COMPREHENSIVE SCIENTIFIC RESEARCH ON NEW VARIETIES OF INDUSTRIAL HEMP FOR MANUFACTURE OF HIGH-QUALITY INDUSTRIAL PRODUCTS

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Abstract. The study presents an in-depth materials-science evaluation of industrial hemp varieties Sofiya and Liryna aimed at determining their suitability for high-performance textile applications. The research encompassed quantitative assessment of stem morphology, fibre yield from scutched stalks, physico-mechanical behavior of scutched fibres, linear density parameters, and cellulose content. Advanced light microscopy was employed to analyze the fibre bundle morphology, characterize the structure of elementary fibres, and evaluate varietal differences in fibre arrangement and uniformity. The results indicate that the Sofiya variety demonstrates a higher number of elementary fibres per technical bundle, improved structural homogeneity and favorable mechanical characteristics, which cumulatively enhance its spinnability for medium to coarse yarn counts (Nm 2.8-3.5) and subsequent textile processing stages. The Liryna variety, while exhibiting slightly lower uniformity and cellulose content, maintains adequate strength and structural integrity for technical yarns and specialized textile materials. The findings expand the understanding of the structure–property relationships of hemp fibres and highlight the technological potential of both varieties. The study provides a scientific basis for optimizing the fibre-extraction techniques, improving upstream processing parameters, and increasing the efficiency of yarn formation and textile material engineering. Integrating morphological, mechanical and chemical analyses is emphasized as a key approach for selecting and tailoring hemp raw materials for industrial-scale textile applications.

Keywords: industrial hemp, Sofiya variety, Liryna variety, scutched fibre, fibre morphology, cellulose content, linear density, mechanical properties, yarn formation, textile materials.

Introduction

The modern textile industry is undergoing an active search for environmentally safe, renewable, and high-quality raw materials capable of ensuring the production of competitive materials with enhanced performance properties. In this context, industrial hemp is attracting particular attention as a promising plant crop characterized by high productivity, rapid biomass renewal, and wide industrial applicability [1-3]. Hemp fibre is distinguished by increased tensile strength, wear resistance, hygroscopicity and biological stability, which determine its relevance for textile production of various end uses. Among domestic varieties of industrial hemp, the Sofia and Liryna cultivars are of significant scientific and practical interest due to their stable yields, high bast fibre content, and potential suitability for textile material production. However, the final quality of hemp fibre is largely determined not only by varietal characteristics but also by the efficiency of biological and technological processing stages, including retting, the degree of fibre bundle separation, scutching, and secondary mechanical treatment.

Industrial processing practice shows that even when sufficiently high tensile strength values of scutched fibre are achieved, significant variations in linear density are often observed, which do not always comply with the established normative requirements. Such deviations may result from incomplete biochemical degradation of pectic substances during retting or insufficient mechanical action during fibre separation [4-6]. Consequently, these factors complicate subsequent stages of textile processing, particularly carding and spinning, and adversely affect the consistency of the final product quality.

At the same time, the available scientific literature lacks systematized data on the comparative technological evaluation of retted stems and fibres of specific industrial hemp varieties, including Sofia and Liryna, from the perspective of their spinnability. Insufficient investigation of the relationships between varietal characteristics, primary processing parameters, and fibre quality indicators hinders the rational selection of raw materials for the production of textile fabrics with predetermined properties.

In this regard, conducting a comprehensive assessment of the quality characteristics of retted stems and fibres of the Sofia and Liryna industrial hemp varieties, determining their technological suitability for spinning and identifying the factors that limit or enhance the efficiency of their use in the textile industry are highly relevant. The aim of this study is to establish the structure–property relationships between the morphological, physico-mechanical, and chemical characteristics of scutched fibres of the

Sofiya and Liryna industrial hemp varieties obtained under real industrial processing conditions, and to determine their technological suitability for the production of medium- and coarse-count textile yarns.

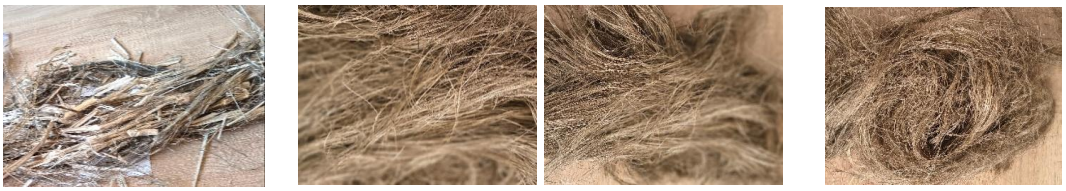
The scientific novelty of this study lies in establishing an integrated structure–property relationship between the morphological organization, physico-mechanical performance, and chemical composition of scutched fibres of the Sofiya and Liryna industrial hemp varieties processed under real industrial conditions. The work provides a comprehensive correlation between elementary fibre distribution within technical bundles and the influence on spinning performance.

Materials and methods

The object of the study was scutched fibre of industrial hemp (Cannabis sativa L.) varieties Sofia and Liryna, obtained after primary mechanical processing of the stems. The investigated raw material originated from crops sown in 2023 and harvested in 2024.

After harvesting, the hemp stems were mown into windrows and left under open-air conditions to form retted stems through field maceration. During field retting, partial degradation of incrusting substances binding the bast fibres to the woody core occurred under the influence of naturally occurring microorganisms and climatic factors, creating favourable conditions for efficient fibre separation.

Mechanical processing of the retted stems was carried out in April 2025 using an industrial Wanhawert scutching line (Belgium). As a result of primary processing, two fibre fractions were obtained: long scutched fibre and short fibre, which were used for further investigation of quality characteristics. The general appearance of the investigated scutched fibre is shown in Fig. 1.



a b c

Fig. 1. **Samples of hemp raw material:** a – Mechanically broken retted stems of industrial hemp; b – Industrial hemp fibre of the Sofia variety; c – Industrial hemp fibre of the Liryna variety

Quality assessment of hemp raw materials, retted stems, and fibres was carried out using adapted methodologies developed on the basis of classical approaches applied to bast fibre crops [7; 8]. The methodological framework of the study was based on general testing principles traditionally used for hemp raw materials, which were employed solely as guidelines for the development of experimental procedures and not for regulatory or normative purposes.

The determination of the main quality indicators was performed using an author-developed methodology, harmonized with the current Ukrainian technical specifications for oil flax straw, retted stems, and fibre. The adaptation of these methodologies for hemp was based on the morphological and structural similarity of bast fibres of flax and hemp, as well as on the similarity of their primary processing technologies [9-11].

During the study, the following parameters were determined:

- for retted stems: degree of maceration, uniformity of incrusting substance degradation, integrity of fibre bundles, and ease of fibre separation from the woody core;
- for long scutched fibre: linear density, tensile strength, fibre length, and mass uniformity;
- for short fibre: fineness, degree of cleanliness, and content of non-fibrous impurities.

The linear density of the fibre was determined by weighing samples of a fixed length followed by recalculation into standard textile units. Tensile properties were evaluated based on fibre bundle tensile tests conducted under laboratory conditions. Fibre cleanliness was assessed visually and gravimetrically by determining the proportion of residual shives and other impurities [12; 13].

All tests were performed under standardized laboratory conditions of temperature and relative humidity. Each measurement was carried out in no fewer than three replicates. The obtained results were processed using descriptive statistical methods to determine mean values and variability indicators. All

recorded measurements were included in statistical processing. Arithmetic means and standard deviations were calculated using descriptive statistical analysis.

The applied set of methods ensured an objective evaluation of the quality characteristics of retted stems and fibres of industrial hemp varieties Sofia and Liryna and enabled the determination of their technological suitability for further textile processing, particularly spinning.

Results and discussion

The technological suitability of hemp largely depends on the quality characteristics of retted stems and scutched fibre, which are formed as a result of the interaction between the biological features of the variety and the conditions of primary stem processing. For the Sofia and Liryna varieties, particularly important parameters include the stem length, the degree of retted stem disruption, the extent of fibre bundle separation, and the compliance of mechanical properties with textile industry requirements. Since retting, maceration, and scutching processes directly affect the structural and physico-mechanical characteristics of fibres, their scientific evaluation is essential for determining the technological potential of the raw material.

Within this study, the research focused on analyzing the quality characteristics of broken retted stems and scutched fibre of the Sofia and Liryna hemp varieties, obtained under real production conditions at Ma'Rijany Hemp Company, using a Wanhawert scutching line.

The experimental work was carried out in the testing laboratory of the Department of Light Industry Technologies at the Lutsk National Technical University, where the quality of broken retted stems and the obtained fibres was assessed. Key measured parameters included the length of retted stems and a set of fibre characteristics determining their suitability for subsequent textile processing.

Thus, this part of the study aimed to provide a comprehensive understanding of the conditions under which raw materials are formed and the technological factors influencing their quality, forming a basis for further analysis of the properties of fibres from the Sofia and Liryna varieties.

Further work focused on determining the length of broken retted stems of industrial hemp, which is one of the key parameters for assessing the quality of the raw material and its suitability for subsequent technological operations. The measured values are presented in Table 1.

Table 1

Measured lengths of retted stems in sample handful

No.	Stem length, cm	No.	Stem length, cm	No.	Stem length, cm	No.	Stem length, cm
1	86.5	10	87.3	19	92.5	28	82.8
2	81.0	11	89.0	20	84.5	29	92.0
3	87.5	12	91.5	21	86.5	30	87.0
4	71.4	13	83.6	22	95.5	31	93.0
5	87.0	14	78.0	23	93.5	32	84.5
6	83.0	15	81.0	24	64.5	33	74.0
7	86.0	16	75.0	25	75.5	34	69.0
8	53.0	17	48.5	26	92.5	-	-
9	84.6	18	83.7	27	85.0	-	-
Mean stem length:		82.5					
Standard deviation (SD)		10.8 cm					
Coefficient of variation (CV)		13.1%					
Standard error (SE)		1.85 cm					
95% Confidence interval (CI)		78.7-86.3 cm					

Analyzing the experimental data presented in Table 1, it can be noted that the lengths of broken retted stems of industrial hemp exhibit a fairly wide range, from 48.5 cm to 95.5 cm. Such variability is characteristic of field-retted raw materials, as the uniformity is influenced by plant growth characteristics, sowing density, weather conditions during the vegetation period, and the conditions under which the stems were formed into windrows. The mean stem length was 82.5 ± 10.8 cm (n = 34; CV = 13.1%). The 95% confidence interval ranged from 78.7 to 86.3 cm, indicating moderate variability

typical for field-retted raw materials. The overall mean stem length of 82.5 cm indicates a high level of preservation of the anatomical structure of the bast portion after retting and primary mechanical disruption. For the scutching process and subsequent carding, it is important that most of the measured values fall within 75-95 cm, which corresponds to the optimal parameters for obtaining long scutched fibres.

From a technological perspective, stem lengths exceeding 80 cm provide the following advantages:

- facilitation of quality separation of fibre bundles during carding;
- reduced proportion of short fractions during scutching;
- high yield of long fibre fractions;
- lower fibre losses during mechanical cleaning;
- more uniform formation of the sliver before spinning.

Considering the mean length and the structure of the variation range, it can be concluded that this batch of retted stems is technologically suitable for the production of semi-rough yarn of approximate count No. 2.8-3.5, as well as coarser yarns of higher counts. This confirms the potential of the obtained fibre for the production of technical and household textile materials, including upholstery, decorative, and blended fabrics based on hemp fibres.

With additional optimization of the scutching process and control of moisture during processing, an increase in the yield of long fibre fractions and improvement of their performance properties can be expected, which is a crucial factor for subsequent use in spinning production.

Such stem lengths allow predicting the potential for combing spinning, which may result in:

- Yarn No. 33 (30 tex): suit fabrics;
- Yarn No. 30 (33 tex): medium-density jersey fabrics, which, in combination with cotton or spandex fibres, can improve elasticity, softness, and stretchability. To achieve this, hemp fibres should be blended with other natural or synthetic fibres with lower linear density, such as cotton, flax cotonnin, or polyester. This enables the production of yarn suitable for fine textile fabrics;
- Yarn No. 20 (50 tex): dense coat fabrics.

The main factors influencing yarn count from hemp fibres are also the technological processes of primary and secondary processing. Therefore, it is important to monitor the intensity of mechanical regimes, especially during secondary processing (carding).

The next stage of the study focused on determining the fibre yield from retted hemp stems, which is one of the key indicators of the efficiency of primary processing and characterizes the proportion of bast fibre suitable for technological use. Fibre yield directly depends on the biological properties of the variety, the degree of retting, the extent of pectic substance degradation, and the quality of mechanical scutching. The evaluation was carried out in accordance with standards, ensuring that the obtained data can be correctly compared with the established standards. The results of fibre yield determination for the investigated samples are presented in Table 2.

Table 2

Measured fibre yield from retted hemp stems

Measured value, %							Mean
54.7	51.2	45.8	37.4	39.2	47.4	58.9	47.8

The results presented in Table 2 indicate that the initial calculation of the fibre yield from retted hemp stems was 47.8%. However, this value is overestimated, as it was determined on already broken stems, from which part of the woody core had been lost during prior mechanical processing. Under such conditions, the mass fraction of fibre relative to the remaining stem artificially increases, which does not reflect the actual technological potential of the raw material.

To obtain more accurate data, an additional manual selection of intact stem fragments up to 20 cm in length was performed. These segments fully preserved the natural structure, including the proportion of bast and woody tissues. Subsequent determination of fibre yield based on this material showed a mean value of 34.7%, which is much closer to the actual biological potential of the Sofia and Liryna hemp varieties.

The reduction of almost 13% compared to the initial calculation highlights several important factors:

- impact of stem damage on calculation accuracy: broken stems contain less woody core, automatically increasing the proportion of fibre in the sample mass;
- varietal sensitivity to mechanical destruction during retting and scutching, as uneven separation of bast can influence the results;
- need for a standardized approach to fibre yield determination. The study clearly demonstrates that accurate results can only be obtained using intact or controlled-prepared raw material.

Thus, the value of 34.7% is more valid for evaluating the Sofia and Liryna varieties and represents the typical yield of long fibres suitable for textile use. This confirms the suitability of the investigated varieties for further technological stages, including the production of semi-rough and coarse yarns.

For a comprehensive assessment of the technological suitability of Sofia and Liryna hemp fibres, the key physico-mechanical quality parameters of scutched fibres were determined.

The evaluation included analysis of the structural and mechanical properties of scutched fibres, allowing for determination of the material's compliance with the spinning requirements and assessment of the potential of each variety for the production of textile yarns with different linear densities. The obtained results are presented in Table 3.

Table 3

Quality characteristics and parameters of scutched fibres of industrial hemp varieties Sofia and Liryna

No.	Parameter	Indicator value									
		Sofia variety					Liryna variety				
1	Tensile strength, daN	14.2	14.8	13.8	15.2	14.7	15.3	14.9	16.1	15.3	15.7
Mean value		 14.5					 15.4				
2	Linear density, tex	65.26					77.18				
3	Cellulose content, %	70.97		73.43			68.70		70.34		
											
Mean value		72.20					69.52				

The results of the study on the physico-mechanical properties of scutched fibres of industrial hemp varieties Sofia and Liryna allow for a comparative assessment of their technological suitability and potential use in textile production. The tensile strength of Sofia fibre ranges from 14.2 to 15.3 daN, while for Liryna it varies between 13.8 and 16.1 daN. The mean values are 14.5 daN for Sofia and 15.4 daN for Liryna. These values comply with the established norms for bast fibres, where the acceptable range is 14.0-29.5 daN, indicating a sufficiently high level of strength for both varieties. Comparative analysis shows a slightly higher tensile strength for Liryna, which may indicate better structural integrity and a more favorable degree of fibre bundle separation.

The linear density of scutched fibre is 65.26 tex for Sofia and 77.18 tex for Liryna. Elevated density values compared to normative requirements suggest the presence of residual incrusting substances, insufficient mechanical cleaning, or incomplete separation of elementary fibres. This indicates that the

primary technological processes (scutching, retting) did not provide optimal fibre fineness. Therefore, the Sofia variety demonstrates slightly lower coarseness, which is a positive factor for subsequent spinning of semi-rough yarns.

Fig. 2. **Analysis of cellulose content in hemp fibre**

Analysis of cellulose content, determined by alkaline cooking (Fig. 2), yielded mean values of 72.2% for Sofia and 69.52% for Liryna. Cellulose content is a key quality indicator of bast fibre, as it determines the fibre strength, elasticity, and technological value in textile material production. The higher value in Sofia suggests potentially better chemical purity and a lower content of pectins and incrusting substances, positively affecting cooking, softening, and subsequent spinning processes. In Liryna, despite higher tensile strength, the slightly lower cellulose content may be associated with uneven stem maturation or varietal biological characteristics.

Overall, the study indicates that the Liryna variety exhibits higher tensile strength, reflecting good mechanical stability, while Sofia demonstrates lower linear density and higher cellulose content, making it more promising for producing finer and higher-quality fibre suitable for semi-rough yarn. Both varieties comply with the strength standards; however, optimization of primary processing is required to reduce the linear density and improve the separation of elementary fibres.

The next stage of the study focused on a detailed investigation of the morphological characteristics of scutched fibres of Sofia and Liryna hemp varieties using light microscopy. Microscopic analysis is an important tool for assessing the structural organization of bast fibres, evaluating the degree of fibre bundle separation, measuring the thickness of elementary fibres, checking the bundle uniformity, and detecting residual incrusting substances after primary mechanical processing (Fig. 3 and 4).

Such analyses enable visualization of the internal structure of the plant material, identification of characteristic features of each variety, and determination of factors that may affect the quality of scutched fibres and their suitability for subsequent technological processes, including carding and spinning.

Fig. 3. **Light microscopy of Sofia variety**

The micrograph shows a bundle of bast fibres with clearly distinguishable elementary fibres. The bundle structure is characterized by a relatively loose arrangement, indicating effective degradation of pectic bonds during retting and scutching. The elementary fibres exhibit a more rounded cross-sectional shape and thinner cell walls. A greater number of fine fibres are observed within a single bundle, contributing to improved uniformity and potentially facilitating the formation of more even sliver during carding. Overall, the microstructure demonstrates good homogeneity and structural uniformity.

The micrograph presents fibre bundles with a denser packing of elementary fibres. The number of elementary fibres per bundle is lower compared to the Sofia variety. Increased cell wall thickness and greater variability in the fibre shape are observed, which may indicate higher structural rigidity. The lower degree of separation between elementary fibres suggests the possible presence of residual incrusting substances or an inherently denser bundle structure, which may complicate further carding and spinning processes. Microscopic observations were performed at ×200 and ×400 magnification. A

total of 20 fibre bundles from each variety were analysed. The obtained microscopic images allowed identification of distinct structural features characteristic of each variety.

Fig. 4. **Light microscopy of Liryna variety**

Analysis of the fibre microstructure revealed that the Sofia variety exhibits a higher number of elementary fibres within the primary bundle compared to Liryna. The elementary fibres of Sofia tend to be more naturally separated, indicating more uniform degradation of pectic components during retting and scutching. In contrast, Liryna displays fewer elementary fibres per bundle with tighter packing, which may indicate insufficient biodegradation of incrusting substances or higher natural rigidity of the bundles. Microscopic analysis also revealed that Sofia fibres have a thinner average wall thickness and a more rounded cross-sectional shape, whereas Liryna fibres exhibit slightly greater wall thickness and more variable shapes, which may contribute to increased rigidity. These characteristics confirm the potentially superior spinning properties of Sofia, as a larger number of fine, well-separated elementary fibres produces a more uniform yarn with lower variation. Overall, the results of light microscopy highlight significant morphological advantages of the Sofia variety in terms of further textile applications and support its suitability for the production of high-quality yarn.

The comparative analysis of the Sofiya and Liryna industrial hemp varieties demonstrates distinct technological orientations for textile applications. The Sofiya variety, characterized by a lower linear density, higher cellulose content, and a greater number of well-separated elementary fibers within technical bundles, exhibits improved structural homogeneity, which is critical for uniform sliver formation and stable spinning performance. These features indicate its higher suitability for the production of medium-count and semi-coarse yarns where evenness, reduced yarn irregularity, and controlled fibre cohesion are essential. In contrast, the Liryna variety demonstrates slightly higher tensile strength and more compact bundle organization, suggesting enhanced mechanical stability and making it more appropriate for technical yarns and textile materials requiring increased strength and rigidity. The results also highlight the necessity of optimizing retting and scutching regimes to improve elementary fibre separation and reduce excessive linear density, which directly affects carding efficiency and yarn formation. Overall, structural homogeneity and the degree of fibre bundle separation appear to be key predictors of spinning quality, confirming the importance of integrating morphological and mechanical evaluation for selecting hemp varieties in industrial-scale textile production.

Conclusions

The conducted study of the industrial hemp varieties Sofia and Liryna allowed a comprehensive assessment of their quality and technological characteristics for textile applications. The main conclusions are as follows.

1. Stem length of retted hemp: The mean value of 82.5 cm indicates the feasibility of applying secondary technological processes, such as fibre cleaning and carding, to obtain long scutched fibres suitable for producing semi-rough yarn (count No. 2.8-3.5).
2. Fibre yield from retted stems: The initial value of 47.8% was overestimated due to evaluation of already damaged stems. Determination based on intact stem segments (mean value 34.7%) provided a more accurate estimate of raw material productivity.
3. Physico-mechanical characteristics of scutched fibres: The tensile strength of fibres from Sofia (14.5 daN) and Liryna (15.4 daN) complies with normative requirements (14.0-29.5 daN), indicating sufficient fibre strength for spinning. The measured linear density highlights the need to optimize fibre extraction processes to achieve standard values.

4. Cellulose content of fibres: Sofia demonstrated a mean value of 72.2%, while Liryna showed 69.52%, confirming the suitability of the fibres for yarn and textile material production.
5. Light microscopy analysis: The Sofia variety exhibits a higher number of elementary fibres per bundle compared to Liryna, indicating its potential for producing high-quality yarn.

Overall, the study results demonstrate the economic and technological feasibility of using the Sofia variety for the production of textile materials with medium and coarse yarn counts, while the Liryna variety may be applied in the manufacture of yarns and fibres for specialized technical applications. The obtained data provide a basis for further research aimed at improving the efficiency of mechanical processing and optimizing technological processes for industrial hemp fibre production.

Author contributions

Conceptualization, B.H.; methodology, H.T.; software, B.H.; validation, P.V.; formal analysis, Sh.O.; investigation, H.T.; data curation, H.T.; original draft preparation, B.H.; writing – review and editing, Sh.O.; visualization, B.Yu,; and project administration, B.H. All authors have read and agreed to the published version of the manuscript.

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