УДК 630*03:674.03:631.363 DOI 10.36910/775.24153966.2025.81.20

О.П. Герасимчук, О.Л. Ткачук, В.О. Волянський

Луцький національний технічний університет

ВПРОВАДЖЕННЯ КОМПЛЕКСНИХ МАШИННО-ТЕХНОЛОГІЧНИХ СИСТЕМ ДЛЯ ЗАГОТІВЛІ ТА ПЕРЕРОБКИ ХВОЇ СОСНИ ЗВИЧАЙНОЇ

Проведено аналіз сучасного стану і проблем заготівлі та переробки хвойних відходів сосни звичайної. Встановлено, що традиційні методи поводження з хвойною лапкою (спалювання або залишення для перегнивання на лісосіці) є екологічно небезпечними та призводять до втрати цінних ресурсів. Визначено перспективні напрями використання хвої: отримання ефірних олій, екстрактів, паливних матеріалів і текстильних волокон. Для реалізації цих напрямів запропоновано комплексну машинно-технологічну систему, котра охоплює всі стадії – від механізованого збирання хвої у лісі до глибокої переробки. Запропонована технологія заготівлі із застосуванням сучасної техніки (звалювально-пакетувальної машини, форвардера, процесора) забезпечує мінімальні втрати хвої і високу якість сировини для подальшої переробки. Універсальна технологічнасхема глибокої переробки хвої поєднує отримання ефірної олії, хвойного екстракту та текстильного волокна. Встановлено, що комбінування цих виробництв є найбільш ресурсоефективним: відходи одного процесу слугують сировиною для іншого, забезпечуючи безвідходність. Зокрема, тверді залишки після перегонки олії або варіння екстракту можуть успішно використовуватися для виділення текстильного волокна. Універсальність запропонованої моделі переробки хвої дозволяє адаптувати її під різні умови та потреби лісогосподарських підприємств України, сприяючи більш раціональному використанню лісових ресурсів та зменшенню негативного впливу на довкілля.

Ключові слова: *хвоя, сосна звичайна, заготівля, пневмотермічний спосіб, ефірна олія, хвойний екстракт, текстильне волокно, м'яття, гідравлічне притискання.*

O.P. Herasymchuk, O.L. Tkachuk, V.O. Volianskyi

IMPLEMENTATION OF INTEGRATED MACHINE-TECHNOLOGICAL SYSTEMS FOR HARVESTING AND PROCESSING SCOTS PINE NEEDLES

The current state and problems of harvesting and processing Scots pine (Pinus sylvestris L.) needle waste have been analyzed. It was established that traditional methods of handling pine foliage (e.g., burning or leaving it to decompose on the logging site) are ecologically hazardous and result in the loss of valuable resources. Promising directions for using pine needles include essential oil extraction, production of aqueous extracts, fuel materials, and textile fibers. To implement these directions, an integrated machine-technological system is proposed, covering all stages from mechanized harvesting to deep processing. The proposed harvesting technology, which utilizes modern equipment (feller-bunchers, forwarders, processors), ensures minimal loss of needles and high-quality raw material. A universal processing line has been developed to obtain essential oils, aqueous extracts, and textile fibers. Combining these production lines ensures maximum resource efficiency, as the waste from one process serves as raw material for another. For example, solid residues after distillation or extraction can be successfully used to isolate cellulose fibers. The universality of the proposed model allows for its adaptation to different conditions and needs of forestry enterprises in Ukraine, promoting more rational use of forest resources and reducing environmental impact.

Keywords: *needles, Scots pine, harvesting, pneumo-thermal method, essential oil, pine extract, textile fiber, crushing, hydraulic pressure.*

Problem Statement. Scots pine (Pinus sylvestris L.) is one of the most widespread coniferous species in Ukraine. During logging operations, a significant amount of by-products is generated, including tree tops, branches, and needles (commonly referred to as "pine foliage") [1]. Currently, a considerable portion of this coniferous biomass is utilized inefficiently: branches with needles are often burned or left to decompose at logging sites, which not only lacks economic benefit but also poses risks of forest fires and environmental pollution [1–5]. Burning or prolonged storage of needles at felling areas leads to the loss of valuable compounds (such as vitamins, essential oils, and chlorophyll) and the release of carbon dioxide and toxic substances into the atmosphere [4, 5]. Therefore, the issue of incorporating coniferous biomass into industrial processing is highly relevant from both environmental and economic perspectives.

Scots pine needles contain biologically active compounds—essential oils, organic acids, phenolic substances, vitamins, and more [6–8]. This makes pine needles a valuable raw material for various industries. Traditionally, they are used for producing pine extract and essential oil, which are utilized in medicine and cosmetics [2]. Research has confirmed that extracts from Scots pine needles possess antioxidant and anticancer properties [7, 8]. Essential pine oil is used in pharmaceuticals and aromatherapy and exhibits antiseptic effects. Additionally, pine needles can serve as raw material for producing animal feed additives and organic fertilizers. In the Volyn region, a unique production facility has been established for manufacturing natural pine extract and essential oil at a forestry enterprise (the Manevychi canning facility)—a direction that remains unique in Ukraine [2].

Alongside biochemical applications, pine needles are being explored as a renewable biofuel. In particular, thermal processing (pyrolysis) enables the production of gaseous and liquid fuels as well as biochar [8, 9]. Coniferous biomass can also be a source of cellulose for the manufacture of paper and

© О.П. Герасимчук, О.Л. Ткачук, В.О. Волянський

nanocellulose [4]. Nanocellulose derived from mechanically and chemically treated pine cellulose is being considered for use in the production of biodegradable packaging materials and composites [8, 9].

One especially promising direction is the production of textile fibers from pine needles—referred to as "forest wool." Historically, pine needle fiber was used in Europe and the USA in the 19th century (a patented technology from 1890) [10], but these technologies never gained industrial traction. Today, the concept of textile fiber production from pine needles is being revived and has gained international recognition (the Forest Wool concept was awarded the Green Product Award) [11]. These natural fibers are environmentally friendly, biodegradable, and can serve as alternatives to cotton or synthetic fibers.

Despite the growing interest in products derived from coniferous raw materials, there is still a lack of efficient and universal technologies capable of industrial-scale processing of Scots pine needles. Existing production facilities (such as the one mentioned above for extract production) typically focus on a single type of product. A comprehensive approach to the harvesting and processing of pine needles that enables the production of multiple end products requires the introduction of new machinery and technologies. Particular attention should be paid to developing a universal model for pine needle harvesting and processing that can be implemented by forestry enterprises in Ukraine.

Analysis of Recent Research and Publications. Modern studies focus on maximizing the utilization of coniferous raw material components. Efforts are directed both at improving traditional uses (extraction of essential oils, cellulose, fuel) and at developing new products such as packaging materials made from pine biomass or textile fibers [1–11]. From a technological standpoint, the creation of equipment for collecting and initially processing pine needles directly at logging sites is particularly relevant [5,6]. Researchers have proposed the use of a pneumo-thermal method for separating needles, which combines branch drying and vacuum pneumo-transportation, as an energy-efficient alternative to existing methods [5,6]. It has been shown that the quality of needles obtained through this process is sufficient for subsequent fiber production [5]. To intensify fiber extraction from needles, various techniques are being explored—from alkaline chemical treatment to mechanical breakdown of needle structure [1, 3, 12]. Specifically, the use of a crushing (rolling) operation between corrugated rollers damages the tough cuticular layer of the needles, facilitating the removal of resins and lignin, and accelerating the process of obtaining cellulose fibers [3]. Thus, an integrated approach involving modern logging equipment, specialized needle separation units, and machinery for advanced processing represents a promising direction for both scientific research and practical implementation.

Task formulation. The objective of this study is to enhance the efficiency of using Scots pine needle biomass by developing an integrated machine-technological system for its harvesting and processing. The research tasks include:analyzing existing technologies for separating needles from branches;developing a scheme for mechanized harvesting of pine foliage with minimal losses;comparing various processing methods for pine needles (for essential oil, extract, fiber) and determining their technological features;designing a conceptual machine-technological scheme for obtaining textile fiber from needles.

Presentation of the Main Material. he implementation of integrated machine-technological systems for the harvesting and processing of coniferous raw materials allows for the rational utilization of the forestry sector's potential and the achievement of new levels of efficiency by minimizing raw material losses and obtaining additional high-value-added products. Traditional methods are often accompanied by significant manual labor costs, partial or complete underutilization of needles and branches, and inefficient transportation, which leads to poorer economic performance and loss of environmental benefits. The introduction of modern equipment (harvesters, processors, forwarders, extraction units) enables a balanced combination of tree felling, needle collection, and preliminary processing, ensuring high-quality raw material transport and the organization of its integrated processing into essential oils, biological extracts, textile fibers, biofuels, and more. This opens new opportunities for increased profitability, as waste is effectively transformed into valuable secondary resources.

A comparison between traditional and integrated harvesting of coniferous raw materials, showing the characteristic features of each approach and expected outcomes from the implementation of modern technologies, is presented in Table 1.

A complete technological line for processing Scots pine needles consists of several stages, starting from raw material collection in the forest and ending with the final products. For effective implementation of each stage, it is advisable to use specialized machines and units.

During the felling stage, it is recommended to use modern machines that ensure maximum preservation of needles on branches. The use of feller-bunchers during tree cutting allows for the careful felling and stacking of trees in bunches without hitting the ground, significantly reducing needle loss (Fig. 1, a). Subsequent transportation of the logs is carried out by forwarders — forest transport machines that carry felled trees elevated above the ground on a platform (Fig. 1, b). Forwarders prevent dragging of tree crowns on the ground, avoiding up to 90% needle loss observed during skidding with tractors. At the intermediate depot, the timber is processed by a processor — it is cleaned of branches (forming piles of needle-rich material) and cut into assortments (Fig. 1, c). As a result of these operations, by-products — branches with needles — are concentrated in a form accessible for collection.

Table 1.

Comparison of Traditional and Integrated Harvesting of Coniferous Raw Materials

Parameter	Traditional Harvesting	Integrated Harvesting
Efficient use of needles	Low, most are left or burned	High, includes mechanisms for collection and preservation of needles
Mechanization level	Predominantly manual labor, minimal mechanization	Modern machines (harvesters, forwarders, processors) and automated lines
Cost and expenses	Higher due to raw material loss, inefficient logistics	Lower due to optimized processes and minimal losses
Environmental impact	Many residues, additional burden on the environment	Efficient use, reduced burning and negative impacts
Processing opportunities	Limited, no established technological lines	Expanded processing into oils, extracts, fiber, fuel, etc.

a b

c

*Fig. 1.***Machines for mechanized harvesting of pine foliage:a – felling and bundling machine; b – forwarder; c – processor.**

To obtain clean needles from the collected pine foliage, a mobile pneumo-thermal unit is proposed for use (Fig. 2) [1, 5, 6]. Alternative methods (mechanical shaking, pneumatic-mechanical separation, electrohydraulic shock, high-frequency treatment, cryogenic freezing) have proven to be either inefficient or excessively energy-intensive for subsequent fiber production [1, 5].

Instead, the pneumo-thermal method consists of short-term drying of branches in a hot air stream to weaken the bond between the needles and twigs. The needles are then vacuum-extracted and separated in

© *О.П. Герасимчук, О.Л. Ткачук, В.О. Волянський*

cyclones (Fig. 2) [1]. In the drying chamber, hot air partially dries the needles; next, a fan (vacuum pump) creates an airflow that detaches the needles and carries them to the cyclone system. In the first cyclone, the needles are separated from the air and collected in a bin, while the second cyclone traps fine bark fragments and debris. The result is clean, dry needles ready for processing, and separately – wood waste (bare branches, fine chips).

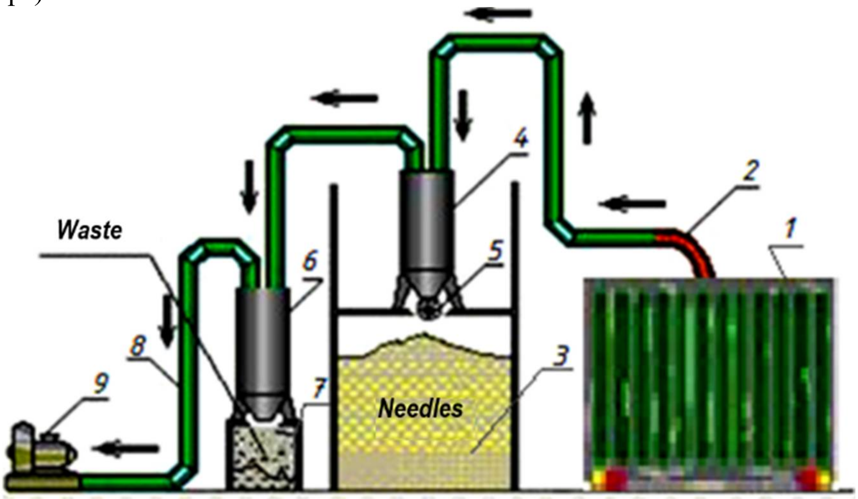

*Fig. 2.***Schematic diagram of the installation for separation of needles by pneumo-thermal method: 1 - drying chamber; 2 - suction pipeline; 3 - needles collector; 4 - cyclone for separating needles; 5 - gate valve; 6 - cyclone for separating waste; 7 - waste collector; 8 - air duct [1].**

A comparison of needle separation methods is presented in Table 2.

Table 2.

Comparison of Methods for Separating Scots Pine Needles from Branches

Method	Brief Description	Disadvantages for Further Processing
Mechanical	Shaking and beating needles off using vibration or rotating mechanisms on branches	Incomplete separation, potential branch fragmentation and mixing of impurities (bark, chips) with needles; high labor intensity
Pneumo-mechanical	Needle detachment by airflow (blowing or suction) without preheating	Requires preliminary crushing or drying of branches; difficult to achieve complete removal of impurities; high energy consumption to generate strong airflow
Electrohydraulic	Shock wave in liquid from a high-voltage discharge separates needles from branches	Complex and hazardous equipment; requires immersion of branches in water; high energy consumption, potential damage to needle fiber structure
High-frequency	Treatment with electromagnetic field (microwave) to heat and detach needles	Expensive equipment; uneven heating of branches; risk of thermal damage to needles and loss of bioactive components; significant electricity consumption
Cryogenic	Freezing branches (e.g., with liquid nitrogen or in natural winter frost) to cause brittle needle detachment	Requires special conditions or reagents; very high energy consumption for artificial freezing; technological complexity and hazard, limited by seasonal availability
Pneumo-thermal	Short-term heating of branches followed by vacuum needle suction (combined method)	Slight reduction in volatile content due to heating; requires heat source and vacuum system, but ensures cleanliness and integrity of needles for further processing

As shown in the table, the proposed pneumo-thermal method for separating pine needles is distinguished by the combined action of heat and vacuum, which ensures the collection of high-quality needles with minimal impurities. Pre-drying of branches facilitates easier needle detachment, while the absence of intense mechanical impact preserves the integrity of the needles for subsequent component or fiber extraction. A certain drawback of this method is the partial loss of essential oils during heating;

however, this can be compensated for by regulating the temperature and drying duration depending on the intended downstream processing. For the production of essential oil and extract, lower drying temperatures are recommended to preserve volatile compounds, whereas in textile fiber production, more intense heating is acceptable since resin removal facilitates subsequent chemical purification of fibrous structures.

The collected clean Scots pine needles can be directed to several production lines depending on the intended end product. Within the framework of an integrated system, it is advisable to ensure technological flexibility, i.e., the ability to combine processing directions. In practice, this means that one part of the needles can be used for steam distillation of essential oil, another part for extracting water-soluble compounds, and the remaining material (or by-products from the first stage) can be processed into cellulose fiber.

Essential oil is obtained using the steam distillation method. Freshly collected or lightly dried needles are placed in a distillation apparatus, through which superheated steam is passed; the volatile aromatic substances evaporate and condense, separating into essential oil and hydrosol (pine water). The distillation process lasts several hours, and the yield of essential oil is approximately 0.3–0.5% of the raw material mass [2].

Pine needle extract is a concentrate of water-soluble compounds (chlorophyll, vitamins, organic acids, and other bioactive substances). In forestry practice, it is obtained by boiling fresh green needles in water followed by partial evaporation of the liquid. At the Manevychi forestry enterprise, an extraction facility operates where green mass is processed in boiling tanks, and the thick extract is bottled for sale [2]. The extract yield is about 2% of the raw material mass. It is a valuable product used in sanatoriums and pharmacies as a tonic and therapeutic agent [2]. After extraction, a large amount of boiled pine mass remains (solid residue). Although this residue is largely free of extractive substances, it contains fiber (cellulose) and can be used as raw material for textile fiber production. Thus, combining extract and fiber production lines allows for waste-free utilization of the needles. The only technological limitation is that after thermal processing in water, the needle structure is partially destroyed, and the fibers are shorter than those obtained from untreated needles. This should be taken into account when selecting further processing parameters.

The production of natural fiber from needles is the most technically challenging processing direction, as it requires extensive breakdown of leaf structures and removal of all non-cellulose components. Scots pine needles have a dense cuticle impregnated with resins and a high lignin content that binds cell walls. The traditional approach to obtaining "forest wool" involved long-term soaking of needles in running water (several months) to allow for biodegradation of binding substances [4]. Modern approaches combine chemical and mechanical treatment to accelerate the process. We have adopted a technological solution to produce fiber from post-extraction residue — that is, boiled needles — as this significantly reduces reagent and time costs. The degreased and softened needles are easier to break down into fibers. The process includes the following stages: (1) mechanical crushing (rolling) of prepared raw material between grooved rollers to destroy the surface layer and cell walls; (2) chemical treatment with alkali (two-stage process, at ~100 °C, with NaOH concentration of 40–50 g/L) to dissolve resins and lignin; rinsing and neutralization of the fiber, and drying. Preceding chemical treatment with mechanical processing significantly enhances fiber yield due to better penetration of alkali into the needles, resulting in quicker and more complete removal of undesirable components. Additionally, if the raw needles were not previously extracted, soaking them in water or weak alkaline solution for several hours before the main processing may be appropriate to aid in resin removal. The obtained cellulose fiber is thoroughly washed and dried. It can be used alone (for coarse textiles, insulation, nonwoven materials) or blended with other fibers.

To perform the crushing operation, a machine design with hydraulic roller pressing is proposed (Fig. 3) [3]. The main working elements of the machine are two parallel grooved rollers through which the needle mass is fed. The lower roller (1) is rigidly mounted and driven, while the upper roller (2) is mounted on a movable platform. Hydraulic cylinders C1 and C2 apply pressure to the platform from above, ensuring the pressing of roller 2 against roller 1 with a constant force. The hydraulic system includes a pump station (motor M1, pump P, tank T), a safety valve SV to limit the maximum pressure, check valves V1 and V2 on the lines to the cylinders, and adjustable pressure valves PV1 and PV2 to maintain constant pressure. This setup compensates for load fluctuations and guarantees uniform crushing across the entire roller width. The rollers have a ribbed surface for better grip and deformation of the needles. The use of hydraulic pressing achieves much higher and more stable crushing force compared to spring or weight-based mechanisms, accelerating the breakdown of the tough epidermis of the needles. Preliminary experiments have shown that crushing before alkali cooking can reduce the chemical processing time by half and increase fiber yield [3].

The integrated system covers all key processes—from needle harvesting during various types of logging operations to the production of final products. Its objective is to minimize material losses through precise synchronization of work stages and the rational use of available equipment and logistical solutions. The structure of such a system involves the use of diverse equipment, with each component performing a specific operation, thereby reducing functional overlap and downtime to a minimum.

A simplified scheme of the main components of the integrated machine-technological system for the harvesting and processing of Scots pine needles is presented in Table 3.

To ensure maximum profitability, it is important to select the most economically advantageous directions for pine needle processing, taking into account market demands, available resources, and existing infrastructure. The extraction of essential oils remains one of the most attractive options due to its steady demand in the pharmaceutical, cosmetic, and food industries. At the same time, the production of textile fibers is gaining increasing relevance, as it offers an environmentally friendly raw material with a relatively high added value. The use of residual needle biomass for the production of fuel briquettes expands marketing opportunities and promotes a zero-waste production cycle.

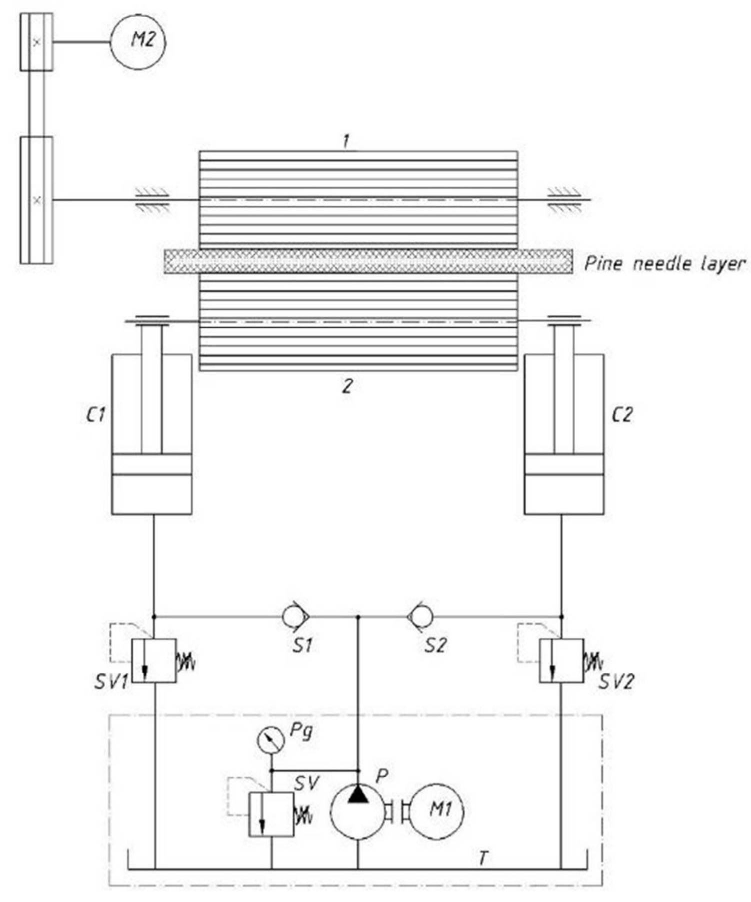

*Fig. 3.***Schematic diagram of a pine needle crushing machine with hydraulic pressure [3]**

Table 3.

Simplified scheme of the main components of the integrated machine-technological system for harvesting and processing Scots pine needles

Stage	Main Equipment	Purpose / Outcome
Felling and primary processing	Harvesters or feller-bunchers	Tree cutting, branch removal, partial needle collection
Transportation	Forwarders, specialized trailers	Transporting logs and needle biomass with minimal losses
Intermediate storage	Containers, sheds, mobile depots	Maintaining proper condition of pine raw material, protection from damage and weather
Processing	Extraction units, textile fiber lines, shredders	Production of essential oils, bio-extracts, fibers, fuel briquettes, etc.

The key directions for integrated processing of Scots pine needles and a brief description of their economic feasibility are presented in Table 4.

Conclusions. Adhering to an integrated approach enables synchronization of the entire chain—from the selection of the harvesting site to the sale of products derived from coniferous residues. The implementation of such systems delivers a positive economic effect by increasing enterprise profitability and simultaneously improving the environmental situation through a reduction in burned residues, lower atmospheric emissions, and overall mitigation of ecological risks.

Table 4

Key directions for the integrated processing of Scots pine needles

Processing Direction	Process Description	Advantages / Output
Essential Oil Extraction	Hydrodistillation, steam extraction, CO_2-extraction	High added value product, broad market demand
Textile Fiber Production	Mechanical and chemical treatment	Nonwoven materials, insulation, fillers, eco-friendly alternative to synthetics
Fuel Briquettes and Pellets	Grinding, pressing, use of post-extraction residue	Utilization of waste, improved energy efficiency
Organic Fertilizers	Composting, fermentation, microbiological treatment	Waste reduction, soil fertility improvement, potential for agricultural sector

For successful operation of these systems, it is essential to provide personnel training, develop efficient logistics, and secure access to investment. However, the long-term benefits typically outweigh the initial costs and open new opportunities for the development of the forestry sector.

References:

1. Herasymchuk O., Tkachuk O. Regarding the question of obtaining natural textile fibers from pine needles // The V-th International Symposium «Creativity. Technology. Marketing», 31 March 2023, Chișinău, Republic of Moldova. – Chișinău: Tehnica-UTM, 2023. – P. 203–209. – URL: https://fd.utm.md/wp-content/uploads/sites/37/2023/11/Simpozion-CTM-2023.pdf(дата звернення: 13.03.2025).

2. Маневицький лісгосп виготовляє хвойний екстракт за унікальною технологією // Район.Маневичі. – 2018. – 20 вересня. – URL: https://manevychi.rayon.in.ua/news/94050-manevitskii-lisgosp-vigotovliae-hvoinii-ekstrakt-za-unikalnoiu-tehnologieiu(дата звернення: 13.03.2025).

3. Герасимчук О. П., Ткачук О. Л., Пуць В. С., Охремов А. І. Отримання текстильних волокон з хвої сосни звичайної за допомогою процесів м'яття // Матеріали міжнар. конф. «MTI-2024», Луцьк, 14–16 травня 2024 р. – Луцьк: Луцький національний технічний університет, 2024. – С. 86–88.

4. Ткачук О., Герасимчук О. Стан та перспективи застосування деревної целюлози для виробництва хімічних волокон // IX Ukrainian-Polish Scientific Dialogues: Conf. Proc. – 20–23 жовтня 2021 р., Хмельницький, Україна. – С. 204–205.

5. Ткачук О. Л., Герасимчук О. П., Резнікова В. В. Пневмотермічний спосіб отримання хвої для виготовлення текстильних волокон // Сільськогосподарські машини. – 2022. – Вип. 48. – С. 67–73. – DOI: https://doi.org/10.36910/acm.vi48.842.

6. Герасимчук О. П., Ткачук О. Л. Обґрунтування режиму роботи пневмотермічної мобільної установки для відокремлення хвої сосни звичайної // Сільськогосподарські машини. – 2023. – Вип. 49. – С. 75–80. – DOI: https://doi.org/10.36910/acm.vi49.1025.

7. Dziedziński M., Kobus-Cisowska J., Stachowiak B. Pinus species as prospective reserves of bioactive compounds with potential use in functional food—current state of knowledge // Plants. – 2021. – Vol. 10, No. 7. – DOI: https://doi.org/10.3390/plants10071306.

8. Bisht A. S., Singh S., Kumar S. R. Pine needles – a source of energy for Himalayan region // International Journal of Scientific & Technology Research. – 2014. – Vol. 3, No. 12. – P. 161–164. – URL: https://www.ijstr.org/final-print/dec2014/Pine-Needles-A-Source-Of-Energy-For-Himalayan-Region.pdf(дата звернення: 13.03.2025).

9. Mandal S., Bhattacharya T. K., Verma A. K., Haydary J. Optimization of process parameters for bio-oil synthesis from pine needles (Pinus roxburghii) using response surface methodology // Chemical Papers. – 2018. – Vol. 72, No. 3. – P. 789–798. – DOI: https://doi.org/10.1007/s11696-017-0306-5.

10. Berry J. B. N. Process of making pine needle fiber. Specification forming part of Letters Patent No. 437,555, dated September 30, 1890. – Application filed March 21, 1889. – Serial No. 304,177. – URL: https://patents.google.com/patent/US437555A/en (дата звернення: 13.03.2025).

11. Forest Wool / Pine needle fiber – Green Product Award 2021. – URL: https://www.gp-award.com/en/produkte/Forest-Wool(дата звернення: 13.03.2025).

12. Tkachuk O. L., Gerasymchuk O. P. Perspective technologies of obtaining natural textile fibers from pine needles // Якість та безпечність товарів: матеріали VII міжнар. наук.-практ. конф., Луцьк, 28 квітня 2023 р. / за ред. В. В. Ткачука. – Луцьк: Вежа-Друк, 2023. – С. 183–185. – URL: https://drive.google.com/file/d/1rADR7tuZmsrwRRmnqYIV_ynN9AXXu6kr/view(дата звернення: 13.03.2025).

Рецензент: Рябчиков Микола Львович, професор кафедри технологій легкої промисловості Л НТУ, д.т.н.

© О.П. Герасимчук, О.Л. Ткачук, В.О. Волянський