



UNIVERSITY
of SOPRON

11th Hardwood Conference

30-31 May 2024
Sopron

11TH HARDWOOD CONFERENCE PROCEEDINGS

Róbert Németh, Christian Hansmann, Holger Militz, Miklós Bak, Mátyás Báder



11TH HARDWOOD CONFERENCE PROCEEDINGS

Sopron, Hungary, 30-31 May 2024

**Editors: Róbert Németh, Christian Hansmann, Holger Militz,
Miklós Bak, Mátyás Báder**



UNIVERSITY OF SOPRON PRESS

SOPRON, 2024

11TH HARDWOOD CONFERENCE PROCEEDINGS

Sopron, Hungary, 30-31 May 2024

Editorial board

Prof. Dr. Róbert Németh

Dr. Christian Hansmann

Prof. Dr. Holger Militz

Dr. Miklós Bak

Dr. Mátyás Báder

[University of Sopron](#) – Hungary

[FATE - Scientific Association for Wood Industry](#) – Hungary

[Wood K Plus](#) – Austria

[Georg-August University of Göttingen](#) – Germany

[University of Sopron](#) – Hungary

[University of Sopron](#) – Hungary

[FATE - Scientific Association for Wood Industry](#) – Hungary

Scientific committee

Prof. Dr. Dr. h.c. Peter Niemz

Prof. Dr. Dr. h.c. Alfred Teischinger

Prof. Dr. George I. Mantanis

Prof. Dr. Bartłomiej Mazela

Prof. Dr. Julia Mihailova

Prof. Dr. Joris Van Acker

Prof. Dr. Ali Temiz

Prof. Dr. Henrik Heräjärvi

Prof. Dr. Andreja Kutnar

Prof. Dr. Goran Milić

Dr. Vjekoslav Živković

Dr. Rastislav Lagana

Dr. Milan Gaff

Dr. Lê Xuân Phương

Dr. Peter Rademacher

Dr. Emilia-Adela Salca

Dr. Galina Gorbacheva

[ETH Zürich](#) – Switzerland / [Luleå University of Technology](#) – Sweden

[BOKU University Vienna](#) – Austria

[University of Thessaly](#) – Greece

[Poznań University of Life Sciences](#) – Poland

[University of Forestry](#) – Bulgaria

[Ghent University](#) – Belgium

[Karadeniz Technical University](#) – Turkey

[Natural Resources Institute Finland \(LUKE\)](#) – Finland

[InnoRenew CoE](#) – Slovenia

[University of Belgrade](#) – Serbia

[University of Zagreb](#) – Croatia

[TU Zvolen](#) – Slovak Republic

[Mendel University Brno](#) – Czech Republic

[Vietnam National University of Forestry](#) – Vietnam

[Eberswalde University for Sustainable Development](#) – Germany

[“Transilvania” University of Brasov](#) – Romania

[Bauman Moscow State Technical University](#) – Russian Federation

Cover design

Ágnes Vörös

[University of Sopron](#) – Hungary

Webservices

Dr. Miklós Bak

[11th Hardwood Conference official website](#)

[University of Sopron](#) – Hungary

ISBN 978-963-334-518-4 (pdf)

DOI <https://doi.org/10.35511/978-963-334-518-4>

ISSN 2631-004X (Hardwood Conference Proceedings)

Constant Serial Editors: Prof. Dr. Róbert Németh, Dr. Miklós Bak

Cover image based on the photograph of Dr. Miklós Bak, 2024

The manuscripts have been peer-reviewed by the editors and have not been subjected to linguistic revision.

In the articles, corresponding authors are marked with an asterisk (*) sign.

[University of Sopron Press](#), 2024 (Bajcsy-Zsilinszky 4, 9400 Sopron, Hungary)

Responsible for publication: Prof. Dr. Attila Fábián, rector of the [University of Sopron](#)

Creative Commons license: CC BY-NC-SA 4.0 DEED



Nevezd meg! - Ne add el! - Így add tovább! 4.0 Nemzetközi
Attribution-NonCommercial-ShareAlike 4.0 International

Sponsors: [University of Sopron](#), Hungary; [Wood K Plus](#), Austria; [Georg-August University of Göttingen](#), Germany; [Scientific Association for Wood Industry](#), Hungary



UNIVERSITY
of SOPRON

WOOD
KPLUS



FATE

Content

Preface to the 11TH HARDWOOD CONFERENCE

Róbert Németh..... 9

Plenary Session - Keynotes of the 11TH HARDWOOD CONFERENCE

- The role of black locust (*Robinia pseudoacacia*) in Czechia
Ivan Kuneš, Martin Baláš, Přemysl Šedivka, Vilém Podrázský 11
- Engineered wood products for construction based on beech and poplar resources in Europe
Joris Van Acker, Liselotte De Ligne, Tobi Hallez, Jan Van den Bulcke 23
- The situation in the hardwood sector in Europe
Maria Kiefer-Polz, Rainer Handl 60

Session I - Silvicultural aspects and forest management of hardwoods

- Monitoring xylogenesis as a tool to assess the impact of different management treatments on wood formation: A study case on *Vitis vinifera*
Angela Balzano, Maks Merela, Meta Pivk, Luka Krže, Veronica De Micco 62
- The History of Forests - Climate Periods of the Middle Ages and Forestry
Emese Berzsenyi, Dóra Hegyesi, Rita Kattein-Pornói, Dávid Kazai..... 63
- Climate change mitigation aspects of increasing industrial wood assortments of hardwood species in Hungary
Éva Király, Zoltán Böröcsök, Attila Borovics..... 71
- Uncovering genetic structures of natural Turkey oak populations to help develop effective climate change strategies for forestry
Botond B. Lados, László Nagy, Attila Benke, Csilla É. Molnár, Zoltán A. Köbölkuti, Attila Borovics, Klára Cseke..... 78
- Ash dieback: infection biology and management
Nina E. Nagy, Volkmar Timmermann, Isabella Børja, Halvor Solheim, Ari M. Hietala..... 86
- The Role of Industrial Hardwood Production Plantations and Long-Term Carbon Sequestration in a Circular Economy via the New *Robinia pseudoacacia* ‘Turbo Obelisk’ Varieties
Márton Németh, Kálmán Pogrányi, Rezső Solymos..... 95
- Initial growth of native and introduced hardwoods at the afforested agricultural lands – preliminary results
Vilém Podrázský, Josef Gallo, Martin Baláš, Ivan Kuneš, Tama Abubakar Yahaya, Miroslav Šulitka
 102

Poster Session

- Light response curve analysis of juvenile Püspökladányi and Üllői black locust
Tamás Ábri, Zsolt Keserű, József Csajbók..... 111
- Revealing the optimum configuration of heat-treated wood dowel joints by means of Artificial Neural Networks and Response Surface Methodology
Bogdan Bedeleian, Cosmin Spîrchez..... 115
- Artificial neural networks as a predictive tool for thrust force and torque during drilling of wood-based composites
Bogdan Bedeleian, Mihai Ispas, Sergiu Răcășan 121

Research on the value retention of hardwood products in the spirit of sustainability <i>Daniel Bodorkós, József Zalavári, Péter György Horváth</i>	126
Abrasive Water Jet Cutting vs. Laser Jet Cutting of Oak Wood Panels <i>Camelia Cosereanu, Gheorghe Cosmin Spirchez, Antonela Lungu, Sergiu-Valeriu Georgescu, Alexandru Catalin Filip, Sergiu Racasan</i>	131
Polyphenol content of underutilized wood species from Hungary <i>Tamás Hofmann, Haruna Seidu, Kibet Tito Kipkoror</i>	136
Wood quality evaluation of 32 grafted clone linages of Keyaki (<i>Zelkova serrata</i>) plus trees 12 years after planting <i>Kiyohiko Ikeda, Shigehiro Yamamoto</i>	141
Influence of the number of belts over vibrations of the cutting mechanism in woodworking shaper <i>Georgi Kovatchev, Valentin Atanasov</i>	146
The impact of litter forest fires on the internal structure of wood from stem of beech trees <i>Elena-Camelia Musat, Costin-Ovidiu Vantoiu, Emilia-Adela Salca</i>	153
Analysing innovative wood joints crafted by laser cut spline curves <i>László Németh, József Garab, Péter György Horváth</i>	158
Dynamic fatigue tests of hardwoods <i>Gábor Orbán, Antal Kánnár</i>	163
Restoration of an old painted oak boardsign - A case study <i>Gabriel Calin Canalas, Emilia-Adela Salca, Elena-Camelia Musat</i>	168
Some physical properties of native and thermo-treated <i>Fraxinus excelsior</i> timber <i>Cosmin Spirchez, Aurel Lunguleasa, Alin Olărescu, Camelia Coşereanu, Bogdan Bedelea</i>	173
The surface morphology of sanded curly maple in comparison with straight grain maple selected for musical instruments <i>Mariana Domnica Stanciu, Lidia Gurau, Florin Dinulica, Catalin Constantin Roibu, Cristian Hiciu, Andrei Mursa, Marian Stirbu</i>	178
Analysis of changes in the composition of beech as an important industrial raw material in Hungary <i>Katalin Szakálosné Mátyás, Attila László Horváth</i>	183
Investigation of old hardwood structure element <i>Fanni Szőke, Antal Kánnár</i>	187
An investigation of the influence of coating film thickness on the light induced colour changes of clear coated maple (<i>Acer pseudoplatanus</i>) wood surfaces with natural aspect <i>Mihai-Junior Torcătoru, Maria Cristina Timar</i>	192
Composite Material Manufacturing from Plantation Paulownia Wood with Using Microwave Technology: Technical and Cost Analyses <i>Grigory Torgovnikov, Peter Vinden, Alexandra Leshchinskaia</i>	198
Thermal modification of wood as a tool for changing the colour of hardwoods <i>Vidholdová Zuzana</i>	203
High termite resistance of kempas (<i>Koompassia malaccensis</i>) hardwood protected with a novel vegetal extracts-cypermethrin wood preservative under outdoor aboveground tropical environment <i>Messaoudi Daouia, Wong Andrew H.H.</i>	209
Comparison of wood properties of pedunculate oak and non-native northern red oak from an anthropogenic site <i>Aleš Zeidler, Vlastimil Borůvka</i>	214
Acoustic Parameters of Pioneer Wood Species <i>Petr Horák, Vlastimil Borůvka</i>	219
Determination of Elastic Parameters of Birch and Oak Wood Using Optical Method <i>David Novák, Vlastimil Borůvka, Petr Horák, Tomáš Kytka</i>	224

Preliminary study on climate change impacts on annual wood growth development in Hungary <i>Péter Farkas, Zsolt György Tóth, Huba Komán</i>	230
Combustion characteristics of Russian olive (<i>Elaeagnus angustifolia</i> L.) <i>Szabolcs Komán, Krisztián Töröcsi</i>	236
Withdrawal capacity of Green ash (<i>Fraxinus pennsylvanica</i> Marsh.) and Box elder (<i>Acer negundo</i> L.) <i>Szabolcs Komán, Boldizsár Déri</i>	241
Formaldehyde emission from wood and wood-based products <i>Szabolcs Komán, Csilla Czók, Tamás Hofmann</i>	246
Finite element analysis of heat transfer of Turkey oak (<i>Quercus cerris</i>) <i>Sándor Borza, Gergely Csiszár, József Garab, Szabolcs Komán</i>	250
Possible alternative to creosote treated railway sleepers, Fürstenberg-System Sleeper (FSS) <i>Szabolcs Komán, Balogh Mátyás Zalán, Sándor Fehér</i> ,.....	255
Investigation of bendability characteristics of wood-based polymer composites <i>S. Behnam Hosseini, Milan Gaff</i>	260
Comparing the blossoming and wood producing properties of selected black locust clones <i>Alexandra Porcsin, Katalin Szakálosné Mátyás, Zsolt Keserű</i>	266
The influence of two different adhesives on structural reinforcement of oak-wood elements by carbon and glass fibres <i>Andrija Novosel, Vjekoslav Živković</i>	271
Investigating Kerf Topology and Morphology Variation in Native Species After CO ₂ Laser Cutting <i>Lukáš Štefančín, Rastislav Igaz, Ivan Kubovský, Richard Kminiak</i>	272
Comparison of fluted-growth and cylindrical hornbeam logs from Hungarian forests <i>Mátyás Báder, Maximilián Cziczzer</i>	279
Thermal modification affects the dynamic vapor sorption of tree of heaven wood (<i>Ailanthus altissima</i> , Mill.) <i>Fanni Fodor, Lukas Emmerich, Norbert Horváth, Róbert Németh</i>	285
How conditions after application affect the depth of penetration of gel wood preservative in oak <i>Jan Baar, Štěpán Bartoš, Anna Oberle, Zuzana Paschová</i>	290
The weathering of the beech wood impregnated by pigmented linseed oil <i>Jakub Dömény, Jan Baar</i>	294
Examination of the durability of beeswax-impregnated wood <i>Miklós Bak, Ádám Bedők, Róbert Németh</i>	299
Preparation of pleated oak samples and their bending tests at different moisture contents <i>Pál Péter Gecseg, Mátyás Báder</i>	304
Bending test results of small-sized glued laminated oak timber consisting of 2, 3 and 5 layers <i>Dénes Horváth, Sándor Fehér</i>	308
Homogenized dynamic Modulus of Elasticity of structural strip-like laminations made from low-grade sawn hardwood <i>Simon Lux, Johannes Konnerth, Andreas Neumüller</i>	314
Impact of varnishing on the acoustic properties of sycamore maple (<i>Acer pseudoplatanus</i>) panels <i>Aleš Straže, Jure Žigon, Matjaž Pavlič</i>	319
The effect of wood and solution temperatures on the preservative uptake of Pannonia poplar and common spruce – preliminary research <i>Luca Buga-Kovács, Norbert Horváth</i>	325

Session II - Hardwood resources, product approaches, and timber trade

Birch tar – historic material, innovative approach <i>Jakub Brózdowski, Monika Bartkowiak, Grzegorz Cofa, Grażyna Dąbrowska, Ahmet Erdem Yazici, Zbigniew Katolik, Szymon Rosołowski, Magdalena Zborowska</i>	330
Beech Wood Steaming – Chemical Profile of Condensate for Sustainable Applications <i>Goran Milić, Nebojša Todorović, Dejan Orčić, Nemanja Živanović, Nataša Simin</i>	336
Towards a complete technological profile of hardwood branches for structural use: Case study on Poisson's ratio <i>Tobias Nennung, Michael Grabner, Christian Hansmann, Wolfgang Gindl-Altmutter, Johannes Konnerth, Maximilian Pramreiter</i>	342
Low-value wood from non-native tree species as a potential source of bioactive extractives for bio-based preservation <i>Viljem Vek, Ida Poljanšek, Urša Osolnik, Angela Balzano, Miha Humar, Primož Oven</i>	349
Hardwood Processing - do we apply appropriate technologies? <i>Alfred Teischinger</i>	357

Session III - Surface coating and bonding characteristics of hardwoods

Influence of pretreatments with essential oils on the colour and light resistance of maple (<i>Acer pseudoplatanus</i>) wood surfaces coated with shellac and beeswax <i>Emanuela Carmen Beldean, Maria Cristina Timar, Dana Mihaela Pop</i>	365
Oak timber cross-cutting based on fiber orientation scanning and mechanical modelling to ensure finger-joints strength <i>Soh Mbou Delin, Besseau Benoit, Pot Guillaume, Viguiet Joffrey, Marcon Bertrand, Milhe Louis, Lanvin Jean-Denis, Reuling Didier</i>	376
From Phenol-Lignin Blends towards birch plywood board production <i>Wilfried Sailer-Kronlachner, Peter Bliem, Hendrikus van Herwijnen</i>	386
Flatwise bending strength and stiffness of finger jointed beech lamellas (<i>Fagus sylvatica</i> , L.) using different adhesive systems and effect of finger joint gap size <i>Hannes Stolze, Adefemi Adebisi Alade, Holger Militz</i>	395
Mode I fracture behaviour of bonded beech wood analysed with acoustic emission <i>Martin Capuder, Aleš Straže, Boris Azinović, Ana Brunčič</i>	402

Session IV - Hardwood structure and properties

Compression strength perpendicular to grain in hardwoods depending on test method <i>Marlene Cramer</i>	410
Compensatory Anatomical Studies on <i>Robinia</i> , <i>Sclerocarya</i> and <i>Ulmus</i> <i>Fath Alrhman A. A. Younis, Róbert Németh, Mátyás Báder</i>	420
The influence of the type of varnish on the viscous-elastic properties of maple wood used for musical instruments <i>Roxana Gall, Adriana Savin, Mariana Domnica Stanciu, Mihaela Campean, Vasile Ghiorghe Gliga</i>	426
XRF investigation of subfossil oak (<i>Quercus</i> spp) wood revealing colour - iron content correlation <i>Nedelcu Ruxandra, Timar Maria Cristina, Beldean Emanuela Carmen</i>	435
Investigating the Development of Heartwood in <i>Quercus robur</i> in Denmark <i>Andrea Ponzeccchi, Albin Lobo, Jill Katarina Olofsson, Jon Kehlet Hansen, Erik Dahl Kjær, Lisbeth Garbrecht Thygesen</i>	445

Modelling tensile mechanical properties of oak timber from fibre orientation scanning for strength grading purpose <i>Guillaume Pot, Joffrey Viguier, Benoit Besseau, Jean-Denis Lanvin, Didier Reuling</i>	452
Green oak building – small diameter logs for construction <i>Martin Huber, Franka Brüchert, Nicolas Hofmann, Kay-Uwe Schober, Beate Hörnel-Metzger, Maximilian Müller, Udo H. Sauter</i>	461
An evaluative examination of oak wood defect detection employing deep learning (DL) software systems. <i>Branimir Jambreković, Filip Veselčić, Iva Ištok, Tomislav Sinković, Vjekoslav Živković, Tomislav Sedlar</i>	466
Comparison of surface roughness of milled surface of false heartwood, mature wood, and sapwood within beech wood <i>Lukáš Adamčík, Richard Kminiak, Adrián Banski</i>	467

Session V - Hardwoods in composites and engineered materials

Developing Laminated Strand Lumber (LSL) based on underutilized Hungarian wood species <i>László Bejő, Tibor Alpár, Ahmed Altaher Omer Ahmed</i>	475
Feasibility study on manufacturing finger-jointed structural timber using <i>Eucalyptus grandis</i> wood <i>Adefemi Adebisi Alade, Hannes Stolze, Coenraad Brand Wessels, Holger Militz</i>	481
A novel approach for the design of flame-retardant plywood <i>Christian Hansmann, Georg Baumgartner, Christoph Preimesberger</i>	486
The use of beech particles in the production of particleboards based on recycled wood <i>Ján Iždinský, Emilia Adela Salca, Pavlo Bekhta</i>	493
Thermal properties of highly porous wood-based insulation material <i>Kryštof Kubista, Přemysl Šedivka</i>	501

Session VI - Modification & functionalization

Quantitative and qualitative aspects of industrial drying of Turkey oak lumber <i>Iulia Deaconu, Bogdan Bedeleian, Sergiu Georgescu, Octavia Zeleniuc, Mihaela Campean</i>	508
Changes in properties of maple by hygrothermally treatment for accelerated ageing at 135-142°C <i>Tobias Dietrich, Herwig Hackenberg, Mario Zauer, Holger Schiema, André Wagenführ</i>	518
Change of chemical composition and FTIR spectra of Turkey oak and Pannonia poplar wood after acetylation <i>Fanni Fodor, Tamás Hofmann</i>	525
Change of cellulose crystal structure in beech wood (<i>Fagus sylvatica</i> L.) due to gaseous ammonia treatment <i>Herwig Hackenberg, Tobias Dietrich, Mario Zauer, Martina Bremer, Steffen Fischer, André Wagenführ</i>	535
Evaluation of weathering performance of acetylated hardwood species <i>Rene Herrera Diaz, Jakub Sandak, Oihana Gordobil, Faksawat Poohphajai, Anna Sandak</i>	539
Unlocking a Potential Deacetylation of Acetylated Beech (<i>Fagus sylvatica</i> L.) LVL <i>Maik Slabohm, Holger Militz</i>	544
Fork and flying wood tests to improve prediction of board stress development during drying <i>Antoine Stéphane, Patrick Perré, Clément L'Hostis, Romain Rémond</i>	549
Modification of different European hardwood species with a bio-based thermosetting resin on a semi-industrial scale <i>Christoph Hötte, Holger Militz</i>	557

Compensatory Anatomical Studies on *Robinia*, *Sclerocarya* and *Ulmus*

Fath Alrman A. A. Younis^{1,2}, Róbert Németh¹, Mátyás Báder^{1*}

¹ University of Sopron, Faculty of Wood Engineering and Creative Industries, Bajcsy-Zs. Str. 4, Sopron, Hungary, 9400

² University of Gezira, Faculty of Forest Sciences and Technology, Al Gezira, Wad Madani, Sudan.

E-mail: fath.alrman.awad.younis@phd.uni-sopron.hu; nemeth.robort@uni-sopron.hu; bader.matyas@uni-sopron.hu

Keywords: *Robinia*; earlywood; wavy vessel; fibre characteristic

ABSTRACT

This study shows the differences in fibre characteristics of *Robinia pseudoacacia* growing in Hungary and *Sclerocarya birrea* growing in Sudan. Also, the analysis and comparison of the growing zone widths (the vessel lumina diameters in the earlywood and the wave amplitudes of the wavy vessel bands) for *Ulmus minor* were studied. The mean values of fibre length (mm), lumen diameter (μm), fibre diameter (μm), and cell wall thickness (μm) of *R. pseudoacacia* were 0.83, 13.18, 18.35, and 513, respectively. While they were 0.82, 26.37, 18.01, and 8.36 for *S. birrea*. The results also show that the fibre characteristics do not change gradually from pith to bark. The anatomical studies of *Ulmus minor* revealed significantly different results in the latewood widths, between 0.775 mm and 2.776 mm. Most vessels in the earlywood are below 0.721 mm diameter. The latewood vessel band amplitudes are mostly between 0.138 and 0.230 mm.

INTRODUCTION

The University of Sopron, Hungary deals extensively with the proper management of trees and wood from both scientific and practical perspectives. The Faculty of Forestry is the only place in Hungary to train, among others, forest engineers and nature conservation engineers, while the Faculty of Wood Engineering and Creative Industries trains, among others, engineers for the wood industry, specialists in the creative industry, and product designers. The former Institute of Wood Science, now part of the Institute of Basic Sciences, deals with the properties and modification possibilities of wood. Good examples are the following scientific publications: (Komán 2022; Fehér et al. 2014; Lublóy et al. 2023; Komán and Varga 2020; Kern et al. 2022; Bak 2012; Horváth and Fehér 2023; Fodor and Bak 2023). Our aim with this study is to present the activities and some of our important results we have carried out in the recent years, in order to present research in connection with the wood industry. We believe that the work we do is globally important. In this article, we mainly present some of our research and results on the anatomical properties of wood.

The comprehensive knowledge of the anatomical features of wood is crucial in the process of selecting the most suitable wood for a certain purpose. Anatomical traits can be classified into two broad categories: macro and micro. The measurement of fibre length in wood is a crucial factor that significantly impacts the overall quality and characteristics of pulp and paper products. Various methods can be employed to measure the fibre lengths of different wood species (Figure 1). Wood species exhibit great variations in their fibre lengths. In general, softwood fibres possess higher length and strength compared to hardwood fibres, hence contributing to the tensile strength of paper, as an example. Hardwood fibres are shorter and opaque, and they add smoothness and better printability to paper (Salminen et al. 2014). Environmental elements, including climate, soil conditions, and silviculture practices, can also exert an influence on the length of fibres in pulpwood (Desch and Dinwoodie 1996). Hence, the assessment of wood fibre length is important in pulp and paper production. Several previous studies investigated the variation in wood anatomical properties (Adamopoulos and Voulgaridis 2002; Chowdhury et al. 2012; Nugroho et al. 2012; Salvo et al. 2017; Rungwattana and Hietz 2018; Liu et al. 2020). This article comprises a couple of parts, with the first part focusing on the investigation of radial variation in fibre characteristics of *Robinia pseudoacacia* and *Sclerocarya birrea* wood species.

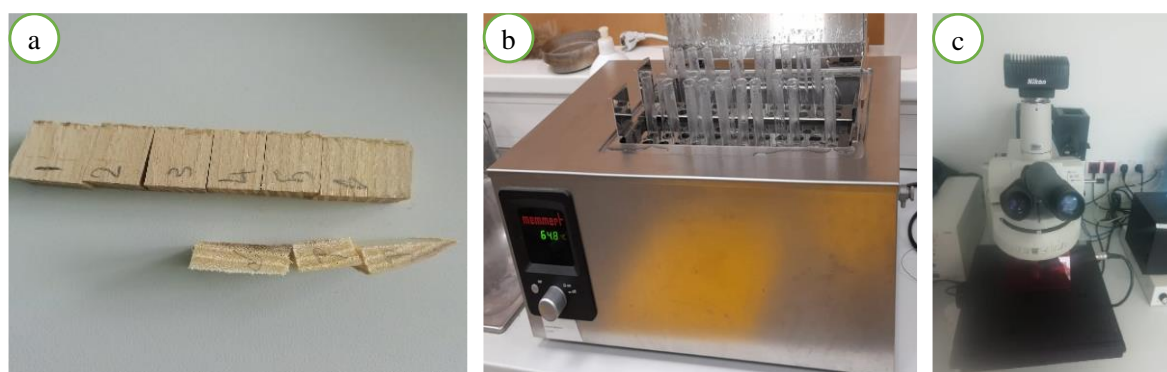


Figure 1: Three stages of measuring fibre characteristics: (a) *R. pseudoacacia* specimens marked from pith to bark, (b) specimens in water bath, (c) microscope with digital camera

Another topic was the examination of some anatomical properties of field elm (*Ulmus minor* Mill.). This wood species has a special vessel arrangement in the latewood region, called wavy vessel bands as it can be seen in Figure 2. The field elm can be classified as a ring-porous wood species, similarly to the *Robinia pseudoacacia*. Its vessels have an average diameter of 35 μm in the latewood and 150 μm in the earlywood. In the latewood, wavy vessel bands can be seen, which are interrupted in some places (Figure 2) (Molnár and Börcsök 2016). The aim of the second part of this article was the analysis and comparison of the growing zone widths; the vessel lumina diameters in the earlywood and the wave amplitudes of the wavy vessel bands.

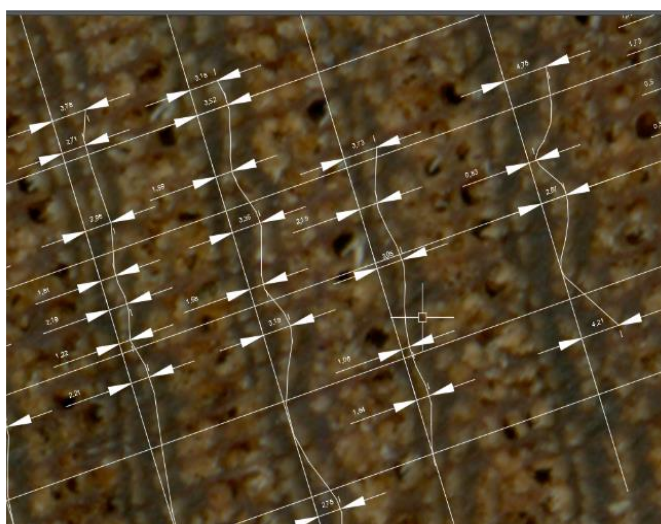


Figure 2: Wavy vessel band measurement in the latewood of field elm

MATERIALS AND METHODS

Fibre characteristics of *Robinia pseudoacacia* and *Sclerocarya birrea*

The wood samples of *S. birrea* were obtained from the Laboratory of Wood Science, Faculty of Forestry at the University of Khartoum, Khartoum, Sudan. The *R. pseudoacacia* wood samples were obtained from trees grown in Hungary and processed at the former Institute of Wood Science, University of Sopron, Sopron, Hungary. The radial strips were used to measure the fibre length (mm), fibre diameter (μm), lumen diameter (μm), and wall thickness (μm).

Continuous removal of small pieces, at intervals of 1 cm, was conducted from the pith to the bark for *R. pseudoacacia*. Similarly, for *S. birrea*, small pieces were continually removed, but at intervals of 2 cm. The wood samples underwent maceration using a Franklin solution, which is composed of glacial acetic acid and hydrogen peroxide in equal quantities. Subsequently, the samples were subjected to a temperature of 60°C for 24 hours (Kitin 1999). The fibre traits were assessed using a Nikon light microscope equipped with a digital camera (BR Nikon E80i) and an image-analysis software (NIS-Elements). A total of fifty wood fibres and twenty-five-lumen diameter and wall thicknesses were measured in each specimen.

Anatomical properties of *Ulmus minor*

The fresh-cut end grains of green *Ulmus minor* mature wood specimens were scanned on a HP Scanjet G4050 (Hewlett-Packard Development Company, USA). In AutoCAD software Autodesk, USA), with the help of a ruler scanned together with the specimens, we were able to scale the images to be able to measure accurate data.

We measured the width of the latewood and earlywood along a predetermined, radial straight line. Since the earlywood widths were almost the same, we later dealt only with the latewood.

In the earlywood vessel diameter examinations, we measured the diameters of the vessels in each annual ring within a 4 mm wide radial band of the test plots, and then calculated the averages and standard deviations.

In the third case, we examined the amplitudes of the vessel bands, that are the heights of the waves of the vessel bands. Along the predetermined 4 mm wide radial band, we marked in AutoCAD a vessel band in each latewood, which does not break in the examined area and well represents the properties of the other vessel bands. We measured the wave heights and calculated the averages and standard deviations.

RESULTS AND DISCUSSION

Table 1 presents the mean values, together with their corresponding standard deviations for fibre length, lumen diameter, fibre diameter, and double cell wall thickness in wood samples of *R. pseudoacacia* and *S. birrea*. The mean values of fibre length and fibre diameter of both species are similar. In comparison, the lumen diameter and cell wall thickness of *S. birrea* are larger than those of *R. pseudoacacia*.

Table 1: Some anatomical results of *R. pseudoacacia* and *S. birrea* wood species

	Fibre characteristics	MIN	MEAN	MAX	STD
<i>R. pseudoacacia</i>	Fibre length (mm)	0.71	0.83	0.99	0.09
	Lumen diameter (µm)	8.40	13.18	18.02	3.06
	Fibre diameter (µm)	14.05	18.35	22.58	2.75
	Wall thickness (µm)	4.56	5.13	5.74	0.38
<i>S. birrea</i>	Fibre length (mm)	0.73	0.82	0.90	0.05
	Lumen diameter (µm)	23.45	26.37	29.69	2.23
	Fibre diameter (µm)	14.81	18.01	21.26	2.18
	Wall thickness (µm)	7.51	8.36	9.48	0.57

The fibre length and cell wall thickness of *R. pseudoacacia* exhibit greater values close to the bark. Nevertheless, we observed that the lumen diameter and fibre diameter revealed a decrease near the bark, as shown in Figure 3. The fibres of *S. birrea* wood exhibited the smallest length near the bark. The length of the fibres revealed a rapid growth from the pith until specimen four, after which they exhibited instability towards the bark. Also, the lumen diameter, fibre diameter, and wall thickness decreased constantly after specimens 4–5 and then increased near the bark, as given in Figure 4.

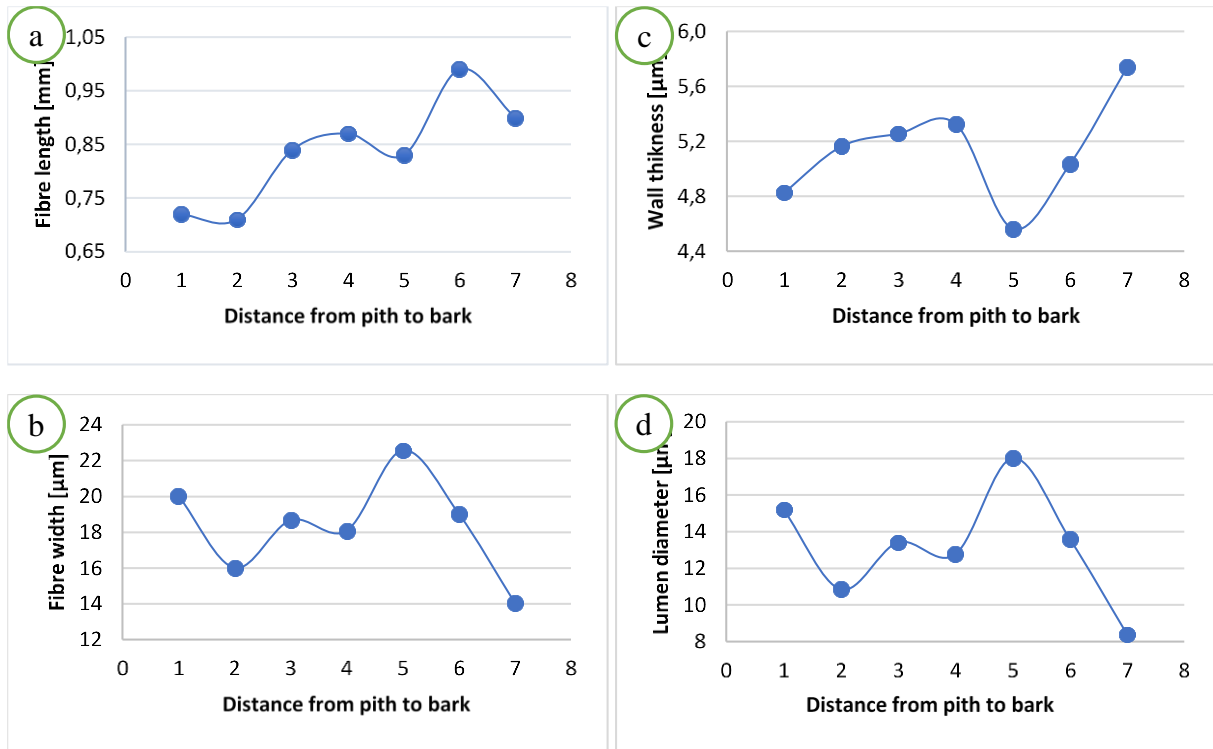


Figure 3: Fibre length (a; mm), fibre width (b; μm), cell wall thickness (c; μm), and lumen diameter (d; μm) of *R. pseudoacacia* from pith to bark

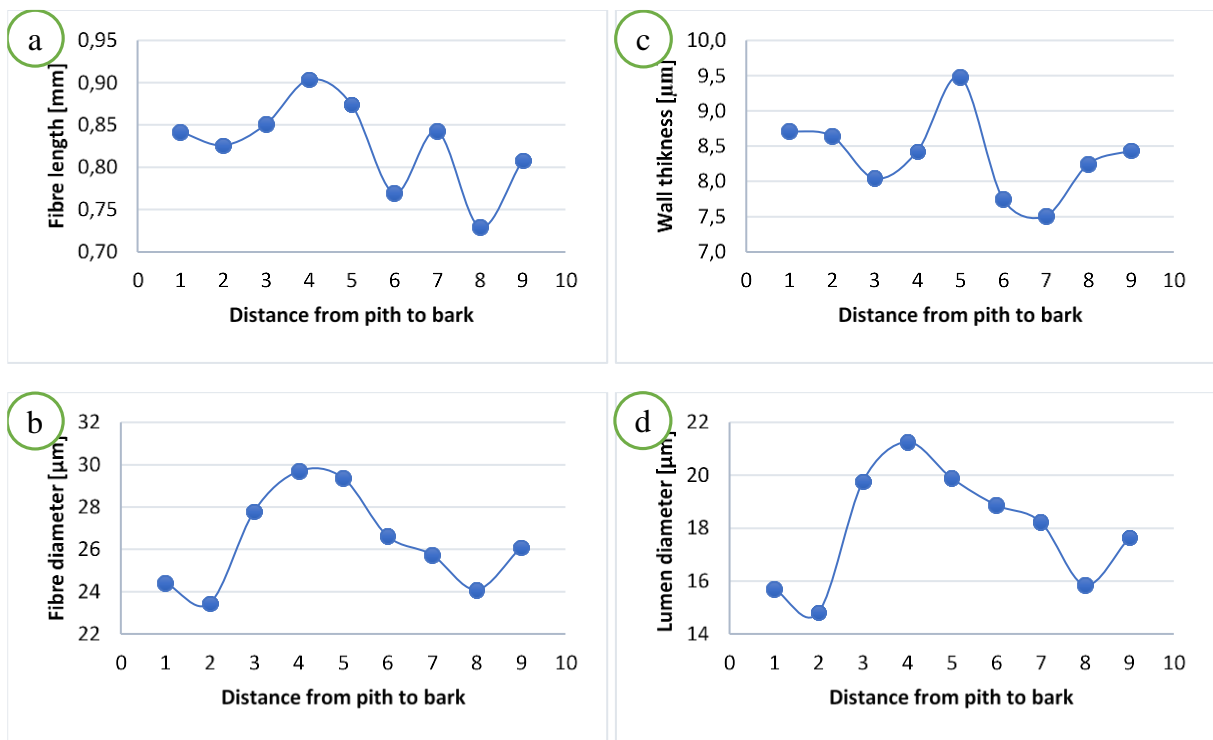


Figure 4: Fibre length (a; mm), fibre width (b; μm), cell wall thickness (c; μm), and lumen diameter (d; μm) of *S. birrea* from pith to bark

Figure 5 illustrates the significant difference in the mean of pair groups of samples for *R. pseudoacacia* (a) and *S. birrea* (b), as observed from the pith to the bark. Whenever, the interval between groups includes zero, it suggests that there is no statistically significant difference in the means of the groups.

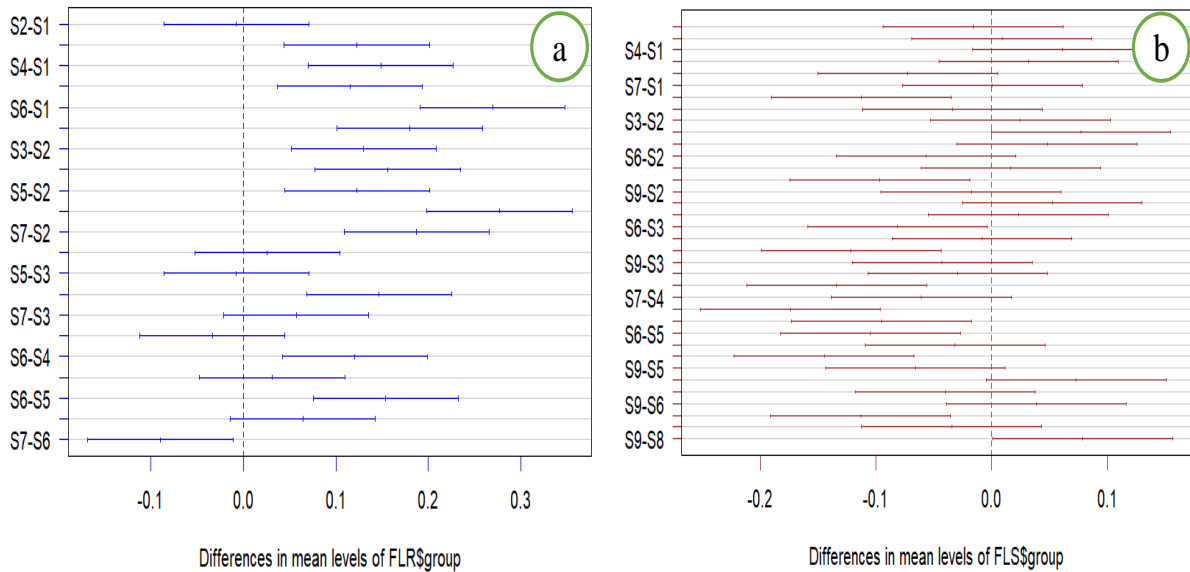


Figure 5: Graphic display of pair-wise comparisons from Tukey's HSD for *R. pseudoacacia* (a) and *S. birrea* (b). If the interval contains zero, that indicates the difference in group means is statistically not significant. Abbreviations: S1-S9: numbered specimens

The next results were obtained from the anatomical properties of the field elm. Comparing the earlywood and latewood widths, the standard deviation in the latewood was greater than in the earlywood, as we measured almost similar values in the earlywood. The average width of the earlywood was 1.018 mm, while that of the latewood was 1.537 mm with a relative standard deviation of 41.7%. That is, the significantly different ring widths of these specimens can be largely attributed to the variability of the latewoods, where very different results were obtained, between 0.765 mm and 2.776 mm. For almost half of the measurements there was an annual ring width of more than 2 mm.

The analysis of the vessel diameters of the earlywood was done taking into account the width of the earlywood. Almost identical vessel diameters are found regardless of the different widths of the earlywood. The mean diameter was 0.202 mm with a standard deviation of 0.045 mm. The relative standard deviation is 22.3%.

The amplitudes of the vessel bands in the latewood region range from very small to very large. Almost half of the results are between 0.138 and 0.230 mm. In some cases, very high results have also occurred, over 0.5 mm. The amplitude of vessel bands arranged in a nearly straight line was 0.104 mm on average, which is a value very close to zero if we take into account the circular shape of the annual ring section of these specimens. The smallest measured amplitude was 0.066 mm. In contrast, the amplitude of vessels clearly arranged in a wavy band was 0.336 mm on average. These waves can already be seen with the naked eye on the end-grain surface. It is worth noting that the length of some vessel bands is quite short, regardless of their amplitude.

CONCLUSIONS

Fibre lengths and fibre diameters of *R. pseudoacacia* and *S. birrea* have similar values. The lumen diameter and cell wall thickness of *S. birrea* are larger than those of *R. pseudoacacia*. The fibre length and cell wall thickness of *R. pseudoacacia* exhibit greater values close to the bark. Nevertheless, it was observed that the lumen diameter and fibre diameter revealed a decrease near the bark.

The earlywood widths were almost the same for the field elm (*Ulmus minor* Mill.). On the contrary, significantly different results were obtained for the latewood widths, from 0.775 mm to 2.776 mm. For vessel diameters in the earlywood, most results are below 0.721 mm. Amplitudes between 0.138 and 0.230 mm were mostly measured for vessels arranged in wavy lines in the latewood. In comparison to the average value, outstanding amplitudes occurred in few cases.

ACKNOWLEDGEMENTS

This article was made in frame of the project TKP2021-NKTA-43 which has been implemented with the support provided by the Ministry of Culture and Innovation of Hungary from the National Research, Development and Innovation Fund, financed under the TKP2021-NKTA funding scheme. The authors would like to thank Ádám Lendvai for his work on the anatomical studies of field elm.

REFERENCES

- Adamopoulos S, Voulgaridis E (2002) Within-tree variation in growth rate and cell dimensions in the wood of black locust (*Robinia pseudoacacia*). *IAWA J* 23:191–199. <https://doi.org/10.1163/22941932-90000297>
- Bak M (2012) The effect of oil-heat-treatment on some major properties of poplar wood (Növényi olajokban hőkezelt nyár faanyag tulajdonságainak vizsgálata). PhD Dissertation, University of West-Hungary
- Chowdhury MQ, Ishiguri F, Hiraiwa T, et al (2012) Variation in anatomical properties and correlations with wood density and compressive strength in *Casuarina equisetifolia* growing in Bangladesh. *Australian Forestry* 75:95–99. <https://doi.org/10.1080/00049158.2012.10676390>
- Desch HE, Dinwoodie JM (1996) *Timber, structure, properties, conversion, and use*, 7th edition. Macmillan Press Ltd, London
- Fehér S, Komán S, Börcsök Z, Taschner R (2014) Modification of hardwood veneers by heat treatment for enhanced colors. *BioResources* 9:3456–3465
- Fodor F, Bak M (2023) Studying the Wettability and Bonding Properties of Acetylated Hornbeam Wood Using PVAc and PUR Adhesives. *Materials* 16:2046. <https://doi.org/10.3390/ma16052046>
- Horváth D, Fehér S (2023) Magas hozzáadott értékű termékek előállítási potenciálja termelésből kieső, alacsony minőségű tölgy alapanyagból: Előzetes eredmények. *Gradus* 10:. <https://doi.org/10.47833/2023.1.ENG.001>
- Kern Z, Árvai M, Urdea P, et al (2022) First report on dendrochronological and radiocarbon studies of subfossil driftwood recovered across the Mureş/Maros Alluvial Fan. *CEuGeol* 65:40–48. <https://doi.org/10.1556/24.2021.00120>
- Kitin P (1999) Variations in the Lengths of Fusiform Cambial Cells and Vessel Elements in *Kalopanax pictus*. *Annals of Botany* 84:621–632. <https://doi.org/10.1006/anbo.1999.0957>
- Komán S (2022) Quality characteristics of the selected variant of *Paulownia tomentosa* (Robust4) wood cultivated in Hungary. *Maderas, Cienc tecnol* 25:. <https://doi.org/10.4067/S0718-221X2023000100401>
- Komán S, Varga D (2020) Physical and mechanical properties of wood from invasive tree species. *Maderas, Cienc tecnol* 23:. <https://doi.org/10.4067/S0718-221X2021000100411>
- Liu Y, Zhou L, Zhu Y, Liu S (2020) Anatomical Features and Its Radial Variations among Different *Catalpa bungei* Clones. *Forests* 11:824. <https://doi.org/10.3390/f11080824>
- Lublóy É, Mészáros DT, Takács LG, et al (2023) Examination of the fire performance of wood materials treated with different precautions. *J Therm Anal Calorim* 148:4129–4140. <https://doi.org/10.1007/s10973-023-12050-2>
- Molnár S, Börcsök Z (2016) Szil (szil fajok) - *Ulmus* spp. (Elm (elm species) - *Ulmus* spp). In: Molnár S, Farkas P, Böcsök Z, et al. (eds) *Földünk ipari fái*. Erfaret Nonprofit Kft, Sopron, Hungary, pp 112–114
- Nugroho WD, Marsoem SN, Yasue K, et al (2012) Radial variations in the anatomical characteristics and density of the wood of *Acacia mangium* of five different provenances in Indonesia. *J Wood Sci* 58:185–194. <https://doi.org/10.1007/s10086-011-1236-4>
- Rungwattana K, Hietz P (2018) Radial variation of wood functional traits reflect size-related adaptations of tree mechanics and hydraulics. *Functional Ecology* 32:260–272. <https://doi.org/10.1111/1365-2435.12970>
- Salminen LI, Liukkonen S, Alava MJ (2014) Ground Wood Fiber Length Distributions. *BioResources* 9:1168–1178. <https://doi.org/10.15376/biores.9.1.1168-1178>
- Salvo L, Leandro L, Contreras H, et al (2017) Radial variation of density and anatomical features of *Eucalyptus nitens* trees. *Wood and Fiber Science* 49:301–311