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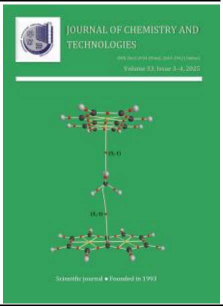

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CHARACTERIZATION OF LIGNOCELLULOSIC BIOMASS COMPLEX FOR UNLOCKING THE POTENTIAL OF SUSTAINABLE BIOFUEL PRODUCTION

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Abstract
The present study investigates the chemical composition and delignification efficiency of various lignocellulosic biomass types as feedstock for bioethanol production. Agricultural residues and dedicated energy crops were identified as the most promising substrates due to their high cellulose (exceeding 40 %) and hemicellulose content (20–28 %), which are crucial for fermentable sugar yield. Non-fibrous biomass with higher lignin content, such as apricot and walnut shells (43–44 % lignin), exhibited structural resistance that hinders the effectiveness of pretreatment. Peracetic acid pretreatment was applied as a selective delignification method, demonstrating significant lignin removal while minimizing polysaccharide degradation. The optimal duration of pretreatment was established to be between 90 and 120 minutes, which provides a balance between preserving substrate yield and maximizing lignin reduction. Despite diffusion limitations in shell biomass, leading to higher residual lignin content, these substrates retained a significant proportion of polysaccharides, highlighting their potential for further use after process optimization. The findings provide critical insights into biomass-specific pretreatment strategies, facilitating enhanced enzymatic hydrolysis and subsequent biochemical conversion to bioethanol.
Keywords: biomass valorization; biofuel; bioethanol; cellulose; pretreatment; agricultural residues.

ХАРАКТЕРИСТИКА ЛІГНОЦЕЛЮЛОЗНОЇ БІОМАСИ ДЛЯ РОЗКРИТТЯ ПОТЕНЦІАЛУ СТАЛОГО ВИРОБНИЦТВА БІОПАЛИВА

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Анотація
У даному дослідженні проаналізовані хімічний склад та ефективність делігніфікації різних видів лігноцелюлозної біомаси як сировини для виробництва біоетанолу. Встановлено, що сільськогосподарські відходи та спеціально вирощувані енергетичні культури є найперспективнішими субстратами завдяки високому вмісту целюлози (понад 40 %) та геміцелюлози (20–28 %), які є критичними для отримання ферментованих цукрів. Неволокниста біомаса з підвищеним вмістом лігніну, така як кісточки абрикоса та шкаралупа волоського горіха (43–44 % лігніну), виявляє структурну резистентність, що ускладнює ефективність попередньої обробки. Як селективний метод делігніфікації було застосовано пероцтову кислоту, яка забезпечила значне видалення лігніну з мінімальними втратами полісахаридів. Оптимальна тривалість попередньої обробки становила 90–120 хв, що дозволяло досягти балансу між збереженням виходу субстрату та максимальним зниженням вмісту лігніну. Попри дифузійні обмеження в кісточках та шкаралупі, що призводили до вищого залишкового вмісту лігніну, ці субстрати зберігали значну частку полісахаридів, що підкреслює їхній потенціал для подальшої утилізації після оптимізації процесу. Отримані результати надають важливі відомості щодо біомасо-специфічних стратегій попередньої обробки, які сприятимуть підвищенню ефективності ферментативного гідролізу та подальшої біохімічної конверсії у біоетанол.
Ключові слова: утилізація біомаси; біопаливо; біоетанол; целюлоза; попередня обробка; сільськогосподарські відходи.

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Introduction

The depletion of fossil fuel reserves, coupled with the environmental degradation caused by their extraction and combustion, has underscored the urgent need for alternative, sustainable energy sources [1]. Fossil fuel dependence not only contributes significantly to greenhouse gas emissions but also presents long-term challenges related to energy security and resource scarcity [2].

Biofuels have emerged as a promising solution, offering renewable energy derived from biological materials [3]. They are generally classified into generations based on the feedstock used and production technologies. First-generation biofuels, derived from food crops, have raised concerns due to their competition with food supply and land use [4]. In contrast, second-generation biofuels utilize non-food biomass, such as agricultural residues, lignocellulosic materials, and industrial waste [5]. This generation presents notable environmental and socio-economic advantages [6], including lower carbon emissions, reduced land-use conflicts, and enhanced resource efficiency [7]. Second-generation biofuels are derived from various types of biomass that are not suitable for human consumption, making them a more sustainable alternative to first-generation fuels. The key categories of biomass used in second-generation biofuel production include: agricultural and forestry residues, dedicated energy crops, organic waste [8]. These biomass sources are abundant, renewable, and environmentally friendly [9]. Their utilization helps reduce competition with food crops and supports circular economy principles by converting waste into valuable energy products.

The structural complexity of lignocellulosic biomass – composed primarily of cellulose, hemicellulose, and lignin – plays a critical role in determining its suitability and efficiency in conversion processes [10]. Cellulose provides a dense crystalline structure, hemicellulose adds to the matrix with its branched polysaccharides, and lignin acts as a protective, hydrophobic barrier that enhances rigidity and resistance to degradation. Understanding these structural components and their interactions is essential for optimizing pretreatment and hydrolysis methods, which are key steps in converting lignocellulose into fermentable sugars for biofuel production [11].

To enhance the efficiency of converting lignocellulosic biomass into fermentable sugars for second-generation biofuel production, various pretreatment methods are employed. Each technique targets the structural complexity of biomass to improve enzyme accessibility and hydrolysis. The main methods include: acid, alkaline, steam explosion and solvent-based pretreatments. Acid pretreatment typically involves dilute sulfuric or hydrochloric acid. This process hydrolyzes hemicellulose into simple sugars and disrupts the lignin structure. It is effective but can lead to the formation of fermentation inhibitors if not controlled [12]. Alkaline pretreatment with sodium hydroxide or ammonia helps remove lignin and extractives and increases porosity, improving cellulose digestibility. This method is particularly effective for biomass with high lignin content [13]. Steam explosion consist in biomass treatment with high-pressure steam followed by rapid depressurization. This mechanical and thermal shock breaks down cell wall structures, partially hydrolyzing hemicellulose and redistributing lignin. It is energy-efficient and widely used [14]. Solvent-based pretreatment involves organic solvents such as ethanol, methanol, or acetone, often combined with catalysts. It selectively dissolves lignin and hemicellulose, resulting in a relatively pure cellulose fraction. This method allows for lignin recovery and potential valorization [15].

Solvent-based, or organosolv, pretreatment has emerged as a highly promising approach for enhancing the bioconversion of lignocellulosic biomass into second-generation biofuels. One of its key advantages is the efficient removal of lignin, which significantly increases the accessibility of cellulose to enzymatic hydrolysis and improves the overall yield of fermentable sugars. Unlike conventional acid pretreatments, organosolv methods generate fewer fermentation inhibitors, leading to improved microbial activity and biofuel productivity. Additionally, this technique produces high-purity fractions of cellulose, hemicellulose, and lignin, which not only simplifies downstream processing but also opens up opportunities for the valorization of lignin into high-value biochemicals. Furthermore, organosolv pretreatment is applicable to a broad range of lignocellulosic feedstocks, offering flexibility and scalability for industrial applications. These features make solvent-based pretreatment an effective and attractive option in the development of advanced biofuel technologies [16; 17].

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Ukraine possesses significant potential for the production of second-generation biofuels through the utilization of lignocellulosic biomass. As a country with vast agricultural lands, Ukraine generates large volumes of biomass residues annually, much of which remains underutilized. Agricultural by-products such as wheat straw, corn stover, and sunflower husks represent a substantial and renewable source of lignocellulose.

The diversity and availability of these feedstocks, combined with Ukraine's favorable agro-climatic conditions, provide a strong foundation for the development of advanced biofuel technologies. The integration of lignocellulosic biomass into bioenergy systems can help reduce dependence on fossil fuels, improve waste management, and support the country's transition toward a low-carbon economy. Moreover, investment in second-generation biofuel production can stimulate rural development and innovation in the bioeconomy sector. Harnessing this potential through the implementation of modern pretreatment and conversion technologies, will be critical in unlocking the full energy value of Ukraine's biomass resources.

Therefore, the purpose of the work is to study the potential of domestic lignocellulosic raw materials for the effective conversion of its polysaccharides into second-generation bioethanol using a universal and flexible technology.

Materials and methods

The methodological approach is structured into three comprehensive components. The first component focuses on the development of a structured scheme for biomass classification, aimed at systematically categorising various types of lignocellulose biomass based on their origin and potential for energy or material recovery. This classification framework is tailored to the specific conditions of Ukraine, where the raw material base primarily includes residues from agriculture (such as straw, corn stalks, and sunflower husks), by-products from the forestry and wood processing industries (e.g., sawdust, bark, and logging residues), as well as dedicated technical and energy crops like miscanthus, switchgrass, and rapeseed. The proposed classification also takes into account regional availability, seasonal generation patterns, and logistical aspects relevant to collection and utilization. This component serves as the foundation for subsequent data analysis and prioritisation of biomass types with the highest potential for sustainable bioenergy production in the Ukrainian context.

The second component emphasizes the definition and selection of key parameters and indicators required to establish a reliable and coherent database. This includes criteria such as data quality, consistency, comparability, and relevance to different biomass categories.

The third component presents a step-by-step framework for data collection, including the identification of data sources, methods for acquiring both quantitative and qualitative information, and strategies for ensuring the accuracy and completeness of the dataset.

The second section of the methodological approach is dedicated to an in-depth analysis of the chemical composition and structural characteristics of lignocellulosic biomass. Particular attention is given to the identification and quantification of both structural components (such as cellulose, hemicellulose, and lignin) and non-structural or extractive substances. Standardised analytical protocols are employed to ensure data consistency and comparability, with methodologies aligned to internationally recognised TAPPI standards - specifically, T 222 cm-02 for lignin determination [18], T 211 om-02 for quantifying ash content [19]. To evaluate solubility in ethanol-benzene and 1% sodium hydroxide solution, TAPPI T 204 cm-97 [20] and T 212 om-12 [21] methods were used, which together made it possible to determine the content of extractive substances. The determination of cellulose content follows the classical Kurschner-Hoffer method [22]. The holocellulose content was measured using the chlorite method [23], while the hemicellulose content was estimated by subtracting the cellulose content from the total holocellulose.

For all chemical treatments, biomass samples are first crushed and screened to a uniform particle size of 0.5 to 1.0 mm to ensure accurate and uniform analysis.

This chemical characterization provides critical insights into the conversion potential and processing behaviour of various types of biomass feedstocks commonly found in Ukraine, including agricultural residues, forestry by-products, and cultivated energy crops.

The final stage represents a step-by-step analysis of the chemical transformation of lignocellulosic complexes under the influence of an environmentally safe mixture of glacial acetic

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acid and 30 % hydrogen peroxide in a ratio of 70 : 30 volume %. The treatment was performed at atmospheric pressure for 30–180 min. The solid:liquid ratio was 5:1 and 10:1 depending on the structure of the plant waste. The processing temperature was 95±3 °C. After treatment, the solid residue enriched in polysaccharide component was separated from the spent solution by filtration and washed with distilled water.

The evaluation of the effectiveness of pretreatment was carried out according to the values of the optimality of lignin removal, which were calculated by the formula [24]:

$$Opt_{lr} = \frac{D_d \cdot S_{lr}}{100}, \% \quad (1)$$

where D_d – the degree of delignification, which is calculated as $D_d = 100 - (\frac{B \cdot C}{A})$ and includes A – lignin content in biomass, %, B - substrate yield, %, C – residual lignin content in the substrate, %; S_{lr} – lignin removal selectivity, which is calculated as:

$$S_{lr} = \frac{B}{100-(A \cdot D_d)/100} \cdot 100, \% \quad (2)$$

Each experiment was performed three times under identical conditions to ensure the reliability and reproducibility of the results. The data obtained from these trials were used to calculate the mean values, with the relative error not exceeding 5 %.

Results and Discussion

Categorization of lignocellulosic biomass for assessing the potential for second-generation bioethanol production

Lignocellulose categorization is an important step in assessing the potential of biomass to meet bioenergy needs, in particular bioethanol production. The work considers the potential of various lignocellulosic biomass in the form of waste from the agro-industrial complex and forestry, as well as energy plants that are grown on the territory of Ukraine. Table 1 lists all biomass representatives that were used in the research.

All plant biomass types presented in the Table represent potential interest for the bioenergy sector due to their availability. Table 1 was based on the analysis of information materials on the website of the Ministry of Agrarian Policy and Food of Ukraine, as well as the Bioenergy Association of Ukraine. However, not all types are equally suitable for bioethanol production due to differences in structural characteristics and chemical composition. The variation in the chemical properties of lignocellulosic biomass necessitates the application of different pretreatment approaches to obtain a polysaccharide-rich substrate for subsequent biochemical conversion into bioethanol. The structure of the biomass also has an influence, as it can be fibrous or non-fibrous. This difference in structure affects the efficiency of the pretreatment.

Table

Categorization of lignocellulosic biomass

Category	Biomass Type	Source	Characterization	Approx. volumes (Mt/year)	Main producing regions	Bioethanol utilization prospects
Agricultural Residues	Cereal straw (wheat, barley, etc.)	Residues from grain harvesting	Abundant biomass with high content of cellulose and hemicellulose	~ 50	Vinnytsia, Poltava, Kharkiv, Kyiv, Dnipropetrovsk	High – efficient after pretreatment
	Corn cobs and stover	Maize harvesting residues	Abundant biomass with high content of cellulose and hemicellulose	~ 30	Poltava, Vinnytsia, Cherkasy, Chernihiv, Kyiv	High – efficient after pretreatment
	Stems of oilseed crops (sunflower, rapeseed)	Post-harvest field residues	Abundant biomass with high content of cellulose and hemicellulose	~ 25	Kirovohrad, Dnipropetrovsk, Vinnytsia, Khmelnytskyi, Poltava	High – efficient after pretreatment
	Husks	Waste from processing of cereal and oilseed grains	Biomass with high lignin and ash contents	~ 5	Vinnytsia, Poltava, Kharkiv, Kyiv, Dnipropetrovsk	Moderate – requires preprocessing steps
Food Industry Waste	Sugar beet pulp	Sugar production	Moist biomass with high sugar content	~ 4	Vinnytsia, Poltava, Khmelnytskyi, Cherkasy, Ternopil	Low - used as livestock feed

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Continuation of Table

	Fruit pomace	Juice and food processing	Moist biomass with high sugar content	~ 1	Zakarpattia, Vinnytsia, Odesa, Khmelnytskyi, Chernivtsi	Low - used as livestock feed
	Stone fruit shells (cherry, plum, apricot)	Fruit processing	Hard and lignified biomass with a high polysaccharide content	~ 0.2	Zakarpattia, Vinnytsia, Odesa, Chernivtsi, Khmelnytskyi	Moderate – requires intensive pretreatment
Industrial Waste	Potato peels and starch waste	Food industry	High starch content	~ 1.5	Zhytomyr, Lviv, Volyn, Chernihiv, Kyiv	Low – used as livestock feed
	Paper sludge	Paper and packaging industry	Multi-component system with low cellulose content	no data available	At all paper industry enterprises, of which there are more than 30 in Ukraine and in every region	Low – needs deep purification before processing
	Flax/kenaf shives	Processing of industrial crops	Biomass with a high cellulose content, produced in small quantities	no data available	Vinnytsia, Zhytomyr, Kyiv, Sumy, Kharkiv, and Cherkasy	From moderate to high – efficient after pretreatment but limited stock
Forestry Waste	Sawdust and wood chips	Wood processing, logging	High lignin content	~ 3	Lviv, Zakarpattia, Ivano-Frankivsk, Chernivtsi, Zhytomyr	Low – requires intensive treatment
	Bark and forest residues	Forest operations	Bulky and heterogeneous composition	~ 2	Lviv, Zakarpattia, Ivano-Frankivsk, Rivne, Zhytomyr	Low – heterogeneous composition
Energy Crops	Miscanthus	Energy crop cultivation	High biomass yield	~ 0.1	Pilot plantations: Kyiv, Poltava, Lviv	High – efficient after pretreatment

Agricultural residues show significant potential for bioethanol production due to the abundance of lignocellulosic materials. Effective pretreatment methods are generally crucial to unlock the fermentable sugars from these sources. Some residues, like sunflower husks, have moderate potential but might require specific preprocessing. Food industry wastes present a mix of opportunities for bioethanol production, but some types of biomasses, such as sugar beet pulp and fruit pomace, are fully consumed by a competing industry, and therefore cannot be considered as a source of alternative fuel. However, the stone fruit shells have no further use and are therefore of interest for bioprocessing. Such biomass is characterized by a very strong structure, which is lignified. Despite this, they contain polysaccharides, which are a potential source of sugars. Potato peels and starch waste, rich in starch, are good candidates for biorefinery, however, there is no surplus of such wastes today. Paper and cardboard waste, although cellulose-based, may contain pollutants of various origins, which requires complex cleaning steps before processing. Sawdust and wood chips, characterized by high lignin content, have low potential for bioethanol due to the need for intensive treatment. Bark and forest residues also have low potential due to their bulky and heterogeneous composition, making them potentially more suitable for heat generation. Dedicated energy crops are identified as having high potential for bioethanol production due to their high biomass yield and composition.

The classification from Table 1 serves as a methodological justification for the selection of research objects. It allows to show the place of specific types of biomass in a wider spectrum of lignocellulosic resources and creates a basis for further comparisons and practical recommendations. Based on the presented analysis, further research regarding the suitability of biomass for bioethanol production will focus on agricultural residues, specifically: cereal straw (Kyiv region), oilseed stalks (Kyiv region), stone fruit shells (Odesa region), and the stalks of an energy crop (Chernihiv region).

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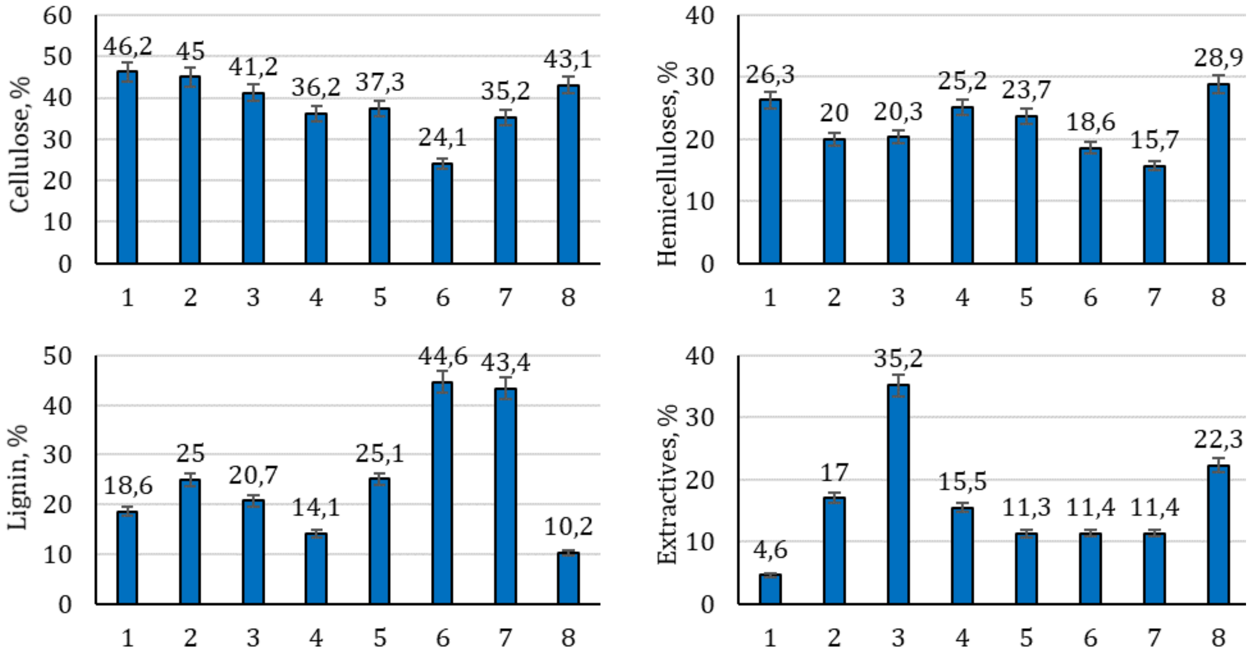
Assessment of biomass potential based on chemical composition analysis

The results of the study of the chemical composition of various representatives of lignocellulosic biomass are presented in Fig. 1. All the investigated biomass representatives are lignocellulosic materials with varying contents of structural and extractive components. Apricot and walnut shells are characterized by a higher lignin content (43 % and 44 %, respectively) compared to the other biomass types. Lignin is a complex, heterogeneous polymer that provides structural rigidity to the plant cell wall. Lignin is not fermentable into ethanol and acts as a major barrier to the enzymatic hydrolysis of cellulose and hemicellulose [25]. Therefore, in the case of lignified biomass, the biochemical conversion (fermentation) of the polysaccharide fraction into bioethanol will be complicated by the presence of the aromatic component (lignin).

Analyzing the mineral component content, it can be stated that it is the lowest in apricot shells and walnut shells (less than 1 %), which is undoubtedly desirable, as this indicator also influences the efficiency of biochemical conversion. High ash content can reduce the overall carbohydrate content available for conversion. Certain minerals can interfere with pretreatment processes [27], enzyme activity [26], or fermentation or even cause operational challenges [28].

Since the cellulosic fraction is of primary interest for conversion into bioethanol, fibrous agricultural wastes are the most attractive from this perspective. Based on the cellulose content values presented in Figure 1, cereal straw and energy crops are characterized by a high cellulose content, making them ideal sources of sugars for bioprocessing. Their cellulose content exceeds 40 %. A higher cellulose content generally leads to a higher potential yield of ethanol. However, the crystalline structure of cellulose and its association with lignin make it resistant to enzymatic breakdown, necessitating effective pretreatment [29]. In particular, different approaches to cellulose extraction have been explored, including conventional delignification techniques [30] as well as the use of ionic liquids [31] to effectively overcome the native recalcitrance of lignocellulose.

Hemicellulose is a branched heteropolymer consisting of various polysaccharides that, during hydrolysis, are converted into simple sugars, e.g. xylose, arabinose, mannose, galactose. Like cellulose, it can be partially hydrolyzed into fermentable sugars, contributing to the overall ethanol yield [32; 33]. However, the variety of sugars in hemicellulose requires a broader range of enzymes for complete hydrolysis [34]. The presented results indicate that straw and stalks of agricultural and industrial crops are characterized by a high hemicellulose content, in the range of 15.7–28.9 %.



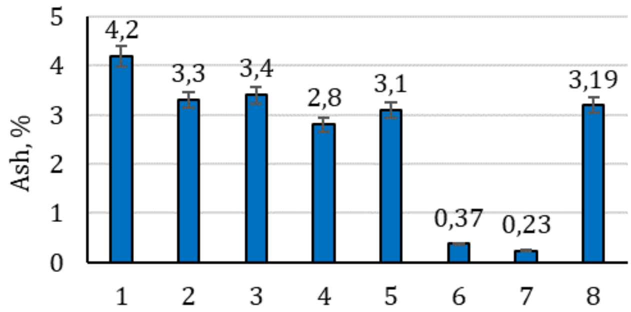


Fig. 1. Chemical composition of the most common representatives of lignocellulosic biomass: 1 – wheat straw, 2 – rye straw, 3 – sunflower stalks, 4 – corn stalks; 5 – rapeseed stalks, 6 – apricot shells; 7 – walnut shells, 8 – miscanthus stalks

For the efficient biochemical conversion of hexose polysaccharides, it is necessary to ensure adequate pretreatment of the biomass to weaken the lignin-polysaccharide chemical bonds or even perform delignification. For the delignification of biomass, it is advisable to choose efficient methods that not only allow the recovery of the polysaccharide fraction but also enable the isolation of lignin for further processing, in order to ensure a comprehensive approach to the valorization of all biomass components.

The effect of organosolv treatment on the selectivity of lignin removal

Peracetic acid delignification stands out as an effective and environmentally promising method for pretreating lignocellulosic biomass to enhance its suitability for subsequent biochemical conversion into valuable products like bioethanol. This method is highly effective in selectively dissolving lignin, causing minimal degradation of carbohydrate fractions. As a result of this treatment, lignin is removed, which visually causes the obtained product to change color from dark to light, indicating its enrichment in cellulose (Fig. 2). Partially or deeply delignified biomass can be used as a substrate for the biochemical conversion of polysaccharides into bioethanol.

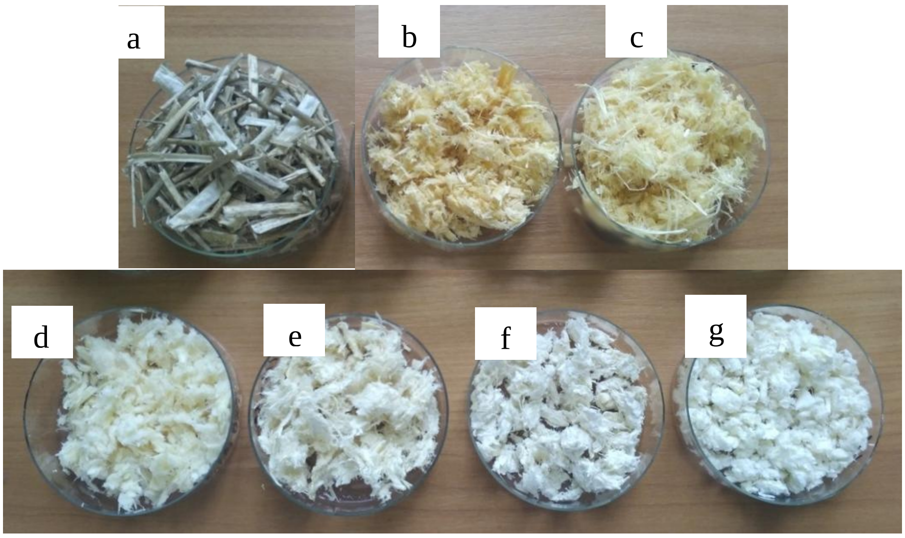


Fig. 2. Visualization of changes in the structure of rapeseed stalks without pretreatment (a) and with pretreatment by peracetic acid during 30 min (b); 60 min (c); 90 min (d); 120 min (e); 150 min (f) and 180 min (g)

The results of determining the substrate yield and assessing the residual lignin content are presented in Fig. 3. It is evident that in all cases, increasing the treatment time leads to a decrease in the substrate yield. A positive effect is observed on the lignin content, which also decreases with increasing treatment duration. Clearly, delignification reactions are occurring, leading to a reduction in the aromatic component content. However, the intensity of these reactions is determined by the type and structure of the biomass. For fibrous raw materials, particularly cereal straw, oilseed processing residues, and energy crops, this process is more effective than for non-fibrous raw materials, such as plant waste in the form of shells.

Apricot shells and walnut shells are characterized by a higher lignin content and a

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rigid, dense structure. All this limits the diffusion of peracetic acid into the biomass structure and the removal of oxidation products into the reaction mixture. Therefore, in all series of experiments, the obtained substrates based on shells are characterized by a higher content of residual lignin.

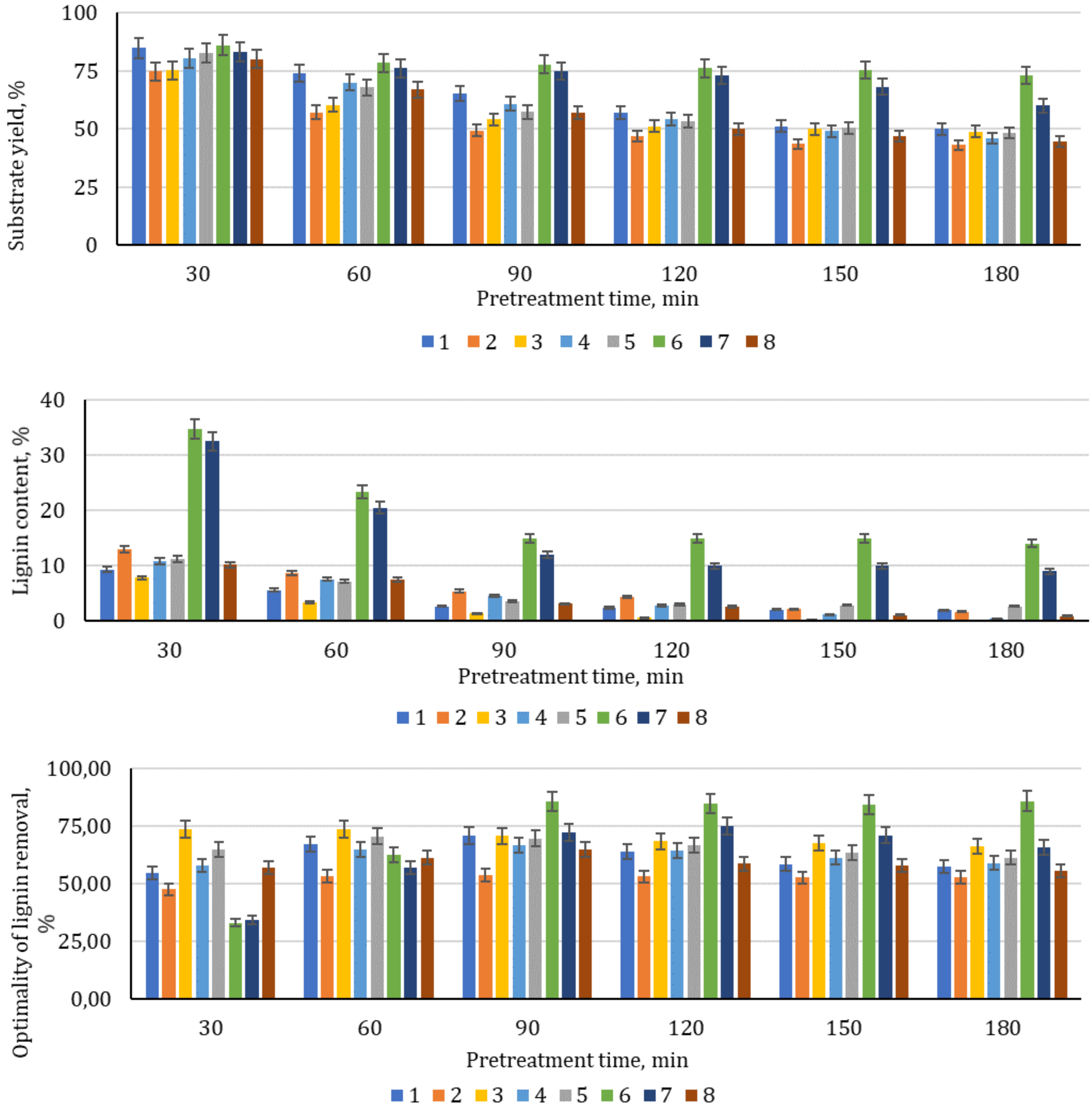

Fig. 3. Effect of pretreatment time on substrate properties based on different biomass: 1 – wheat straw, 2 – rye straw, 3 – sunflower stalks, 4 – corn stalks; 5 – rapeseed stalks, 6 – apricot shells; 7 – walnut shells, 8 – miscanthus stalks

Despite the higher residual lignin content, based on a comprehensive assessment of yield and aromatic component content, apricot shells and walnut shells still exhibit greater optimality in lignin removal. This indicates that in the case of shells, a larger portion of the polysaccharide component is retained within the substrate structure.

Overall, it is evident from Fig. 3 that the optimal lignin removal values for all samples exhibit a visual maximum within the 90–120 min time range. This suggests that increasing the pretreatment duration beyond this range is not advisable, as partial destruction of the polysaccharide component occurs alongside the delignification reactions, as indicated by the more intensive decrease in yield. Therefore, it can be recommended to carry out the delignification process for 90–120 minutes.

Thus, it has been demonstrated that peracetic acid pretreatment allows for the enrichment of biomass in cellulose, and therefore the obtained substrate can be effectively used for biochemical conversion into bioethanol.

The issue of the impact of the pretreatment stage on the economic efficiency of bioethanol

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production requires additional and deep evaluation. On the one hand, such a technological step will significantly increase the efficiency of enzymatic conversion by improving the availability of cellulose and hemicellulose for the action, which contributes to an increase in the yield of biofuel. On the other hand, a new cost element is added to the process – the cost of reagents, energy consumption, depreciation of additional equipment and disposal of secondary waste. Thus, the feasibility of implementing this stage should be assessed through the prism of the ratio between additional investments and productivity gains. Therefore, it is necessary to conduct comparative technical and economic calculations for different delignification schemes, including a life cycle analysis of production. Another important aspect is the use of non-standard agricultural raw materials, in particular apricot and walnut shells. Its high density and rich lignocellulosic composition make it promising for biofuel production. However, on an industrial scale, specific challenges arise: uneven supply due to seasonality, dispersion of raw material sources, transportation costs and the need for a centralized collection system. In addition, there is competition with other sectors that also actively use such biomass. Therefore, it is important to consider such raw materials not as the main, but as an auxiliary resource, focused on regions where there is a possibility of systematic procurement and use of such waste.

Therefore, the introduction of additional stages of pretreatment should be evaluated taking into account their complex impact on the cost, and the use of specific raw materials - through the prism of logistical and market restrictions. Such an approach will allow to form a realistic strategy for scaling up bioethanol production technologies in Ukraine.

Conclusions

Lignocellulosic biomass categorization is essential for identifying viable feedstocks for bioethanol production. Among the various types analyzed, agricultural residues and dedicated energy crops demonstrate the highest potential due to their high availability and favorable chemical composition, particularly high cellulose and hemicellulose content.

The variability in the structural and chemical characteristics of biomass influences its suitability for biochemical conversion. Fibrous residues, such as cereal straw and oilseed stalks, are more easily delignified and hydrolyzed, making them ideal candidates for bioethanol production. In contrast, non-fibrous and highly lignified materials, such as apricot and walnut shells, present greater resistance to pretreatment due to their rigid structure. Pretreatment with peracetic acid has proven to be a highly effective method for delignification of lignocellulosic biomass. It selectively removes lignin while preserving carbohydrate components, thereby improving enzymatic accessibility and facilitating subsequent fermentation. Optimal treatment time was found to be within the 90–120-minute range, which provides a balance between effective lignin removal and minimal polysaccharide degradation. Beyond this time, excessive treatment may lead to a reduction in substrate yield due to partial degradation of cellulose and hemicellulose.

While apricot and walnut shells demonstrated lower delignification efficiency due to diffusion limitations, they retained a relatively high proportion of polysaccharides in the final substrate, suggesting their potential value with process optimization.

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