Fig. 6), among them *Aesculus hippocastanum* L. – vulnerable category (VU), *Fraxinus excelsior* L. – near threatened (NT), *Juglans cinerea* L. – endangered (EN).

Thus, 176 species of woody plants grow on the territory of 11 PMLAs, of which 119 species are listed

in the IUCN Red List (57% – category of least concern (LC)) (Dzyba, 2021). In four parks, the number of species has increased by 75-129% since the beginning of its creation, and the number of arboreal rarities is 77-81%. In six parks, dendro-diversity decreased by 13-71%, with 29-87% of woody plant species remaining, among which 66-94% are arboreal rarities. The results confirm the significance of PMLAs of Ukrainian Polissya and the need to replenish collections of woody plants.

Conclusions

PMLAs, created during the second half of the 20th century, are located unevenly in the Ukrainian Polissya. Three PMLAs are represented in Volyn, Rivne, Zhytomyr oblasts, and only one in Kyiv and Chernihiv oblasts. Three PMLAs are created on the basis of natural oak stands, “Ovrutskyi” – based on artificial stands. The remaining seven parks were rebuilt from autochthonous and introduced woody plant species. They have regular, landscape, and combined planning styles, in size – small, medium, large with star-shaped,

axial, fan-shaped, loop, cross-shaped, and combined planning structures. On the territory of four PMLAs, there are reservoirs and memorial complexes, monuments, an obelisk in honour of those who died in the Second World War. On the territory of PMLA “Slovyanskyi”, there is a monument to T.H. Shevchenko and a memorial “Prince’s Alley”. A Museum of agricultural history of Volhynia – Skansen was created on the territory of PMLA “Bayrak”. 176 species of

woody plants grow on the territory of 11 PMLAs, of which 119 are listed in the IUCN Red List.

11 PMLAs are valuable centres of dendro-diversity and unique plantings of Ukrainian Polissya, an example of the establishment of didactic, ethnographic, memorial, children’s, culture and recreation, combined parks that require further protection and expansion of the area and collection. Some parks require landscaping.

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Особливості формування парків-пам'яток садово-паркового мистецтва другої половини ХХ століття Українського Полісся

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Анотація. Проаналізовано формування парків-пам'яток садово-паркового мистецтва (ППСПМ) в історичному аспекті. На Українському Поліссі у другій половині ХХ ст. створено 11 парків-пам'яток садово-паркового мистецтва: два загальнодержавного і дев'ять місцевого значення. Призначення ППСПМ – охорона та збереження найбільш визначних і цінних зразків паркового будівництва з метою їхньої використання в естетичних, виховних, наукових, природоохоронних та оздоровчих цілях. Мотивацією до створення ППСПМ було збереження, відтворення та збагачення в умовах Українського Полісся дендрорізноманіття. У парках висаджували технічні, швидкорослі, рідкісні, цінні для лісового та садово-паркового господарства види деревних рослин із подальшим використанням їх із науковою та господарською метою. Частина насаджень у парках були пам'ятними, ювілейними або присвяченими знаменним подіям (річниці Жовтневої революції та дню народження В.І. Леніна). На Українському Поліссі є три парки, що створено на основі наявних дубових насаджень («Клеванський парк», «Парк Антонівка», «Бондарецький»), один – на основі штучних насаджень з *Acer platanoides* L., *Carpinus betulus* L., *Fraxinus excelsior* L., *Tilia cordata* Mill. («Овруцький»). Три парки культури і відпочинку («Городнянський», «Високівський», «Слов'янський», зокрема лугопарк «Слов'янський»), дитячий парк («Бондарецький»), чотири дендропарки («Дубечненський», «Байрак», «Новоставський парк», «Жорнівський») з часом трансформувались або їм було надано статус ППСПМ. За розміщенням у планувальній структурі населених пунктів виділяють загальноміські, сільські та районні парки. За розмірами є ППСПМ малі, середні, великі з зірчастою, осьовою, віялоподібною, петельною, хрестоподібною та комбінованою планувальною структурами. У чотирьох ППСПМ є штучні та природні водойми, фонтан. П'ять парків є комбінованими (меморіальний та парк культури і відпочинку), де зосереджено меморіальні комплекси, пам'ятники, обеліск. Насадження парків представлені групами, солітерами, алеями, рядовими посадками, живоплотами, іноді галями та масивами. На території 11 ППСПМ зростає 176 видів деревних рослин, із них 119 занесені до Червоного списку Міжнародного союзу охорони природи. У чотирьох парках від початку створення збільшилась кількість видів на 75-129 %, у шести парках дендрорізноманіття зменшилось, залишилось від 29 до 87 % видів деревних рослин, серед них 66-94 % дендрораритети. 11 ППСПМ є цінними осередками дендрорізноманіття та унікальних насаджень Українського Полісся, прикладом формування дидактичних, етнографічного, меморіальних, дитячого, культури та відпочинку, комбінованих парків, які потребують подальшої охорони та розширення площі й колекції. Деякі парки потребують реконструкції насаджень

Ключові слова: історія, парк, види, планувальна структура

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Relief geoplastics as a means of shaping the perception of landscape compositions using the example of the Pechersk Landscape Park in Kyiv

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Abstract. Geoplastics as a method of vertical planning is becoming increasingly popular among landscape architects because this method gives the landscape aesthetic unity, expressiveness, and a peculiar feature. The study considers the influence of geoplastic changes in the terrain on the viewer's perception of the environment. These factors are extremely important in the creation and design of the park, allow presenting key elements, while creating harmonious combinations of composition in the space, which can cause admiration and thereby contribute to increasing the number of visitors to the landscape object. Pechersk Landscape Park is located on the picturesque slopes of the Dnipro River in the city of Kyiv, has a landscape type of layout, which is characterised by large areas of lawns with groups of bushes and trees, lack of symmetry in the placement of alleys and other elements of open planning. The park itself covers an area of 32.92 hectares. The location in difficult terrain conditions contributes to the use of geoplastics, which can be utilised to improve and develop the park space. The highlighted studies are based on the analogy method, which transfers analogue elements of geoplastics to the results obtained during a full-scale survey of a park area in difficult terrain conditions. Graphic materials were developed using the ArchiCad 21 software suite based on the original map data. A detailed analysis of the problematic aspects of the Pechersk Landscape Park outlined the main task of determining the adaptability of the territory for the needs of visitors, in the context of improving the comfort of stay, improving the natural landscape, and arranging natural areas of the park terrain. Techniques and methods were used to improve the territory, such as terracing of slopes, creating eco-chairs, and using artificial relief on playgrounds. The impact of these changes on visitors' stay and the environment in general was summarised and predicted. The use of geoplastics in the context of the perception of landscape compositions would provide a solution to the problematic relief and exposition aspects of the Pechersk Landscape Park, which would increase its recreational potential

Keywords: vertical layout, landscape, urbanisation, terracing, landforms

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Introduction

Relief is a particularly significant factor for the art of landscape design. Urbanisation determines the need for a special attitude to the land fund. Therefore, some territories that are not intended for construction are used for landscape objects. Parks with difficult terrain conditions are mostly dangerous areas, according to the municipal organisation Institute of the General Plan of Kyiv City (Eco urban planning forecast). This information confirms the special status of such territories, the danger of which is manifested in existing erosion processes, the possibility of landslides and mudslides (Minder & Sidorenko, 2014). Therefore, the organisation of safety in recreational areas, within difficult terrain, is an integral part of design and executive work. The use of anthropogenic landforms in landscape design is also relevant as a means of creating vivid emotions in the viewer (Bondarenko, Kokhan, Gonchar & Bondarenko, 2019).

Pechersk Landscape Park in the city of Kyiv is an example of using a territory with complex terrain for landscaping. Due to the processes of urbanisation and a good location on the banks of the Dnipro River, the recreational load on this park increases, which serves both for the recreation of residents and guests of the city, and for holding mass events (concerts, festivals, exhibitions). Therefore, there is a need to adjust the park to the needs of society, adapt hard-to-reach areas of the territory, increase the comfort of staying in the park space and improve the natural landscape, which will favourably affect the psychological state of a person in a megalopolis. Since many exhibition events are held in the Pechersk Landscape Park, it is important to arrange certain areas of the park terrain for the convenience of viewing landscape and exhibition compositions. Vertical planning of the area is part of any green area project and is carried out during the initial period of both design and construction (Sokhnych, 2010; Pikhalo & Omelianchuk, 2017).

A large number of visitors come to exhibitions and festivals in the Pechersk Landscape Park every year, which significantly increases the recreational

potential of the park. It is this park that has become a traditional venue for exhibitions and festivals due to the fact that the complex terrain contributes to the placement of compositions on the slopes, which can be viewed from different angles, revealing to the observer the fullness of three-dimensional and flat landscape paintings. Given the importance of these events and the annual increase in interest in them as a result of urbanisation processes, there is a need for compositional enrichment of the park, expansion and arrangement of recreation areas, which will create more comfortable conditions for staying on the territory of a landscape object. Geoplastics as a tool for artificial terrain change allows improving the park area, enhancing the view of exhibition elements and the general perception of space by creating new and improving existing landforms, and establishing modern recreation areas.

Analysis of recent studies and publications. Complex terrain conditions are an important factor in organising the landscape of a park area, in particular, dividing the surface into separate forms, each of which becomes a separate element of the composition. In addition, the nature of the terrain is an important compositional condition that determines the emotional perception of the park area (Starke & Simonds, 2013).

The visual quality of urban recreational areas is a factor that directly affects the requirements of users of these territories. Polat & Akay (2015) have identified the relationship between the visual quality of the landscape and the structural design of territories, and between the aesthetics and functional requirements of visitors.

Pieczara (2019) noted the importance of shaping the landscape based on its visual qualities. This approach reflects the importance of all visible features of the territory in terms of their aesthetic appeal, which is often used in landscape research. The potential for measuring visual phenomena, which are often the subject of intuitive and experimental design, is considered by Nijhuis (2011). The main activity of landscape architecture is the establish-

ment of open and closed spaces. The visible form, which also acts as a relief, is crucial, since it provides movement through its formations and areas, through its spatial orientation, and causes an emotional impact with visual composition. Quite important in landscape perception is the observer's point of view and programming of visual impressions based on the theory of dynamic visual perception (Xiaogang, Xiaogang & Hui, 2021).

Understanding the visual quality of urban park landscapes in complex terrain conditions requires a comprehensive approach to its study. The urban park area under study belongs in its form of relief to parks on a hill, which have a significant impact on the development of the urban landscape, create a peculiar silhouette of the city, serve as landmarks in the spatial organisation of development, and determine the scale of various structural parts of the urban organism (Sydorenko & Minder, 2018).

The purpose of the study is to develop project proposals to improve the perception of the territory of the Pechersk Landscape Park using terrain geoplastics techniques.

Materials and Methods

During the research, the method of analogy of selection and transfer of analogous elements of artificial geoplastics to the results of a full-scale survey of the park territory was used. The synthesis determined the factors of influence of landforms, both natural and artificial, on the landscape planning organisation of the territory, which outlined the locations of the proposed geoplastics techniques. The study and

analysis of the territory was carried out by the cartographic method based on a topographic survey of Kyiv city on a scale of 1:2,000 (Topographic maps). The master plan was developed using the ArchiCad 21 graphics software suite.

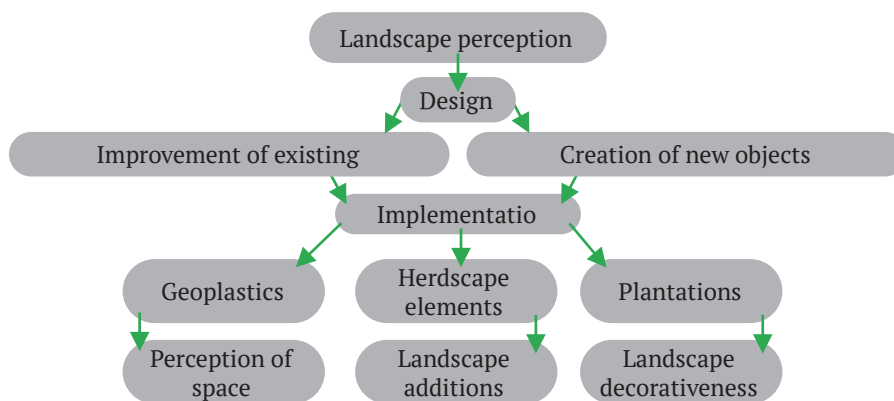
The object of research is the formation of artificial terrain as the main means in the perception of landscape compositions. The subject of the research is the territory of the Pechersk Landscape Park in Kyiv.

Results and Discussion

Geoplastics are used to improve existing or create new forms, to restore natural landforms, etc. The advantage of geoplastics is that despite the artificial method of changing the terrain, objects have a natural appearance. To achieve this result, it is important to work through each stage, starting from the design and ending with the direct implementation of the project. Earthworks are difficult, as it is necessary to create harmonious proportions without disturbing the natural outlines of the terrain (Kuznecova, 2011).

Human perception of the landscape is one of the main goals in designing and creating a park. Each element should make a special impression on the person. This can be achieved with various landscape techniques that depend on the goal and task. Certain objects can be hidden from view, and some need to be opened in a timely manner so that the viewer gets the strongest possible impression.

Having revealed all the landscapes and secrets to the viewer at once, the park loses its sense of mystery and begins to disappoint. The task of forming the perception of the environment can be handled



by the features of the terrain and the location of various types of plantings on the territory (Fig. 1).

Figure 1. Design scheme of park space perception

For example, positive landforms affect a person's perception of park space from a certain viewpoint. They can be used to "gradually reveal" the view or play the role of a screen, hiding unwanted elements, technical park structures, etc. Relief affects the perception of space and human perception. Smooth landforms can promote relaxation, it is an ideal terrain for rest, since it does not require energy consumption for movement, it is comfortable for sitting, but a terrain with a height difference helps to excite the nervous system. Similarly, the slope of a surface affects spatial perception. A person feels more protected when standing on a flat surface. At the same time, the sloping landscape encourages movement.

This property of the human psyche can be used to encourage visitors to move in certain directions (Norman, 1979). The gradual disclosure of the exposition elements of the exhibitions of the Pechersk Landscape Park can be ensured by shaping the movement of visitors in difficult terrain conditions.

The overall configuration of the park area is compact. The height difference of the terrain is 80 m. The lowest absolute mark (100 m) is located in the north-eastern part of the park, and the highest (180 m) is located in the north-western part of the park. The southern part of the park has a hilly rise with a natural height difference of 50 m (Sydorenko & Minder, 2018).

To provide the viewer with the maximum view of the territory, it is necessary to raise it higher above the element or area on which the accent is made. The steeper the slope, the larger the external space is felt. Hilly terrain is used to create spatial boundaries of park areas, to divide it into functional zones.

The openness of the gentle terrain allows visually combining the elements of the park and observing them for a long time without interference. However, the disadvantage of the flat area is the lack of protection from wind, sun, and the impossibility of privacy of park visitors, resulting in a feeling of

"nudity" (Bauer, 2011).

Vertical terrain elements help in spatial definition and contribute to the comfort of visitors. Hills on both sides set the edges of personal space (Lynn, 2004). Placing objects on hilltops creates a sense of its importance and focuses the visitor's attention on it.

Artificial terrain can be used to direct attention to certain objects along the lines of least resistance to open space. By creating artificial hills, it is possible to control the sunlight during the day. This aspect should be considered when holding exhibitions, since natural light affects the perception of compositions. Depending on what time the events are held, it is possible to determine on which side of the slope the exhibition elements should be placed or to plan the placement of the stage so that sunlight does not interfere with the visitor's observation and even helps in the overview (Bakurova & Efimov, 2015).

The conducted studies on the influence of the existing terrain on the nature of illumination of the territory of the Pechersk Landscape Park in the cardinal directions during the day established the following features of their expositions:

- west side: indirect illumination by morning sun; illumination by hot sun in the afternoon;
- east side: illumination in the morning; indirect illumination in the afternoon;
- south side: all-day illumination; aggressive direct sunlight at noon;
- north side: in summer, illumination is only in the morning and evening; in winter, there is no direct illumination during the day.

The principles of relief changes are outlined, and the nature of illumination of the territory is considered in the project proposals for improving the park environment. As noted, the Pechersk Landscape Park is a popular venue for exhibitions. For such open-air events, it is a very good solution to place the exhibition on the surface of the slope, the view of which opens from below. Such a surface can be formed by geoplastics methods. To do this, the site is raised using an embankment of earth using a frame made of geoplastic materials and fixed with a

retaining wall. The resulting “canvas” will serve for the subsequent creation of various compositions, such as flower arrangements, the review of which would become more convenient and better perceived by the viewer.

To reveal new angles on the compositional el-



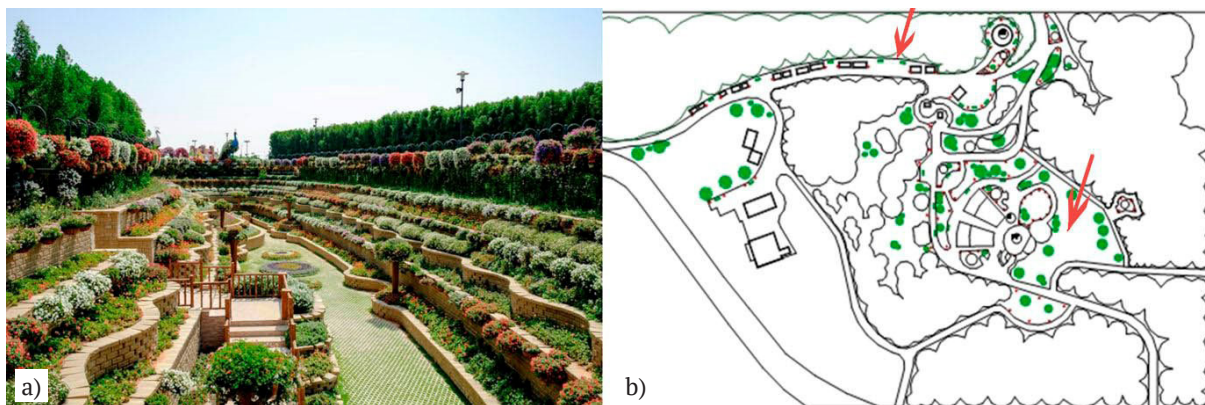
allow visitors not only to contemplate flower arrangements from the bottom up, but also to walk between them (Fig. 2).

Figure 2. Terracing of slopes with paths along the edge of terraces: *a* – analogue image (<http://surl.li/axskp>); *b* – suggested location within the park

One of the options for the compositional solution is terracing with retaining walls of var-

ements of the annual flower exhibitions on the territory of the Pechersk Landscape Park, a relief solution using geoplastics can be used. An example is the terracing of the slopes of the eastern exposition of the central part of the park, combined with a road network along the edge of the terraces. This would

ious shapes. The use of vegetation on architecturally terraced slopes (Pikhalo, Bagatskaya & Kudrenko, 2019) will ensure the establishment of space in difficult terrain conditions. This solution is proposed to be used on the slopes of the southern and western expositions of the central part of



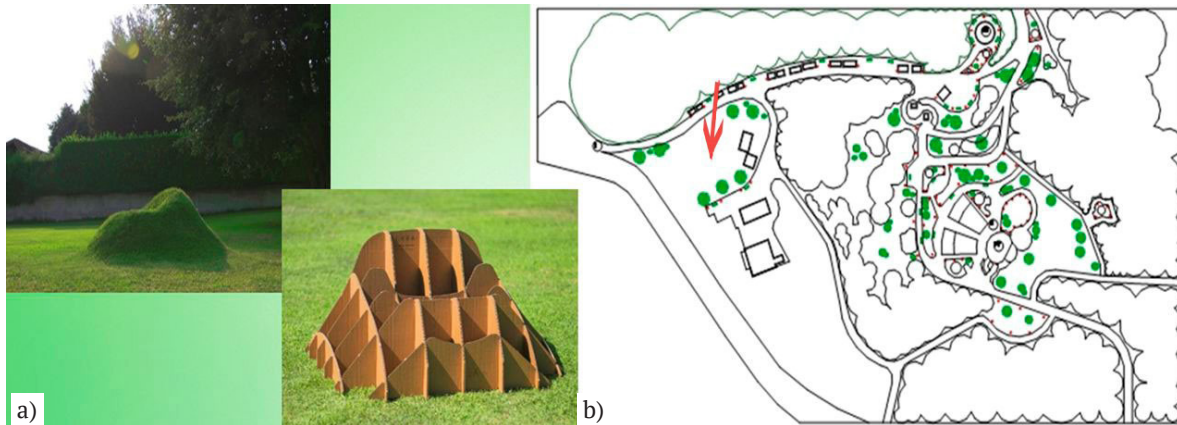
the Pechersk Landscape Park (Fig. 3), due to which it is possible to provide different intensity of illumination of this territory and create new compositional accents.

Figure 3. Terracing with retaining walls of various shapes: *a* – analogue image (<http://surl.li/axsnw>); *b* – suggested location within the park

For a comfortable rest of visitors, it is advisable to install eco-chairs in quiet recreation areas, which are created using geoplastics (Fig. 4). This does not require much effort, it is quite economical, since secondary raw materials can be used for the

frame of the eco-chair. The cavities of the frame are filled with a mixture of uncompressed soil and sown

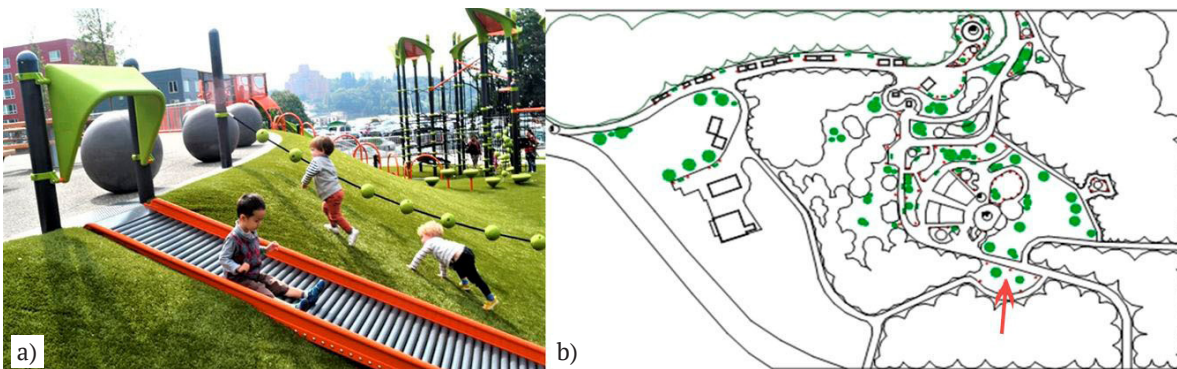
with lawn grass seeds. The creation of such green furniture lasts about two months. Artificially created



eco-style with its smooth lines harmoniously fits into the landscape and does not look alien. Within the park, it is proposed to place eco-chairs on the highest positive points of the terrain, which would allow visitors to observe the panorama of flower exhibitions.

Figure 4. Eco-chairs: *a* – analogue image (<http://surl.li/axsql>); *b* – suggested location within the park

The upper parts of the slope of the northern exposition of the Pechersk Landscape Park, which are not occupied by exhibition flower arrangements, are proposed to be used to create playgrounds (Fig. 5). This relief is ideal for children’s slides, which in combina-



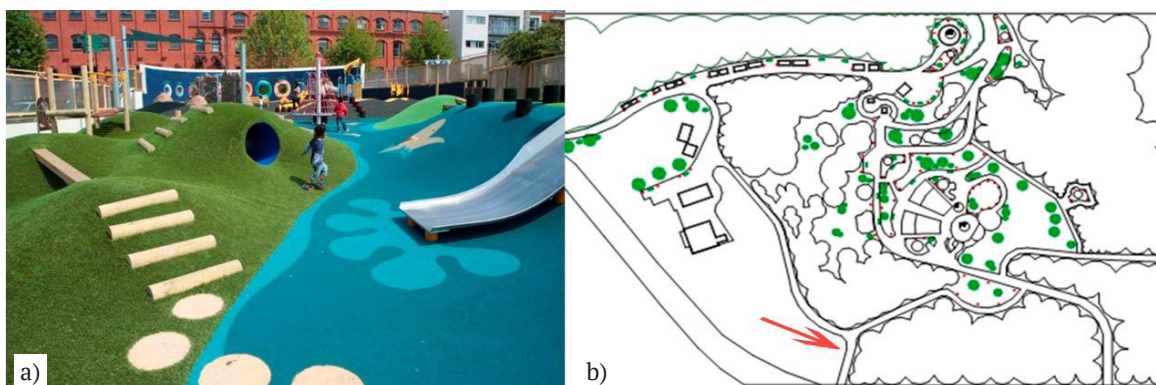
tion with natural materials of the site will create a sense of unity with nature. At the same time, the relief changes

will be insignificant: the organisation of smooth lines of the slope and the platform at its base will contribute to the safe descent of children from the slide.

Figure 5. Children’s playgrounds: *a* – analogue image (<http://surl.li/axsvm>);

b – suggested location within the park

Another interesting solution may be to create artificial hills on playgrounds for children. Tunnels can be laid in them, bridges and ladders can be created between hills, which would develop the spatial



orientation of children. For a site of this type, which has a non-standard appearance, it is proposed to place harmoniously integrated artificial hills in the existing relief from the additional entrance from Lavrska Street

on the slope of the north-eastern exposition (Fig. 6).

Figure 6. Artificial hills on playgrounds for children:

a – analogue image (<http://juegos1.rockthefashions.com/>);

b – suggested location within the park

Imitating the elements and topography of natural landscapes, architects and designers rely on the needs of the citizen – to make their childhood more natural and close to the natural landscape.

Conclusions

Geoplastics, as a method of creating a completely new terrain or improving an existing one, is gaining wide popularity among landscape architects, because this method gives the landscape originality and expressiveness and at the same time makes it durable.

Having carried out a detailed analysis of the

vegetation; creation of eco-chairs as geoplastic elements; use of existing terrain and creation of artificial hills on playgrounds. The impact of these changes on visitors' stay in the park and on the overall environment is summarised and predicted.

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Геопластика рельєфу як засіб формування сприйняття ландшафтних композицій на прикладі Печерського ландшафтного парку у місті Києві

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Анотація. Геопластика як метод вертикального планування набуває все більшої популярності у ландшафтних архітекторів, адже цей метод надає ландшафту естетичної єдності, виразності, своєрідної особливості. У роботі розглянуто вплив геопластичних змін рельєфу на людину, сприйняття глядачем навколишнього середовища. Ці фактори є надзвичайно важливими при створенні та проектуванні парку, дають змогу подати ключові елементи, при цьому створивши гармонійні поєднання композиції у просторі, які здатні викликати захоплення і тим самим сприяти збільшенню кількості відвідувачів ландшафтного об'єкта. Печерський ландшафтний парк розташований на мальовничих схилах Дніпра в місті Києві, має ландшафтний тип планування, для якого характерні великі площі газонів із групами кущів та дерев, відсутність симетрії в розміщенні алей та інших елементів вільного планування. Безпосередньо паркова зона займає площу 32,92 га. Розташування в умовах складного рельєфу сприяє застосуванню засобів геопластики, які можна використати для вдосконалення і розвитку паркового простору. Висвітлені дослідження базуються на методі аналогії, за допомогою якого перенесено аналогові елементи геопластики на отримані результати під час натурного обстеження паркової території в умовах складного рельєфу. Графічні матеріали розроблено за допомогою програмного пакета ArchiCad 21 на основі вихідних картографічних даних. Проведений детальний аналіз проблемних аспектів Печерського ландшафтного парку окреслив основне завдання щодо визначення пристосованості території для потреб відвідувачів, у розрізі підвищення комфорту перебування, покращення природного пейзажу, облаштування природних зон паркового рельєфу. Застосовано прийоми та методи щодо покращення території, такі як: терасування схилів, створення екостільців, використання штучного рельєфу на дитячих майданчиках. Узагальнено та спрогнозовано вплив цих змін на перебування відвідувачів і на середовище загалом. Використання геопластики в розрізі сприйняття ландшафтних композицій забезпечить вирішення проблемних рельєфних та експозиційних аспектів Печерського ландшафтного парку, що підвищить його рекреаційний потенціал

Ключові слова: вертикальне планування, ландшафт, урбанізація, терасування, форми рельєфу

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Establishment of regularities of the influence of polymeric shell on wood biodegradation

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Abstract. The analysis of the process of biological degradation of wood is carried out. It is established that neglect of environmentally friendly safe biosecurity products leads to the destruction of wood structures under the influence of microorganisms. The study of wood protection conditions allows creating new types of protective materials that help reduce water absorption and the amount of substances that are a medium for the development of wood-destroying fungi. In this regard, an analytical-experimental method for determining the proportion of destroyed material under the action of microorganisms using an antiseptic has been developed. Analysis of the results shows that the maximum mass loss in the case of biodegradation of untreated wood samples was from 7.6% to 16%, and the mass loss of samples of thermally modified wood did not exceed 3%, in those treated with an antiseptic water repellent – was less than 2%. It was determined that the protection in the case of treatment of thermally modified wood with wax oil and lasur increases in comparison with untreated wood by more than 4 times in terms of biodegradation, and in the case of treatment of non-thermally modified wood – by more than 8 times. Notably, the presence of wax oil and lasur leads to blockage of the wood surface, which prevents the penetration of moisture and microorganisms. Therefore, the intensity of development of wood-destroying fungi on the surface of different samples varies. Obviously, such a mechanism of influence of the protective coating is the factor in regulating the process, due to which the integrity of the object is preserved. Based on experimental data and modelling equations, the dynamics of the microbial population in the volume of material and the function of increasing the number of dead organisms are derived. In particular, a polymer shell was created on the surface of the sample, which significantly reduced the penetration of microorganisms into the wood, and the loss of wood mass during biodegradation did not exceed 2.5%. Additional application of protective substances on the surface increases the level of protection of untreated pine wood by 72%, thermally modified at 190°C – by 25%, at 220°C – by 37%. Similar results are obtained for hornbeam wood – 60%, 37%, and 28%, for oak – 50%, 37%, and 37%, respectively

Keywords: wood, efficiency of thermal modification, antiseptics, protective coatings, bio-degradation, wood stability

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Introduction

The search for highly effective means of protecting wood from degradation is a pressing issue in construction since outdoor operation makes wood vulnerable to environmental conditions, leads to a significant decrease in its natural durability and eventually destruction..

Thermal modification of wood causes chemical changes that significantly affect the physical, mechanical, and biological properties of wood (Tsapko *et al.*, 2021). Therefore, it is important to investigate these changes to make better use of the products. In particular, Kubovský *et al.* (2020) conducted thermal modification of wood using Thermowood technology at temperatures of 160°C, 180°C, and 210°C. Researchers claim that hemicelluloses are less heat-resistant than cellulose. Polysaccharide chains are split into shorter ones, which leads to a decrease in the degree of polymerisation and an increase in polydispersity. Crosslinking reactions also occur at the highest processing temperature (210°C). At lower temperatures, lignin degradation reactions predominate, while higher temperatures mainly cause condensation reactions and an increase in molecular weight. Chemical changes in the main components of thermally modified wood mainly affect its mechanical properties, which should be considered when designing a variety of wooden structures.

Thermal modification of wood is a promising alternative to chemical and biocidal modification processes, which increases the biological strength and dimensional stability of wood. The main purpose of the study, as reported by Candelier *et al.* (2020), was to determine the biological stability of ash wood treated with thermal modification and to evaluate the antifungal and antithermic activity of extractive compounds from heat-treated ash wood, depending on the intensity of the modification process (2 hours at 170°C, 200°C, 215°C, 228°C). Untreated and heat-treated wood samples were extracted with water or acetone. The extracts were then used to determine the effectiveness of inhibition against white rot (*Trametes versicolor*) and brown rot (*Rhodonia placenta*) fungi. It was found that the degree of

antifungal activity of these extracts depends on the solvent used during the extraction, and varies depending on the intensity of heat treatment. The extracts were more effective against brown rot than white rot fungi. However, the anti-termite activity of heat-treated ash wood extracts was not significant. In addition, new chemical elements are formed as a result of thermal decomposition of wood polymers (lignin and hemicellulose), in particular, aliphatic acids, monosaccharides, and other products obtained as a result of their dehydration reaction. The most common element was syringaldehyde from lignin-derived compounds, which may explain the antifungal effect of heat-treated ash wood extracts.

The most common defects of structural elements are biological damage to the support zones of the coating and structures of the floor beam, and the use of impregnation with a polymer mixture in the destruction zones allows restoring the physical and mechanical properties of wood and preserving the appearance of the architectural structure. The paper by Gribanov *et al.* (2020) presents the results of X-ray tomography of reconstructed samples of destroyed wood, and a method for testing samples for crushing and cutting along fibres. It was found that the increase in the strength of reconstructed wood samples during crushing along the fibres was 77% compared to samples of destroyed wood and 83% during chipping.

The weather resistance of thermally modified wood was slightly better compared to untreated wood, but over time, the surface weathering occurred and additional processing became necessary. For this purpose, Miklečić *et al.* (2010) recommend the penetration treatment that oil-based coatings can provide.

To protect thermally modified wood, changes in some of its properties should be considered. Akyildiz & Kesik (2014) found that thermally modified wood has a more hydrophobic surface, absorbs little water, but still requires the use of elastic coatings, in particular, oil-based ones.

Features of the structure of wood as a material contribute to changes on a global scale in

construction. Wang *et al.* (2018) note that numerous multi-storey buildings made of solid wood are in the planning stage, under development, or have already been built. The effectiveness of their construction will change the way architects and engineers think of wood as a material. Although all materials can break down when wetted, the potential for wood biodegradation in a wooden building requires special study. Identifying and eliminating the conditions that can lead to this degradation will be crucial to ensure proper wood performance in such structures. This study examines and compares potential sources of biodegradation that exist for traditional wood construction with those used in mass construction, and identifies methods for limiting the risk of degradation.

Teacă *et al.* (2019) note that one of the most effective ways to prevent wood degradation is to apply protective coating layers by chemical modification of the surface. Recent trends in this area involve the use of natural products on a biological basis – extractives, oils, waxes, resins, biopolymers, biological control agents, for which the main classification criterion is represented by the type of protection. However, there are still unresolved issues related to the resistance of these coatings to atmospheric fluctuations when used in outdoor conditions.

Pavlič *et al.* (2021) studied the compatibility of various coatings with thermally modified Scots pine wood. Coatings applied to thermally modified wood showed better performance, including lower equilibrium moisture content, lower water permeability, increased dimensional stability, better UV resistance, and resistance to blue fungi compared to non-modified wood. Better penetration of the coating into modified wood and better wetting of thermally modified wood with protective coatings were also observed. In addition, oil-based paint and varnish materials showed better results after one year of external weathering compared to water-based coatings.

Oils provide the best protection for wood products, but their use is limited to their long-term

polymerisation, in addition, they guarantee protection for no more than 3 years. Arminger *et al.* (2020) investigated the behaviour of linseed and tung oil, in particular, tung oil gave hydrophobicity to all wood samples after application, even without drying. Linseed oil took longer to dry, and it was more susceptible to the effects of thermally modified wood.

Thus, from the literature sources it is established that during the use of wood, its components gradually degrade, which requires effective protection with environmentally friendly substances. The scarcity of data to explain and describe the process of wood biosecurity and neglect of the use of organic substances for elastic coatings leads to inefficient use of protective equipment. This indicates the expediency of conducting a study to determine the effectiveness of protecting wood products with protective coatings, which will increase the service life of building structures in environmental conditions.

The purpose of this study is to identify patterns of wood biodegradation when microbiological factors affect the protective coating.

Materials and Methods

Determination of the process of biological degradation of wood. Studies were conducted on samples of pine and oak as structural materials and hornbeam wood as alternatives to expand the areas of use. In total, 9 groups (10 units each) of samples of each species were used, measuring 20×20×20 mm. Groups 1, 2, and 3 were untreated wood without and with additional surface protection with a water-repellent antiseptic, and groups 4-9 were thermally modified at 190°C and 220°C for 10 hours without and with additional treatment. Two types of materials were chosen as antiseptic water repellent – WAX OIL Bionic House and Lasur Colortex Komposit. The protective substances were applied by immersion with repeated treatment after the first layer dried in 24 hours. The average amount of coating applied corresponded to about 170 g/m² (Fig. 1).

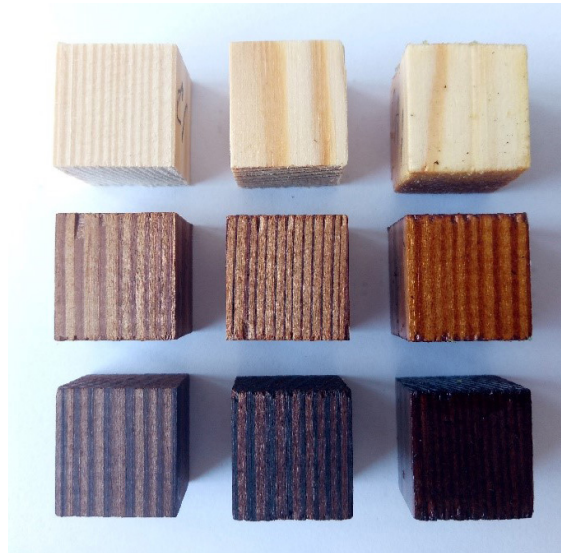


Figure 1. Model sample of pine wood: 1 – unmodified; thermally modified: 2 – at a temperature of 190°C for 10 hours; 3 – at a temperature of 220°C for 10 hours

The determination of biological degradation of wood was carried out according to a working methodology, the essence of which was to experimentally determine the mass loss of protected wood under the influence of soil microflora under certain air and moisture conditions and for a certain time. Wood is considered bio-resistant if the average mass loss of samples is no more than 5%.

The proportion of destroyed wood was calculated using the equation:

$$X_e = \frac{m_1 - m_2}{m_2}, \quad (1)$$

where m_1 – weight of the sample before the test, g; m_2 – weight of the sample after testing, g.

Modelling of parameters of microbial penetration into wood and its destruction. It is assumed that the proportion of wood volume involved in the biochemical metabolic process and depending on the size of the microbial population can be determined from a system of differential equations:

$$\left. \begin{aligned} \frac{dN}{dt} &= (\alpha - \beta \cdot N) \\ \frac{dR}{dt} &= \gamma \cdot N \\ \frac{dX}{dt} &= k \cdot (a - X) \cdot N \end{aligned} \right\} \quad (2)$$

where N – the number (size) of the population of active (live) microorganisms in the volume of wood V (m^3); t – time of action of microorganisms on wood,

days; X – proportion of wood volume involved in the biochemical metabolic process; R – the function of reducing the number (bioprotective substances), the values of which are equal to the proportion of microorganisms that have stopped vital activity as a result of adverse conditions: accumulation of decomposition products of enzymatic activity; release of toxic substances during metabolic processes; increase in insulating ability; α – maximum specific growth rate of microorganisms; β – specific rate of decrease in the number of microorganisms; γ – population reduction rate; k – coefficient of permeability of microorganisms to the material; a – total proportion of organic matter.

First, the independent system of the first two equations of system (1) is solved and the following is obtained (Tsapko, 2013):

$$N = \frac{N_m}{ch^2 \left[\left(1 - \frac{t}{t_m}\right)^{\frac{\Delta}{2}} \right]}, \quad (3)$$

where N_m – maximum number of microorganisms in wood, %; t_m – time of development of the maximum number of microorganisms in wood, days; Δ – parameter of microbial penetration; a solution for the function of reducing the number of active organisms in the form of:

$$R = \frac{1}{2} \left\{ 1 - th \left[\frac{1}{2} \left(1 - \frac{t}{t_m} \right) \cdot \Delta \right] \right\}. \quad (4)$$

Based on experimental data (Tsapko, 2013) and modelling equations (3) and (4), the dynamics of the microbial population in the volume of material and the function of increasing the number of dead organisms are derived.

As can be seen from Figure 2, at the initial time point, the population of active microorganisms in the material is low: $N(0)=N_0$, but increases over time, and this function necessarily has a global maximum point (the maximum possible number

of microorganisms) at a certain time $t=t_m$, in which $N(t_m)=N_m$. Over time, the amount of nutrients decreases and the population of microorganisms die off.

These results give an idea of the reproduction of microbacteria in the material and their death, and, accordingly, show changes in the metabolic processes of microorganisms. Protective substances in the material increase the suspended animation of microbacteria and allow controlling the process of countering biodegradation.

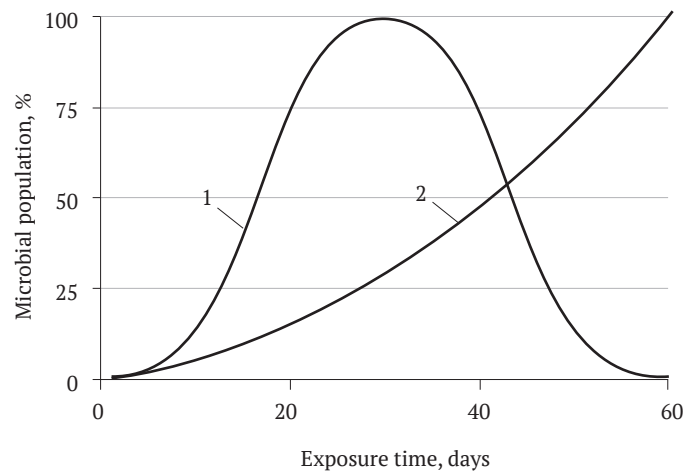


Figure 2. Dynamics of the microbial population in the volume of material: 1 – spread of microorganisms, 2 – increase in the number of dead organisms

After integrating the third equation of system (2), given that the proportion of destroyed material cannot exceed 1 or take negative values, and after substituting in its right-hand side instead of N for equation (3), the following equation is obtained:

$$X = 1 - e^{-2kN_m \frac{t_m}{\Delta} \left\{ th \frac{\Delta}{2} - th \left[\left(1 - \frac{t}{t_m} \right) \cdot \frac{\Delta}{2} \right] \right\}}. \quad (5)$$

Figure 3 shows the calculation of the proportion of material that is destroyed by microorganisms.

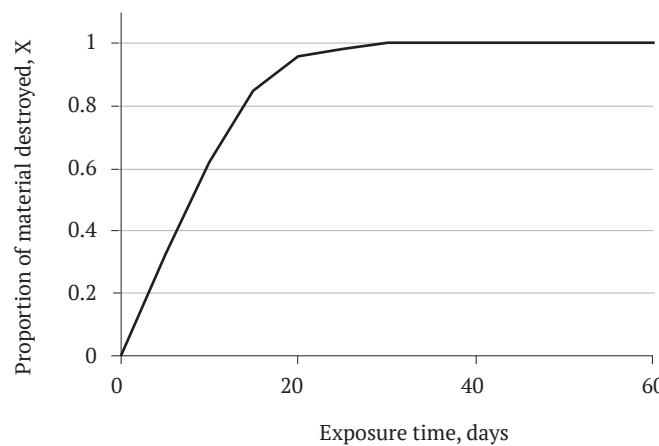


Figure 3. Proportion of material destroyed by microorganisms

Results and Discussion

The process of biological degradation of wood has an incubation period – a period of time after which intensive destruction begins. It is assumed that the duration of this period coincides with the time interval t_m at which the microbial population will reach a critical size. In addition, it is necessary to find the parameter value of biodegradation process Δ , permeability coefficient k and determine the maximum number of microorganisms in the wood N_m .

Experimental samples were kept for two calendar months in laboratory conditions at the Department of Technology and Design of Wood Products of the NUBIP of Ukraine. A culture of the wood-destroying fungus *Hericium erinaccus* was planted in the soil (Fig. 4). This type of fungus has the same effect on both coniferous and deciduous wood species. The medium parameters were also monitored and maintained at the required level: medium temperature – $25 \pm 2^\circ\text{C}$, soil moisture – 75-80%.



Figure 4. Determination of wood resistance to biological pests: *a* – cultures of fungi *Hericium erinaccus*; *b* – experimental samples of wood in laboratory conditions

During the test, the development of fungal lesions on the surface of the samples was monitored.

After six days, white fluffy mycelium of the fungus was observed in all the boxes on the soil surface (Fig. 5).

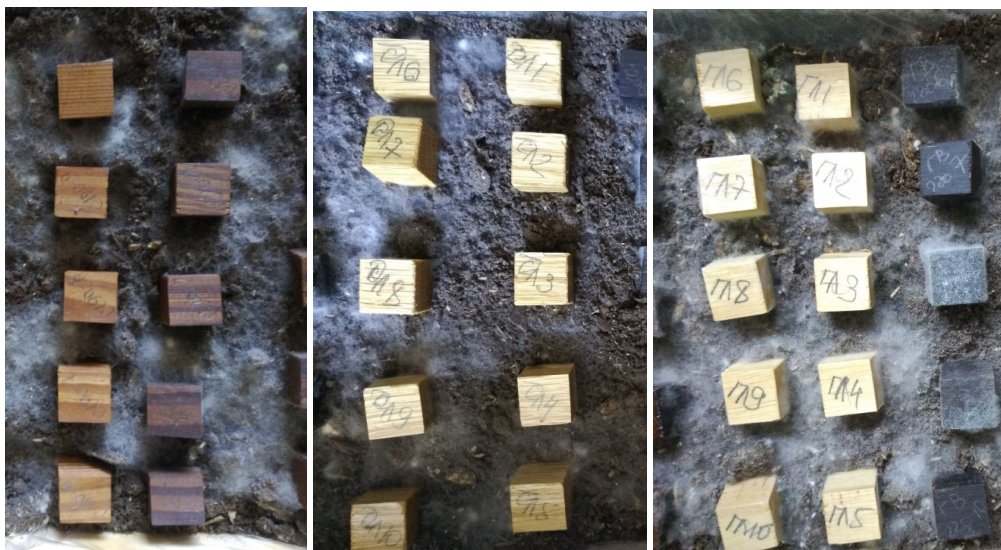


Figure 5. Appearance of mycelium on the soil surface in boxes with wood samples in the first week of the study: *a* – pine; *b* – oak; *c* – hornbeam

The mycelium of the wood-destroying fungus partially spread on the surface of samples of all the studied wood species with additional treatment with

lasur. A cotton-like mycelium of green colour can be observed on samples of pine wood untreated and treated with wax oil (Fig. 6).



Figure 6. View of pine wood samples on Day 6 of the exposure in a box with soil: *a* – untreated; *b* – surface is treated with wax oil

On Day 8, a similar mycelium appeared on samples of pine wood thermally modified at 190°C and 220°C with wax oil treatment. Brown spots were

observed on samples of untreated hornbeam wood (Fig. 7). Over time, the number of damaged samples and the area of damage increased.



Figure 7. Changing the appearance of hornbeam wood samples after a week of exposure in a soil box

On samples of oak wood modified at a temperature of 220°C with a surface treated with wax oil, fluffy green mycelium began to appear on Day 16, but it was different in appearance from what was found on pine. At this time, powdery grey mycelium was found on hornbeam wood thermally modified

at 190°C without surface treatment. On hornbeam wood without thermal modification with a surface treated with lasur, a fluffy mycelium of grey-green colour was found.

At this stage, the untreated oak wood began to turn yellow (Fig. 8).



Figure 8. View of untreated oak wood after two weeks of research

On Day 20, pine wood was covered with dirty green mycelium over a larger area. Hornbeam wood, thermally modified at 190°C and with additional treatment with wax oil, began to become

covered with a grey coating. After another four days, black spots began to appear on the ends of pine wood samples with surface treatment with wax oil (Fig. 9).



Figure 9. Appearance of black spots on oil-waxed pine wood samples on Day 24

Samples of oak wood, thermally modified at 190°C and treated with lasur, were partially covered with green powdery mycelium at this time.

The prototypes continued to be kept in

conditions favourable for the development of wood-destroying fungi. A week later, the appearance of green and red fungi on untreated pine wood was observed. Samples of untreated oak actively

collected moisture during this period and were coloured yellow. Moreover, at the ends, a cotton-like mycelium of green colour was visible in some places. A similar phenomenon occurred on samples of oak wood modified at a temperature of 220°C. The hornbeam wood remained unchanged.

On Day 38 of exposure in laboratory boxes, pine wood actively collected moisture from the soil

and acquired a yellow colour. The same situation was with samples of oak wood treated with wax oil, on some surfaces a red colour was noticeable. White mycelium appeared on the ends of samples of oak wood, thermally modified at 190°C and treated with lasur. A very small proportion of yellow mycelium was visible on samples of untreated hornbeam wood (Fig. 10).



Figure 10. Appearance of untreated hornbeam samples on Day 38 of exposure under aggressive conditions

After another 10 days of the experiment, samples of pine treated with wax oil accumulated moisture and turned yellow. Samples of pine thermally modified at 220°C showed white mycelium on a significant surface. The end surface of pine wood, modified at 220°C with additional application of lasur,

was covered with light green mycelium. The appearance of the hornbeam treated with wax oil has also changed: yellow mycelium was visible on the end surfaces, and a reticulated web of hyphae was visible on the upper part (opposite from the point of contact with the soil) (Fig. 11).



Figure 11. Appearance of hornbeam wood samples treated with wax oil

On samples of untreated hornbeam, brown spots changed to black in some places. After two months of exposure of the samples in aggressive conditions, darkening of the lower part, which was directly in contact with the soil, was noticeable.

After the experimental study was completed, the samples were cleaned of soil, weighed after drying, and the effect of wax oil and lasur coating on the resistance of wood to biodegradation was determined (Table 1).

Table 1. Results of the study of the effect of wax oil and lasur on the resistance of wood to biodegradation

Test object	Sample weight, g		Mass loss of wood, %	Proportion of destroyed wood
	before testing	after testing		
1	2	3	4	5
Untreated pine	4.9	4.1	16.330000	0.195122
Untreated pine+wax oil	4.33	4.12	4.850000	0.053528
Untreated pine+lasur	4.7	4.5	4.250000	0.044444
Pine T.M.* at 190°C	4.86	4.7	3.290000	0.034043
Pine T.M. at 190°C+wax oil	5.65	5.51	2.480000	0.025408
Pine T.M. at 190°C+lasur	4.46	4.36	2.240000	0.022936
Pine T.M. at 220°C	4.49	4.36	2.890000	0.029817
Pine T.M. at 220°C+wax oil	5.45	5.35	1.830000	0.018692
Pine T.M. at 220°C+lasur	3.87	3.8	1.810000	0.018421
Untreated hornbeam	6.89	6.32	8.272859	0.090190
Untreated hornbeam +wax oil	7.24	6.99	3.453039	0.035765
Untreated hornbeam+lasur	6.99	6.77	3.147353	0.032496
Hornbeam T.M. at 190°C	6.7	6.54	2.38806	0.024465
Hornbeam T.M. at 190°C +wax oil	7.31	7.2	1.504788	0.015278
Hornbeam T.M. at 190°C+lasur	7.13	7.03	1.402525	0.014225
Hornbeam T.M. at 220°C	6.48	6.36	1.851852	0.018868
Hornbeam T.M. at 220°C+wax oil	6.9	6.81	1.304348	0.013216
Hornbeam T.M. at 220°C+lasur	6.8	6.71	1.323529	0.013413
Untreated oak	5.44	4.98	8.455882	0.092369
Untreated oak+wax oil	4.98	4.76	4.417671	0.046218
Untreated oak+lasur	4.75	4.55	4.210526	0.043956
Oak T.M. at 190°C	4.14	4.02	2.898551	0.029851
Oak T.M. at 190°C+wax oil	5.29	5.19	1.890359	0.019268
Oak T.M. at 190°C+lasur	5.14	5.05	1.750973	0.017822
Oak T.M. at 220°C	4.43	4.31	2.708804	0.027842
Oak T.M. at 220°C+wax oil	4.3	4.22	1.860465	0.018957
Oak T.M. at 220°C+lasur	4.29	4.22	1.631702	0.016588

* T.M. – thermally modified

Thus, thermal modification increases the resistance of wood to biological pests. In particular, the mass loss of thermally-modified samples at 190°C during exposure in contaminated soil decreased by 5 times for pine wood, by 3.5 times for hornbeam, and by 3 times for oak. Exposure to a temperature of 220°C helps reduce the indicator by 5.6, 4.5, and 3.1 times, respectively. Additional application of protective substances on the surface increases the level of protection of untreated pine wood by 72%, thermally modified at 190°C – by 25 %, at 220°C – by 37%. Similar results are obtained for hornbeam wood – 60%,

37%, and 28%, for oak – 50%, 37%, and 37%, respectively.

Considering the presented results for determining the proportion of destroyed wood, such as pine, using a three-factor simplex – the central method of planning an experiment in the mathematical environment Statistica 12, statistical processing of the results was carried out.

The following factors were chosen as variation factors: thermal modification temperature, °C (factor X_1); amount of coating, g/m² (factor X_2), the changes of which are shown in Table. 2.

Table 2. Variation factors

Factors	Code	Variation levels			Variation interval
		-1	0	+1	
Temperature of thermal modification, °C	X_1	100	190	220	30
Amount of coating, g/m ²	X_2	160	170	180	10

The proportion of destroyed material was chosen as the initial parameter (response function), the values of which were recorded on samples exposed

to microbacteria. The experiment planning matrix and its mathematical implementation are shown in Table. 3.

Table 3. Experiment matrix and its implementation

No.	Factors, type		Planning matrix		Response function	
	X_1	X_2	Temperature of thermal modification, °C	Amount of coating, g/m ²	Y fact.	Y calc.
1	1	1	220	180	0.029	0.03
2	1	-1	220	160	0.034	0.04
3	-1	1	100	180	0.2	0.20
4	-1	-1	100	160	0.16	0.16
5	1	0	220	170	0.031	0.03
6	-1	0	100	170	0.18	0.18
7	0	1	190	180	0.042	0.05
8	0	-1	190	160	0.048	0.04
9	0	0	190	170	0.044	0.04
10	0	0	190	170	0.043	0.04
11	0	0	190	170	0.045	0.04

As a result of modelling, regression equations are obtained and ternary surfaces of changes in the

initial parameter are constructed depending on changes in variation factors (Fig. 12).

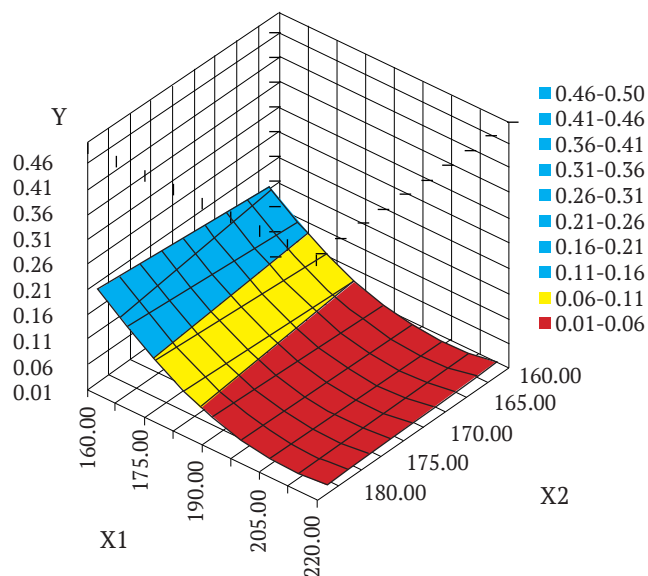


Figure 12. Ternary surfaces of changes in the output parameter depending on changes in the factors of variation of wax oil

Regression equation:

$$Y_{calc} = 0.044 - 0.074X_1 + 0.005X_2 + 0.061X_{11} + 0.0001X_{22} - 0.011X_1X_2.$$

Similarly, for hornbeam and oak wood:

$$Y_{calc} = 0.036 - 0.051X_1 + 0.006X_2 + 0.035X_{11} - 0.0001X_{22} + 0.003X_1X_2,$$

$$Y_{calc} = 0.042 - 0.081X_1 - 0.002X_2 + 0.066X_{11} - 0.0004X_{22} - 0.006X_1X_2.$$

Based on the computer modelling performed, the best value of the modification temperature and the amount of protective coating that ensures the fulfilment of the task was determined, namely, the lowest value of the proportion of destroyed material.

Conclusions

The positive effect of creating a protective coating film on the wood surface on increasing resistance to biological pests was revealed. Analysis of the results shows that the maximum mass loss in the case of biodegradation of untreated wood samples was from 7.6% to 16%, and the mass loss of samples of thermally modified

wood did not exceed 3%, treated with wax oil and lasur – less than 2%. The idea of reproduction of microbacteria in the material and their death is revealed, which accordingly show changes in the metabolic processes of the vital activity of microorganisms.

It was found that the use of surfaces treated with wax oil and lasur reduces the biodegradation process by more than 8 times for untreated samples. This coating significantly increases the service life of wood. The findings also allow purposefully solving further problems of creating new means and methods of wood protection in accordance with the conditions of wood operation at various facilities.

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Встановлення закономірностей впливу полімерної оболонки на біоруйнування деревини

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Анотація. Проведено аналіз процесу біологічного руйнування деревини. Встановлено, що нехтування екологічно безпечними засобами біозахисту призводить до руйнування конструкцій із деревини під дією мікроорганізмів. Дослідження умов захисту деревини допомагає створити нові типи захисних матеріалів, які сприяють зниженню водопоглинання, а також зменшенню кількості речовин, які є середовищем для розвитку дереворуйнівних грибів. У зв'язку з цим розроблено розрахунково-експериментальний метод визначення частки зруйнованого матеріалу під дією мікроорганізмів із застосуванням антисептика. Аналіз результатів показує, що максимальна втрата маси в разі біоруйнування необроблених зразків деревини склала від 7,6 % до 16 %, а втрата маси зразків термічно модифікованої деревини не перевищила 3 %, в оброблених антисептиком-гідрофобізатором – була менше ніж 2 %. Визначено, що захист у разі оброблення термічно модифікованої деревини масловоском і лазур'ю збільшується порівняно з необробленими у понад 4 рази за показником біоруйнування, а оброблення нетермомодифікованої – у понад 8 разів. Слід зазначити, що наявність масловоску та лазури призводить до закупорки поверхні деревини, що перешкоджає проникненню вологи і мікроорганізмів. Тому інтенсивність розвитку дереворуйнівного гриба на поверхні різних зразків різниться. Вочевидь такий механізм впливу захисного покриття є тим фактором регулювання процесу, завдяки якому зберігається цілісність об'єкту. На основі експериментальних даних і шляхом моделювання рівнянь виведено динаміку популяції мікроорганізмів в об'ємі матеріалу та функції підвищення чисельності загиблених організмів. Зокрема, на поверхні зразка було створено полімерну оболонку, що значно знизила проникнення мікроорганізмів до деревини, а втрата маси деревини при біодеструкції не перевищила 2,5 %. Додаткове нанесення захисних речовин на поверхню посилює рівень захисту деревини сосни необробленої на 72 %, термомодифікованої за 190 °C – на 25 %, за 220 °C – на 37 %. Схожі результати для деревини граба – 60 %, 37 % і 28 %, для дуба – 50 %, 37 % і 37 % відповідно

Ключові слова: деревина, ефективність термічної модифікації, антисептики, захисні покриття, біоруйнування, стійкість деревини

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Primary morphogenesis of *Sorbus torminalis* (L.) grantz in *in vitro* culture

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Abstract. Nowadays, *in vitro* methods in combination with *ex situ* methods are becoming increasingly important means of preserving and maintaining the level of stability of phytodiversity. *Sorbus torminalis* L. is a tree of the *Rosaceae* family, which grows on the territory of Ukraine, belongs to the rare, valuable native species, and is listed in the Red Book of Ukraine with an endangered status. The paper describes specific features of *in vitro* introduction of centuries-old representatives of *S. torminalis* using various types of explants, sterilising substances, cultivation conditions, and nutrient medium composition. For the introduction of *S. torminalis* into *in vitro* culture, annual shoots with apical and lateral buds 15-25 cm long are optimal. The influence of various sterilisation options on the development of primary microshoots was investigated. For the sterilisation of artificially awakened and young shoots, it is most effective to use a 0.1% AgNO₃ solution (7 min) and a 15% H₂O₂ solution (10 min). Proven method of *S. torminalis* explants sterilisation provided 80-90% yield of aseptic plant material. It was found that the sterilisation regime did not significantly affect the primary morphogenesis of explants and proceeded uniformly. Optimal components of nutrient media at the stage of introduction into *in vitro* culture and primary morphogenesis of *S. torminalis* were determined. For cultivating different types of *S. torminalis* explants, WPM nutrient media was used with the addition of synthetic plant growth regulators: 6-benzylaminopurine (BAP), tidiazuron (TDZ), kinetin 0.5-1.5 mg·l⁻¹ and α-naphthylacetic acid (NAA) 0.01-0.05 mg·l⁻¹ both separately and in combination with each other. In particular, WPM medium with the addition of BAP 1.5 mg·l⁻¹ + NAA 0.5 mg·l⁻¹ and WPM + TDZ 0.5 mg·l⁻¹ with the addition of PVP 200 mg·l⁻¹ are effective for plant regeneration from lateral and apical buds of explant. To induce the laying of additional buds and shoots on explants from apical meristems, BAP 4.0 mg·l⁻¹ + NAA 0.01 mg·l⁻¹ with the addition of PVP 200 mg·l⁻¹ should be introduced to the medium

Keywords: *Sorbus torminalis* L., aseptic culture, morphogenesis

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Introduction

Changes in natural areas, their degradation caused by human activity and climate change, accelerate the extinction of species and populations (Shpak, 2019, 2021). Cultivation of rare plant species to preserve their gene pool is one of the main tasks of our time.

Genus *Sorbus* L. belongs to the family *Rosaceae* and has 84 species and a large number of hybrid forms that grow in the temperate zone of the Northern Hemisphere. *S. torminalis* is one of the species of woody plants that grow on the territory of Ukraine, has strong wood, a smooth and slender trunk with a height of more than 25 m, a dense and very decorative crown (Kokhno *et al.*, 2002). It belongs to rare, extremely valuable native species. The widespread use of *S. torminalis* has led to the extermination of this plant. Now this tree is listed in the Red Book of almost 10 countries, including Ukraine, with an endangered status of this tree (Vasyliuk, 2017; Grynyk *et al.*, 2019).

The oldest representatives of checker trees in Ukraine were recorded in Podillia in the early 20th century. In different climatic zones, the life span of trees varies from 80 to 400 years (Diduch, 2009, Grynyk *et al.*, 2019). Moreover, isolated individuals or groups of 3-5 trees have been preserved, especially in areas that are not suitable for forestry (Bondar, 2002). Centuries-old specimens of checker trees are available in some botanical gardens and arboretums in Kyiv.

Sorbus torminalis is protected on the territory of the Yalta mountain and forest, Karadag, Crimean, and Medobory nature reserves; in the Podilski Tovtry and Karmeliukove Podillia national nature parks; Chernivtsi and Dnister Canyon landscape parks; Sofiyivka National Arboretum of the National Academy of Sciences of Ukraine; and in protected tracts and natural monuments in Chernivtsi, Ivano-Frankivsk, Ternopil, and Vinnytsia oblasts. Selective felling of checker trees and destruction of places of their natural renewal is prohibited (Shpak, 2019, 2018, 2021).

To preserve this plant, it is recommended to cultivate valuable specimens in artificial conditions, in particular, by microclonal propagation of plants

in vitro (Dunstan *et al.*, 1986; Chalupa, 2002; Bilous *et al.*, 2019; Chornobrov *et al.*, 2019). The relevance of microclonal reproduction of this particular species *in vitro* is conditioned by the fact that conventional methods are not effective enough and have certain disadvantages (Bendorz, 2004; Syplyva, 2009; Grynyk *et al.*, 2019).

In addition, the preservation of valuable specimens of centuries-old *S. torminalis* trees as elements of natural complexes on the territory of the nature reserve fund of Ukraine is currently possible only with the use of isolated tissue cultures. Therefore, the development of basic approaches at each stage of microclonal reproduction is the only way to obtain the required amount of morphologically stable and genetically homogeneous planting material with a minimum number of mother plants in a short time (Boulay, 1987; Bajaja, 1986; Arrillaga *et al.*, 1991; Bilokurova, 2010).

The purpose of the study is to determine the features of direct plant regeneration of *S. torminalis* (L.) at the initial stages of *in vitro* cultivation of isolated microshoots depending on the genotype, explant type, cultivation conditions, and nutrient medium composition.

Materials and Methods

Experimental work was carried out in the laboratory of biotechnology and cell engineering of the National University of Life and Environmental Sciences of Ukraine. The object of research was *S. torminalis* plant which grows on the territory of the arboretum of the NUBIP of Ukraine and is a valuable decorative introduced species, and centuries-old specimens growing in the city of Kyiv.

To perform experiments, explants were selected from February to March from donor plants of old trees. These were parts of annual shoots from 15 to 25 cm long with apical and lateral buds. Cut shoots were placed in a thermal cabinet for 14 days for germination at an air temperature of +24°C. The formed growth from the buds was used for introduction into

the *in vitro* culture. Lignified fragments of shoots were also used as explants. Grafts 3-4 cm in size were cut from isolated shoots at the initial stages of seasonal development of *S. torminalis*. During this period, their contamination is much lower, and the increased hormonal background contributes to a more effective introduction into the *in vitro* culture.

The first stage of sterilisation was carried out under non-sterile conditions, washing plant fragments in a soapy solution with the addition of Twin-20, stirring constantly for 15 minutes. After that, it was washed for 15 minutes in running water and transferred to sterile distilled water (dH₂O).

70% ethanol (for 30-60 seconds), 0.1% silver nitrate solution (AgNO₃) (5-15 min), and 0.1% aqueous solution of HgCl₂ (5-15 min) were used for sterilisation of *S. torminalis* plant material. For the regeneration of microshoots, hormone-free (h/f) Woody Plant Media (WPM) modified with antioxidants was used as a nutrient medium (NM) (Chalupa, 1987, 1992; Lloyd & McCown, 1980).

To study the regenerative capacity, shoot fragments of *S. torminalis* with a length of 1.0-1.5 cm were cultured on WPM base with the addition of synthetic plant growth regulators: BAP 0.5-2.0 mg·l⁻¹, NAA 0.01-0.5 mg·l⁻¹, and PVP 200-500 mg·l⁻¹.

Results and Discussion

The process of obtaining aseptic culture from explants of centuries-old trees is complicated due to endogenous and exogenous tissue damage and intensive release of secondary metabolites into the nutrient medium.

The effectiveness of obtaining aseptic explants capable of further development in *in vitro* culture is influenced by a number of factors, including the type of sterilant, exposure, and growth stage of the donor plant.

Considering all the features of explants from centuries-old trees, a sterilising solution was selected, which was easily washed out of the tissues with distilled water or decomposed to avoid damaging plant tissues.

To obtain a primary morphogenic culture of explants, the following sterilisation scheme was optimal: first, the explants were immersed in a 0.1% HgCl₂ solution for 30-60 seconds, next – in 70% ethanol solution (C₂N₅OH) for 30 seconds, then in 0.1% mercury chloride solution (HgCl₂) for 5-8 minutes. The explants were then washed twice in sterile dH₂O and the third time were immersed in a gallic acid solution (5 mmol) for 5 minutes. Thus, it was possible to reduce the amount of secondary metabolites released by explants at the initial stages and increase the efficiency of sterilisation by 30%. It was also found out that the use of 15% hydrogen peroxide H₂O₂ solution according to the same scheme provides even less release of phenols by *S. torminalis* explants.

Analysis of the number of sterile and infected explants after applying various sterilising solutions (Table 1) shows that the most effective method of sterilisation was No. 2 using a 0.1% AgNO₃ solution with an exposure of 7 minutes and subsequent exposure in a 15% solution of H₂O₂ within 10 minutes.

Table 1. Result of *S. torminalis* explant sterilisation

No.	Sterilising agent, %		Exposure, min	Number of explants per 3 days, %		
				infected	morphogenically capable	dead
1	AgNO ₃	0.1	7	5	60	35
2	H ₂ O ₂	25	10			
2	AgNO ₃	0.1	7	5	85	10
			10			
3	AgNO ₃	0.1	10	80	20	-
4	AgNO ₃	0.1	7	90	-	10

Table 1, Continued

No.	Sterilising agent, %		Exposure, min	Number of explants per 3 days, %		
				infected	morphogenically capable	dead
5	HgCl ₂	0.1	10	40	50	
6	HgCl ₂	0.1	7	3	90	7
7	HgCl ₂	0.1	5	40	30	30

This approach provided 85% of aseptic and viable explants on Day 3 of cultivation. Explant sterilisation using only AgNO₃ solution (7-10 minutes) did not give positive results.

In this case, oxidation and tissue damage by fungal and bacterial pathogens were observed.

In contrast, a 0.1% HgCl₂ solution could be

used both for lignified and artificially awakened shoots without combining with other solutions. For artificially awakened shoots, the efficiency was 90%.

As a result, sterilisation option No. 2 was the most optimal, since isolated explants showed the ability to morphogenesis on Day 14 of cultivation (Fig. 1).

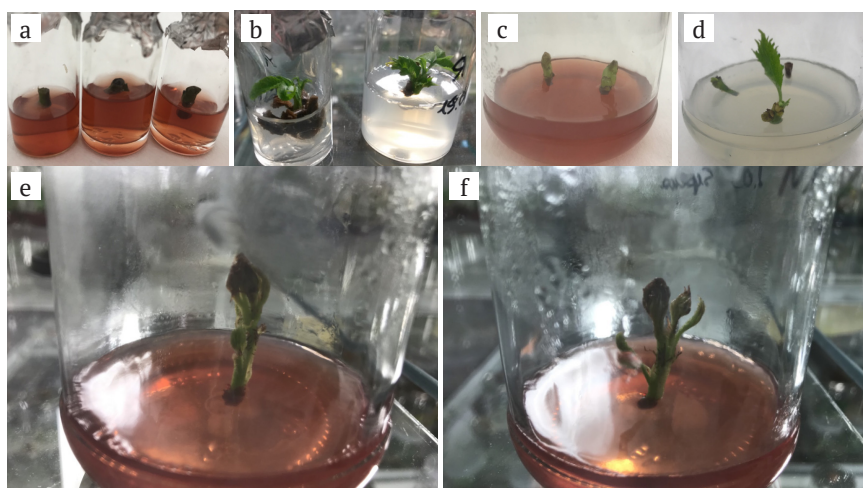


Figure 1. Aseptic and regenerative explants of *S. torminalis* *in vitro*: a – Day 3; c – Day 7; b, d – Day 14; e, f – Day 21

Since sterilisation is a stress for the plant, the influence of the sterilisation method on the features of primary morphogenesis of *S. torminalis* was investigated.

As a result, there was no significant violation in the passage of primary morphogenesis and explant development. After the first passage, the

formation of microshoots occurred within 60 days. To stimulate the primary regeneration of *S. torminalis* microshoots from the meristem culture, WPM NM supplemented with plant growth regulators (PGR) were used: BAP 0.5-4.0 mg·l⁻¹, TDZ, kinetin, NAA 0.01-0.5 mg·l⁻¹ (Table 1).

Table 2. Effect of growth regulators on the ability to regenerate microshoots in *S. torminalis* explants

NM	Plant growth regulators, mg·l ⁻¹				Number of explants with proliferation, %	Microshoots multiplication factor	Average height of microshoots, cm
	BAP	NAA	TDZ	Kin			
Control WPM	-	-	-	-	22.68±4.25	1.67	1.36±0.17
WPM 1	0.5	0.2	-	-	40.00±5.03	1.24	1.41±0.12

Table 2, Continued

NM	Plant growth regulators, mg·l ⁻¹				Number of explants with proliferation, %	Microshoots multiplication factor	Average height of microshoots, cm
	BAP	NAA	TDZ	Kin			
WPM 2	1.0	0.01	-	-	88.89±3.14	3.88	2.65±0.65
WPM 3	1.5	0.05	-	-	81.97±3.48	3.13	4.89±0.45
WPM 4	4.0	0.01			92.20±2.68	2.43	2.72±0.36
WPM 5	-	0.1	0.5	-	59.64±2.80	2.33	2.73±0.79
WPM 6	-		-	0.5	42.65±3.46	1.51	1.26±0.19
WPM 7	-		-	0.25	34.62±4.17	1.20	1.16±0.37

Additionally, agar 7 g·l⁻¹, mesoinositol 0.1 g·l⁻¹ were added to NM, and sucrose and glucose 10-30 g·l⁻¹ served as the source of carbohydrate nutrition. The basic chelated form of iron – *Fe-chelate* and a highly effective chelated form of iron – ferrous ethylenediamine dihydroxyphenyl acetate iron 6% (*FeEDDHA*), polyvinylpyrrolidone (PVP) 200-500 mg·l⁻¹, which performs an anti-oxidant function inside cells under stress were used as a source of iron, pH of the medium was 5.6.

The most optimal type of primary explants of *S. torminalis* for obtaining an aseptic *in vitro* culture are artificially awakened buds.

For a successful *in vitro* inoculation, WPM medium with the addition of 30 mg·l⁻¹ of sucrose, 7 g·l⁻¹ of agar-agar with PH=5.6, and cultivation conditions: illumination 4,000 Lux, temperature +25±1°C, and 16-hour photoperiod are best suited.

For *in vitro* stabilisation of *S. torminalis* regenerants, it is recommended to use WPM NM supplemented with BAP 1.0 mg·l⁻¹ and TDZ 0.5 mg·l⁻¹; after 40-60 days of *in vitro* cultivation, all regenerants showed the induction of additional buds.

In variants of WPM nutrient media with the addition of BAP and NAA at different concentrations, the multiplication coefficient of microshoots ranged from 1.2-3.88, and the number of explants that gave bud proliferation was (40.00±5.03 to 92.20±2.68%). In these variants, explants had strong stems and dark green leaves.

In the WPM + BAP 1.5 mg·l⁻¹ + NAA 0.05 mg·l⁻¹ variant, the number of explants that gave bud proliferation was 81.97±3.48%, the shoot multiplication coefficient was 3.13, while the shoots were well

developed, green in colour, and about 4.89±0.45 cm long. This variant is optimal for bud development. In the medium variant WPM + BAP 1.0 mg·l⁻¹, NAA 0.01 mg·l⁻¹, the reproduction rate of microshoots was 3.88, and the length of microshoots was 2.65±0.65 cm. When kinetin was added to the NM at various concentrations, the multiplication coefficient ranged from 1.20-1.51, and the number of explants that gave bud proliferation reached 42.65±3.46%. In these variants, the development of medium-length buds with a light green colour was observed. As a result, it can be concluded that the addition of kinetin is not optimal for improving the regenerative capacity of primary explants of *S. torminalis*.

In turn, WPM medium + sucrose 30 g·l⁻¹ + agar 7 g·l⁻¹ + BAP 1.5 mg·l⁻¹ and WPM medium + sucrose 30 g·l⁻¹ + 7 agar g·l⁻¹ + BAP 1.0 mg·l⁻¹ + NAA 0.5 mg·l⁻¹ are the best for propagating microshoots from primary aseptic explants of *S. torminalis*.

Cultivation of explants on this nutrient medium ensured the development of the central shoot and the formation of additional adventitious shoots on 21-60 days of cultivation.

Conclusions

The results revealed the specific features of direct regeneration of primary microshoots of *S. torminalis* at the stage of *in vitro* introduction and the initial stages of cultivation of isolated microshoots depending on the type of explant, cultivation conditions, and composition of the nutrient medium.

The most optimal plant material of *S. torminalis* for introduction to *in vitro* culture are annual shoots.

It is found that sterilisation according to the following scheme: treatment with a soap solution on a stirrer for 15 minutes + washing in water for 10 minutes + transfer to sterile water + immersion in ethanol solution for 30 seconds + holding in 0.1% HgCl₂ solution within 7 minutes with three times washing for 7 minutes provides the highest sterilisation efficiency of 96% of aseptic viable explants.

For artificially awakened and young shoots, effective is the use of complex sterilisation with solutions of 0.1% AgNO₃ (7 min) and 15% H₂O₂ (10 min) and three times washing for 10 min, which provides 85% of aseptic and morphogenic explants.

It was found that the sterilisation regime did not significantly affect the morphogenesis of explants and passed evenly on all suitable sterilisation options.

Addition of PVP 200 mg·l⁻¹ had a positive effect on the development of all explants, browning of the nutrient medium and explant was not observed.

The nutrient medium for regeneration of

plants from lateral and apical explant buds (WPM + BAP 1.5 mg·l⁻¹ + NAA 0.5 mg·l⁻¹ and WPM medium + TDZ 0.5 mg·l⁻¹ with the addition of PVP 200 mg·l⁻¹) was optimised.

To induce the development of additional buds and shoots on explants from apical meristems, BAP 4.0 mg·l⁻¹ + NAA 0.01 mg·l⁻¹ with the addition of PVP 200 mg·l⁻¹ should be added to the medium.

Activation of morphogenesis from vegetative explants of old checker trees was uneven.

Comparing the data of previous years with those obtained, it can be concluded that the regenerative ability of explants directly depended on the genotype of the donor plant, the totipotency of cells, and their genetic potential.

It was established that for balanced growth and development of primary aseptic explants from centuries-old trees *in vitro* and to prevent exposure to secondary metabolites, it is most effective to use PVP 200-500 mg·l⁻¹. The use of activated carbon and glutathione is ineffective.

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Первинний морфогенез *Sorbus Torminalis* (L.) grantz у культурі *in vitro*

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Анотація. Нині методи *in vitro* у поєднанні з *ex situ* стають усе важливішими засобами збереження та підтримання рівня стабільності фіторізноманіття. *Sorbus torminalis* L. – дерево родини розових (*Rosaceae*), що росте на території України, належить до рідкісних, цінних аборигенних видів і занесене до Червоної книги України, з наданням йому охоронного статусу – таке, що зникає.

У роботі наведено особливості введення в культуру *in vitro* багатовікових представників *S. torminalis* із використанням різних типів експлантів, стерилізувальних речовин, умов культивування та складу живильного середовища. Для введення в культуру *in vitro* *S. torminalis* оптимальними є однорічні пагони з апікальними та латеральними бруньками завдовжки 15-25 см. Вивчено вплив різних варіантів стерилізації на розвиток первинних мікропагонів. Для стерилізації штучно пробуджених і молодих пагонів найефективніше використовувати 0,1 % розчин AgNO_3 (7 хв) та 15 % розчин H_2O_2 (10 хв). Відпрацьована методика стерилізації експлантів *S. torminalis* забезпечила 80-90 % вихід асептичного рослинного матеріалу. Встановлено, що режим стерилізації суттєво не впливав на первинний морфогенез експлантів і проходив рівномірно. Визначено оптимальні складові живильних середовищ на етапі введення у культуру *in vitro* та первинного морфогенезу *S. torminalis*. Для культивування різних типів експлантів *S. torminalis*, використовували живильні середовища WPM із додаванням до їх складу синтетичних регуляторів росту рослин: 6-бензиламінопурин, тидіазурон, кінетин $0,5-1,5 \text{ мг}\cdot\text{л}^{-1}$ й α -нафтилоцтової кислоти $0,01-0,05 \text{ мг}\cdot\text{л}^{-1}$ як окремо, так і в поєднанні між собою. Зокрема, для регенерації рослин із бічних та апікальних бруньок експлантів ефективним є середовище WPM із додаванням БАП $1,5 \text{ мг}\cdot\text{л}^{-1}$ + $0,5 \text{ мг}\cdot\text{л}^{-1}$ НОК та середовище WPM + ТДЗ $0,5 \text{ мг}\cdot\text{л}^{-1}$ із додаванням РVP $200 \text{ мг}\cdot\text{л}^{-1}$. Для індукції закладання додаткових бруньок і пагонів на експланті з апікальних меристем у середовище слід додавати $4,0 \text{ мг}\cdot\text{л}^{-1}$ БАП + $0,01 \text{ мг}\cdot\text{л}^{-1}$ НОК із додаванням РVP $200 \text{ мг}\cdot\text{л}^{-1}$

Ключові слова: *Sorbus torminalis* L., асептична культура, морфогенез

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Red-flowered apple tree in the collection of the National University of Life and Environmental Sciences of Ukraine

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Abstract. Apple trees with red flowers are particularly attractive during the flowering period, which makes them a desirable component of ornamental plantings. 30 samples of apple trees with anthocyanin colouration of organs were studied in the collection of educational and research laboratory “Genetic resources, introduction and selection of non-traditional fruit and ornamental crops”, located at the Agronomic Experimental Station of the separate division of NUBIP of Ukraine. In 2001, phenological observations were made during flowering, morphometric analysis of flowers and leaves was carried out, and the decorative value of samples was evaluated. The dominant gene that controls anthocyanin pigmentation of organs in apple trees comes from *Malus Niedzwetzkyana* – Nedzvetsky apple trees. Now the rank of this taxon is lowered to a variety – *M. domestica* var. *niedzwetzkyana*. The Nedzvetsky apple tree was involved in crossing with small-fruited apple species to create decorative hybrids, some of which received hybrid names and were used in the selection of fruit varieties and rootstocks of *M. domestica*. According to the International Code of Nomenclature of cultivated plants, varieties with anthocyanin colouration of petals that have *M. domestica* var. *niedzwetzkyana* in the pedigree can be distinguished as *Malus Niedzwetzkyana* Group. If it is supplemented with varieties with anthocyanin colouration of petals, originating from other types of apple trees, for example, *M. halliana* and *M. spectabilis*, then the extended group can be called *Malus Purpurea* Group. At the same time, some varieties may belong to other groups, in particular, *Malus Pendula* Group, *Malus Redflesh* Group, etc. The highest decorative value (5 points) during flowering is inherent in samples No. 2332 ‘Makamik’, 2947, 3100 ‘Aldenhamensis’, 3157 ‘Pionerka’, 3305, 3382, 3540, 3592, 3601, 3603, 3656, 3691, 3692, 4292, and hybrids ‘17-279’, ‘17-316’, ‘18-275’, ‘18-293’, ‘18-325’. The use of these samples allows creating a conveyor of elongated flowering of red-flowered apple trees at green construction sites

Keywords: decorative apple tree, flowering, varieties, types, anthocyanin colouration, Nedzvetsky apple tree

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Introduction

The topic of landscaping has become quite popular over the 20th century due to the spread of ideas of environmental friendliness (Kuznetsova & Tkach, 2016). Plants have a good effect on the central nervous system, create the illusion of contact with nature, purify the air, etc. A special role in landscaping belongs to woody plants. Intensive urbanisation, transport, and other elements of technological progress create unfavourable conditions for human life, which requires environmental protection. Green spaces play an important role in shaping the environment. They have the properties to improve sanitary and hygienic conditions, so they occupy a leading place in the improvement and architecture of settlements and are one of the main elements that form the complex of a modern city, play an important role in creating its silhouette (Kostyrko, 2006).

Types and varieties of apple trees (*Malus* Mill.) are widely used in gardens and parks as ornamental trees (Kolesnikov, 1974; Krüssmann, 1977; Kokhno & Trofimenko, 2005; Firsov, Vasiliev & Tkachenko, 2015; Honcharovska, 2019). A special group of ornamental apple trees includes taxa with flowers that have an anthocyanin pigment, which is controlled by a special dominant gene. This peculiar and rare red colour of flowers provides them with a prominent place in decorative plantings (Oleksiichenko & Mavko, 2017; Stoliar & Mamchur, 2017). According

to the International Code of Nomenclature of cultivated plants, they are classified as *Malus Niedzwetzkyana* (Purpurea) Group. The same variety can be classified into different groups based on certain characteristics (Mezhenskyj, 2008).

Materials and Methods

Samples of the collection of educational and research laboratory “Genetic resources, introduction and selection of non-traditional fruit and ornamental crops”, located at the Agronomic Experimental Station of the separate division of NUBIP of Ukraine (Pshenychne village, Bilotserkivskiyi district, Kyiv Oblast). It includes, in particular, species and varietal samples of the genus *Malus* and hybrids of the apple tree breeding fund. The introduction of specimens was carried out in 1999-2016 from scientific institutions and amateur gardeners in Austria, Belarus, Italy, Germany, Russia, and Ukraine (Table 1). Grafted trees are placed in the collection garden according to the 5x3 m scheme. In 2021, phenological observations were made during flowering. Morphometric analysis of flowers and leaves was performed, measuring the central flowers in the inflorescence and leaves from the middle part of annual vegetative increments. Assessment of decorative value was carried out on a 5-point scale (Lobanov, 1973; Kalinichenko, 2003).

Table 1. Origin of the specimens of *Malus* under study

No.	Introduction number	Name under which the specimen was received	Origin of the specimen
1.	1723	<i>Malus ×gloriosa</i> Lemoine ‘Gazonnaya Krasnolepnaya’	Experimental gardening station, Yekaterinburg, Russia
2.	2332	<i>M. niedzwetzkyana</i> Dieck ‘Makamik’	Donetsk Botanical Garden, Donetsk, Ukraine
3.	2550	‘62-396’	I.V. Michurin All-Russian Institute of Fruit Crop Genetics and Breeding, Michurinsk, Russia
4.	2947	<i>M. niedzwetzkyana</i>	Jurgen Rekin, Schorfheide, Germany
5.	3098	<i>M. ×purpurea</i> (E.Barbier) Rehder	Nikitskyi Botanical Garden, Nikita, Ukraine
6.	3100	<i>M. ×purpurea</i> ‘Aldenhamensis’	Nikitskyi Botanical Garden, Nikita, Ukraine
7.	3157	‘Pionerka’	All-Russian Research Institute of Fruit Crops Breeding, Orel, Russia
8.	3305	<i>Malus</i> sp.	I.V. Michurin’s main nursery, Michurinsk, Russia
9.	3314	‘Royalty’	Park plantings, Moscow, Russia

Table 1, Continued

No.	Introduction number	Name under which the specimen was received	Origin of the specimen
10.	3375	<i>M. ×gloriosa</i> 'Chorna Perlyna'	Donetsk Botanical Garden, Donetsk, Ukraine
11.	3382	<i>M. spectabilis</i>	M.M. Hryshko National Botanical Garden, Kyiv, Ukraine
12.	3505	'Redlove Sirene'	Vladimiro Rocco, Stangella, Italy
13.	3540	<i>M. ×purpurea</i>	Central Botanical Garden of the Academy of Sciences of Belarus, Minsk, Belarus
14.	3592	'3-34'	Donetsk Botanical Garden, Donetsk, Ukraine
15.	3601	<i>Malus</i> sp.	Research station of Botanical Institute, Otradnoye, Russia
16.	3603	<i>M. halliana</i> Koehne	Research station of Botanical Institute, Otradnoye, Russia
17.	3656	<i>M. halliana</i>	Botanical garden of V.L. Komarov Botanical Institute, St. Petersburg, Russia
18.	3657	<i>M. pumila</i> Mill. 'Umbraculifera Rubrifolia'	Botanical garden of V.L. Komarov Botanical Institute, St. Petersburg, Russia
19.	3691	'Pionerka'	Agrobiotechnology Research and Production Centre, Pushkino, Russia
20.	3692	<i>M. niedzwetzkyana</i>	Agrobiotechnology Research and Production Centre, Pushkino, Russia
21.	3805	<i>M. domestica</i> Borkh. 'Krasnyi Shtandart'	Pavlovsk Experimental Station of VIR, Pavlovsk, Russia
22.	3971	<i>M. niedzwetzkyana</i> '21-49'	Institute of Horticulture, Kyiv, Ukraine
23.	4067	'54-490'	Bakhmut experimental nursery station, Bakhmut, Ukraine
24.	4292	<i>M. niedzwetzkyana</i>	Park plantings, Kyiv, Ukraine
25.	4339	'Velarma'	Julian Geiger, Graz, Austria
26.	–	<i>M. ×gloriosa</i> '17-279'	NUBIP of Ukraine, Pshenychne, Ukraine
27.	–	<i>M. ×gloriosa</i> '17-316'	NUBIP of Ukraine, Pshenychne, Ukraine
28.	–	<i>M. ×gloriosa</i> '18-275'	NUBIP of Ukraine, Pshenychne, Ukraine
29.	–	<i>M. ×gloriosa</i> '18-293'	NUBIP of Ukraine, Pshenychne, Ukraine
30.	–	<i>M. ×gloriosa</i> '18-325'	NUBIP of Ukraine, Pshenychne, Ukraine

Results and Discussion

The dominant gene controlling anthocyanin pigmentation of organs originated from the apple tree *M. niedzwetzkyana* (Niedzwetzky apple tree) (Lewis & Crane, 1938). This taxon, whose natural range is located in Central Asia, is named after a German botanist Georg Dieck *M. niedzwetzkyana* Dieck in honour of the discoverer, however, according to the WFO database (2021), it is interpreted as ambiguous, and the later name is recognised *M. niedzwetzkyana* Dieck ex Koehne. Later, the rank of the taxon was lowered to a variety: *M. pumila* Mill. var. *niedzwetzkyana* (Dieck) C.K.Schneider (GRIN-Global, 2021) or *M. sieversii* (Ledeb.) M.Roem. var. *niedzwetzkyana*

(Dieck) Langenf. (WCVP, 2021), which are now considered synonymous with *M. domestica* (Suckow) Borkh. (POWO, 2021; WCVP, 2021). Specific epithet *niedzwetzkyana*, which is formed from the surname Nedzvetsky, originally has the form of an adjective (Mezhensky, 2010).

Due to its decorative flowers, the Nedzvetsky apple tree quickly spread around the world. It was involved in crossing with small-fruited apple tree species, which formed hybrids that were given note-like names: *M. ×purpurea*, *M. ×gloriosa*, *M. ×moerlandsii* Door, etc. It was also widely used in the selection of fruit varieties *M. domestica* and

its rootstocks. Domestic dendrologists often do not distinguish such hybrids, referring apple trees with anthocyanin-coloured petals as the Nedzvetsky apple tree. The origin of some forms is very complex, for example, '54-490', used as a clone rootstock of an apple tree, is created as a result of crossing $\{M. domestica \text{ 'M 8'} \times [(M. prunifolia \text{ (Willd.) Borkh.} \times M. domestica \text{ 'Sinap Kandille')} \times M. baccata \text{ (L.) Borkh.}] \times \{M. domestica \text{ 'M 8'} \times [(M. domestica \text{ 'Pepinka Litovska'} \times M. prunifolia) \times M. domestica \text{ 'Reinette d'Orleans'}] \times M. domestica \text{ 'Rubinovoye'}\}$, where only the last hybrid 'Rubinovoye' comes directly from the Nedzvetsky apple tree. The ornamental variety 'Aldenhamensis' comes from a three-species cross $(M. halliana \times M. sieboldii \text{ (Regel) Rehder}) \times M. domestica \text{ var. niedzwetzkyana}$.

Attempts to classify cultigenic interspecific hybrids involving the Nedzvetsky apple tree using the International Code of Nomenclature for algae, fungi, and plants are ineffective, so it is better to apply the provisions of the International Code of Nomenclature for cultivated plants, which regulates the names of varieties and groups of varieties. Thus, varieties with anthocyanin colouration of petals that have in the pedigree *M. domestica* var. *niedzwetzkyana*, can be distinguished as *Malus* *Niedzwetzkyana* Group. If it is supplemented with other varieties with anthocyanin colouration of the petals, originating, for example, from *M. halliana*, *M. spectabilis*, etc., then the extended group can be called *Malus* *Purpurea* Group. At the same time, some varieties may belong to other groups, in particular, *Malus* *Pendula* Group covers the varieties with a weeping crown "Gazonnaya

Krasnolepstinaya', 'Umbraculifera Rubrifolia' and 'Chorna Perlyna', and *Malus* (Plena Group) – double flowered 'Aldenhamensis' and '3-34'. Fruit varieties 'Krasnyi Shtandart', 'Redlove Sirene', '164', etc., are classified as *Malus* Redflesh Group.

Identification of samples obtained under the same varietal name indicates that specimen 3157 corresponds to the description of the 'Pionerka' variety, while sample 3691 does not. The latter is a kind of small-fruited derivative of the Nedzvetsky apple tree.

Due to seed propagation, the offspring may differ quite a lot from the original mother plant, such as sample No. 3656 *M. halliana*, which is a seedling of sample No. 3603. Also selected forms of *M. gloriosa* '17-279', '17-316', '18-275', '18-293', '18-325' have noticeable differences both among themselves and from sample No. 1723 'Gazonnaya Krasnolepstinaya', which is their mother form (Tables 2-3, Figures 1-3). Recombination of genes and the development of new traits based on them allow selecting forms with a different manifestation of certain traits.

The diameter of the flowers in most samples ranges from 4.5-6.0 cm, while sample No. 3692 has very large flowers 6.0-8.0 cm in diameter. Since flowering apple trees are observed from a distance, the size of the flowers does not affect the decorative value. The difference in the size of the flowers becomes noticeable only when they are observed from a close distance. As a rule, the unfolded petals are lighter in colour than those of the buds and fade slightly over time. Flowers differ not only in size and intensity of red colour, but also in the shape of the petals and the degree of their overlap.

Table 2. Characteristics of flowers of the specimens of *Malus* under study

Introduction number	Lim		Bud colouring*	Petal colouring*	Pubescence of the calyx and pedicel	Length of sepals, mm
	Flower diameter, cm	Pedicel length, cm				
1723	4.5-5.0	2.0	d.-red	red	present	8
2332	6.0-6.5	3.5-4.0	red	pink	present	12
2550	5.0	2.5	red	red	present	8
2947	5.0-6.0	1.5-2.0	red	pink	present	7
3098	4.5-5.0	1.5	d.-red	red	present	4
3100	4.0-4.5	3.0-4.0	red	red	present	8
3157	3.0	3.0	red	pink	absent	6

Table 2, Continued

Introduction number	Lim		Bud colouring*	Petal colouring*	Pubescence of the calyx and pedicel	Length of sepals, mm
	Flower diameter, cm	Pedicel length, cm				
3305	6.0	4.0-4.5	d.-red	red	present	10
3314	4.5-5.5	3.0-5.0	d.-red	d.-red	absent	8
3375	4.0-4.5	2.5-4.0	d.-red	d.-red	absent	5-10
3382	5.0	3.5	red	d.-pink.	present	4
3505	4.5-5.0	2.0	red	pink	present	5-6
3540	4.5-5.5	3.0-3.5	d.-red	red	present	4
3592	4.0-5.0	3.0-3.5	red	pink	present	8-10
3601	4.5-5.0	4.0-5.0	red	pink	present	10
3603	4.0-5.0	3.0	d.-red	red	present	10-14
3656	4.0-4.5	4.0-4.5	red	pink	absent	10
3657	4.5	3.0-4.0	red	pink	present	7
3691	5.0-6.0	3.5-5.0	d.-red	pink	present	10
3692	6.0-8.0	3.0	pink	l.-pink	present	10
3805	4.5	2.0	d.-red	red	present	8
3971	5.5-6.0	1.5-2.0	red	pink	present	8
4067	5.0-6.0	3.5	d.-red	pink	present	10
4292	4.0-4.5	3.0-3.5	red	d.-pink	present	7
4339	4.5-5.5	1.5	red	red	present	7
17-279	5.0-6.0	1.5	d.-red	red	absent	8
17-316	5.0-5.5	2.5	red	pink	present	12
18-275	5.0-5.5	2.5	red	pink	absent	8
18-293	4.5-5.0	2.0	d.-red	red	present	10
18-325	5.0-5.5	3.0-5.0	red	pink	present	10

* l.-pink. – light-pink, d.-pink. – dark-pink, d.-red – dark-red

Table 3. Characteristics of the leaves of the specimens of *Malus* under study

Introduction number	Leaf blade					Petiole
	Form*	Average length, cm	Average width, cm	Edge**	Pubescence from the bottom	Average length, cm
1723	ellipt.	9.0	2.5	dent.	along the veins	2.5
2332	ov.	8.5	6.0	d.-dent.	absent	1.5
2550	ov.	7.0	5.0	cren.	available	1.0
2947	ov.	9.0	5.0	cren.	available	3.0
3098	ellipt.	6.0	3.5	dent.	available	2.5
3100	ov.	8.0	5.0	d.-dent.	along the veins	1.5
3157	ellipt.	6.0	3.5	ser.	along the veins	2.5
3305	ov.	7.5	5.5	cren.	along the veins	2.5
3314	ov.	8.0	8.0	d.-dent.	absent	2.0
3375	ellipt.	7.5	3.5	ser.	along the veins	2.0
3382	e.-ovoid	12.0	4.0	ser.	along the veins	2.5
3505	ov.	9.0	5.0	d.-dent.	available	3.0
3540	ov., lobed	10.0	9.0	cren.	available	2.0

Table 3, Continued

Introduction number	Leaf blade					Petiole
	Form*	Average length, cm	Average width, cm	Edge**	Pubescence from the bottom	Average length, cm
3592	ov.	6.5	4.0	d.-ser.	absent	1.5
3601	ellipt.	9.0	4.0	dent.	along the veins	2.5
3603	e.-ov.	8.0	3.5	ser.	along the veins	1.5
3656	e.-ov.	8.0	4.5	cren.	absent	2.5
3657	ellipt.	5.0	2.5	ser.	along the veins	1.5
3691	ov.	9.0	5.5	cren.	along the veins	2.0
3692	ov.	10.0	6.5	ser.	available	2.0
3805	ov.	8.5	6.0	dent.	available	3.0
3971	ov.	8.0	4.5	ser.	available	2.0
4067	ov.	6.0	4.0	cren.	along the veins	1.0
4292	ellipt.	6.5	3.5	cren.	along the veins	2.0
4339	ellipt.	7.0	4.0	cren.	available	2.0
17-279	ov.	6.5	4.5	cren.	absent	2.5
17-316	ov.	7.0	5.0	cren.	along the veins	2.0
18-275	ellipt.	6.0	3.0	ser.	absent	3.0
18-293	ellipt.	8.5	3.5	ser.	absent	2.0
18-325	ov.	7.5	5.0	cren.	available	3.0

* e. – elongated, ellipt. – elliptical, ov. – ovoid

** cren. – crenated, d.-dent. – double-dentated, d.-ser. – double-serrated, dent. – dentated, ser. – serrated

30.05.2021

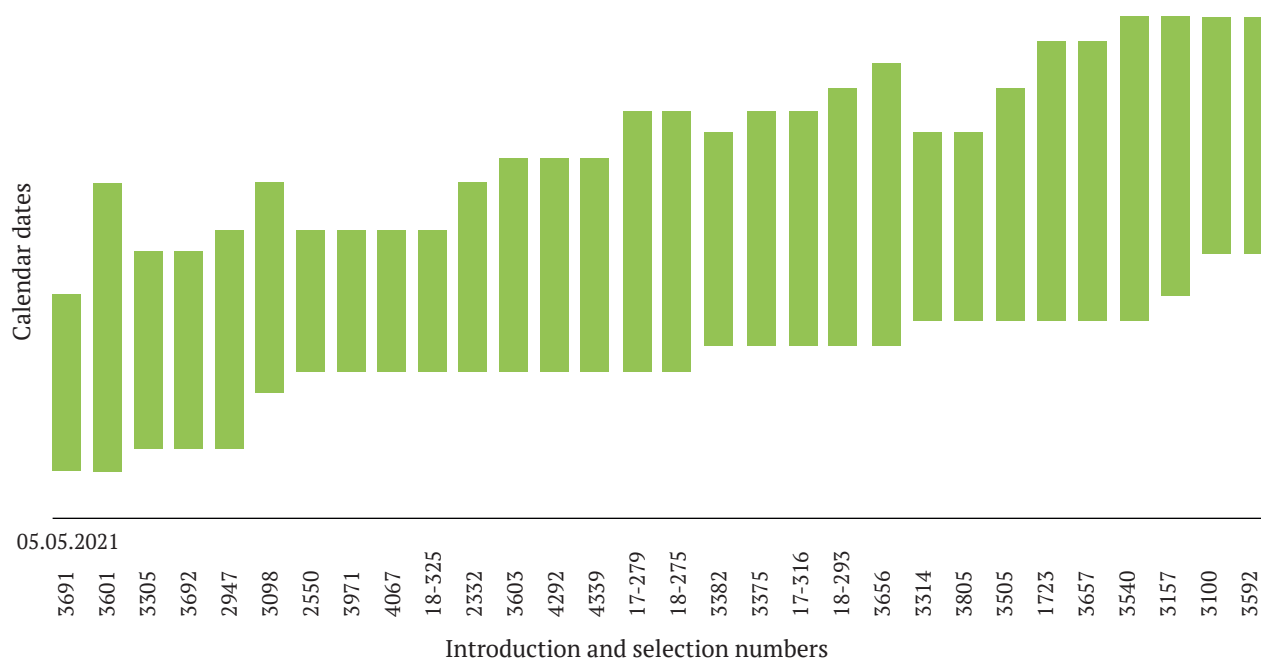


Figure 1. Flowering calendar of the specimens of *Malus* under study

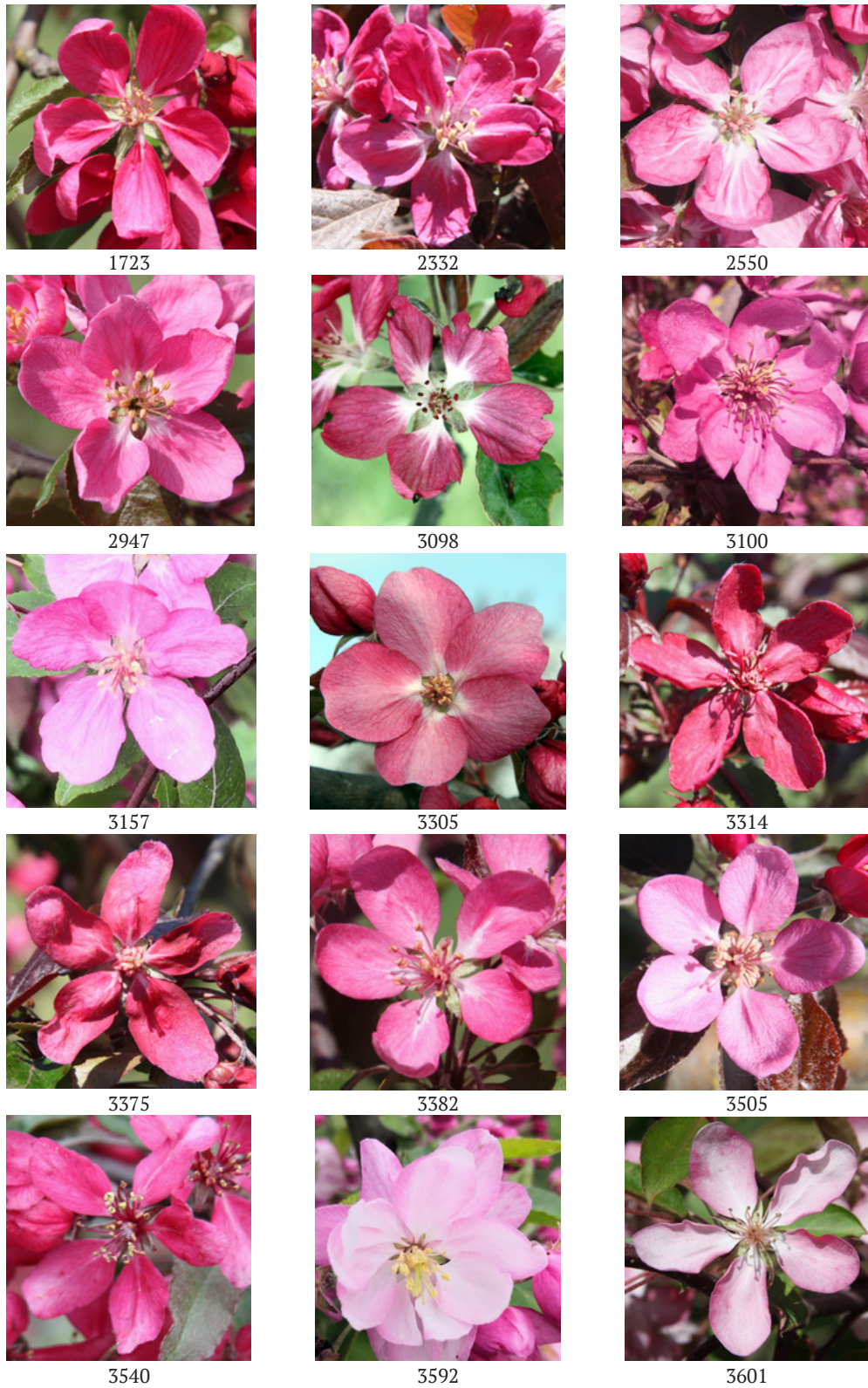


Figure 2. Flowers of the specimens of *Malus* under study

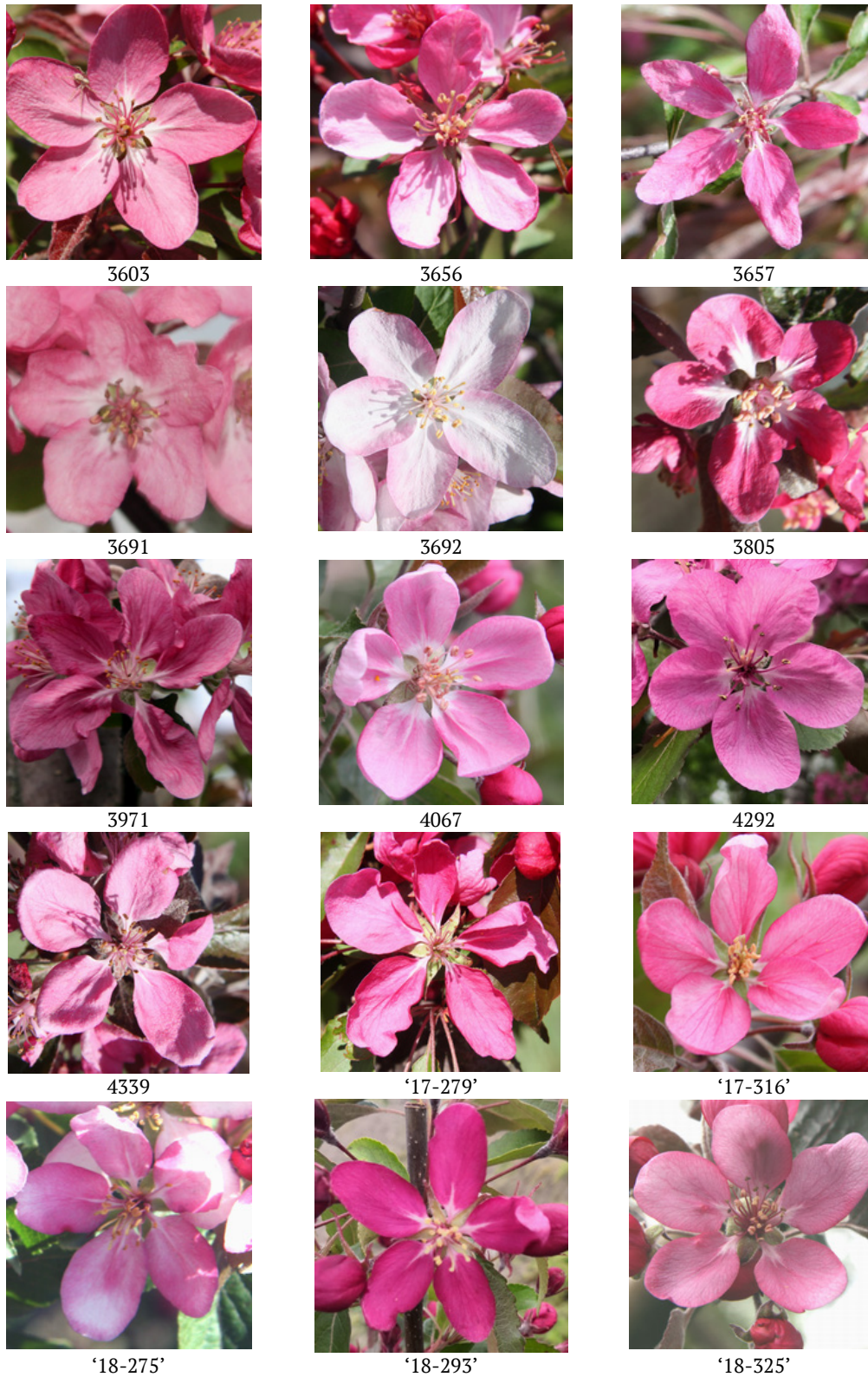


Figure 3. Flowers of the specimens of *Malus* under study

The apple tree is characterised by abundant flowering and looks especially attractive during flowering, regardless of the colour of the petals – from light pink to dark red. Samples with a flowering score of 5 received the highest decorative value score of 5 points. Trees with a flowering score of 4 – sample No. 3691 – have a slightly lower rating. The authors of this study suggest that samples No. 3314 ‘Royalty’, 3375 ‘Chorna Perlyna’ with dark red flowers are less decorative, because the flowers are lost against the background of purple leaves covering the trees during flowering. Compared to them, other samples with purple leaves, but lighter flowers have a higher decorative value. However, due to the difference in leaf colour, all purple-leaved trees have a certain advantage over apple trees covered with green leaves. At the same time, the purple colour mainly of the apical leaves of young shoots does not particularly affect the overall decorative value during flowering. Sample No. 3657 ‘Umbraculifera Rubrifolia’ with smallish leaves and flowers does not acquire a high decorative value during flowering, which is rated with a score of 4. In sample No. 3540, in the year of research, the leaves had pronounced blades on the tops of young shoots, which was not observed before.

Decorative value of samples No. 2550 ‘62-396’, 3505 ‘Redlove Sirene’, 3805 ‘Krasnyi Shtandart’, 3971 ‘21-49’, 4067 ‘54-490’, 4339 ‘Velarma’ with a flowering score of 2-3 under the conditions of the collection per year of research is estimated at 3 points (decorative value is insignificant), but this estimate is not final, because the degree of flowering of these samples was somehow affected by the frequency of fruiting and they require additional observations. In addition, fruit varieties of red-flowered apple trees with large fruits are less suitable for park plantings

than small-fruited samples, so the profusely blooming sample No. 2947 should not be used in gardening.

The vast majority of specimens have simple five-petaled flowers. Semi-double flowers are found in specimens No. 3110 ‘Aldenhamensis’ and 3592, but this does not extend the duration of their flowering.

The average duration of flowering depends on the air temperature at this time and is about one week in most samples, but in some specimens, it can reach and exceed 10 days. Specimens No. 3601, 3691 began to bloom at the earliest (May 9), and at the latest (May 18) – No. 3100 ‘Aldenhamensis’, 3592 ‘3-34’, which stopped blooming on May 27. Thus, the total flowering period of red-flowered samples in the collection was 19 days.

Conclusions

Varieties and collections of red-flowered apple trees, which originates from *M. domestica* var. *niedzwetzkyana*, and also *M. halliana* and *M. spectabilis* can be extremely decorative during flowering due to the anthocyanin colouration of the petals. The highest decorative value (5 points) during flowering is inherent in samples No. 2332 ‘Makamik’, 2947, 3100 ‘Aldenhamensis’, 3157 ‘Pionerka’, 3305, 3382, 3540, 3592, 3601, 3603, 3656, 3691, 3692, 4292, and hybrids ‘17-279’, ‘17-316’, ‘18-275’, ‘18-293’, ‘18-325’. Samples No. 1723 ‘Gazonnaya Krasnolep-estnaya’, 3314 ‘Royalty’, 3375 ‘Chorna Perlyna’ are somewhat inferior to them in decorative properties, but they have a special habit or intense anthocyanin colouration of the leaves, which gives them certain advantages. Sample No. 2947, despite the abundant flowering, is not recommended for landscaping parks due to the large fruits. The use of these samples allows creating a conveyor of elongated flowering of red-flowered apple trees at green construction sites.

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Червоноквіткова яблуня в колекції Національного університету біоресурсів і природокористування України

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Анотація. Яблуні з червоними квітками вирізняються особливою привабливістю в період квітування, що робить їх бажаним компонентом декоративних насаджень. Досліджено 30 зразків яблуні з антоціановим забарвленням органів у колекції ННВЛ «Генетичних ресурсів, інтродукції та селекції нетрадиційних плодкових та декоративних культур», розміщеній у ВП НУБіП України «Агрономічна дослідна станція». У 2001 році проведено фенологічні спостереження під час квітування, здійснено морфометричний аналіз квіток і листків та оцінено декоративність зразків. Домінантний ген, що контролює антоціанову пігментацію органів у яблуні, походить від *Malus Niedzwetzkyana* – яблуні Недзвецької. Нині ранг цього таксону понижено до різновиду – *M. domestica* var. *niedzwetzkyana*. Яблуню Недзвецьку було залучено до схрещування з дрібноплодими видами яблуні для створення декоративних гібридів, деякі з яких отримали нотовидові назви та були використані в селекції плодкових сортів і підщеп *M. domestica*. Згідно з Міжнародним кодексом номенклатури культурних рослин сорти з антоціановим забарвленням пелюсток, що мають у родоводі *M. domestica* var. *niedzwetzkyana*, можна виокремити як *Malus Niedzwetzkyana* Group. Якщо її доповнити сортами з антоціановим забарвленням пелюсток, що походять від інших видів яблуні, наприклад *M. halliana* і *M. spectabilis*, то розширену групу можна назвати *Malus Purpurea* Group. Водночас деякі сорти можуть належати до інших груп, зокрема, *Malus Pendula* Group, *Malus Redflesh* Group тощо. Найвища декоративність (5 балів) під час квітування притаманна зразкам № 2332 'Makamik', 2947, 3100 'Aldenhamensis', 3157 'Пионерка', 3305, 3382, 3540, 3592, 3601, 3603, 3656, 3691, 3692, 4292 та гібридам '17-279', '17-316', '18-275', '18-293', '18-325'. Використання зазначених зразків дає змогу створити конвеєр подовженого квітування червоноквіткової яблуні на об'єктах зеленого будівництва

Ключові слова: декоративна яблуня, квітування, сорти, види, антоціанове забарвлення, яблуня Недзвецька

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Effect of rutin-ammonium complex on the physiological state of Scots pine seedlings

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Abstract. In the plant organism, phenolic compounds have a non-specific effect on the processes of morphogenesis and perform a wide range of regulatory and protective functions. Of particular interest are the processes associated with the complex formation of flavonoids as a result of their interaction with ammonium forms of nitrogen. Polar compounds that are formed in tissues by chemical transformation are quite mobile in soil solutions and exhibit high biological activity. The properties of phenol-ammonium complexes are of considerable interest in terms of morphogenesis, physiology of resistance, and in the system of interaction of plants with soil microorganisms. This is also extremely important in the production of high-quality planting material that is resistant to unfavourable factors. The effect of the phenol-ammonium complex was studied on seeds and seedlings of Scots pine. Quantitative indicators of germination energy and similarity were determined by the seed germination method. Biochemical profiling of seedling tissue extracts was performed by high-performance thin-layer chromatography. It has been experimentally confirmed that rutin (quercetin-3-o-rutinoside) after interaction with a 10% aqueous solution of ammonia forms a complex of substances, among which polar products were detected by chromatography, which potentially affect growth regulation. At a total concentration of 15 mg/l, these substances significantly increased germination energy and germinating ability. In pine seedlings, they stimulated the growth of roots and shoots. The effect of the complex of organic compounds on seedlings depended on the concentration, duration of seed treatment, and had a prolonged effect. The resulting phenol-ammonium complex at a concentration of 10-15 mg/l contributed to an increase in the amount of chlorophylls and carotenoids in the tissues of seedlings, and at 20-40 mg/l it increased the content of phenolic synthesis products

Keywords: rutin, flavonoids, ammonium, growth regulator, Scots pine, seeds

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Introduction

Phenolic compounds are one of the important components of the synthesis of secondary metabolites in the plant body (Lattanzio, 2013). The functions of phenolic compounds are extremely diverse and require a comprehensive study (Buer *et al.*, 2010; Caretto *et al.*, 2015). Plant phenols perform mechanical, structural and signalling functions, protect tissues from UV, perform the functions of antioxidants, chelate transition metal ions, remove radioactive elements from the body, protect the plant organism from the effects of adverse factors, pests, and pathogens (Blokhina *et al.*, 2003; Naikoo *et al.*, 2019; Tegelberg *et al.*, 2001; Zagoskina & Nazarenko, 2016; Winkel-Shirley, 2002).

When obtaining planting material, considerable attention is now paid to the investigation of physiological reactions of plants to the action of biologically active substances, organic and mineral fertilisers, which are used to improve the quality of planting material and increase plant resistance to adverse factors (Kovalevsky & Taranenko, 2013; Pinchuk, *et al.*, 2017; Pinchuk & Likhanov, 2018).

The secondary metabolism of most higher plants is aimed at the active synthesis of phenolic compounds. However, the concentration of different classes of phenols in plant tissues may differ significantly. In particular, the amount of phenol carboxylic acids in the leaves correlates with the concentrations of phytohormones. This is conditioned by the fact that oxycoric and oxybenzoic acids have a non-specific effect on morphogenesis processes (Santelia, 2008; Volynech, 2013) and perform a wide range of regulatory and protective functions (Zaprometov, 1993; Grana *et al.*, 2017). To understand the role of individual oxycoric and oxybenzoic acids, as well as flavonoids, it is of great interest to model the conditions of their individual and complex effects on the plant organism. In addition, important but poorly understood processes are those associated with the complexation of phenolic compounds, in particular flavonoids, in plant tissues and the rhizosphere during their entry into the soil (Grodzinsky, 1973; Boyer *et al.*, 1989).

Phenolic compounds are actively secreted by physiologically active root zones. Some flavonoids (in particular, quercetin and its glycosides) have high reactivity to ammonium cations (Likhanov *et al.*, 2021). Polar compounds that are established as a result of chemical transformation of polyphenols are quite mobile in soil solutions and exhibit high biological activity (Melnychuk *et al.*, 2011). Their effect on growth processes, development of root system, synthesis of plastid pigments and secondary metabolic products is already observed at a concentration of 20 µg/ml. A similar effect, for example, was confirmed for kaempferol-3-O-β-D-glucoside. An increase in its concentration from 15 µg/ml and above increased the elongation of shoots of *Echinochloa colonum* L. (Li Jun, 2011). Current research also confirms that invasive plants *Triadica sebifera* (L.) Small are characterised by a high content of quercetin in root exudates. It is assumed that in the composition of exudates, this flavonol is a key in the signalling interactions of plants with mycorrhizal fungi and other soil microorganisms (Anand *et al.*, 2016; Tian, 2021).

Since the biological activity of compounds formed as a result of the interaction of flavonols with ammonium forms of nitrogen has not been sufficiently investigated, the purpose of this study was to consider the effect of the rutin-ammonium complex on the physiological state of Scots pine seedlings.

Materials and Methods

Preparation of polar complexes based on rutin with an aqueous solution of ammonia. A test tube containing 10 mg of rutin (Merck, Germany) was stirred on a vortexer in 300 µL of distilled water for 60 s. Then 100 µL of a 10% aqueous ammonia solution was added and stirred for 30-40 seconds until rutin was completely dissolved. The resulting solution acquired a rich brown colour. The volume of the solution was adjusted with bidistilled water to 1 ml and stored at +4°C. The resulting stock solution contained 10 mg/mL of polar compounds. To investigate the effect of the rutin-ammonium complex on seeds

and seedlings of Scots pine, the initial solution was diluted with distilled water. Seeds were soaked in prepared solutions (concentrations – 10, 15, 20, and 40 µg/ml) for 3 and 24 hours before germination.

Method for determining the germination energy and germinating ability of Scots pine. Determination of germination energy and germinating ability of Scots pine was carried out according to DSTU 8558:2015 “Seeds of trees and shrubs. Methods for determining seed qualities (germinating ability, viability, good quality)” (SSU, 2015). Seed germination was performed in Jacobsen apparatuses with a photoperiod of 12 hours at a constant temperature ($22\pm 2^\circ\text{C}$). Seeds of Scots pine, prepared for germination, were laid out on a bed of 100 seeds, not allowing touching each other, in order to avoid transmission of infection from diseased to healthy seeds. After decomposition of seeds of one medium sample, the work surface, bed, cap and tweezers were disinfected with alcohol. To determine the indicators of germination energy and germinating ability, 4 samples were laid in triplicate. Evaluation and accounting of sprouted seeds were carried out on days 5, 7, 10, and 14. Determination of germination energy for Scots pine seeds was carried out on Day 7, germinating ability – on Day 14.

High-performance thin-layer chromatography methods. Biochemical profiling of extracts from Scots pine seedling tissues was performed by the HPTLC method on silica gel G60 plates (Merck, Germany).

Flavonoid separation was performed in solvent systems: ethylmethylketone-ethyl acetate-methanol-water (v/v/v/v – 30:20:5:5); ethyl acetate-formic acid-acetic acid-water (v/v/v/v – 100:11:11:25). To determine the chemical nature of the substances, the chromatograms were treated with 0.5% NP reagent and 1% PEG 400 followed by heating (5 min at 105°C).

Separation of chlorophylls, carotenoids, and xanthophylls was performed in the system: toluene-ethyl acetate-formic acid (v/v/v – 2:6:1). Visualisation of phenolic compounds and plastid pigments was performed in UV for $\lambda_{\text{max}}=365\text{ Nm}$.

The mobility coefficients of individual compounds (R_f) were determined photodensitometrically using the Sorbfil TLC Videodensitometer software suite ver. 2.3.0.2994 (JSC Sorbopolymer, RF).

Statistical data processing. The obtained data were presented as an average value \pm standard error ($X\pm SE$). The validity of differences between the mean values ($p<0.05$) was determined by the method of univariate analysis of variance (one-way ANOVA) and Tukey’s honest significance test (HSD) in the XLSTAT software suite (Addinsoft Inc., USA, 2010).

Results and Discussion

It has been experimentally confirmed that rutin (quercetin-3-o-rutinoside) after interaction with a 10% aqueous solution of ammonia forms a complex of substances that contain products that play an important role in regulating the processes of plant growth and development. Chromatographic studies have confirmed that after the interaction of rutin with an aqueous solution of ammonia, 5 new products are formed, which, according to the mobility coefficients (R_f), belong to midpolar and polar substances (Fig. 1).

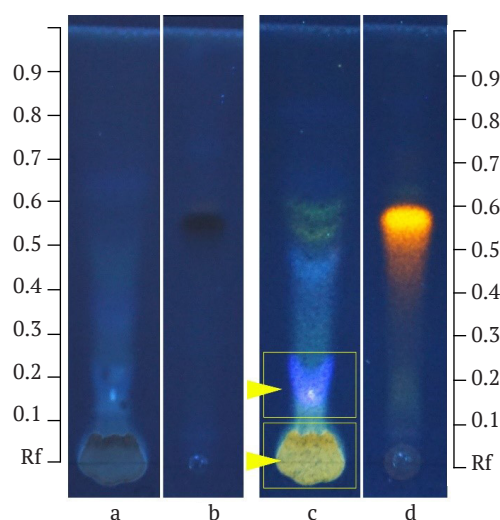


Figure 1. Chromatogram of the rutin-ammonium complex before (a) and after (c) treatment with NP reagent; standard rutin solution before (b) and after (d) processing; arrows indicate bioactive candidate substances

After 72 hours, no rutin was detected in the resulting solution. Thus, over time, a complete biochemical transformation of flavonol occurred. On the chromatogram, after treatment with NP reagent, two products with $R_f \sim 0.53$ and 0.58 with flavonol-characteristic UV fluorescence ($\lambda=365$ Nm) were detected in small amounts. The highly polar compound with bright blue fluorescence with an R_f of ~ 0.18 and the substance that remained on the starting line were fairly stable. This gives grounds to consider them as candidate substances with high biological activity and the ability to influence the growth processes of plants. The effect depends on

the concentration of the rutin-ammonium complex solution. Prolonged exposure indicates the ability of water-soluble polar compounds, which are part of the phenol-ammonium complex, to penetrate through the seed shells into living tissues, remain stable in them and further participate in the regulation of root growth.

In particular, the pretreatment of Scots pine seeds with various dilutions of the initial solution of the rutin-ammonium complex showed that at a concentration of $10 \mu\text{g/ml}$, the indicators of germination energy and germinating ability do not significantly differ from the control (Table 1).

Table 1. Effect of rutin-ammonium complex on germination energy and germinating ability of Scots pine ($n=3$, $\bar{X} \pm \text{SE}$)

Concentration, $\mu\text{g/ml}$	Germination energy, %	Germinating ability, %
0 (control)	58.0 ± 1.73	69.7 ± 1.45
10	60.3 ± 0.88	72.0 ± 1.15
15	$67.7 \pm 1.45^{**}$	$78.0 \pm 1.73^*$
20	$64.0 \pm 0.59^*$	72.3 ± 1.45
40	$52.0 \pm 1.15^*$	63.7 ± 2.03

Note: the significance of differences was evaluated using univariate analysis of variance and Tukey's honest significance test (HSD); * – the difference with the control is significant for $p < 0.05$, ** – for $p < 0.01$

When the concentration of the complex of active substances in the solution increases to 15 and $20 \mu\text{g/ml}$, these indicators increase, but significantly decrease when the concentration reaches $40 \mu\text{g/ml}$.

Further observations of the processes of germination and seedling development revealed the prolonged effect of organic compounds (Fig. 2).



Figure 2. Seedlings of Scots pine after treatment of seeds with rutin-ammonium complex (1 – 2 hours; 2 – 24 hours); ruler – 20 mm; a – control; b, c, d, e – sprouts that were pretreated with solutions with concentrations of 10, 15, 20, and 40 $\mu\text{g/ml}$, respectively

Soaking the seeds in solutions with different concentrations for 24 hours stimulated the growth of seedlings. At concentrations of 10 and 20 $\mu\text{g/ml}$, the growth processes of stems and cotyledons were more sensitive to bioactive substances (Fig. 3, a).

Under conditions of increasing concentration

of phenolic compounds, the growth rate of stems slowed down, and roots, on the contrary, increased (Fig. 3, b). The difference in the growth processes of roots and shoots indicates the presence of a certain tissue specificity in the plant body, which is conditioned by the anatomical structure and functions of aboveground and underground organs.

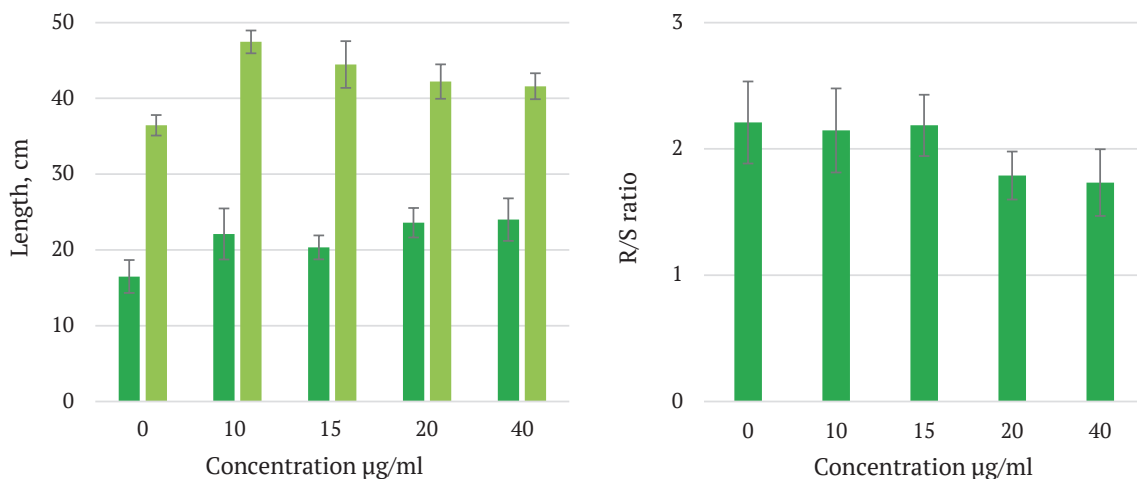


Figure 3. Effect of rutin-ammonium complex on root and shoot growth rates (a) and their relationship (b) in seedlings of Scots pine

Stimulating root system development is an important element of a plant survival strategy in the face of fierce competition for spatial resources and nutrients, especially in conditions of moisture deficiency. For adventitious species with a wide range of adaptive responses, active root system development is one of the main strategic features that ensure the successful naturalisation of plants in new conditions.

A significant influence of the rutin-ammonium complex on the qualitative composition of photosynthetic pigments included in light-harvesting complexes and auxiliary pigments – xanthophylls and carotenoids – was also revealed. In Scots pine seedlings that were treated with a solution with concentrations of 10 and 15 $\mu\text{g/ml}$, the total amount of plastid pigments increased (Fig. 4, *a, c, d*). The amount of chlorophylls in *a* and *b* also increased.

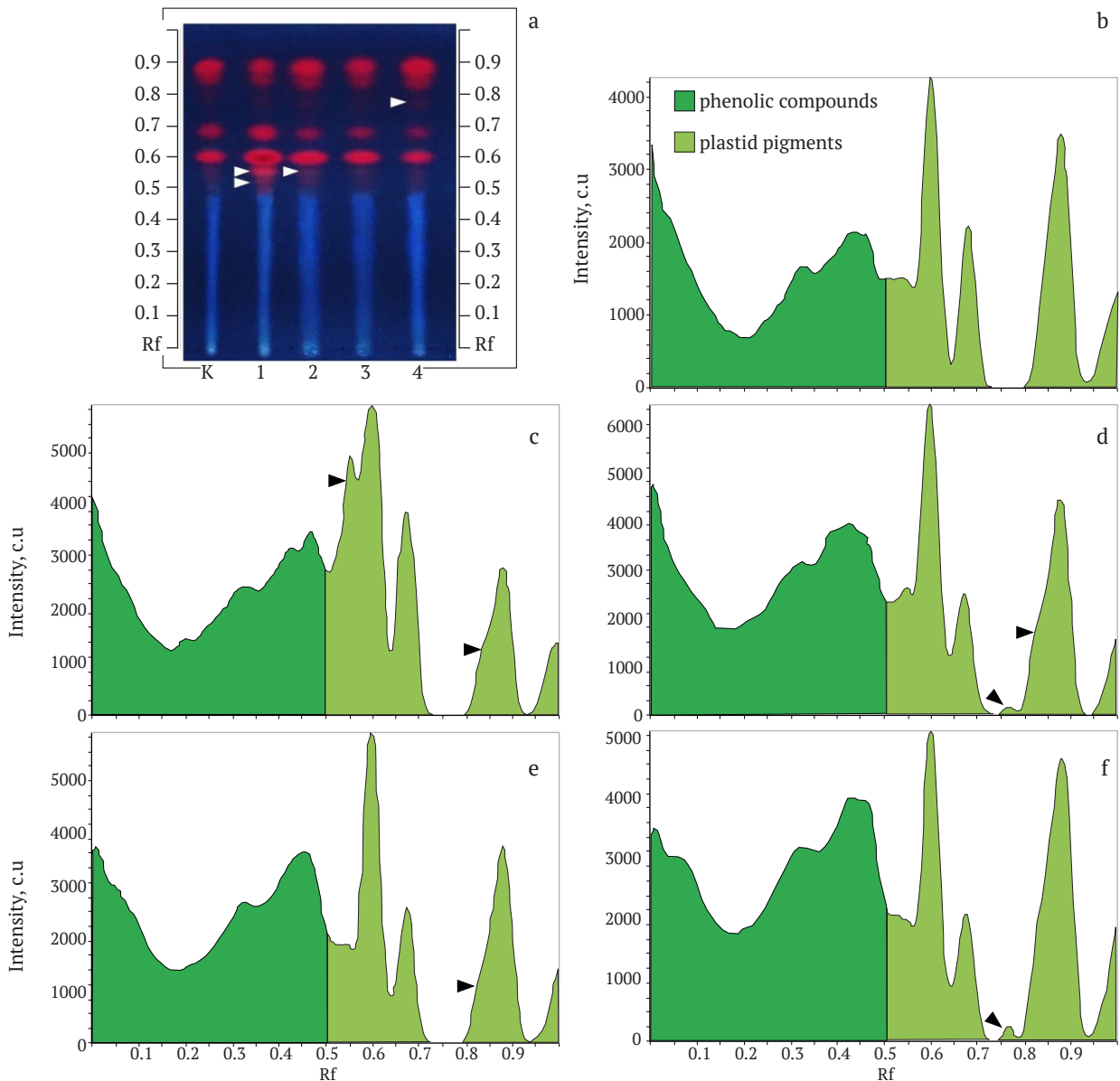


Figure 4. Photodensitograms of plastid pigments in cotyledons of Scots pine seedlings on Day 14 of germination; *b* – control; *c, d, e, f* – photodensitograms of seedling extracts that were pretreated with solutions with concentrations of 10, 15, 20, and 40 $\mu\text{g/ml}$, respectively; arrows show peaks that differ significantly in their area from the control group

A different trend was observed in the qualitative composition of phenolic compounds. Under conditions of increasing the concentration of the phenol-ammonium complex, the number of phenols in seedling tissues increased (Fig. 5).

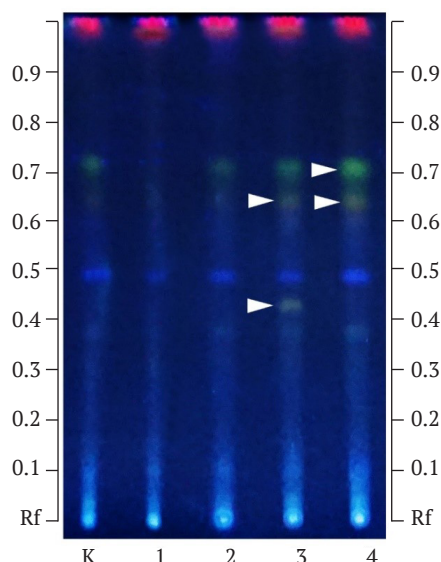


Figure 5. Chromatogram of phenolic compounds of Scots pine seedlings on Day 14 of germination; *K* – control, *1-4* – plant extracts after seed treatment with rutin-ammonium complex with concentrations of 10, 15, 20, and 40 µg/ml, respectively; arrows show flavonoids, the content of which is much higher than the control

When seeds were treated with a solution with a concentration of 20 and 40 µg/ml in methanol extracts, the content of flavonoids with *Rf* ~0.63 and 0.71 significantly increased (Fig. 5, 3, 4). The compound with an *Rf* of ~0.43 was found exclusively in seedling extracts treated with a solution of 20 µg/ml. Treatment of seeds with rutin-ammonium complex with the lowest concentration caused the opposite effect. Under such conditions, the qualitative composition and total pool of phenolic compounds in seedling tissues decreased (Fig. 5, 1).

The opposite dependence of the synthesis of phenols and terpenoids can be caused by different ways of synthesis of these compounds, except for

flavonoids, the development of which can compete with carotenoids for a substrate common to the corresponding enzymes. Carotenoids are polyene derivatives of isoprene, whose molecules have double bonds. These pigments are mainly localised in chloroplasts, where they are synthesised from acetyl-CoA (Della Penna and Pogson, 2006). Most plant phenols are formed from shikimic acid in chloroplasts and cytosols. At the same time, the synthesis of flavonoids and carotenoids is also possible from acetyl-CoA under conditions of its carboxylation in acetyl-CoA carboxylase and the subsequent establishment of malonyl-CoA, which is a substrate for the synthesis of flavonoids. Therefore, the accumulation of flavonoids in seedlings against the background of a simultaneous decrease in the content of carotenes and xanthophylls may indicate the ability of the phenol-ammonium complex to selectively affect the enzyme systems responsible for the synthesis of substances formed from acetyl-CoA.

Conclusions

Quercetin glycoside rutin (quercetin-3-*o*-rutinoside) after interaction with an aqueous solution of 10% ammonia forms a complex of medium- and high-polar organic compounds with high biological activity.

These substances, when treated with loblolly pine seeds, can affect germination energy, germinating capacity, and subsequently seedling growth. The effect of the complex of organic compounds formed from the rutin-ammonium complex depends on the concentration and duration of seed treatment.

A solution with a concentration of 15 µg/ml increased seed germination, while concentrations of 10 and 15 µg/ml promoted the synthesis of plastid pigments. The total pool of phenolic compounds increases when seeds are treated with solutions with concentrations of 20 and 40 µg/ml. Therefore, the phenol-ammonium complex is able to regulate the processes of growth and development, and affect the secondary metabolism of Scots pine seedlings. The identified effects reveal a new, still poorly understood aspect of the role of flavonoids in the plant body.

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Вплив рутин-амонійного комплексу на фізіологічний стан проростків сосни звичайної

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Анотація. У рослинному організмі фенольні сполуки неспецифічно впливають на процеси морфогенезу і виконують широкий спектр регуляторних і захисних функцій. Особливий інтерес становлять процеси, які пов'язані з комплексотворенням флавоноїдів у результаті їхньої взаємодії з амонійними формами азоту. Полярні сполуки, які утворюються в тканинах у результаті хімічної трансформації, достатньо рухомі у ґрунтових розчинах і виявляють високу біологічну активність. Властивості фенол-амонійних комплексів викликають значне зацікавлення в аспекті морфогенезу, фізіології стійкості, а також у системі взаємодії рослин із ґрунтовими мікроорганізмами. Це також надзвичайно актуально при виробництві якісного та стійкого до несприятливих факторів садивного матеріалу. Дослідження впливу фенол-амонійного комплексу проводили на насінні і проростках сосни звичайної. Кількісні показники енергії проростання та схожості визначали методом пророщування насіння. Біохімічне профілювання екстрактів тканин проростків виконували методом вискоєфективної тонкошарової хроматографії. Експериментально підтверджено, що рутин (кверцетин-3-О-рутинозид) після взаємодії з 10 % водним розчином аміаку утворює комплекс речовин, серед яких методом хроматографії виявлено полярні продукти, які потенційно впливають на регуляцію росту. За сумарної концентрації 15 мг/л ці речовини достовірно підвищували показники енергії проростання та схожості насіння. У проростків сосни вони стимулювали ріст коренів і пагонів. Ефект дії комплексу органічних сполук на проростки залежав від концентрації, тривалості оброблення насіння і мав пролонговану дію. Отриманий фенол-амонійний комплекс за концентрацією 10-15 мг/л сприяв підвищенню кількості хлорофілів, каротиноїдів у тканинах проростків, а за 20-40 мг/л збільшував уміст продуктів фенольного синтезу

Ключові слова: рутин, флавоноїди, амоній, регулятор росту, сосна звичайна, насіння

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