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ВИКОРИСТАННЯ БІОРОЗКЛАДНИХ МАТЕРІАЛІВ ІЗ ЦЕЛЮЛОЗИ ОЛІЙНОГО ЛЬОНУ ДЛЯ ХАРЧОВОЇ УПАКОВКИ

У статті досліджено перспективи використання біорозкладних матеріалів на основі целюлози олійного льону для виготовлення харчової упаковки. Перехід до циркулярної економіки та необхідність зменшення обсягів пластикових відходів зумовлюють активний пошук альтернативних екологічно безпечних рішень у пакувальній галузі. Методологія дослідження охоплює аналіз сучасних тенденцій у виробництві біополімерних матеріалів, оцінку фізико-механічних властивостей біорозкладних матеріалів із целюлози олійного льону та прогноз їх впровадження на ринку. Проведено порівняльний аналіз властивостей целюлози олійного льону у зіставленні з іншими природними біополімерами. Значну увагу приділено можливим сферам застосування льонової целюлози в різних галузях промисловості. У дослідженні показано високий вихід біоволокон з ацетату целюлози, які стійкі до впливу кислотного та сольового середовищ, що робить їх перспективними для використання в харчовій та медичній промисловості. Аналіз життєвого циклу льонових волокон підтверджує їхні екологічні переваги та мінімальний вплив на довкілля. Результати свідчать про те, що застосування біорозкладних матеріалів на основі олійного льону є ефективним засобом зменшення залежності від синтетичних полімерів. Дослідження сприяє впровадженню інноваційних, екологічно безпечних технологій в українській пакувальній індустрії, що, своєю чергою, сприяє скороченню пластикових відходів. Використання целюлози олійного льону може суттєво покращити екологічну ситуацію та сприяти сталому розвитку аграрного сектору шляхом створення замкненого циклу виробництва, в якому всі компоненти рослини використовуються без утворення відходів.

Ключові слова: *біорозкладна упаковка, олійний льон, льонова целюлоза, сталі матеріали, біоосновні полімери, циркулярна економіка, харчова упаковка, утилізація сільськогосподарських відходів*

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USE OF BIODEGRADABLE MATERIALS FROM OIL FLAX CELLULOSE FOR FOOD PACKAGING

The article explores the prospects of using biodegradable materials based on oil flax cellulose for food packaging. The transition to a circular economy and the need to reduce plastic waste drive the development of alternative environmentally friendly solutions in the packaging industry. The research methodology includes an analysis of current trends in biopolymer material production, an assessment of the physicomechanical properties of biodegradable materials derived from oil flax cellulose, and a forecast of their market implementation. A comparative analysis was conducted to evaluate the properties of oil flax cellulose against other natural biopolymers. Significant attention is given to the potential applications of oil flax cellulose in various industrial sectors. The study demonstrates a high yield of cellulose acetate biofibers, that exhibit resistance to acidic and saline environments, making them promising for use in the food and medical industries. The life cycle analysis of flax fiber confirms its environmental benefits and minimal ecological impact. The results indicate that using biodegradable materials based on oil flax is an effective tool for reducing dependence on synthetic polymers. The research contributes to the implementation of innovative environmentally safe technologies in Ukraine's packaging industry, thus contributing to the reduction of plastic waste. The utilization of oil flax cellulose can significantly improve the ecological situation and promote sustainable development in the agricultural sector by creating a closed-loop production system that fully utilizes all plant components without generating waste.

Keywords: *biodegradable packaging, oil flax, flax cellulose, sustainable materials, bio-based polymers, circular economy, food packaging, agricultural waste utilization*

Introduction. The transition to a circular economy and the reduction of waste have led to increased production and consumption of biopolymer-based packaging solutions. In developed countries, there is a growing trend of scientific research, development, and innovation for packaging materials aimed at minimizing environmental impact.

Since 2022, due to the full-scale invasion of the Russian Federation, Ukrainian agricultural producers have faced significant risks and have been forced to seek new opportunities to ensure the sustainability and development of agribusiness. One of the niche technical crops that has gained increasing relevance under wartime conditions is oil flax. This is a relatively uncommon technical crop that yields two types of valuable products simultaneously: seeds and fiber. The efficient utilization of all parts of the plant contributes to the creation of environmentally friendly products while reducing environmental impact, aligning Ukraine with European eco-standards.

Thus, the production of food packaging from oil flax cellulose presents a highly promising direction for agribusiness in Ukraine, given its projected high profitability and environmental benefits.

Analysis of recent studies. A review of recent scientific publications indicates an increasing interest among researchers in the development and utilization of oil flax as a promising raw material for

producing various materials. O. Havrylenko and B. Plishyvyi conducted a study analyzing the current state and future prospects of the global market for biodegradable packaging materials [1]. T. Tovstanovska and I. Polyakova examined the agrobiological aspects of oil flax cultivation in Ukraine. They identified optimal growth conditions, including soil composition, climatic factors, and agronomic practices. Their research is significant, as the quality of raw materials for cellulose production largely depends on cultivation conditions [2]. S. Yaheliuk and V. Didukh analyzed the current state of oil flax and fiber flax processing, identifying key directions for utilizing the obtained products. They emphasized the environmental advantages of flax cellulose and its potential in the production of biodegradable materials. This study is crucial for understanding the prospects of flax cellulose applications in the packaging industry [3]. O. Fursa, A. Arkhip, and V. Yevtushenko examined the technological properties of oil flax straw and its suitability for cellulose processing. They discovered that due to its chemical composition and physical characteristics, this raw material can be used to produce environmentally friendly packaging materials. Their research contributes to improving technologies for processing oil flax straw into biodegradable materials [4].

The study conducted by N. A. Mostafa and co-authors focused on an efficient method for obtaining cellulose acetate biofibers from flax and cotton linters. The process yielded 81% for flax and 54% for cotton. The resulting bioplastics are characterized by biodegradability and resistance to acidic and saline environments, making them promising for applications in the food and medical industries [5]. A study led by Baley examined the properties of flax fibers for use in composite materials. The authors analyzed the mechanical characteristics, structure, and influence of various factors on fiber quality, highlighting their potential in the production of environmentally friendly materials [6]. R. Kumar and co-authors conducted an analysis of the bioenergy potential of livestock waste and agricultural residues in India. Their study emphasizes the possibility of using these waste materials for energy and material production, including biodegradable packaging, contributing to reduced reliance on traditional energy and material sources [7]. A. Gómez-Campos and colleagues presented a life cycle analysis of flax fiber intended for technical textiles. Their research covers all stages of flax fiber production and utilization, emphasizing its environmental advantages and potential to reduce ecological impact [8]. N. M. Stark and L. M. Matua reviewed contemporary trends in bio-based packaging materials. The authors analyzed different types of biopolymers, their properties, and application prospects, emphasizing the importance of developing sustainable packaging solutions to mitigate environmental damage [9]. Boyko G. and co-authors explored modifications of hemp and its potential industrial applications. The authors examined its properties for biomedical and industrial purposes. [10]. They investigated the renewed interest in hemp as a sustainable material. The authors emphasized that due to its natural properties and environmental benefits, hemp has become an attractive choice for consumers and is gaining new relevance in modern sustainability-oriented developments. A. Kulma and co-authors analyzed biotechnological approaches to flax cultivation and processing in Europe and China. Their research covered genetic modifications aimed at increasing the content of beneficial compounds in flax, such as polyhydroxybutyrate, which can be used in biodegradable plastic production. The authors stressed the importance of international collaboration in flax research for the advancement of new materials and products [11]. Yaheliuk, S and co-authors investigated the potential of converting agricultural waste into value-added products. The authors analyzed the economic and environmental benefits of this approach, highlighting the potential of flax waste for producing eco-friendly packaging materials. This study underscores the importance of sustainable practices in agriculture and industry [12]. P. Gupta and co-authors (2022) reviewed current trends in the development of biodegradable packaging films using plant-based and food waste. The authors discussed various methods for obtaining and modifying these films, their properties, and potential applications. Special attention was given to the use of flax cellulose waste as a promising material for sustainable packaging solutions [13].

These studies highlight the wide range of possibilities for utilizing flax and its by-products in biomedical and industrial applications, fostering the development of sustainable and eco-friendly materials. This represents a crucial step toward sustainable development and reducing environmental impact.

The aim of this article is to explore and analyze scientific approaches to the development and application of biodegradable materials based on cellulose derived from oil flax.

Materials and Methods. The research methodology employs a comprehensive approach that integrates analytical, experimental, and predictive methods to assess the effectiveness of using oil flax cellulose in the production of biodegradable packaging materials.

A review of literature sources enabled an evaluation of current trends in biopolymer material production and identified the prospects of using oil flax as a raw material for packaging. Scientific

publications were analyzed to highlight the chemical and physical properties of flax cellulose, along with experimental findings related to its processing.

Experimental methods included the assessment of the physicomechanical properties of the obtained materials, particularly their strength, flexibility, and moisture resistance. The research was conducted in accordance with international packaging material evaluation standards.

The primary data sources for the analysis included the State Statistics Service of Ukraine, which provided information on oil flax cultivation and processing volumes.[14] To visualize the results, a graphical method was employed, allowing for the tracking of trends in the production and utilization of biodegradable packaging materials based on oil flax. A forecasting method was used to estimate the potential adoption of oil flax cellulose packaging materials in Ukraine and possible development scenarios for this industry until 2030. The predictions were based on statistical reports and econometric models that accounted for demand trends and environmental regulatory changes. The selected timeframe for the study (2010–2023) was chosen to analyze long-term trends in oil flax cultivation and its application in the packaging industry.

The obtained results provide insights into the efficiency of using oil flax cellulose for producing environmentally friendly packaging materials, contributing to the implementation of a circular economy in Ukraine's agricultural sector.

Results. The development of the bio-packaging industry is particularly relevant for Ukraine due to growing environmental challenges and the urgent need to reduce the use of conventional plastics. According to the State Statistics Service of Ukraine, as of 2023, the country generates over 2 million tons of plastic waste annually, of which only 7% are recycled [14].

Flax has historically been one of the oldest cultivated crops in modern Ukraine, grown primarily for its fibers. Flax fibers were widely used for producing textiles, cords, ropes, and other essential goods, playing a significant role in household and industrial activities. The peak of flax cultivation occurred in the 19th century. Following Ukraine's independence, this sector experienced a gradual decline, but in the last decade, a slow revival of flax cultivation has been observed. Modern flax farming in Ukraine is now primarily focused on oil flax cultivation.

To analyze trends, we examine data from the State Statistics Service of Ukraine on sown area dynamics, production trends, and yield changes [14].

Until 2010, oil flax cultivation areas remained relatively small (around 2,000–4,000 hectares). However, there was a sharp increase, reaching 58,900 hectares in 2010 and further expanding to 62,200 hectares by 2015. In 2020, a significant decline in cultivated areas occurred, dropping to 13,800 hectares. However, in 2021–2022, the areas began to increase again, reaching 33,100 hectares by 2022.

The primary driver of this growth has been agricultural enterprises, whereas households and small-scale farms have almost ceased flax cultivation since 2015 (see figure).

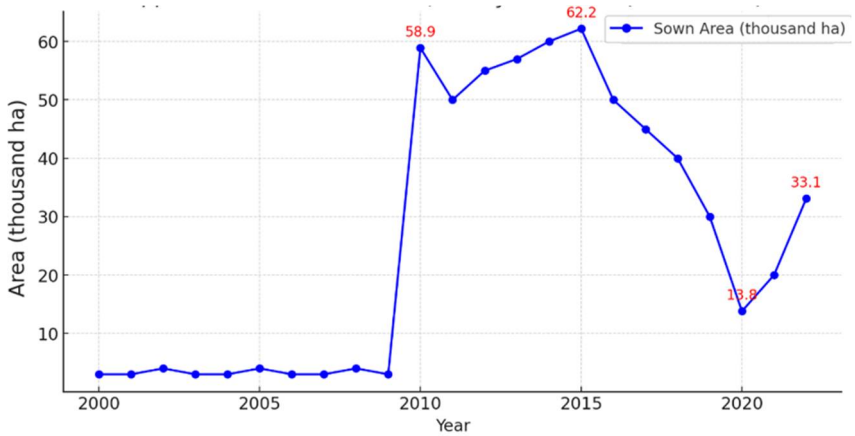

Fig. 1. **Dynamics of Oil Flax Sown Areas (thousand hectares)**
Source: Compiled by the authors using [5]

Between 2010 and 2015, oil flax experienced a peak in production, but after 2020, dynamics of sown areas, production volumes, and yields declined. The primary contribution to oil flax cultivation and production was made by agricultural enterprises, while households and small farms nearly ceased cultivation after 2015 due to lower levels of mechanization and technology. However, in the last two years,

signs of industry recovery have emerged, indicating the potential for a new development cycle. Enterprises play a dominant role in this process.

Forecasting oil flax production in Ukraine during wartime conditions remains a complex task due to numerous uncertainties. However, based on available data and econometric modeling methods, some projections can be made. By 2022, oil flax sown areas were increasing, and data for 2022–2023 indicate a 20% growth in sown areas compared to the previous season, reaching the highest level in the past five years. This demonstrates a degree of resilience in the industry despite the war. The expansion of sown areas could lead to higher production volumes, provided that weather conditions are favorable and major military conflicts do not disrupt key agricultural regions. Yields are expected to remain at previous levels or slightly decrease due to potential difficulties in accessing resources and equipment.

These findings are supported by a study by Yaheliuk, S., Fomych, M., & Rechun, O., which highlights the increased relevance of oil flax production under wartime conditions. The author characterizes the fluctuating dynamics of oil flax production in Ukraine, contrasting it with the dominance of cash crops. The study reveals that nearly 70% of oil flax is sold within Ukraine for domestic processing, and purchase prices for oil flax have traditionally remained high [15].

Thus, despite challenges posed by the war, oil flax production in Ukraine shows signs of resilience. The increase in sown areas in 2022 and 2023 indicates that farmers are adapting to new conditions. However, for a more accurate forecast, it is crucial to consider further developments in the military situation and its impact on the agricultural sector.

Oil flax is a promising raw material for biodegradable packaging materials due to its high cellulose content in its stems. Notably, flax straw contains up to 50% cellulose, making it suitable for the production of various types of paper and cardboard [7].

The cellulose derived from oil flax offers several advantages over other natural biopolymers (see Table).

Table 1.

Comparative Analysis of Oil Flax Cellulose with Other Natural Biopolymers

Biopolymer	Main characteristic	Advantage	Disadvantage
Oil flax cellulose	High strength, biodegradability, resistance to moisture and chemical exposure	Environmentally friendly, can be used in the production of bioplastics	Requires special processing
Wood-derived cellulose	High strength and durability	Suitable for creating paper, textiles	Requires significant water and energy consumption
Starch	Easy to decompose, affordable	Cheap raw materials, environmental friendliness	Low strength, high hygroscopicity
Chitin and chitosan	Antimicrobial properties, biocompatibility	Used in medicine and food industry	High cost, need for special processing

Source: *compiled by the authors based on multiple sources*

Oil flax cellulose is one of the most promising biopolymers, widely used in industry due to its unique physicochemical properties. According to Baley et al. (2019), the main characteristics of this cellulose include:

- High cellulose content – up to 80% in processed flax fibers.
- High mechanical strength – flax fibers exhibit superior mechanical properties compared to wood cellulose [6].
- Studies by Mostafa et al. confirm that flax cellulose has good moisture resistance and acid resistance [5].
- Cellulose decomposes naturally by microorganisms without generating harmful residues [16].

The use of oil flax cellulose has significant potential in the packaging and textile industries due to its unique properties. Further advancements in processing technologies will promote broader applications of this material.

The extraction of cellulose from oil flax involves several key stages:

- Mechanical processing – shredding stems to separate the fiber portion.

- Chemical treatment – using alkaline solutions (NaOH, H_2O_2) to remove lignin and hemicellulose.
- Filtration and washing – cleaning fibers from chemical reagents.
- Drying and grinding – obtaining final cellulose in the form of powder or fibers.

Research indicates that efficient mechanical processing includes initial stem mixing, pre-drying, repeated retting, and optimal blending of fibers from different stem parts. Additional fiber purification steps can enhance product quality but may increase production costs.

In industrial flax production, key processing steps include breaking and scutching, which determine fiber quality. Pre-crushing of stems facilitates easier removal of shives. However, intensive mechanical processing can damage the fibers, highlighting the need for improved equipment.

According to Y. Berezovsky, one limiting factor is the lack of affordable equipment for small- and medium-scale producers. Manufacturers are advised to implement double-pass processing of raw materials, which enhances fiber quality. However, this technique disrupts process continuity, necessitating the development of low-cost processing methods [17].

Improving oil flax processing technologies will contribute to:

- Higher long-fiber yield
- Reduced waste
- Expanded industrial applications

These advancements will strengthen the role of oil flax cellulose in the development of sustainable and biodegradable materials across various industries.

Oil flax cellulose exhibits high mechanical strength, flexibility, and resistance to chemical exposure. Due to its structural properties, it can be used as a base material for bioplastics and packaging, reducing dependence on synthetic polymers. A life cycle analysis of flax fiber has confirmed its environmental benefits and minimal ecological impact. Flax can be processed into cellulose acetate biofibers with an 81% yield, which are characterized by high biodegradability and resistance to acidic and saline environments. This makes them promising for applications in the food and medical industries. Additionally, research has explored the potential use of flax waste for biogas and alternative fuel production, further enhancing the environmental efficiency of this crop [15]. Oil flax cellulose possesses unique properties that distinguish it from other natural biopolymers. Wood-derived cellulose is known for its high durability and strength, making it suitable for paper and textile production. However, its manufacturing process requires significant water and energy consumption, limiting its environmental sustainability. Flax fibers have high mechanical strength and ecological advantages, allowing their use in composite materials. Oil flax cellulose stands out for its high strength, flexibility, and resistance to chemicals, making it an ideal material for biodegradable products, including paper, textiles, and bioplastics. Thus, using oil flax for biodegradable packaging materials represents an environmentally friendly solution, reducing dependence on synthetic polymers and minimizing negative environmental impact.

Oil flax cellulose is a promising material for eco-friendly products. It can be applied in various industries, including paper production, textiles, and composites. Unlike synthetic materials, flax cellulose contains no artificial additives, simplifying its biodegradation process.

Flax cellulose decomposes naturally with the help of microorganisms such as bacteria and fungi, which break it down into simpler compounds. The byproducts of cellulose decomposition do not harm the environment—instead, they return to the soil, enhancing fertility and supporting the natural nutrient cycle.

Microorganisms release enzymes that break down cellulose into simple sugars, which are easily absorbed by other organisms. This accelerates and completes the biodegradation process, making flax cellulose an excellent alternative to traditional polymers.

According to researchers, by 2030, the biodegradable packaging market is expected to reach 22 million tons, driven by stricter environmental regulations. The food industry alone is projected to account for over 42% of this demand. Ukraine has significant agricultural potential, which can be leveraged to develop biodegradable packaging materials. The advantages of bio-based packaging from oil flax include substantial environmental benefits. Producing bio-packaging from agricultural waste significantly reduces CO_2 emissions compared to traditional polymer materials. In EU countries, the implementation of biodegradable packaging technologies has already led to reduced taxation on environmentally friendly products. These findings highlight the growing importance of oil flax cellulose as a sustainable alternative to conventional packaging, with significant economic and environmental benefits.

The obtained results confirm the promising potential of using oil flax in the production of biodegradable packaging materials. An important aspect is that the production of such materials helps reduce environmental impact and contributes to the development of the circular economy. A review of

scientific sources indicates the high potential of oil flax cellulose as an alternative to synthetic polymer materials.

Research has shown that biofibers derived from flax exhibit high strength, moisture resistance, and environmental safety. These properties make them suitable for various applications, including packaging materials, textiles, and bioplastics. At the same time, it is essential to consider the specifics of cellulose extraction and processing, as they directly impact the final material properties.

The study highlights the importance of considering the mechanical characteristics of flax fibers when developing composite materials. This opens up new opportunities for using flax cellulose in packaging solutions for the food and pharmaceutical industries. Additionally, flax waste has been proven to be a valuable raw material for bioenergy, supporting sustainable development strategies. A life cycle analysis of flax confirms that its use contributes to reducing negative environmental impact.

A comparative analysis of oil flax cellulose with other natural biopolymers, such as wood cellulose, starch, and chitosan, has demonstrated its competitiveness. It has better mechanical properties than starch and is more environmentally friendly than chitosan, which is derived from animal-based raw materials. However, for large-scale adoption, it is necessary to improve flax processing technologies and develop cost-effective methods for cellulose extraction.

Future research should focus on optimizing cellulose extraction technologies, enhancing its mechanical properties, and evaluating its long-term environmental benefits. An important direction is the implementation of innovative cellulose modification methods, which will improve its strength, barrier properties, and biodegradability.

Additionally, it is advisable to explore the possibility of combining oil flax cellulose with other natural biopolymers to develop materials with enhanced properties. This opens the door to the development of hybrid bioplastics, which could replace traditional petrochemical polymers in various industrial applications.

Conclusions

Today, various countries are exploring ways to maximize the full potential of flax, as disposal through burning poses both an environmental and economic challenge worldwide. With a well-structured and stable approach, and considering the current unstable conditions, Ukraine has strong prospects for profitable agribusiness and processing activities aimed at producing high-value-added products.

The dynamics of oil flax production in Ukraine show a trend toward recovery after a decline, creating favorable conditions for further development. Using oil flax cellulose for food packaging is an environmentally friendly solution that helps reduce dependence on synthetic polymers and minimize environmental impact.

The use of biodegradable materials derived from oil flax is an effective strategy for reducing reliance on synthetic polymers. These materials exhibit high strength, flexibility, and rapid biodegradation without producing harmful residues. Ukraine has great potential for utilizing oil flax cellulose in the production of biodegradable packaging materials. A review of scientific research indicates a growing interest in this topic, particularly in agrobiological aspects of flax cultivation, processing technologies for its straw, and methods for obtaining high-quality cellulose.

Thus, the production of biodegradable packaging materials based on oil flax cellulose represents a promising direction for agribusiness, aligning with modern environmental trends and promoting the sustainable development of the country. The utilization of oil flax cellulose can significantly improve the environmental situation and contribute to the sustainable development of the agricultural sector by establishing a closed-loop production system where all parts of the plant are used without waste.

References

1. Havrylenko, O., Plishyvyi, B. (2023) World trends in the development of the market of biodegradable packaging materials. *Scientific Bulletin of Uzhhorod National University.* 47. C. 160-165. URL: http://www.visnyk-econom.uzhnu.uz.ua/archive/47_2023ua/30.pdf (accessed 02.02.2025).

2. Tovstanovska T.G., Poliakova I.O. Agrobiological features of oil flax cultivation in Ukraine // Agronom. 2007. № 24. C. 156-157.

3. Yaheliuk S.V., Didukh V.F. Directions of use of oil flax and flax-dolgunts processing products. Commodity Bulletin. 2020. T. 1, № 13. C. 292-305. URL: https://doi.org/10.36910/6775-2310-5283-2020-13-25 (accessed 02.02.2025).

4. Fursa O., Arkhip A., Yevtushenko V. Suitability of oil flax straw for processing into fibre. Herald of Khmelnytskyi National University. Technical sciences. 2024. T. 331, № 1. C. 343-346. URL: https://doi.org/10.31891/2307-5732-2024-331-52 (accessed 02.02.2025).

5. Production of biodegradable plastic from agricultural wastes / N. A. Mostafa et al. Arabian Journal of Chemistry. 2018. Vol. 11, no. 4. P. 546-553. URL: https://doi.org/10.1016/j.arabjc.2015.04.008 (date of access: 14.02.2025).

6. Baley, C., Gomina, M., Breard, J., Bourmaud, A., Drapier, S., Ferreira, M., Le Duigou, A., Liotier, PJ, Ouagne, P., Soulat, D., & Davies, P. (2019). Characteristics of flax fibres for the manufacture of composite materials. International Journal of Material Formation, 12, 1023-1052. doi: 10.1007/s12289-018-1455-y .

7. Kumar R, Kumar V and Nagpur AS (2023). Bioenergy potential of available livestock wastes and crop residues: an analysis of 602 rural districts in India. Science of The Total Environment , 889, article number 163974. doi: 10.1016/j.scitotenv.2023.163974 .

8. Gómez-Campos, A., Viallé, C., Rui, A., Sablayrolles, C., and Hamelin, L. (2021). Linseed fibre for technical textiles: a life cycle assessment. Journal of Cleaner Production, 281, article number 125177. doi: 10.1016/j.jclepro.2020.125177

9. Stark N. M., Matuana L. M. Trends in sustainable biobased packaging materials: a mini review. Materials Today Sustainability. 2021. Vol. 15. P. 100084. URL: https://doi.org/10.1016/j.mtsust.2021.100084 (date of access: 14.02.2025).

10.Boyko, G; Evtushenko, V; Berezovsky, Y; Fursa, O; Yaheliuk, S; Holovenko, T; Maksimchenko, Y; Kraglik, V; Kapitonov, A; Momotok, E (2023) Dependence of hydrophobic properties of textile material on the anatomical structure bof hemp fibers in its basic. AD ALTA-Journal of Interdisciplinary Research. 13(2), 234-237 Spesial Issue. https://www.webofscience.com/wos/woscc/full-record/WOS:001027993900038

11.Kulma, A., Zhuk, M., Dovgy, S., Qiu, C., Wang, Y., Jankauskene, S., Preisner, M., Kostin, K., & Szopa, J. (2015). Biotechnology of fibrous flax in Europe and China. Technical Crops and Products, 68, 50-59. https://doi.org/10.1016/j.indcrop.2014.08.032

12.Yaheliuk, S., Didukh, V., Boyko. G. (2020) The improved technology of biomass processing to obtain products of various applications. *Agricultural machines* No 45 p. 155-164

13.Gupta, P., Toksha, B., & Rahaman, M. (2022). A Review on Biodegradable Packaging Films from Vegetative and Food Waste. The Chemical Record, 22(7), e202100326. https://doi.org/10.1002/tcr.202100326

14.State Statistics Service. https://www.ukrstat.gov.ua/. URL: https://www.ukrstat.gov.ua/ (accessed 14.02.2025).

15.Yaheliuk, S., Fomych, M., & Rechun, O. (2024). Global market trends of grain and industrial crops. *Commodity Bulletin,* 17(1), 134-145. doi: 10.62763/ef/1.2024.134. (date of access: 02.02.2025).

16.Stark N. M., Matuana L. M. Trends in sustainable biobased packaging materials: a mini review. Materials Today Sustainability. 2021. Vol. 15. P. 100084. URL: https://doi.org/10.1016/j.mtsust.2021.100084 (date of access: 14.02.2025).

17.Berezovsky Y. V. Application of New Technical Decisions in the Industrial flax Production. Science and innovation. 2016. Vol. 12, no. 4. P. 51-68. URL: https://doi.org/10.15407/scin12.04.051 (date of access: 14.02.2025).