ASSESSMENT OF SUITABILITY OF FLAX PULP FOR PRODUCTION OF FOOD PACKAGING PAPER

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Abstract. The growing demand for sustainable and safe materials for food packaging has intensified interest in non-wood cellulose sources. Flax biomass represents a promising alternative due to its high cellulose content and relatively low lignin content compared to wood-based raw materials. This study evaluates the suitability of cellulose obtained from fiber flax and oilseed flax through alkali and soda treatments for the production of paper intended for food-contact applications. Fourier Transform Infrared (FTIR) spectroscopy was used as a qualitative tool to assess functional groups, chemical structure, and general purity of the obtained cellulose. The FTIR spectra are consistent with a polysaccharide-dominated structure, indicating preservation of β-1,4-glycosidic bonds and the presence of hydroxyl groups essential for fiber bonding and paper strength. No dominant high-intensity bands typically associated with non-cellulosic components were observed, suggesting a reduction of accompanying constituents. The results indicate that flax-derived cellulose has a favourable chemical profile for food packaging paper and represents a promising non-wood alternative to conventional wood-based pulp, subject to further technological and safety evaluation. The use of agricultural flax residues for pulp production also contributes to the valorisation of biomass and reduction of pressure on forest resources. Such an approach supports the development of more sustainable and resource-efficient packaging materials for the food industry.

Keywords: flax pulp, cellulose, food packaging paper, FTIR spectroscopy, non-wood fibers, alkaline treatment.

Introduction

The development of sustainable materials for food packaging has become a major research priority due to the environmental burden associated with petroleum-based plastics and the intensive use of forest resources for conventional paper production. In this context, lignocellulosic biomass from agricultural crops is increasingly considered a renewable raw material for biodegradable fiber-based materials and paper products [1; 2].

Non-wood biomass has attracted particular interest in the pulp and paper sector because many agricultural residues contain substantial amounts of cellulose and, in some cases, lower lignin content than wood, which may simplify chemical pulping and reduce the severity of treatment conditions [1; 3; 4].

Among these resources, flax biomass is regarded as especially promising. Flax stems are characterised by a high cellulose content and relatively low lignin content compared with many woody plants, which increases their technological attractiveness for pulp production. In addition, flax cultivation is widespread in many agricultural regions, and considerable volumes of stem residues remain underutilised after fiber or seed harvesting [5-7].

Recent studies have demonstrated that agricultural crop residues, including flax stems, can be effectively converted into various value-added products. In particular, Yaheliuk and Fomich [9] investigated the optimisation of fuel rolls produced from crop residues using a comprehensive quality indicator, showing that the structural characteristics of plant biomass and technological processing parameters significantly affect the quality of the final product. Further research by Yaheliuk et al. [10] confirmed that agricultural stem biomass can be successfully processed into energy-efficient materials when technological conditions are properly optimised. These studies highlight the broader potential of flax biomass as an industrial resource and demonstrate that crop residues should be considered not as waste, but as a valuable raw material.

One of the promising directions of biomass valorisation is the production of cellulose pulp suitable for paper manufacturing. Compared with many other non-wood plants, flax stems contain relatively low lignin content, which facilitates the removal of non-cellulosic components during pulping and increases the suitability of flax fibers for paper production [3; 4; 11]. These characteristics make flax biomass a promising alternative raw material for the production of cellulose pulp intended for paper-based packaging materials.

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For food packaging applications, however, not only the availability of fiber resources is important but also the chemical purity and structural integrity of the isolated cellulose. Residual lignin, hemicelluloses and extractive substances may affect the colour, strength and hygienic properties of paper materials intended for contact with food products [3; 4; 10]. Therefore, the selection of appropriate chemical treatment methods plays a key role in obtaining purified cellulose suitable for such applications.

The evaluation of cellulose structure and purity requires reliable analytical methods. Cellulosic fibers exhibit a complex hierarchical structure that influences their behaviour during pulping, paper formation and recycling processes [11]. Natural plant fibers such as flax contain cellulose as the main structural component, together with hemicelluloses and lignin, which determine the physicochemical properties of fiber-based materials [12]. The structural organisation of cellulose, including the arrangement of polymer chains and the degree of crystallinity, significantly affects the mechanical and thermal properties of cellulose-based materials [13]. Modern instrumental analytical approaches have proven effective in the characterisation of materials in various technological fields. For example, Artyukh et al. [14] demonstrated the effectiveness of spectroscopic methods in determining the structural composition of materials, highlighting the broader applicability of advanced analytical techniques for material characterisation. Fourier Transform Infrared (FTIR) spectroscopy is widely used for the identification of functional groups and for confirming the preservation of β-1,4-glycosidic bonds forming the cellulose macromolecule. In addition, FTIR analysis enables the identification of characteristic absorption bands associated with cellulose structure and provides valuable information about chemical modifications occurring during fiber processing [15]. Complementary techniques such as X-ray diffraction (XRD) are frequently applied to evaluate the crystalline structure of cellulose and to determine the distribution of cellulose polymorphs within plant fibers [16].

Despite the growing interest in the utilisation of agricultural biomass, the potential of cellulose obtained from flax residues for the production of food packaging paper has not been sufficiently investigated, particularly with regard to the structural integrity of cellulose after different chemical treatments. In particular, further investigation is required to evaluate the structural characteristics of cellulose isolated from different flax biomass sources and to determine the influence of chemical treatment methods on the preservation of cellulose structure.

Therefore, the aim of this study was to assess the suitability of cellulose obtained from fiber flax and oilseed flax for the production of paper intended for food packaging applications using FTIR-based structural analysis.

Materials and methods

Flax fibers used in the study were obtained from oilseed flax cultivar Aisberg grown on the experimental field of the university and from fiber flax cultivar Miandr cultivated both on the university field and on a local farm. The plant material was used as a raw source for cellulose extraction.

Cellulose was isolated from flax fibers using a standard pulping procedure commonly applied for lignocellulosic biomass processing. Two sets of samples were prepared. The first set was treated using an alkaline method based on sodium hydroxide (NaOH), while the second set was processed using a soda method with sodium bicarbonate ($NaHCO_3$). These chemical treatments were applied to remove accompanying non-cellulosic components while preserving the structural integrity of the fibers. The treatments were performed using 10% aqueous solutions of NaOH and $NaHCO_3$. Thermal processing was carried out under conditions of moderate boiling of the solution for 60 minutes at atmospheric pressure. After treatment, the samples were thoroughly washed with distilled water until neutral pH was reached. The FTIR spectra of cellulose obtained from fiber flax cultivar Miandr (university and farm samples) and oilseed flax cultivar Aisberg (university sample) after alkaline and soda treatments were recorded using an IRAffinity-1S Fourier transform infrared spectrophotometer (Shimadzu, Japan) equipped with a QATR-10 attenuated total reflectance (ATR) accessory. The spectra were measured in the wavenumber range of 4000-400 cm^{-1} with a spectral resolution of 4 cm^{-1}. Each spectrum was recorded as an average of 32 scans to improve signal stability.

For spectral measurements, the samples were placed on the working surface of the ATR crystal (Crystal Puck) mounted in the magnetic holder of the QATR-10 unit and evenly distributed as a thin layer over the contact area. To ensure proper optical contact between the sample and the crystal surface, the samples were pressed against the ATR crystal using the built-in pressure clamp of the ATR accessory.

Results and discussion

The FTIR spectra of cellulose obtained from fiber flax cultivar *Miandr* (university and farm samples) and oilseed flax cultivar *Aisberg* (university sample) after alkaline and soda treatments are presented in Figs. 1–3. The spectra of the university sample of fiber flax *Miandr* are shown in Fig. 1, the farm sample in Fig. 2, and the oilseed flax *Aisberg* sample in Fig. 3.

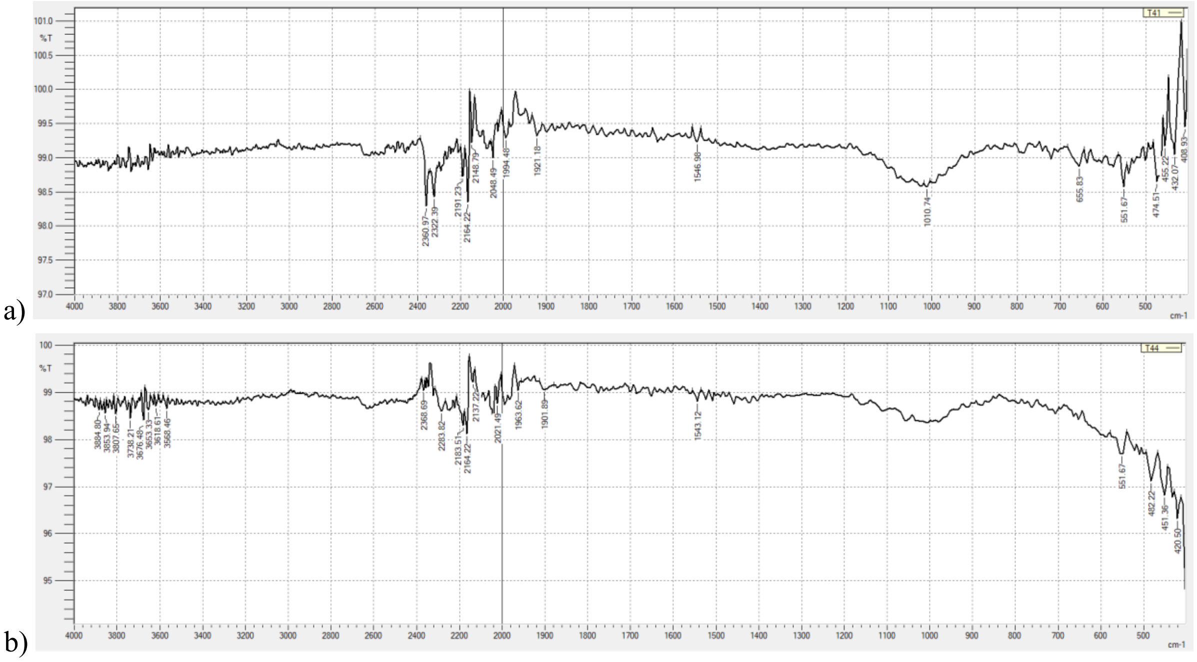

Fig. 1. **FTIR spectra of fiber flax cultivar *Miandr* (university sample):**
a – NaOH treatment; b – $NaHCO_3$ treatment

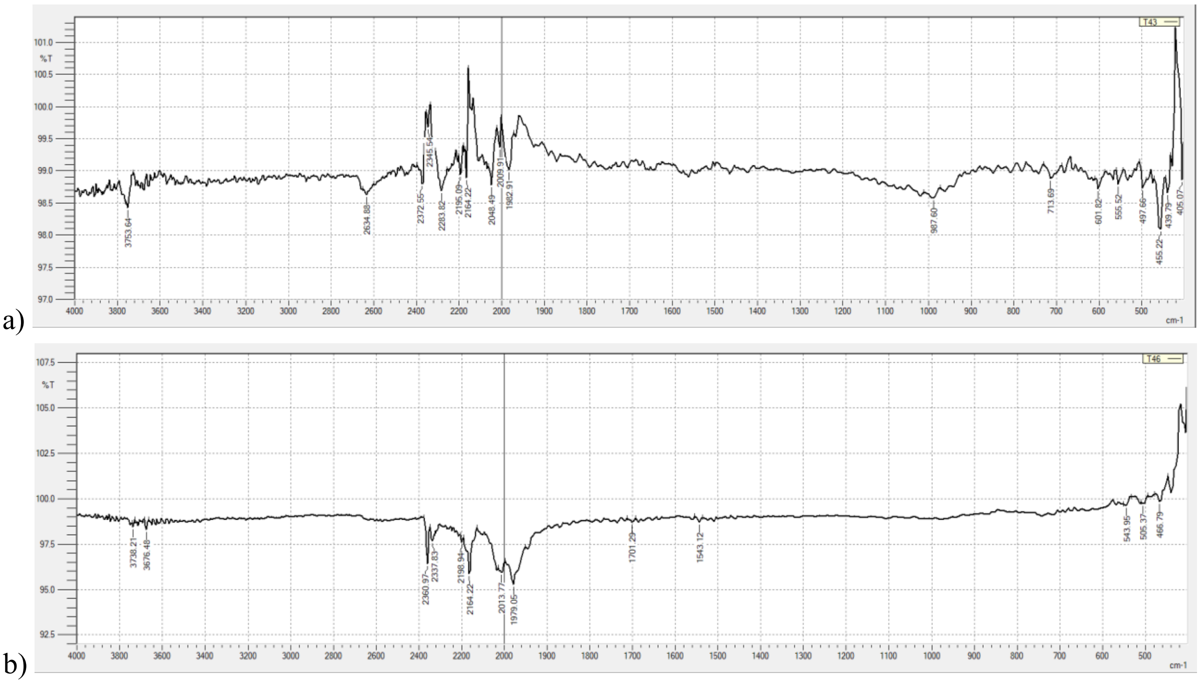

Fig. 2. **FTIR spectra of fiber flax cultivar *Miandr* (farm sample):**
a – NaOH treatment; b – $NaHCO_3$ treatment

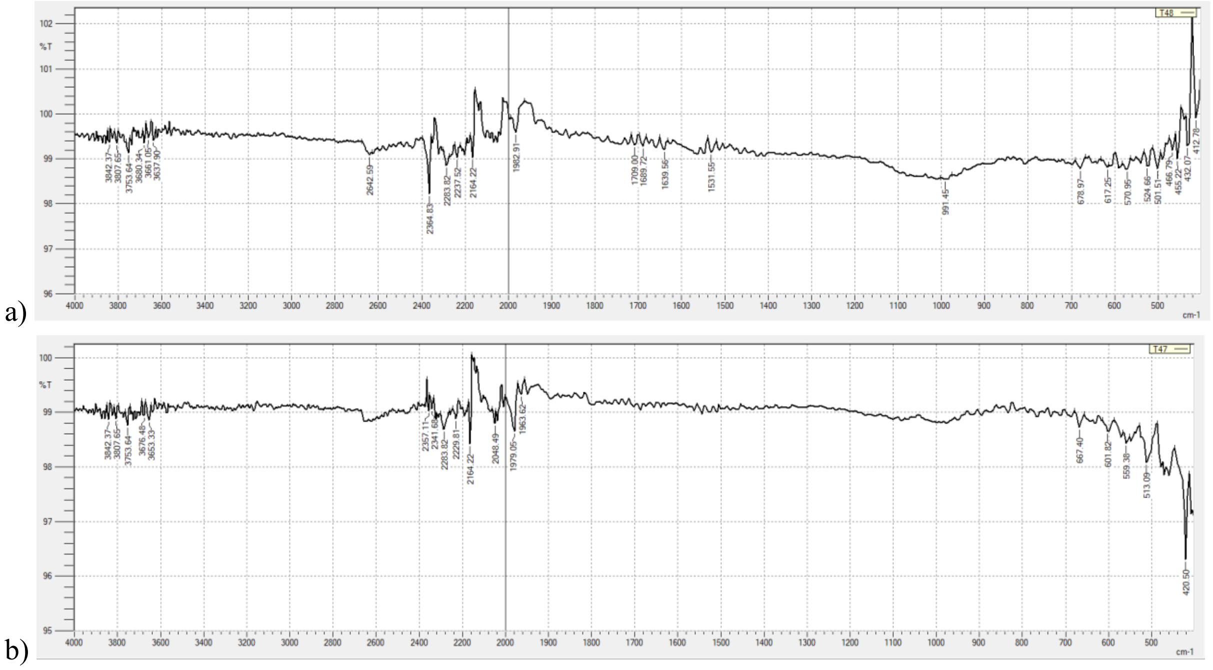

Fig. 3. **FTIR spectra of oilseed flax cultivar *Aisberg* (university sample):**
a – NaOH treatment; b – $NaHCO_3$ treatment

In the high-frequency region of 3842-3753 cm^{-1}, a broad band assigned to O-H stretching vibrations is observed, indicating an extensive system of intra- and intermolecular hydrogen bonding in cellulose. These hydrogen bonds play an important role in the formation of strong interfiber interactions and the mechanical stability of paper materials. The bands at 2920-2850 cm^{-1} correspond to C-H stretching vibrations of methylene ($-CH_2-$) groups associated with the pyranose ring structure and confirm the preservation of the aliphatic backbone of the polysaccharide chain.

Absorption bands in the regions of 2372-2345 cm^{-1} and near 2283 cm^{-1} are associated with atmospheric CO_2 absorption and are not related to the cellulose structure, whereas weak signals in the ranges of 2195-2164 cm^{-1} and 2048-2009 cm^{-1} may be attributed to background noise or minor spectral artefacts. The main diagnostic features of cellulose are located in the fingerprint region. Bands at 1160-1020 cm^{-1} correspond to C-O-C and C-O stretching vibrations of the pyranose ring, while the signal near ~1030-1050 cm^{-1} is typically associated with vibrations of glycosidic bonds in cellulose chains. A weak band near ~898 cm^{-1} corresponds to vibrations at the anomeric carbon of β-1,4-glycosidic bonds, which is considered a characteristic spectral feature confirming the cellulosic nature of the material and the preservation of its polymer backbone.

In the low-frequency region of 713-439 cm^{-1}, skeletal vibrations of the cellulose macromolecule were observed. These bands correspond to collective vibrations of the cellulose framework and are typical for polysaccharide-based materials. After soda treatment ($NaHCO_3$), additional or intensified bands appeared near ~1430, ~880 and ~650 cm^{-1}, which may be associated with carbonate-related vibrations originating from residual soda compounds on the fiber surface. In contrast, alkaline treatment with NaOH resulted in a comparatively cleaner FTIR profile with less pronounced secondary bands, suggesting a more effective removal of accompanying non-cellulosic components. Overall, these spectral features indicate the preservation of the cellulose polymer backbone after chemical treatment. The interpretation of the main FTIR absorption bands observed in the spectra of flax cellulose is summarised in Table 1.

FTIR analysis confirmed the preservation of β-1,4-glycosidic bonds and the polysaccharide backbone in all investigated samples, indicating the chemical stability of the obtained cellulose. The spectra obtained after soda treatment suggest the preservation of cellulose structures favourable for fiber bonding, whereas NaOH treatment resulted in a higher degree of purification from non-cellulosic components, producing a comparatively cleaner spectral profile. Thus, both treatments can be considered promising approaches for obtaining flax-derived pulp, although the final suitability of the material for food packaging paper should be further evaluated through mechanical, technological and safety testing.

Table 1

Interpretation of the main FTIR absorption bands of flax cellulose

Wavenumber, cm^{-1}	Functional group	Structural interpretation	Significance for paper materials
3600-3200	O-H stretching	Hydrogen-bonded hydroxyl groups in cellulose	Formation of intermolecular bonding in paper fibers
2920-2850	C-H stretching	Methylene groups of pyranose rings	Confirms preservation of polysaccharide backbone
2370-2340	CO_2 absorption	Atmospheric carbon dioxide	Not related to cellulose structure
1160-1020	C-O-C and C-O stretching	Vibrations of pyranose ring and glycosidic linkages	Characteristic cellulose absorption region
~1030-1050	C-O stretching	Vibrations of cellulose chain structure	Confirms integrity of cellulose macromolecule
~898	C-H deformation (β-linkage)	β-1,4-glycosidic bond	Diagnostic feature of cellulose
~1430	CO_3^{2-} related vibrations	Carbonate residues after soda treatment	Indicates influence of chemical processing
713-439	Skeletal vibrations	Cellulose macromolecular framework	Confirms polymer structure

The characteristic absorption bands observed in the FTIR spectra correspond well with the typical spectral features of cellulose. As shown in Table 1, the broad band in the region of 3600-3200 cm^{-1} is associated with O-H stretching vibrations reflecting the extensive hydrogen-bonding network within the cellulose structure. The bands at 2920-2850 cm^{-1} correspond to C-H stretching vibrations of methylene groups in the pyranose ring, confirming the preservation of the aliphatic backbone of cellulose chains.

The most important diagnostic features are located in the fingerprint region. In particular, bands in the range of 1160-1020 cm^{-1} correspond to C-O-C and C-O stretching vibrations of the pyranose ring structure, while the absorption band near 898 cm^{-1} is characteristic of β-1,4-glycosidic bonds linking the glucose units in cellulose. The presence of these bands confirms the preservation of the polymeric structure of cellulose after chemical treatment.

Additional bands observed near 1430 cm^{-1} in samples treated with $NaHCO_3$ may indicate the presence of carbonate-related vibrations associated with residual soda compounds. The skeletal vibration region below 713 cm^{-1} reflects collective vibrations of the cellulose macromolecular framework. Overall, the spectral features presented in Table 1 confirm that the main structural elements of cellulose were preserved in all investigated samples.

A comparison of cellulose obtained from fiber flax (long-staple) and oilseed flax under the same boiling conditions showed no significant differences in the main FTIR spectral features. Characteristic absorption bands corresponding to the cellulose polymer backbone were preserved in all samples, indicating that both types of flax biomass are suitable raw materials for pulp production.

Conclusions

The FTIR analysis confirmed the preservation of the main structural features of cellulose in all investigated flax samples. The presence of absorption bands associated with β-1,4-glycosidic bonds and vibrations of the pyranose ring indicates the stability of the cellulose polymer backbone after chemical treatment.

Both fiber flax (Miandr) and oilseed flax (Aisberg) demonstrated similar characteristic FTIR spectral patterns, suggesting that these agricultural residues can serve as suitable sources of cellulose for pulp production.

The soda treatment ($NaHCO_3$) preserved the characteristic cellulose absorption pattern and showed spectral features that may indicate the presence of carbonate-related residues on the fiber surface. In contrast, alkaline treatment using NaOH provided more efficient removal of accompanying non-cellulosic components, resulting in a comparatively cleaner cellulose structure.

Overall, the obtained results indicate that cellulose derived from flax biomass exhibits a favourable chemical profile for the production of paper-based packaging materials and may serve as a promising non-wood alternative to conventional wood pulp. However, its suitability for food-contact packaging applications should be confirmed by additional studies of mechanical properties, technological performance and safety characteristics of the obtained paper materials.

Author contributions

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

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