Atlas of charcoal - Wood identification of charcoal products traded on the European market

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Contents

Summary

The globally increasing production of charcoal, particularly in (sub-) tropical regions with a high risk of illegal deforestation, necessitates extensive protective measures. In Europe, these measures are implemented within the framework of the European Union Deforestation Regulation (EUDR; Regulation (EU) 2023/1115), which prohibits the import and sale of commodities originating from deforested land (cut-off date: 31 December 2020). Under the EUDR, large enterprises (from 30 December 2026) and micro- and small enterprises (from 30 July 2027) are obliged to conduct a due diligence procedure when placing their products on the European market for the first time, thereby ensuring that charcoal and briquettes originate from legal production throughout the entire supply chain and fully comply with the requirements of the EUDR (European Commission, 2025; European Parliament, 2025).

As part of the implementation of the EUDR, wood identification is employed, among other measures, to verify declared wood compositions in barbecue charcoal products and to support assessments under species protection legislation, including the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). To facilitate this process, an atlas for the identification of wood species in charcoal was developed at the Thünen Institute of Wood Research using 3D reflected-light microscopy. This atlas contains a selection of wood species from different climatic regions, since Europe imports a large part of its growing demand for charcoal from non-European countries (FAO, 2024).

References for a total of 34 wood species are compiled in a microphotographic atlas that illustrates the structural changes in wood tissue resulting from the carbonization process and documents the associated adaptions in preparation and microscopy techniques. The feature list for the identification of hardwoods (according to IAWA, 1989) is supplemented with example micrographs of charred structural features. In addition, important guidance is provided on the use of quantitative data, as charcoal exhibits substantial dimensional shrinkage. Features whose observation in carbonized wood is limited or not possible are also systematically listed. Overall, this comprehensive information contributes to avoiding incorrect processes in charcoal identification and to increasing the success rate of reliable identification at the genus and/or species level.

Keywords: EUDR, environmental protection, anthracology, barbecue charcoal, charcoal identification, wood anatomy, microscopy, 3D reflected light microscopy

Zusammenfassung

Die weltweit zunehmende Produktion von Holzkohle, insbesondere in (sub-)tropischen Regionen mit einem hohen Risiko illegaler Entwaldung, erfordert umfangreiche Schutzmaßnahmen. Diese erfolgen in Europa im Rahmen der Europäischen Entwaldungsverordnung (EUDR/ (EU) 2023/1115), die ein Import- und Verkaufsverbot von Waren vorsieht, die auf entwaldeten Flächen (Stichtag: 31.12.2020) entstanden sind. Mit der EUDR werden Großunternehmen (ab dem 30.12.2026) und Mikro-/Kleinunternehmen (ab dem 30.07.2027) dazu verpflichtet, bei der Erstinverkehrbringung ihrer Waren auf den Europäischen Markt ein Sorgfaltspflichtverfahren (Due Diligence) durchzuführen und damit zu gewährleisten, dass Holzkohle und -Briketts entlang der gesamten Lieferkette aus einer legalen Erzeugung stammen und die Anforderungen der EUDR vollständig erfüllen (European Commission, 2025; European Parliament, 2025).

Für die Umsetzung der EUDR werden u.a. Holzartenbestimmungen durchgeführt, mit denen die Deklaration der enthaltenen Hölzer in Grillkohlesortimenten überprüft und artenschutzrechtliche Bewertungen nach dem Washingtoner Artenschutzabkommen (CITES) vorgenommen werden können. Um diesen Prozess zu erleichtern, wurde am Thünen-Institut für Holzforschung unter Anwendung der 3D-Auflichtmikroskopie ein Atlas für die Holzartenbestimmung von Holzkohle und -briketts entwickelt. Dieser Atlas enthält eine Auswahl von Hölzern verschiedener Klimaregionen, da Europa einen Großteil seines wachsenden Bedarfs an Grillkohle aus außereuropäischen Ländern importiert (FAO, 2024).

Die Referenzen von insgesamt 34 Holzarten sind in einem mikrophotographischen Atlas zusammengefasst, der die strukturellen Veränderungen des Holzgewebes infolge des Verkohlungsprozesses darstellt und die daraus resultierende, angepasste Präparations- und Mikroskopie-Technik dokumentiert. Darüber hinaus wurde die Merkmalliste für die Bestimmung von Laubhölzern (nach IAWA, 1989) übernommen und mit beispielhaften Aufnahmen verkohlter Strukturmerkmale unterlegt. Ergänzend werden wichtige Hinweise zur Verwendung quantitativer Daten von Strukturmerkmalen gegeben, da Holzkohle einen hohen Dimensionsverlust aufweist. Zudem werden alle Merkmale aufgeführt, deren Beobachtung an verkohltem Holz nur eingeschränkt oder gar nicht möglich ist. Insgesamt sollen diese umfangreichen Informationen dazu beitragen, fehlerhafte Identifizierungsprozesse bei der Holzartenbestimmung von Holzkohle zu vermeiden und die Erfolgsrate einer sicheren Zuordnung auf Gattungs- und/oder Artenebene zu erhöhen.

Stichworte: EUDR, Umweltschutz, Anthrakologie, Grillkohle, Holzkohleidentifizierung, Holzanatomie, Mikroskopie, 3D-Auflichtmikroskopie

1 Preface

Wood identification of charcoal is of great importance for a wide range of scholarly disciplines and practical applications, including archaeological studies, botany, palaeontology, climate research, dendrochronology, etc. Furthermore, the control of charcoal production with regard to forest protection is of global interest for sustainability and nature conservation. Since June 2023 all charcoal products (charcoal and briquettes) in Europe are subject to the Regulation on EU Deforestation Regulation (EUDR (EU) No 2023/1115). This legislation aims to reduce greenhouse gas emissions and combat biodiversity loss. Charcoal products entering the European market for the first time are subject to a due diligence obligation. Traders must provide information on the supply chain and origin of these products – large enterprises are required to comply with this obligation from 30 December 2026, and micro- and small enterprises must follow from 30 July 2027). They are also required to ensure that the charcoal originates from legal sources. In the event of non-compliance, financial penalties and criminal sanctions may be imposed (European Commission, 2025; European Parliament 2025).

According to these regulations, barbecue charcoal products on the European domestic market must provide a confirmable wood species declaration. Tests for this purpose are available from the Thuenen Centre of Competence on the Origin of Timber (Germany). Large-scale European studies with the World Wide Fund for Nature (WWF) (Haag et al., 2020; WWF, 2017; WWF, 2018) have shown that European countries cover the majority of their charcoal requirements through global imports (Zahnen et al., 2020). Charcoal produced of African and South American wood species are entering the European domestic market and the illegal logging of natural forests and trees of protected species from these regions is a significant concern (Braga Junior et al., 2021; Haag et al., 2020).

The selection of wood species for the microscopic charcoal atlas is based on empirical data from previous studies. Thirty-four of the most relevant wood species were chosen to support the implementation of due diligence systems in Europe. These species, sourced from their natural distribution areas, have been confirmed to be present in European charcoal products, making them highly significant for this purpose. They may be traded with or without restrictions, as indicated on the wood data sheets for simplified application. It is important to note that the Checklist of CITES listed species is continuously updated and is freely accessible (http://checklist.cites.org). The atlas contains high-resolution photomicrographs of diagnostic anatomical features of all listed species created with the Keyence 3D-Reflected Light Microscope (Zemke et al., 2020).

All reference woods were provided by the scientific wood collection of the Thuenen Institute of Wood Research (Germany), which was also the location of the laboratory tests.

The project was financially supported by the German Environmental Foundation (Deutsche Bundesstiftung Umwelt, DBU) and Gesellschaft der Förderer und Freunde der Holzwissenschaften in Hamburg e.V.

2 Why a Charcoal Atlas?

This Charcoal Atlas contains wood species that are increasingly found in charcoal products (charcoal and briquettes) on the European market. It is suitable for the direct identification and monitoring of charcoal products, as required by the EU. Reference data is necessary, specifically for charred wood species.

The charring process results in changes in wood structure, making traditional wood identification a real challenge as many anatomical features are either difficult to detect or completely altered. The limited number of features can severely impair the process of charcoal identification. The anatomical features that are still visible must be carefully analyzed, as some of them have been changed or damaged by the high temperature of the charring process.

The risk of misidentification is high, and analysis requires experience. This applies in particular to charcoal briquettes. Nevertheless, such charcoal fragments can be successfully analyzed with specific high-resolution microscopes (Balzano et al., 2020; Zemke et al., 2020).

The charring process causes dimensional changes in the wood tissues, rendering solid wood databases inadequate for charcoal identification since numerical size values of vessel elements, intervessel pits and rays have changed (Zemke et al., 2025).

3 Structural Changes of Wood During Carbonization

A charring process occurs when wood is exposed to temperatures of at least 300°C in an oxygen-free environment" (Kwon et al., 2009). The ensuing physical and chemical reaction changes the structure of the wood (Braadbart and Poole, 2008). Volatile substances are released during this process, which is evident by the presence of a flame. The charring process is finished as soon as the flame extinguishes. There occurs a transformation of the three main chemical components in the wood, which takes place at different temperatures: Hemicelluloses (200-300°C), cellulose (from 240°C) and lignin (from 280°C). Cellulose is converted; hemicelluloses and lignin change to a graphite-like structure (Slocum et al., 1978).

Physical changes also occur, leading to a noticeable change in colour. Charcoal is dark grey to black and has a matt to slightly shiny surface. Marbling such as streaking or similar is no longer recognizable after charring. The strength properties also change during the charring process, as our experiments have shown; liquid components in the wood volatilize and the material loses mass. Measurements conducted before and after charring show different weight loss depending on wood species and temperature. According to literature sources, the range is roughly between 40 to 85% loss. Our experiments have shown weight losses between 59% and 81% (n = 30). This also changes the form and dimensions of structural components in the radial, tangential and in cross sections. In their studies, Bowyer et al. (2011) also confirm a higher shrinkage in the tangential than in the radial direction, with a factor of 1.5-3.0. Charred wood often exhibits changes in shape, with noticeable geometric distortions. The specific gravity, determined from the weight (g) over volume (cm^3), can no longer be determined due to the physical and chemical alterations caused by the charring process (Rossen and Olson, 1985).

4 Preparation and Microscopy of Charcoal

Classical light microscopy cannot be used for the analysis of charcoal due to structural changes in the woody tissue during the charring process. The material becomes compressed and brittle while the colour shifts from gray to black. Charcoal often contains deposits of minerals or fungal hyphae, further complicating the analysis. These changes significantly impact the quality of wood identification of charcoal and increase the risk of incorrect taxon identification (Prior and Gasson, 1993; Figueiral and Mosbrugger, 2000; Scheel-Ybert, 2000; Scott, 2000; Gerisch, 2004; Bird et al., 2008; Braadbart and Poole, 2008; Di Pasquale et al., 2008; Boutain et al., 2010; Dias Leme et al., 2010; Théry-Parisot et al., 2010; Ascough et al., 2011; Hubau et al., 2013; Haag et al., 2017; Zemke et al., 2020). Notwithstanding these shortcomings, many anatomical features are generally well preserved (Prior and Alvin, 1983: 1986; Prior and Gasson, 1993; Kim and Hanna, 2006; Kwon et al., 2009; Dias Leme et al., 2010; Gonçalves et al., 2012, Hubau et al., 2013).

Thin sections of charcoal for light microscopic examination can only be prepared with very unsatisfactory results. Experiments, such as those by Cousins (1973; 1975), Smith and Gannon (1973) and Schweingruber (1978; 2012), have shown that microscopic sections of charcoal can only be produced with elaborate embedding. Figural and Mosbrugger (2000) state that embedding can be done with kerosene, resin or a mixture of epoxy resins. Often the embedded samples can only be identified in transverse section as the brittle structure of the charred tissue breaks in the longitudinal planes during microtome sectioning despite the adhesive (Schweingruber, 2012). Since information from longitudinal sections is also required for the identification of most wood species, this method is rarely suitable for the in-depth analysis of charcoal specimens (Zemke et al., 2020).

Another method involves the production of thin sections by grinding the charcoal embedded in resin. The specimen is ground down until it becomes thin enough for light to pass through, enabling microscopy of the anatomical structure (Couvert, 1968; Hather, 2000). However, this procedure is highly time consuming and has largely been replaced by more advanced techniques. Consequently, the uneven surfaces of the broken charcoal are usually observed directly by high-end microscopes. For this purpose, the charcoal is first split along the three anatomical structural planes (transverse/tangential/radial) either manually or with a knife, (Koeppen, 1972; Gale and Cutler, 2000; Gerisch, 2004; Dias Leme et al., 2010; Gonçalves et al., 2012; Nelle and Bankus, 2012; Hubau et al., 2013; Gonçalves et al., 2014; Gonçalves et al., 2016; Gonçalves and Scheel-Ybert, 2016; Scheel-Ybert, 2016). Different microscopy methods can be used for the subsequent analysis of the charred wood structure.

Reflected light microscopy (= RLM, binocular):

In normal reflected light microscopy (RLM), light passes through the objective directly onto the opaque charcoal surface, allowing the observation of anatomical structures on the surface. RLM is commonly used to pre-sort samples by grouping those with similar anatomical features (Carcaillet and Thinon, 1996; Chabal et al., 1999; Höhn and Neumann, 2012; Hubau et al., 2012; Hubau et al., 2013). This is followed by a detailed observation using electron microscopy (Figueiral, 1999; Hubau et al., 2013; Gonçalves and Scheel-Ybert, 2016; Scheel-Ybert and Gonçalves, 2017) or digital 3D-Reflected Light Microscopy (Zemke et al., 2020).

3D-reflected light microscopy (= 3D-RLM):

The digital 3D-Reflected Light Microscopy technique is suitable for studying the structure of charcoal pieces as well as very small fragments found in charcoal briquettes. As with classic RLM, a complex preparation is not necessary. The freshly broken untreated samples can be observed directly under the microscope. The examinations can be carried out with various 3D scanning system based microscopes available on the market. The present study was carried out with a Keyence (VHX-5000) 3D microscope. The microscope can digitally scan the uneven surfaces of charcoal within a programmable area, assemble the details into a three-dimensional image which can be converted into a two-dimensional representation. The 3D-RLM produces high-quality images which largely correspond to the results and requirements of traditional light microscopy. The integrated polarization technology of the 3D-RLM leads to high-resolution images of the smallest cell structures, such as septate fibres and spiral thickenings. The light flow can be controlled with a polarization filter and analyzer. The amount and type of light varies depending on the alignment of the two filters. The 'normal', i.e. non-polarized light, is defined by movements of the field vectors perpendicular to the direction of propagation. A polarizing filter linearly polarizes the light waves and absorbs light of other wavelengths. The nature of these light waves changes the basic colour of the microscopic image so that it appears green." (Zemke et al., 2020).

Electron microscopy (= SEM):

Wood identification of charcoal can also be performed using SEM technology (Blankenhorn et al., 1972; Cutter et al., 1980; Figueiral, 1999; Figueiral and Willcox, 1999; Figueiral and Mosbrugger, 2000; Boutain et al., 2010; Gonçalves and Scheel-Ybert, 2016; Heu et al., 2019; Zemke et al., 2020). Gerisch (2004) has summarized the standard works explaining electron microscopy methodology applied by Wischnitzer (1981), Robinson (1985), Watt (1985), Robinson et al. (1987) and Goodhew (1991). The charcoal must be broken into small fragments of about 1 x 1 x 0.2 cm^3. It is important that the surfaces are prepared exactly along the structural planes (transverse/tangential/radial) as these are the surfaces that will later be analyzed under the microscope. The specimens are then glued to aluminium stubs with carbon paste (Zemke et al., 2020). Another way for producing fresh fractures of very small charcoal fragments is described by Boutain et al., (2010). It involves gluing the nearly flat ground top and bottom of the specimen to a stub. Once the adhesive has hardened, a fracture is created, allowing the surfaces to be observed under the microscope. Blankenhorn et al., (1972) and Cutter et al., (1980) carried out observations under the electron microscope directly afterwards without further surface treatment. To improve the image quality, a fine vaporization of the surface with gold (Gonçalves and Scheel-Ybert, 2016) or with platinum (Heu et al., 2019) is often applied according to the current state of the art.

Computed tomography (Nano-CT and HT-μCT):

Computed tomography can be used for the non-destructive examination of charcoal specimens. The inner structure is scanned layer by layer so that selected areas can be viewed individually or as a three-dimensional volumetric representation (Van den Bulcke et al., 2009; Mannes et al., 2010; Hubau et al., 2013; Haag et al., 2022).

Resume:

In summary, there are several methods for examining charcoal. The most suitable method depends on the sample material (conservation status, number of fragments, destructive and non-destructive method, processing time, complexity of preparation). The advantages and disadvantages of the microscopic techniques are summarized and compared by Zemke et al. (2020).

Further (non-microscopic) methods have been developed for the identification of charcoal specimens, such as non-destructive infrared spectroscopy (NIR) (Davrieux et al., 2010; Muñiz et al., 2013; Muñiz et al., 2016; Nisgoski et al., 2016).

5 Method for Creating Wood Data Sheets

The wood data sheets for this charcoal atlas were created using additional information from the following scientific sources. Each data sheet includes specific references to the authors whose work was consulted.

Botanical names:
Catalogue of life (https://www.catalogueoflife.org/col/search)
World Plants (https://www.worldplants.de/ Hassler 2004 onwards)
World Wide Wattle (http://worldwidewattle.com/speciesgallery/ Maslin and Wilson, 2022)

Trade names:
Richter and Dallwitz (2000 onwards)
Takawira-Nyenya (2005)
DIN EN 13556:2003-10 (https://dx.doi.org/10.31030/9444492)

Code of DIN EN 13556:2003-10:
DIN EN 13556:2003-10 (https://dx.doi.org/10.31030/9444492)

CITES regulation and Conservation Status:
A check of the CITES status and Conservation status with the associated databases is recommended as the status can change over time.
CITES (http://checklist.cites.org)
Conservation Status (IUCN, 2024)

Geographic distribution:
Catalogue of life (https://www.catalogueoflife.org/col/search)
Plant Resources of Tropical Africa PROTA4U (https://www.prota4u.org)
Sosef et al., (1998)
Richter and Dallwitz (2000 onwards)
World Plants (https://www.worldplants.de/ Hassler 2004 onwards)
World Wide Wattle (http://worldwidewattle.com/speciesgallery/ Maslin and Wilson 2022)
WCSP (http://wcsp.science.kew.org)

Description of anatomical features (Introduction to anatomical features):

Evans et al. (2006), Grosser (1977), Microscopic Features for Hardwood Identification (IAWA Committee 1989), Richter and Dallwitz (2000 onwards).

Description of anatomical features:

Pearson and Brown (1932), Brazier and Franklin (1961), Kribs (1968), Baas (1973), Ayensu and Bentum (1974), Grosser (1977), Olvera et al. (1980), Quirk et al. (1983), Miller and Cahow (1989), Schweingruber (1990), Jansen et al. (1997), Sosef et al. (1998), Höhn (1999), Hather (2000), Richter and Dallwitz (2000 onwards), Inside Wood (2004 onwards), Schoch et al. (2004), Fagg et al. 2005, Evans et al. (2006), Sousa et al. (2009), Whinder et al. (2013), Roskov et al. (2014), Tian et al. (2021).

6 Material and Selection of Wood Species

The species selected for this atlas are based on research conducted at the Thünen Institute for Wood Research. Included are a number of collaborative projects developed in cooperation with regional NGOs (WWF, 2017; WWF, 2018) and, in particular, by the study “The European Charcoal transition” (Haag et al., 2020), conducted at the Thünen Institute in 2019 and 2020. For this study, charcoal and briquette material received from eleven European countries were examined. Of the approximately 4500 individual charcoal fragments examined and identified, about one third is of (sub-)tropical and two-thirds of boreal/temperate origin. Most of the identified fragments could be assigned to botanical genera, but in certain cases only to the family, especially in the case of tropical woods. For example, 1171 fragments could only be assigned to Fabaceae, and could not be further differentiated due to the anatomical similarities between so many genera. A similar situation holds true for woods assigned to families such as Sapotaceae, Apocynaceae, or Combretaceae.

For the atlas, we selected woods that are locally important for wood charcoal production in South America, Africa, and Europe, or are frequently listed in product declarations. These include woods like *Aspidosperma quebracho-blanco* from South America, whose charcoal is notable for properties like odour and combustion temperature, as well as wood species commonly processed into charcoal due to forestry management measures or as by-products of wood production plantations. In addition, wood species were selected that are documented to be traded through supply chains either into or within Europe, as well as those expected to be incorporated into European products in the future. The 34 wood species that were finally selected for the present atlas are listed in Table 2.

Specimens from the scientific collection of the Thünen Institute for Wood Research (RBHw, Hamburg, Germany) served as reference material. In addition to the information on origin and accompanying bibliographical data, all were microscopically analyzed and described using the IAWA Feature List, Inside Wood and databases (IAWA Committee, 1989; Richter and Dallwitz, 2000 onwards; Wheeler, 2011).

For the Feature chapter, samples from the scientific collection were also used in the same way as for the reference collection of the atlas and were supplemented with samples sourced from the international charcoal trade or provided directly by a charcoal kiln.

Table 1 List of wood species alphabetically ordered by family affiliation.

No.	Family	Species	Trade name
1	APOCYNACEAE	*Aspidosperma quebracho-blanco* Schltdl.	Quebracho blanco
2	AQUIFOLIACEAE	*Ilex aquifolium* L.	English holly
3	BETULACEAE	*Alnus glutinosa* (L.) Gaertn.	Common alder
4	BETULACEAE	*Betula pubescens* Ehrh.	Birch
5	BETULACEAE	*Carpinus betulus* L.	Common hornbeam
6	BURSERACEAE	*Aucoumea kleineana* Pierre	Okoumé
7	DIPTEROCARPACEAE	*Rubroshorea leprosula* (Miq.) P.S.Ashton & J.Heck.	Light red meranti
8	EBENACEAE	*Diospyros crassiflora* Hiern	Black ebony
9	FABACEAE-CAESALPINIOIDEA	*Afzelia africana* Pers.	Afzelia
10	FABACEAEA-CAESALPINIOIDEA	*Copaifera paupera* (Herzog) Dwyer	Copaiba
11	FABACEAE-FABOIDEAE	*Pterocarpus angolensis* DC.	Muninga
12	FABACEAE-FABOIDEAE	*Robinia pseudoacacia* L.	False Acacia
13	FABACEAE-MIMOSOIDEAE	*Acacia dealbata* Link	Akasia
14	FABACEAE-MIMOSOIDEAE	*Acacia melanoxylon* R.Br.	Akasia
15	FABACEAE-MIMOSOIDEAE	*Cedrelinga cateniformis* (Ducke) Ducke	Tornillo
16	FABACEAE-MIMOSOIDEAE	*Dichrostachys cinerea* (L.) Wight & Arn.	Marabù
17	FABACEAE-MIMOSOIDEAE	*Senegalia chundra* (Roxb. Ex Rottler) Maslin	Cutch
18	FABACEAE-MIMOSOIDEAE	*Vachellia nilotica (L.)* P.J.H.Hurter & Mabb.	Babul Acacia
19	FAGACEAE	*Fagus sylvatica* L.	Beech
20	FAGACEAE	*Quercus petraea* (Matt.) Liebl.	White oak
21	FAGACEAE	*Quercus suber* L.	Cork oak
22	JUGLANDACEAE	*Juglans nigra* L.	Black walnut
23	MALVACEAE	*Triplochiton scleroxylon* K. Schum.	Wawa
24	MORACEAE	*Milicia excelsa* (Welw.) C. C. Berg	Iroko, kambala
25	MYRTACEAE	*Eucalyptus grandis* W. Hill ex Maiden	Flooded gum
26	OLEACEAE	*Fraxinus excelsior* L.	European ash
27	PAULOWNIACEAE	*Paulownia elongata* S. Y. Hu	Kiri
28	RHAMNACEAE	*Ziziphus mucronata* Willd.	Buffalo thorn
29	RUBIACEAE	*Coffea arabica* L.	Arabian coffee
30	RUBIACEAE	*Nauclea diderrichii* (De Wild.) Merr.	Bilinga, opepe
31	SALICACEAE	*Populus alba* L.	White poplar
32	SAPINDACEAE	*Acer pseudoplatanus* L.	Sycamore maple
33	SAPOTACEAE	*Autranella congolensis* (De Wild.) A. Chev.	Mukulungu
34	ULMACEAE	*Ulmus minor*	Field elm

Source: Thünen-Institut/ Authors own illustration

7 Feature List for Charcoal

Due to the exposure to excessive heat during the charring process, anatomical features may be lost, making them undetectable and therefore unavailable for identification (Pearsall, 2000; Ferguson, 2005; Boutain et al., 2010). Based on the IAWA Feature List for Hardwood Identification (IAWA Committee, 1989), the following list is adapted for charcoal (Table 3). The original numbering of features was retained in order to match databases and identification keys also based on the IAWA numbering system.

The quality of wood identification depends on the observer´s subjective perception of the diagnostic features. Despite advancements in microscopy techniques, in some studies of globally traded commercial wood species identification cannot go beyond the family or genus level, particularly for charcoal of subtropical and tropical origin (Nelle and Bankus, 2012; Gonçalves and Scheel-Ybert, 2016; Muñiz et al., 2016). For charcoal production, however, also lesser-known species are increasingly being used for which no data have yet been collected. It is highly advantageous to work with reference specimens from a scientific collection for comparison when analyzing charcoal. Meanwhile, numerous scientific institutions have established charcoal collections summarized by Scheel-Ybert (2016).

Table 3. Feature List for Charcoal, according to the IAWA Feature List (IAWA Committee 1989).

GROWTH RINGS
#1. Growth ring boundaries distinct
#2. Growth ring boundaries indistinct or absent
VESSELS
POROSITY
#3. Wood ring-porous
#4. Wood semi-ring-porous
#5. Wood diffuse-porous
VESSEL ARRANGEMENT
#6. Vessels in tangential bands
#7. Vessels in diagonal and/or radial pattern
#8. Vessels in dendritic pattern
VESSEL GROUPINGS
#9. Vessels exclusively solitary (90% or more)
#10. Vessels in radial multiples of 4 or more common
#11. Vessel clusters common
SOLITARY VESSEL OUTLINE
#12. Solitary vessel outline angular
PERFORATION PLATES
#13. Simple perforation plates
#14. Scalariform perforation plates
#15. Scalariform perforation plates with ≤ 10 bars
#16. Scalariform perforation plates with 10 –20 bars
#17. Scalariform perforation plates with 20– 40 bars
#18. Scalariform perforation plates with ≥ 40 bars
#19. Reticulate, foraminate, and/or other types of multiple perforation plates
INTERVESSEL PITS: ARRAGEMENT AND SIZE
#20. Intervessel pits scalariform
#21. Intervessel pits opposite
#22. Intervessel pits alternate
#23. Shape of alternate pits polygonal
#24. Minute – ≤ 4 µm
#25. Small – 4–7 µm
#26. Medium – 7–10 µm
#27. Large – ≥ 10 µm
#28. Range of intervessel pit size (µm)
VESTURED PITS
#29. Vestured pits
VESSEL-RAY PITTING
#30. Vessel–ray pits with distinct borders; similar to intervessel pits in size and shape throughout the ray cell
#31. Vessel–ray pits with much reduced borders to apparently simple: pits rounded or angular
#32. Vessel–ray pits with much reduced borders to apparently simple: pits horizontal (scalariform, gash-like) to vertical (palisade)
#33. Vessel–ray pits of two distinct sizes or types in the same ray cell
#34. Vessel–ray pits unilaterally compound and coarse (over 10 µm)
#35. Vessel–ray pits restricted to marginal rows
HELICAL THICKENINGS
#36. Helical thickenings in vessel elements present
#37. Helical thickenings throughout body of vessel element
#38. Helical thickenings only in vessel element tails
#39. Helical thickenings only in narrower vessel elements
TANGENTIAL DIAMETER OF VESSEL LUMINA
#40. < 50 µm
#41. 50-100 µm
#42. 100-200 µm
#43. > 200 µm
#44. Mean, + /– Standard Deviation, Range, n = x
#45. Vessels of two distinct diameter classes, wood not ring-porous
VESSELS PER SQUARE MILLIMETRE
#46. ≤ 5 vessels per square millimetre
#47. 5–20 vessels per square millimetre
#48. 20–40 vessels per square millimetre
#49. 40–100 vessels per square millimetre
#50. ≥ 100 vessels per square millimetre
51. Mean, +/– Standard Deviation, Range, n = x

Feature List for Charcoal

TYLOSES AND DEPOSITS IN VESSELS
#56. Tyloses common
#57. Tyloses sclerotic
#58. Gums and other deposits in heartwood vessels
WOOD VESSELLESS
#59. Wood vesselless
FIBRES
GROUND TISSUE FIBRES
#61. Fibres with simple to minutely bordered pits
#62. Fibres with distinctly bordered pits
#63. Fibre pits common in both radial and tangential walls
#64. Helical thickenings in ground tissue fibres
SEPTATE FIBRES AND PARENCHYMA-LIKE FIBRES BANDS
#65. Septate fibres present
#67. Parenchyma-like fibre bands alternating with ordinary fibres
FIBRES WALL THICKNESS
#68. Fibres very thin-walled
#69. Fibres thin- to thick-walled
#70. Fibres very thick-walled
AXIAL PARENCHYMA
APOTRACHEAL AXIAL PARENCHYMA
#76. Axial parenchyma diffuse
#77. Axial parenchyma diffuse-in-aggregates
PARATRACHEAL AXIAL PARENCHYMA
#78. Axial parenchyma scanty paratracheal
#79. Axial parenchyma vasicentric
#80. Axial parenchyma aliform
#81. Axial parenchyma lozenge-aliform
#82. Axial parenchyma winged-aliform
#83. Axial parenchyma confluent
#84. Axial parenchyma unilateral paratracheal
BANDED PARENCHYMA
#85. Axial parenchyma bands more than three cells wide
#86. Axial parenchyma in narrow bands or lines up to three cells wide
#87. Axial parenchyma reticulate
#88. Axial parenchyma scalariform
#89. Axial parenchyma in marginal or in seemingly marginal bands
AXIAL PARENCHYMA CELL TYPE/STRAND LENGTH
#90. Fusiform parenchyma cells
#91. Two cells per parenchyma strand
#92. Four (3– 4) cells per parenchyma strand
#93. Eight (5–8) cells per parenchyma strand
#94. Over eight cells per parenchyma strand
#95. Unlignified parenchyma
RAYS
RAY WIDTH
#96. Rays exclusively uniseriate
#97. Ray width 1 to 3 cells
#98. Larger rays commonly 4- to 10-seriate
#99. Larger rays commonly > 10-seriate
#100. Rays with multiseriate portion(s) as wide as uniseriate portions
101. Aggregate rays
#102. Ray height > 1 mm

#103. Rays of two distinct sizes
CELLULAR COMPOSITION
#104. All ray cells procumbent
#105. All ray cells upright and /or square
#106. Body ray cells procumbent with one row of upright and /or square marginal cells
#107. Body ray cells procumbent with mostly 2– 4 rows of upright and/or square marginal cells
#108. Body ray cells procumbent with over 4 rows of upright and/or square marginal cells
#109. Rays with procumbent, square and upright cells mixed throughout the ray
#110. Sheath cells
#111. Tile cells
#112. Perforated ray cells
#113. Disjunctive ray parenchyma cell walls
#117. Wood rayless
STORIED STRUCTURE
#118. All rays storied
#119. Low rays storied, high rays non-storied
#120. Axial parenchyma and/or vessel elements storied
#121. Fibres storied
#122. Rays and /or axial elements irregularly storied
SECRETORY ELEMENTS AND CAMBIAL VARIANTS
OIL AND MUCILAGE CELLS
#124. Oil and /or mucilage cells associated with ray parenchyma
#125. Oil and /or mucilage cells associated with axial parenchyma
#126. Oil and /or mucilage cells present among fibres
INTERCELLULAR CANALS
#127. Axial canals in long tangential lines
#128. Axial canals in short tangential lines
#129. Axial canals diffuse
#130. Radial canals
#131. Intercellular canals of traumatic origin
TUBES/TUBULES
#132. Laticifers or tanniniferous tubes
CAMBIAL VARIANTS
#133. Included phloem, concentric
#134. Included phloem, diffuse
#135. Other cambial variants
MINERAL INCLUSIONS
PRISMATIC CRYSTALS
#136. Prismatic crystals present
#137. Prismatic crystals in upright and /or square ray cells
#138. Prismatic crystals in procumbent ray cells
#139. Prismatic crystals in radial alignment in procumbent ray cells
#140. Prismatic crystals in chambered upright and /or square ray cells
#141. Prismatic crystals in non-chambered axial parenchyma cells
#142. Prismatic crystals in chambered axial parenchyma cells
#143. Prismatic crystals in fibres
DRUSES
#144. Druses present
#145. Druses in ray parenchyma cells

#146. Druses in axial parenchyma cells
#147. Druses in fibres
#148. Druses in chambered cells
OTHER CRYSTAL TYPES
#149. Raphides
#150. Acicular crystals
#151. Styloids and /or elongate crystals
#152. Crystals of other shapes (mostly small)
#153. Crystal sand
OTHER DIAGNOSTIC CRYSTAL FEATURES
#154. More than one crystal of about the same size per cell or chamber
#155. Two distinct sizes of crystals per cell or chamber
#156. Crystals in enlarged cells
#157. Crystals in tyloses
#158. Cystoliths
SILICA
#159. Silica bodies present
#160. Silica bodies in ray cells
#161. Silica bodies in axial parenchyma cells
#162. Silica bodies in fibres
#163. Vitreous silica

Source: Thünen-Institut/ Authors own illustration, based on the IAWA Feature List (IAWA Committee 1989)

8 The Features

Anatomical features are illustrated by charcoal images and accompanied by relevant information for identification to ensure recognition using the Charcoal Feature List. Feature definitions and some comments are adopted from the IAWA List of Microscopic Features for Hardwood Identification (IAWA Committee, 1989), occasionally complemented by remarks related to the specific circumstances of charcoal identification. In a separate chapter the use of the quantitative features for charcoal identification is explained.

Growth rings (Figs. 1 A-B)

#1. Growth ring boundaries distinct (Fig. 1A) = Growth rings with an abrupt structural change at the boundaries between them, usually including a change in fibre wall thickness and/or fibre radial diameter. Growth ring boundaries can be marked by one or more of the following structural changes:

a) Thick-walled and radially flattened latewood fibres versus thin-walled earlywood fibres.
b) Marked differences in vessel diameter between latewood and earlywood of the following ring as in semi-ring-porous or ring-porous woods.
c) Marginal parenchyma (terminal or initial). Irregularly zonate tangential parenchyma bands without associated abrupt changes in fibre diameter and wall thickness are not considered marginal and do NOT represent distinct growth ring boundaries.
d) Vascular tracheids and very narrow vessel elements very numerous or forming the ground tissue of the latewood, and absent from the earlywood.
e) Decreasing frequency of parenchyma bands towards the latewood resulting in distinct fibre zones.
f) Distended rays.

The differences between 'indistinct' and 'distinct' boundaries are somewhat arbitrary, and there are intermediates. Growth rings may appear distinct when observed macroscopically, yet have indistinct boundaries at the light microscopic level; distinctness of the ring boundaries should be judged with a microscope.

#2. Growth ring boundaries indistinct or absent (Fig. 1B) = Growth rings vague and marked by more or less gradual structural changes at their poorly defined boundaries, or not visible.

Vessels (Figs. 1 C-E)

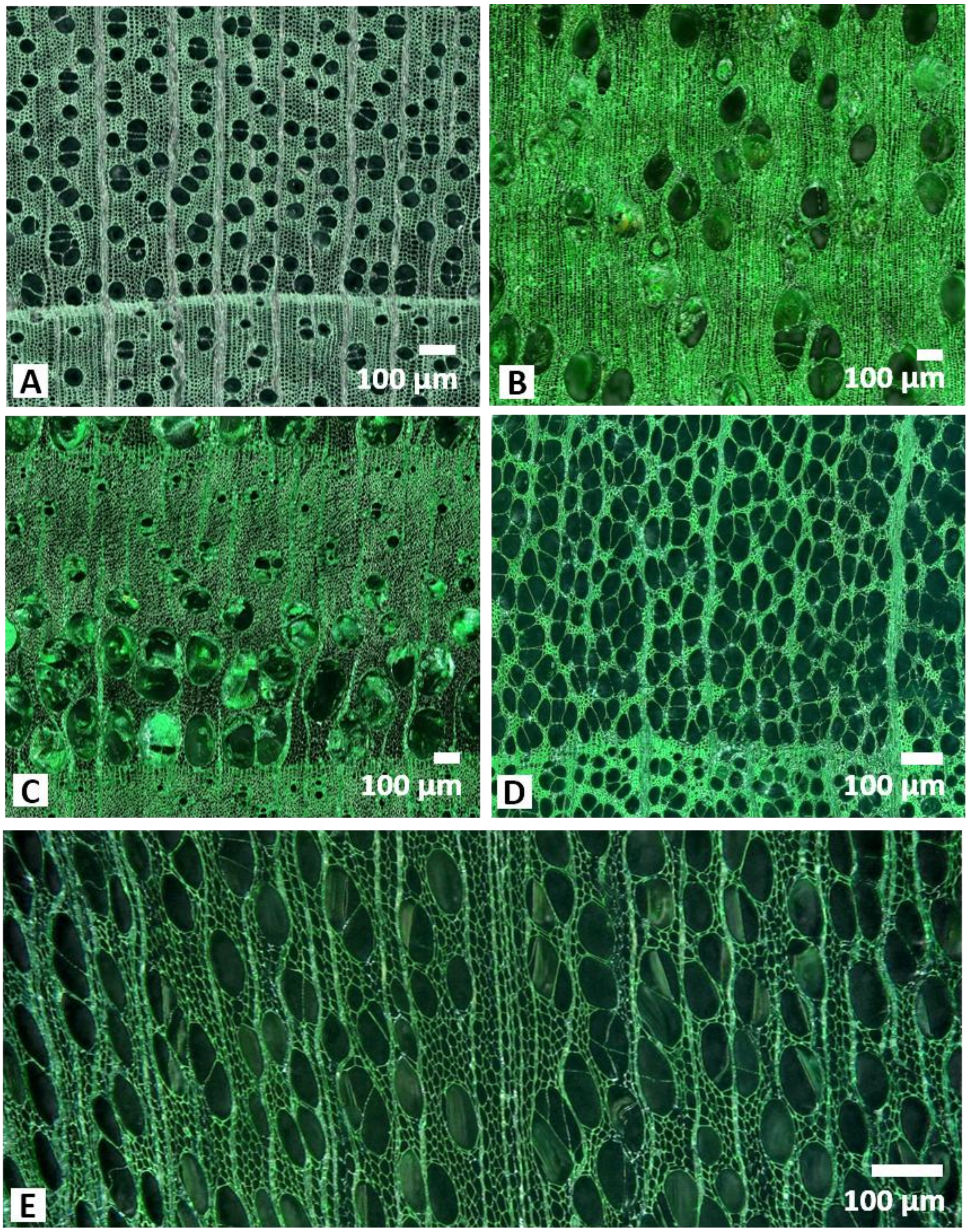
Porosity

#3. Wood ring-porous (Fig. 1C) = wood in which the vessels in the earlywood are distinctly larger than those in the latewood of the previous growth ring, and form a distinct zone or ring, and in which there is an abrupt transition to the latewood of the same growth ring. This feature is mostly found in trees of temperate regions whose growth is subject to distinct seasonal climate changes, rarely in species from subtropical or tropical regions (*Cedrela* spp., *Peronema canescens*, *Tectona grandis*).

#4. Wood semi-ring-porous (Fig. 1D) = 1) wood in which the vessels in the earlywood are distinctly larger than those in the latewood of the previous ring, but in which there is a gradual change to narrower vessels in the intermediate and latewood of the same growth ring; or 2) wood with a distinct ring of closely spaced earlywood vessels that are not markedly larger than the latewood vessels of the preceding ring or the same growth ring.

#5. Wood diffuse-porous (Fig. 1E) = wood in which the vessels have more or less the same diameter throughout the growth ring.

Fig. 1 **Growth ring boundaries distinct: *Acer pseudoplatanus* (A); Growth ring boundaries indistinct or absent: *Apuleia leiocarpa* (B); wood ring-porous: *Fraxinus excelsior* (C); wood semi-ring-porous: *Fagus sylvatica* (D); wood diffuse-porous: *Alnus glutinosa* (E).**



Source: Thünen-Institut/ Valentina Zemke

Vessel arrangement (Figs. 2 A-D)

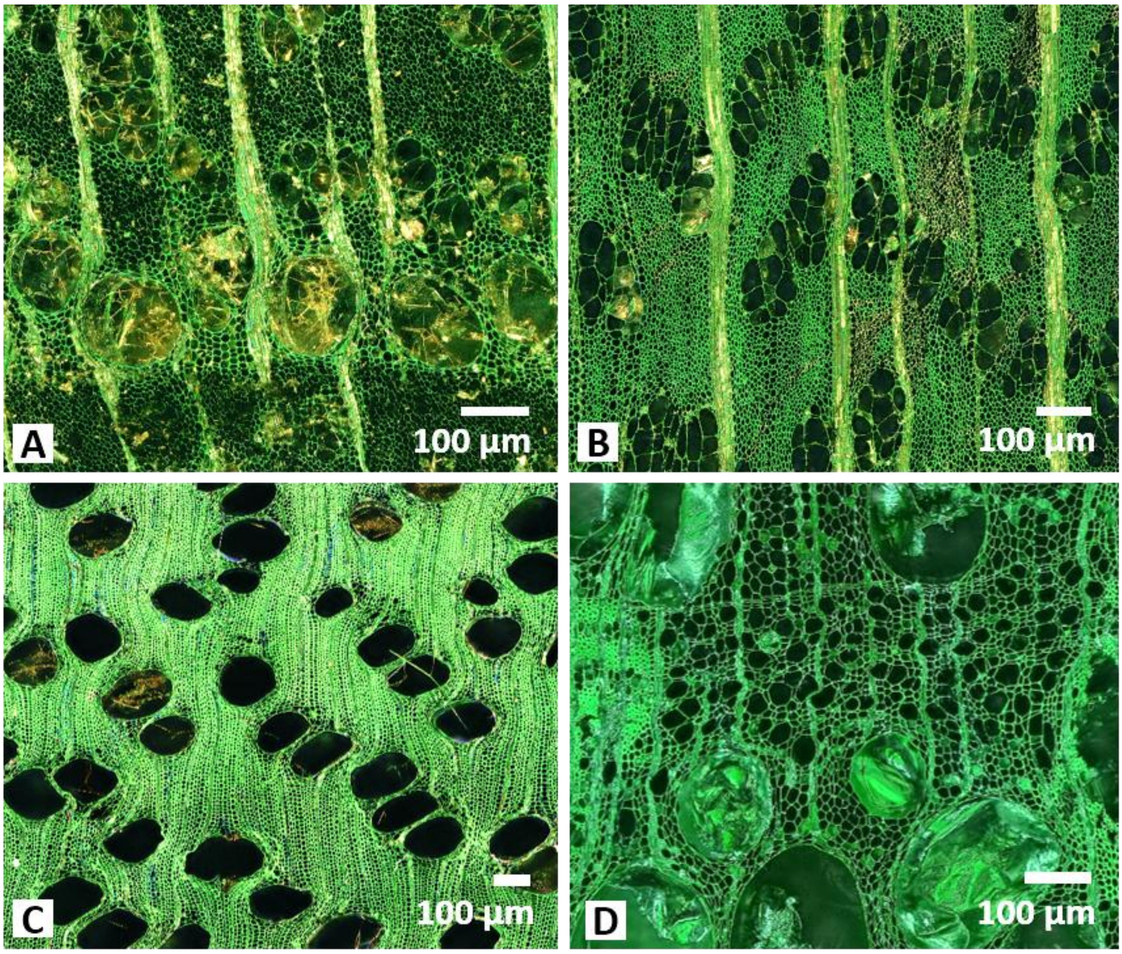
#6. Vessels in tangential bands (Figs. 2 A+B) = vessels arranged perpendicular to the rays and forming short or long tangential bands; these bands can be straight or wavy; includes the terms 'ulmiforn' and 'festooned'.

#7. Vessels in diagonal and/or radial pattern (Fig. 2C) = vessels arranged radially or intermediate between tangential and radial (i.e., oblique or diagonal). Synonym for diagonal: 'in echelon'.

#8. Vessels in dendritic pattern (Fig. 2D) = vessels arranged in a branching pattern, forming distinct tracts, separated by areas devoid of vessels. Synonym: 'flame like'.

Vessel distribution patterns are determined from the cross section at a low magnification, and are recorded only when there is a distinct pattern. In ring-porous woods, only the intermediate-wood and latewood are examined. The ring at the beginning of the growth ring of ring-porous woods is not considered when determining vessel distribution pattern.

Fig. 2 **Vessels in tangential bands: *Ulmus* sp (A); latewood vessels in tangential bands: *Ulmus* sp. (B); vessels in diagonal and/or radial pattern: *Eucalyptus* sp. (C); vessels in dendritic pattern: *Quercus petraea* (D).**



Source: Thünen-Institut/ Valentina Zemke

Vessel groupings (Figs. 3 A-C)

#9. Vessels exclusively solitary (Fig. 3A) = 90% or more of the vessels are completely surrounded by other elements, i.e., 90% or more appear not to contact another vessel, as viewed in cross section.

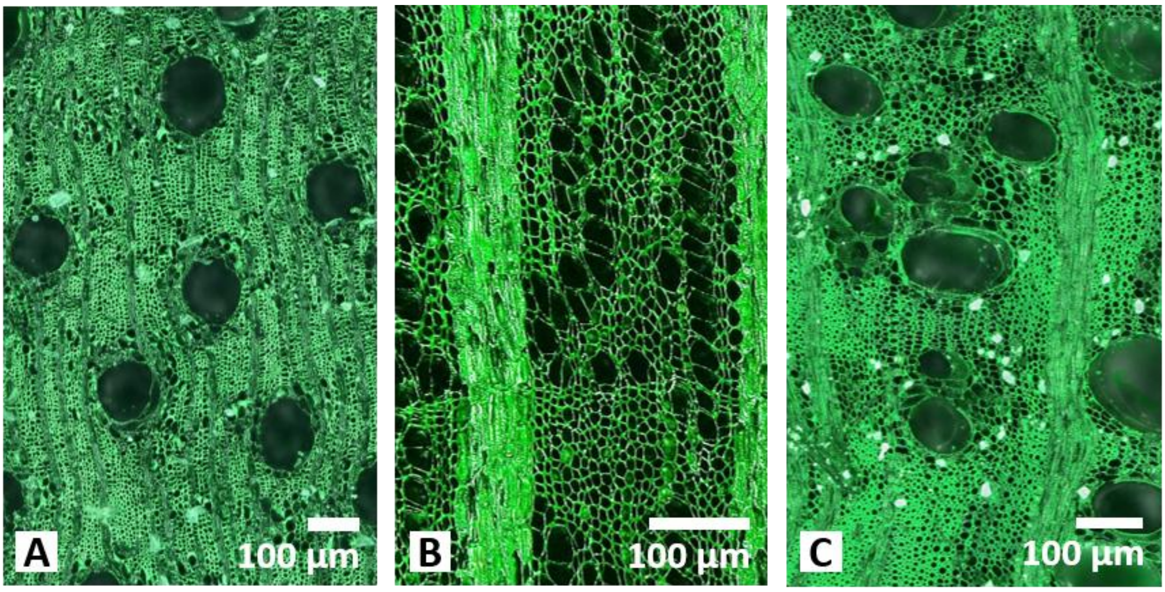
#10. Radial multiples of 4 or more common (Fig. 3B) = radial files of 4 or more adjacent vessels of common occurrence. This character should be used only when radial multiples of 4 or more are an obvious feature of the transverse section.

#11. Clusters common (Fig. 3C) = groups of 3 or more vessels having both radial and tangential contact, and of common occurrence. This character applies only when clusters are frequent enough that they are easily observed during a quick scan of a cross section. Clusters and radial multiples are not mutually exclusive and can occur in combination. Woods with vessels in tangential bands often have clusters.

The most common vessel grouping is radial multiples of 2 to 4 with a variable proportion of solitary vessels present. The absence of features 9-11 automatically implies this condition.

CARLQUIST (2001) recommends to count all vessel elements of at least 25 occurrences, regardless whether solitary or grouped, and to divide the total number by 25. A calculated index (quotient) of 1.00 corresponds to exclusively solitary vessel elements.

Fig. 3 **Vessels exclusively solitary: sample from Colombia, botanical name unknown (A); vessels in radial multiples of 4 or more common: *Ilex aquifolia* (B); vessel clusters common: sample from Kenya, botanical name unknown (C).**



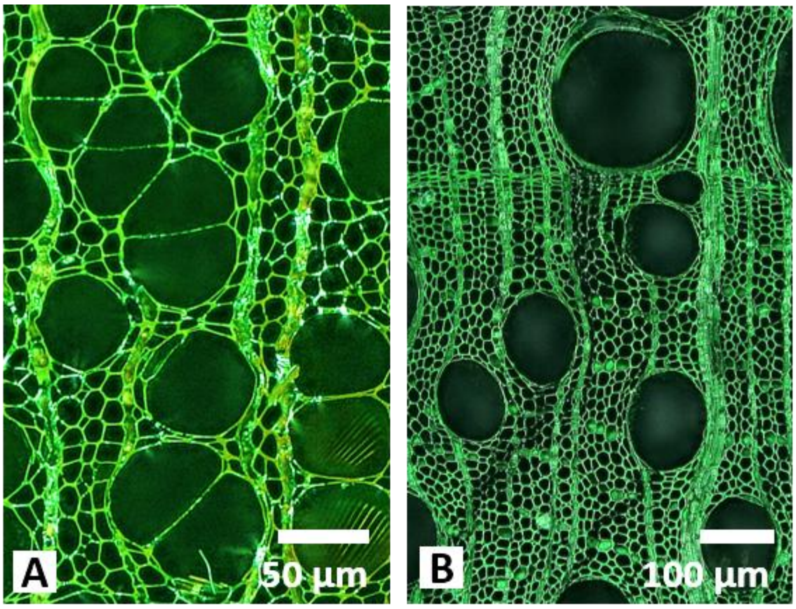
Source: Thünen-Institut/ Valentina Zemke

Solitary vessel outline (Figs. 4 A-B)

#12. Solitary vessel outline angular (Fig. 4A) = shape of solitary vessel outline angular as viewed in cross section. In ring-porous/semi-ring-porous woods, examine the latewood because in these woods the earlywood vessels are almost always circular to oval in outline. Use only the outline of solitary vessels because the common walls of vessels in multiples can be flattened giving part of the vessel an angular outline.

Solitary vessel elements with a rounded outline are shown in **Fig. 4B**.

Fig. 4 **Vessels with angular outline: *Alnus glutinosa* (A); with rounded outline: *Juglans nigra* (B).**



Source: Thünen-Institut/ Valentina Zemke

Perforation plates (Figs. 5 A-B)

#13. Simple perforation plate (Fig. 5A) =perforation plate with a single circular or elliptical opening.

#14. Scalariform perforation plate (Fig. 5B) = perforation plate with elongated and parallel openings separated by one or many mainly unbranched bars.

#15. Scalariform perforation plate with ≤ 10 bars.

#16. Scalariform perforation plate with 10 –20 bars.

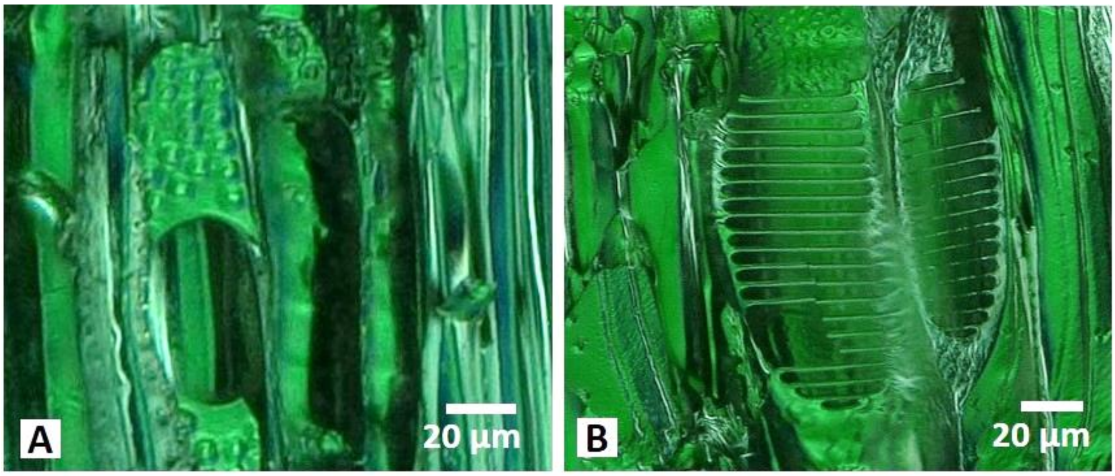
#17. Scalariform perforation plate with 20– 40 bars.

#18. Scalariform perforation plate with ≥ 40 bars.

#19. Reticulate, foraminate, and other types of multiple perforation plates = a reticulate perforation plate is a plate with closely spaced openings separated by wall portions that are much narrower than the spaces between them, or with a profuse and irregular branching of wall portions resulting in a netlike appearance. A foraminate perforation plate is a plate with circular or elliptical openings like a sieve; the remaining wall portions can be thicker than in the reticulate type.

Determine the type(s) of perforation plate from radial sections; preferably examine at least 25 vessel elements. For scalariform perforation plates, record all the feature categories that encompass the range of the number of bars.

Fig. 5 **Simple perforation plates: *Populus alba* (A); scalariform perforation plates: *Alnus glutinosa* (B).**



Source: Thünen-Institut/ Valentina Zemke

Intervessel pits: arrangement and size (Figs. 6 A-D)

#20. Intervessel pits scalariform (Fig. 6A) = elongated or linear intervessel pits arranged in a ladder-like series.

#21. Intervessel pits opposite (Fig. 6B) = intervessel pits arranged in short to long horizontal rows, i.e., rows oriented transversely across the length of the vessel.

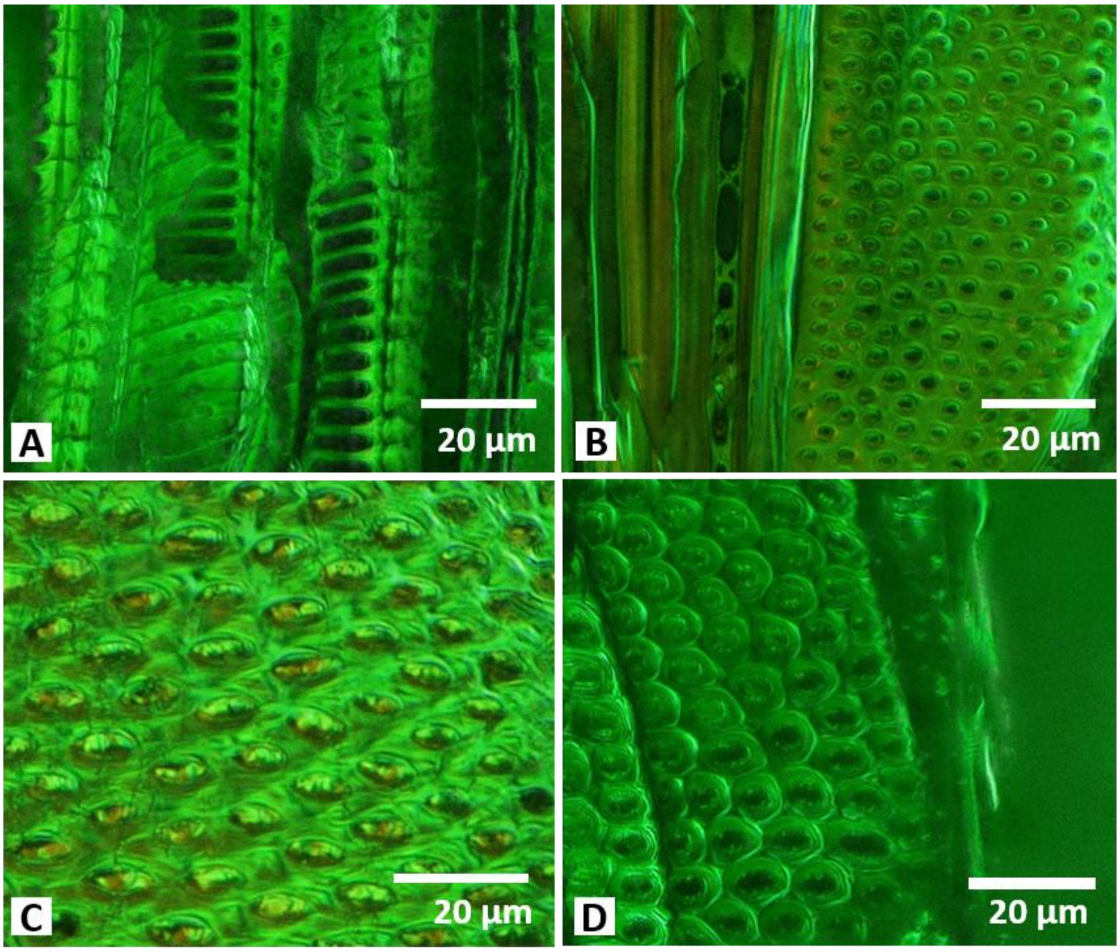
#22. Intervessel pits alternate (Fig. 6 C+D) = intervessel pits arranged in diagonal rows.

#23. Shape of alternate pits polygonal = intervessel pits of an angular outline with mostly 5 (pentagonal) to 6 (hexagonal) sides.

Generally, intervessel pits are easiest to find in tangential sections because radial multiples are the most frequent type of vessel multiples, and so intervessel pits are most frequent in tangential walls. When vessels are in tangential bands or clusters, radial sections also provide a surface view of intervessel pits. In woods with (almost) exclusively solitary vessels, intervessel pits will be extremely rare and often not visible in a single longitudinal section. In such woods, intervessel pit shape and size must be observed in overlapping end wall portions in a single vessel.

#24 to #28. Size of intervessel pits: Detailed Information on measuring intervessel pits is given in Chapt. 9.

Fig. 6 **Intervessel pits scalariform: *Ilex aquifolia* (A); intervessel pits opposite: *Alnus glutinosa* (B); intervessel pits alternate: *Aucoumea kleineana* (C); intervessel pits alternate with vestured pits: *Robinia pseudoaccacia* (D).**



Source: Thünen-Institut/ Valentina Zemke

Vestured pits

#29. Vestured pits (Fig. 6D) = pits with the pit cavity and/or aperture wholly or partly lined with projections (outgrowths) of the secondary cell wall. Contrary to observations under a common light microscope, the feature can be observed without special preparation techniques when it comes to charcoal identification. No water or glycerine or bleach is needed, as is used for light-microscopic wood identification.

Vessel-ray-pitting

#30. Vessel–ray pits with distinct borders; similar to intervessel pits in size and shape throughout the ray cell (Fig. 7A): as per feature descriptor.

#31. Vessel–ray pits with much reduced borders to apparently simple: pits rounded or angular (Fig. 7B+C): as per feature descriptor**.**

#32. Vessel–ray pits with much reduced borders to apparently simple: pits horizontal (scalariform, gash-like) to vertical (palisade): as per feature descriptor.

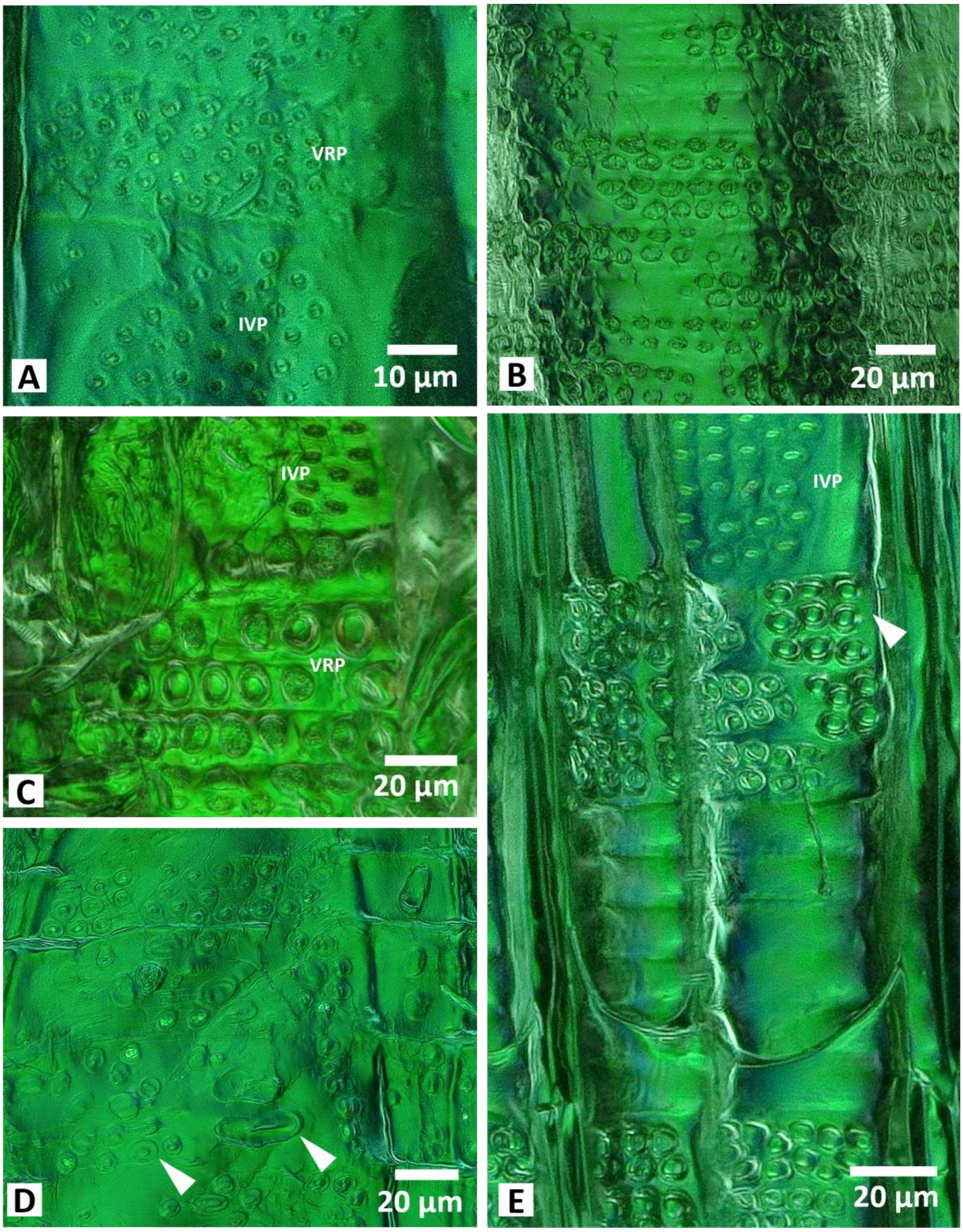
#33. Vessel–ray pits of two distinct sizes or types in the same ray cell (Fig. 7D): as per feature descriptor.

#34. Vessel–ray pits unilaterally compound and coarse (over 10 µm): as per feature descriptor.

#35. Vessel–ray pits restricted to marginal rows (Fig. 7E): as per feature descriptor.

Various combinations of the above features may occur and should be recorded. Vessel-ray pits in the body of the ray may differ from those in the ray margins. Record the features for both types of pits. If a wood has predominantly solitary vessels, comparison of vessel-ray pits with intervessel pits often is not possible. If the vessel-ray parenchyma pits in such woods are uniform in size and shape and have borders, then use feature #30; if not, any of features #31 to #35 may apply. Vessel-axial parenchyma pitting usually resembles vessel-ray parenchyma pitting, and it is therefore not included as a separate listing of almost identical descriptors.

Fig. 7 **Vessel-ray pits (VRP) with distinct borders; similar to intervessel pits (IVP) in size and shape: *Alnus glutinosa* (A); Vessel-ray pits with much reduced borders to apparently simple: pits rounded: *Juglans nigra* (B), *Eucalyptus* sp. (C); Vessel-ray pits of two distinct sizes in the same ray cell: *Autranella congolensis* (D); Vessel-ray pits restricted to marginal rows: *Populus alba* (E).**



Source: Thünen-Institut/ Valentina Zemke

Helical thickenings (Fig. 8)

#36. Helical thickenings in vessel elements = helical thickenings are ridges on the inner face of the vessel element wall in a roughly helical pattern. Synonym: Spiral thickenings.

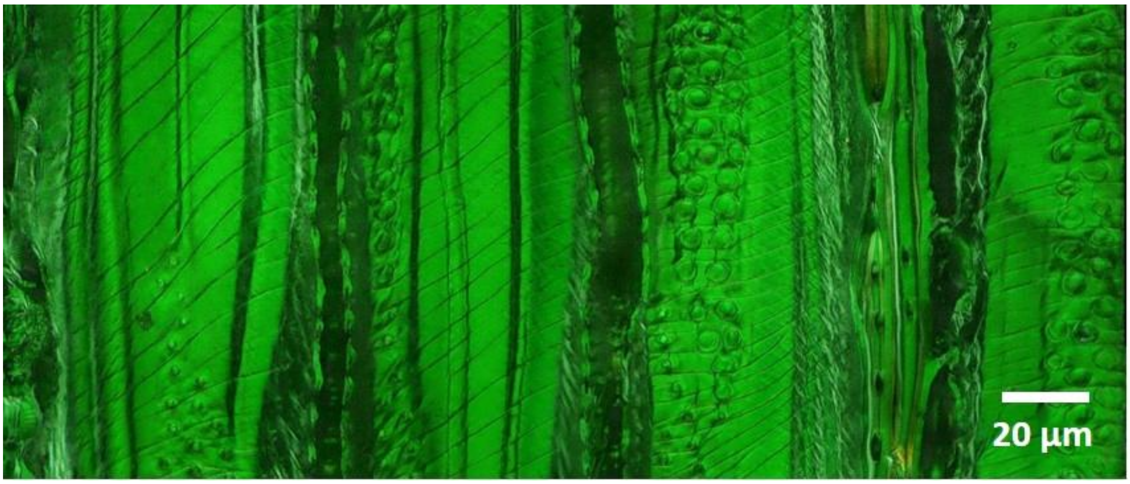
#37. Helical thickenings throughout body of vessel element (Fig. 8): as per feature descriptor. They can be recognized very clearly in charcoal as they are present in the entire vessel element focussing on different sections of the vessel.

#38. Helical thickenings only in vessel element tails: as per feature descriptor.

#39. Helical thickenings only in narrower vessel elements: as per feature descriptor; they are often indistinct or not recognizable at all in charcoal. This is due to the fact that the presence of helical thickenings can only be inferred from their contact points with the vessel walls. Melting of these areas or deposits of particles that occur after the forming process of the fractures leads to a more difficult visualization. In addition, there is usually a thin mesh superimposed by adjacent cell wall components if the observed surface is not perfectly aligned.

Helical thickenings are rather variable in terms of thickness (fine to coarse), inclination angle (nearly horizontal to steeply inclined, branching (branched or unbranched), and spacing (close to wide). It is recommended that observations of these variations be included in wood descriptions. Helical thickenings can also occur in vascular/vasicentric tracheids, and in ground tissue fibres, and very rarely in axial parenchyma.

Fig. 8 **Helical thickenings throughout body of vessel element *Carpinus betulus*.**



Source: Thünen-Institut/ Valentina Zemke

Tyloses and deposits in vessels

Tyloses (Figs. 9 A-E)

#56. Tyloses common (Figs. 9 A-C): as per feature descriptor.

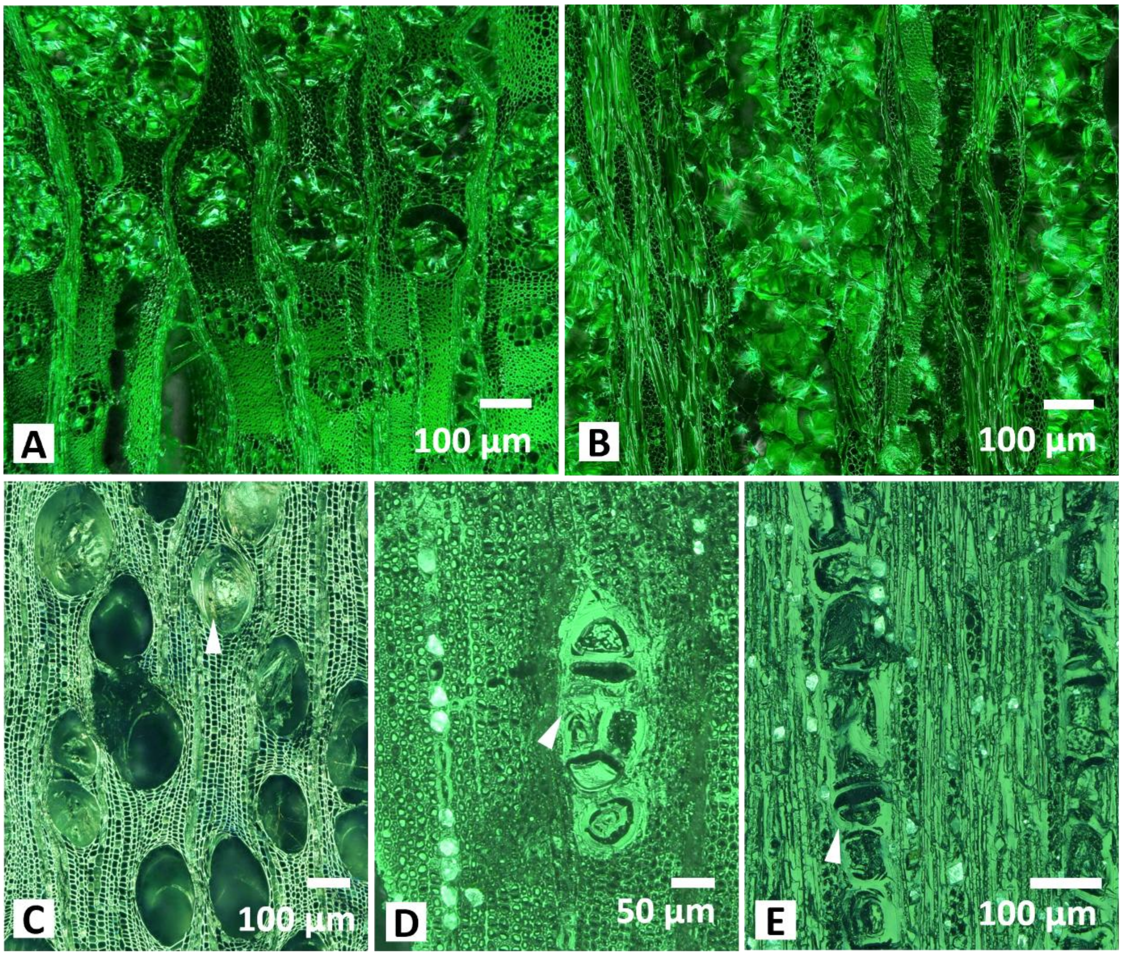
#57. Tyloses sclerotic (Fig. 9D+E) = tyloses with very thick, multilayered, lignified walls.

Tyloses are a result of heartwood formation, and serve the occlusion of the vessel lumina. Tyloses are absent in sapwood, as the vessels are still required for the water transport. Tyloses can also be formed in the wood due to traumatic injuries. Such tyloses cannot be used as a diagnostic feature for wood identification. Tyloses are primarily formed in the early formed wood of ring-porous species and are less frequent in latewood vessels.

Tyloses are characterized by their bubbly and irregular net-like structure. They are outgrowths from an adjacent ray or axial parenchyma cell through a pit in the vessel wall often completely blocking the vessel lumen, and of common occurrence in many species.

In charcoal tyloses are often easily recognized due to their "crystalline" appearance after the charring process and can be identified due to the strong microscopic light reflection. Tyloses are mostly thin-walled as in *Aucoumea kleineana,* and it can be difficult to distinguish them in charred material from other vessel contents.

Fig. 9 **Thin-walled tyloses common as seen in *Robinia pseudoaccacia:* crossection (A) and longitudinal section (B); tyloses rare and thin-walled: *Aucoumea kleineana* (C); tyloses sclerotic: *Brosimum* sp. (D+E).**



Source: Thünen-Institut/ Valentina Zemke (A, B, C), Volker Haag (D, E)

Gums and other deposits

#58. Gums and other deposits in heartwood vessels = organic substances deposited during heartwood formation. Studies have shown that the stored substances are sometimes present even after the charring process. Moreover, melted components (e.g. sand particles) are also deposited as a product of the charring process, which must be distinguished from the "normal" organic deposits. Therefore, it is recommended to check if gums and deposits are only present in vessel elements and not in other tissues.

Wood vesselless

#59. Wood vesselless: Vesselless dicotyledonous woods are relatively uncommon. They are composed only of imperforate tracheary elements and parenchyma, and are distinguished from conifers by tall multiseriate rays.

Fibres

Ground tissue fibres (Figs. 10 A-B)

#61. Fibres with simple to minutely bordered pits = fibres (libriform fibres) with simple or bordered pits with the pit chambers less than 3 µm in diameter.

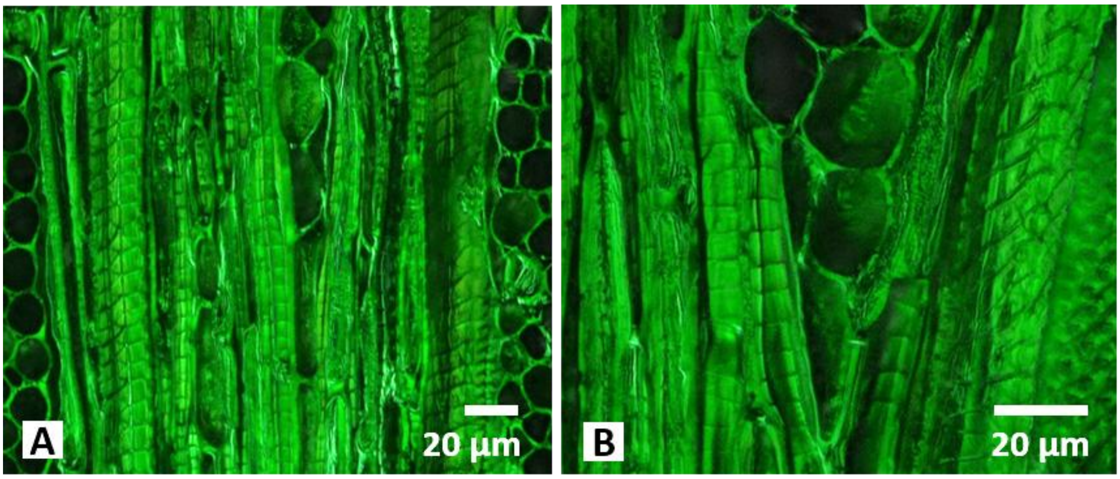
#62. Fibres with distinctly bordered pits = fibres (or fibre tracheids or ground tissue tracheids) with bordered pits with pit chambers over 3 µm in diameter.

#63. Fibre pits common in both radial and tangential walls = fibre pits, bordered or simple, common in radial and tangential walls.

#64. Helical thickenings in ground tissue fibres (Figs. 10 A+B). as per feature descriptor (see definition of helical thickenings).

Fibres with helical thickenings usually occur in woods that also have helical thickenings in the vessel elements. However, the opposite is not true, i.e., many species with helical thickenings in their vessel elements do not have helical thickenings in the ground tissue fibres. Helical thickenings are much more common in fibres with distinctly bordered pits than in fibres with simple or minutely bordered pits. They also occur more frequently in temperate woods than in tropical woods.

Fig. 10 Helical thickenings in ground tissue fibres (A+B) *Ilex aquifolia*.



Source: Thünen-Institut/ Valentina Zemke

Septate fibres and parenchyma-like fibre bands (Fig. 11)

#65. Septate fibre present (Fig. 11) = fibres with thin and unpitted transverse wall(s).

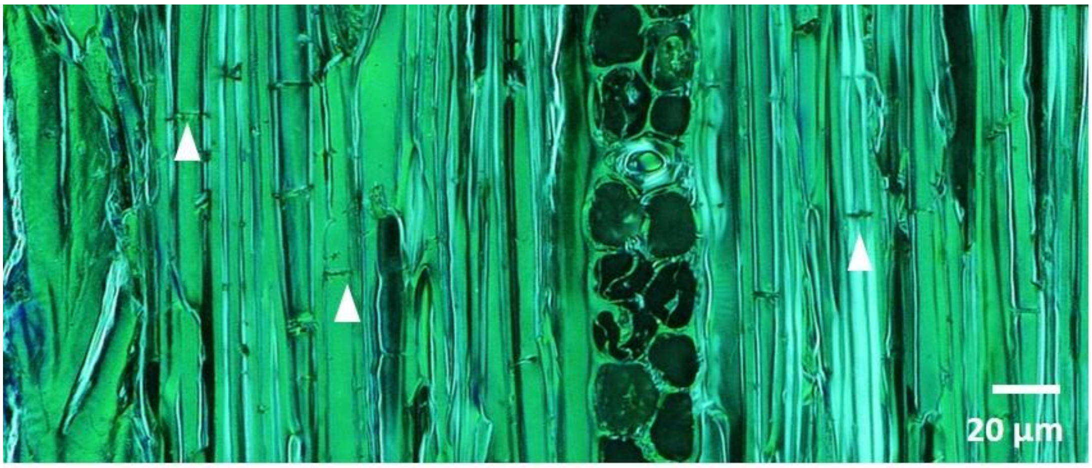
Septa are formed after the secondary fibre wall has been deposited; they therefore do not extend to the compound middle lamella between adjacent fibres. Septa are usually unlignified and thin.

The visibility of septate fibres in charcoal depends much on the conservation conditions of the material. Sometimes debris from of other cells (e.g., cell wall remains, tyloses), deformations of the cell wall or deposits of fungal hyphae can be mistaken for septa.

In some woods, all fibres are septate. In other woods, septate and non-septate fibres occur together. The septate fibres may then either be scattered irregularly or situated near the vessels or the rays. The number of septa varies between wood species from at least one to several per fibre (Van Vliet, 1976). Species which naturally form only few septate fibres are difficult to identify in charcoal.

#67. Parenchyma-like fibre bands alternating with ordinary fibres = tangential bands of relatively thin-walled fibres alternating with bands of thicker-walled fibres.

Fig. 11 **Septate fibres present: *Aucoumea kleineana.***



Source: Thünen-Institut/ Valentina Zemke

Axial parenchyma

A distinction is made between parenchyma strands and fusiform parenchyma cells. The parenchyma strands are rectangular-prismatic cells lined up vertically to form a strand and show a taper at the of top and bottom cells of the strand. If these structures have no subdivisions (transverse walls), they are denominated fusiform parenchyma cells (Grosser, 1977).

The patterns formed by axial parenchyma can best be examined in transverse section. Three types are distinguished: apotracheal axial parenchyma, paratracheal axial parenchyma and banded axial parenchyma.

Apotracheal axial parenchyma (Figs. 12 A-B)

Definition: Apotracheal axial parenchyma not associated with the vessels.

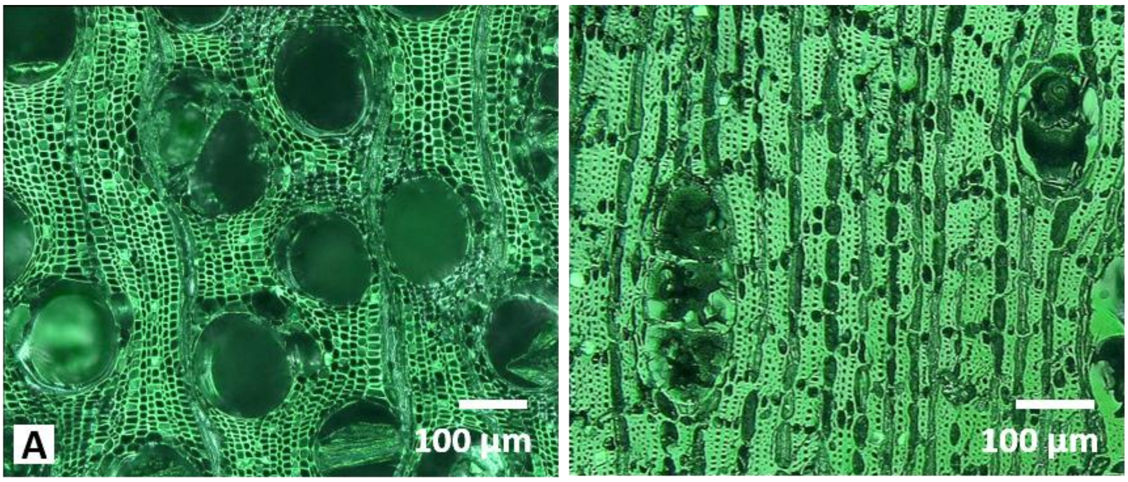
#76. Axial parenchyma diffuse (Fig. 12A) = single parenchyma strands or pairs of strands distributed irregularly among the fibrous elements of the wood.

#77. Axial parenchyma diffuse-in-aggregates (Fig. 12B) = parenchyma strands grouped into short discontinuous tangential or oblique lines.

Because there is a continuous range of axial parenchyma from diffuse, diffuse-in-aggregates to parenchyma in narrow bands (feature #86) or scalariform (feature #88), for some taxa it will be necessary to record more than one feature for apotracheal parenchyma. Diffuse and diffuse-in-aggregates frequently occur in combination.

Although by definition apotracheal parenchyma is not associated with vessels, woods with abundant diffuse or diffuse-in-aggregates parenchyma may exhibit several strands touching the vessels. Such random contacts should not be recorded as paratracheal parenchyma. Apotracheal diffuse parenchyma sometimes occurs primarily close the rays (Carlquist, 2001) and should not be confused with sheath cells in rays.

Fig. 12 **Axial parenchyma diffuse: botanical name unknown (A), axial parenchyma diffuse-in-aggregates: *Diospyros crassiflora* (B).**



Source: Thünen-Institut/ Valentina Zemke

Paratracheal axial parenchyma (Figs. 13 A-G)

Definition: Axial parenchyma associated with the vessels or vascular tracheids: types of paratracheal parenchyma are scanty paratracheal, vasicentric, aliform (subtypes: lozenge-aliform, winged aliform), confluent, and unilateral paratracheal.

#78. Axial parenchyma scanty paratracheal (Fig. 13A) = occasional parenchyma cells associated with the vessels or an incomplete sheath around a vessel.

#79. Axial parenchyma vasicentric (Fig. 13B) =parenchyma cells forming a complete circular to oval sheath around a solitary vessel or vessel multiple.

#80. Axial parenchyma aliform (Fig. 13C) = parenchyma surrounding or to one side of the vessel and with lateral extensions. For examples see the two subtypes below.

#81. Axial parenchyma lozenge-aliform (Fig. 13D) = parenchyma surrounding or to one side of the vessel with lateral extensions forming a diamond-shaped outline.

#82. Axial parenchyma winged-aliform (Fig. 13E) = parenchyma surrounding or to one side of the vessel with the lateral extensions being elongated and narrow.

#83. Axial parenchyma confluent (Fig. 13F) = coalescing vasicentric or aliform parenchyma surrounding or to one side of two or mor vessels, often forming irregular short bands.

#84. Axial parenchyma unilateral paratracheal (Fig. 13G) = paratracheal parenchyma forming semi-circular hoods or caps only on one side of the vessels, and which can extend tangentially or obliquely in an aliform or confluent or banded pattern.

Banded parenchyma (Figs. 14 A-F)

#85. Axial parenchyma bands more than three cells wide (Fig. 14 A+B) = as per feature descriptor.

#86. Axial parenchyma in narrow bands or lines up to three cells wide (Fig. 14C) = as per feature descriptor.

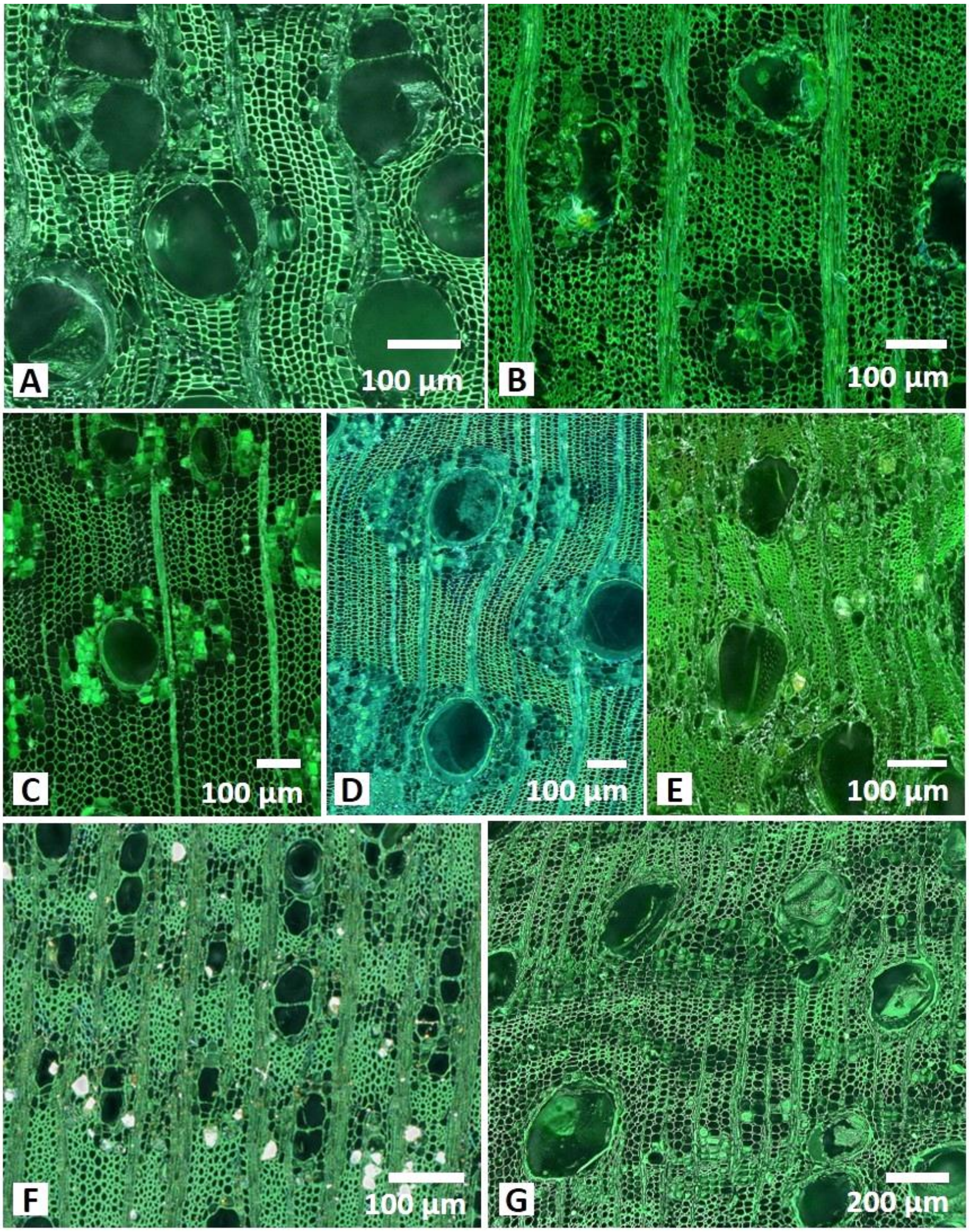
#87. Axial parenchyma reticulate (Fig. 14D) = parenchyma in continuous tangential lines of approximately the same width as the rays, regularly spaced and forming a network with them. The distance between rays is approximately equal to the distance between parenchyma bands.

#88. Axial parenchyma scalariform = parenchyma in fairly regularly spaced fine lines or bands, arranged horizontally or in arcs, appreciably narrower than the rays and with them producing a ladder-like appearance in cross section. The distance between rays is greater than the distance between parenchyma bands.

#89. Axial parenchyma in marginal or in seemingly marginal bands (Fig. 14 E+F) = parenchyma bands which form a more or less continuous layer of variable width at the margins of a growth ring or are irregularly zonate. Marginal bands include ‘terminal’ (formed at the end of a growth period) and ‘initial’ (formed at the beginning of a growth period) parenchyma.

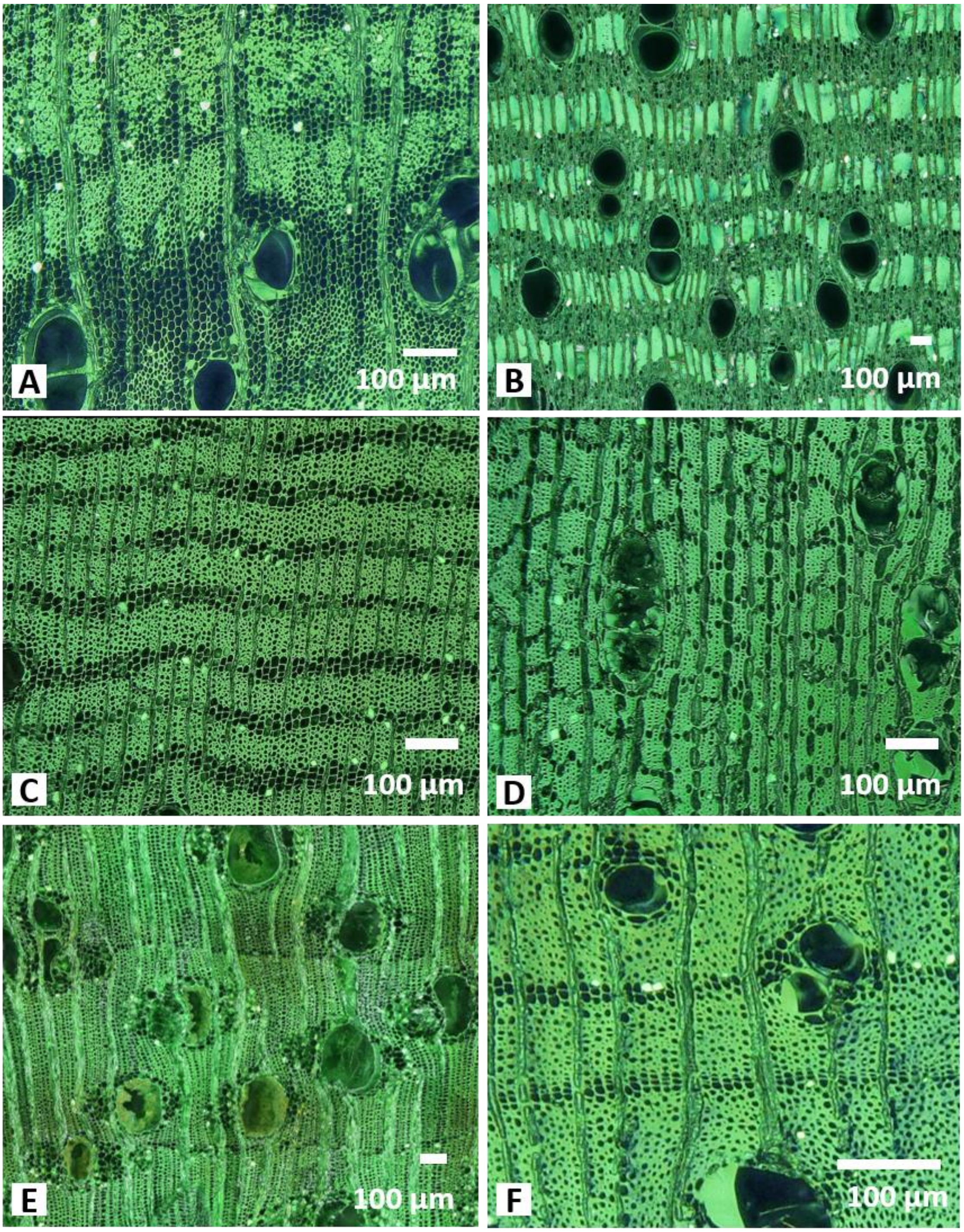
Comments: Parenchyma bands may be mainly independent of the vessels (apotracheal), definitely associated with the vessels (paratracheal), or both. Bands may be wavy, diagonal, straight, continuous or discontinuous (the latter often intergrading with confluent). The number of bands varies and may be useful as a diagnostic feature in some groups of taxa. Bands over three cells wide are visible to the unaided eye. For woods with reticulate, scalariform, or marginal parenchyma, the band width should also be recorded. Sometimes parenchyma bands are associated with axial intercellular canals.

Fig. 13 **Axial parenchyma scanty paratracheal: botanical name unknown (A); axial parenchyma vasicentric: *Senegalia chundra* (B); axial parenchyma aliform *Paulownia elongata* (C); axial parenchyma lozenge-aliform: *Afzelia* sp. (D); axial parenchyma winged-aliform: *Terminalia oblonga* (E); axial parenchyma confluent: cf. *Colophospermum mopane* (F); axial parenchyma unilateral paratracheal: *Pterocarpus angolensis* (G).**



Source: Thünen-Institut/ Valentina Zemke (A, B, C, D, E, G), Volker Haag (F)

Fig. 14 **Axial parenchyma bands more than three cells wide: botanical name unknown (A+B); axial parenchyma in narrow bands or lines up to three cells wide: botanical name unknown (C); axial parenchyma reticulate: *Diospyros crassiflora* (D); axial parenchyma in marginal bands: *Afzelia africana* (E); axial parenchyma in seemingly marginal bands: botanical name unknown (F).**



Source: Thünen-Institut/ Valentina Zemke

Axial parenchyma cell type/strand lenght (Figs. 15 A-B)

#90. Fusiform parenchyma cells **(Fig. 15A)** = parenchyma cells derived from fusiform cambium initials without subdivision or tip growth. In shape they resemble a short fibre.

An axial parenchyma strand **(Fig. 15B)** is a series of axial parenchyma cells formed through transverse division(s) of a single fusiform cambium initial. Strand length can differ between species and also between earlywood and latewood of the same growth ring or between vessels associated parenchyma and parenchyma which is not in contact with the vessels. Strands are distinguished according to the number of cells per strand:

#91. Two cells per parenchyma strand = as per feature descriptor.

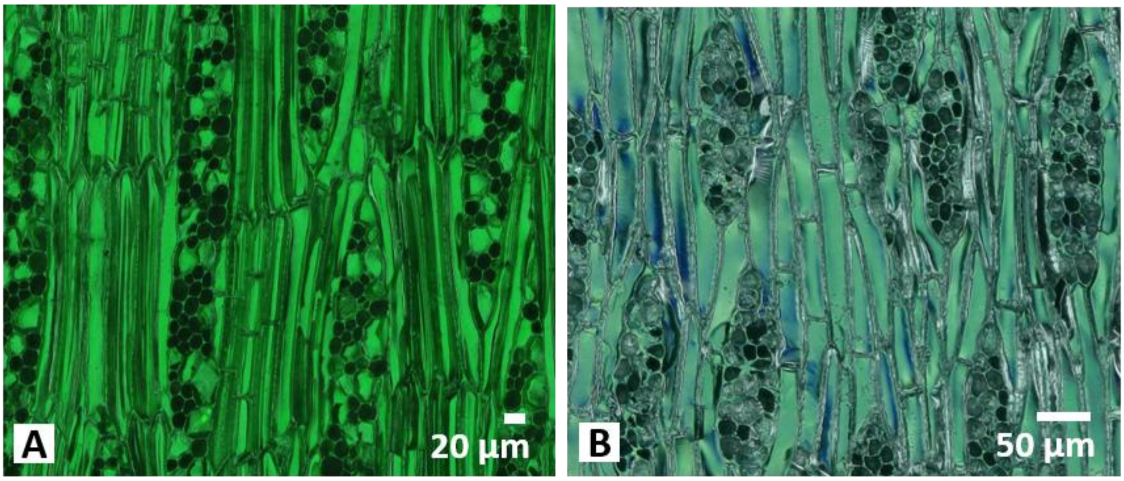
#92. Four (3– 4) cells per parenchyma strand = as per feature descriptor.

#93. Eight (5–8) cells per parenchyma strand = as per feature descriptor.

#94. Over eight cells per parenchyma strand = as per feature descriptor.

#95. Unlignified parenchyma = unlignified parenchyma usually occurs in broad bands and is restricted to a small number of taxa.

Fig. 15 Fusiform parenchyma cells: *Triplochitron scleroxylon* (A); axial parenchyma in strands: *Afzelia africana* (B).



Source: Thünen-Institut/ Valentina Zemke

Rays

Rays are composed of parenchymatous cells forming bands that extend radially (from the pith to the perimeter of a tree); they are usually well preserved after the charring process. Rays can be observed in all sections (transverse, tangential and radial) and analyzed according to many criteria (width in terms of the number of cells or in µm, height, composition, etc.).

Ray widt (Figs. 16 A-D)

Ray width is determined on the tangential section by counting the number of cells in the widest portion of the rays, perpendicular to the ray axis. When rays are of two distinct sizes, record the width of the larger size class. Aggregate ray width is not considered a separate size class. The description of ray width in charred material in this atlas encompasses all the sizes observed and also specifies the exact width of the ray in µm. The procedure for measuring ray width is described in Chapter 9.

#96. Rays exclusively uniseriate (Fig. 16A) = as per feature descriptor.

#97. Ray width 1 to 3 cells (Fig. 16B) = as per feature descriptor.

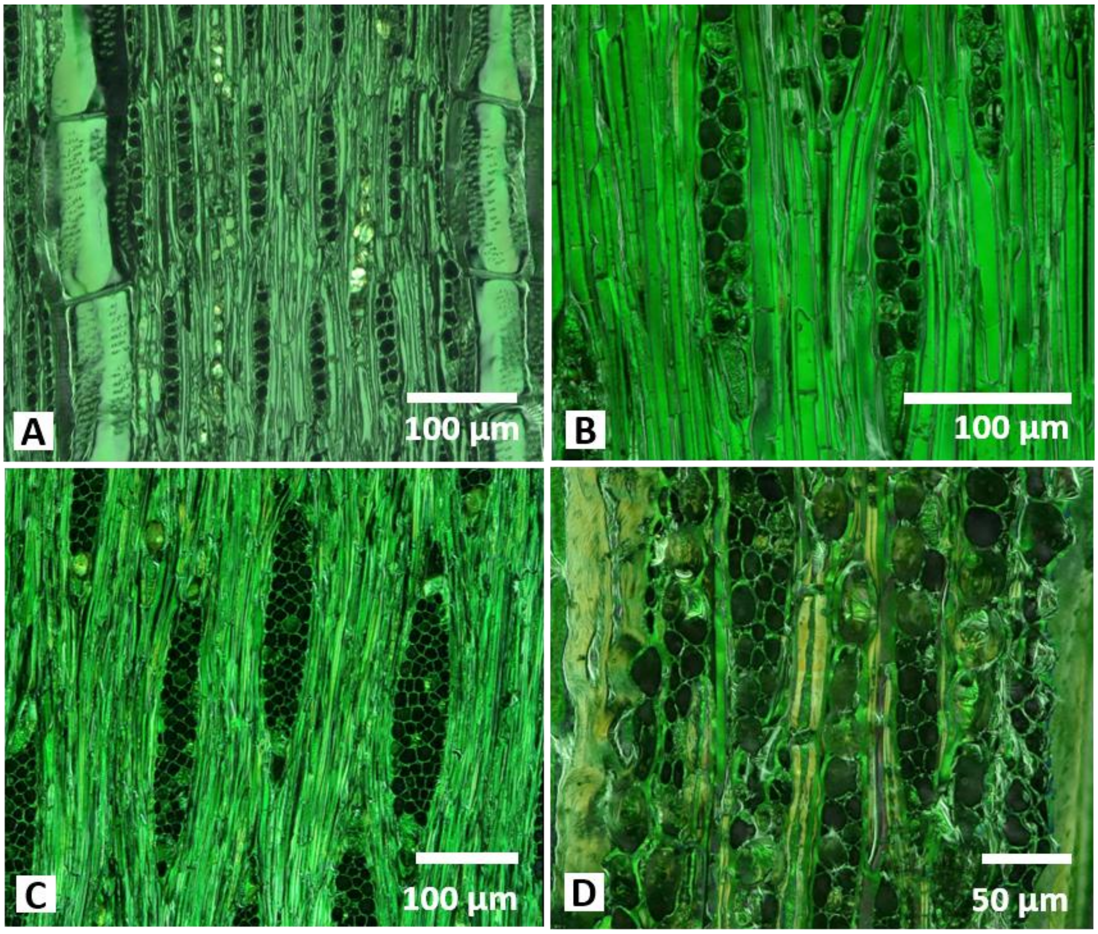
#98. Larger rays commonly 4- to 10-seriate (Fig. 16C) = as per feature descriptor.

#99. Larger rays commonly > 10-seriate = as per feature descriptor.

#100. Rays with multiseriate portion(s) as wide as uniseriate portions (Fig. 16D) = as per feature descriptor; this feature is only considered present if it occurs regularly and is present over the entire surface of the specimen.

Caution: These features for ray width do not apply to rays containing radial intercellular canals or to rays composing an aggregate ray. Thus, for a wood with exclusively uniseriate rays, except for the rays with radial canals, describe the wood by recording for 'exclusively uniseriate rays' and the feature for 'radial canals present'.

Fig. 16 **Rays exclusively uniseriate: botanical name unknown (A); ray width 2 cells: *Aucoumea kleinaneana* (B); rays with up to 5 cells: *Milicia excelsa* (C); rays with multiseriate portion(s) as wide as uniseriate portions: *Nauclea diderrichii* (D).**



Source: Thünen-Institut/ Valentina Zemke

 # 101. Aggregate rays (Figs. 17 A+B) = a number of individual rays so closely associated with one another that they appear macroscopically as a single large ray, often also referred to as "false ray". The individual rays are separated by axial elements, i.e. fibres and/or axial parenchyma. There is variation in the size of the individual rays of aggregate rays. In some species the aggregate rays are composed of narrow rays, while in others they are composed of fairly broad rays. Aggregate rays occur in few taxonomic groups of temperate and (sub-) tropical climate regions

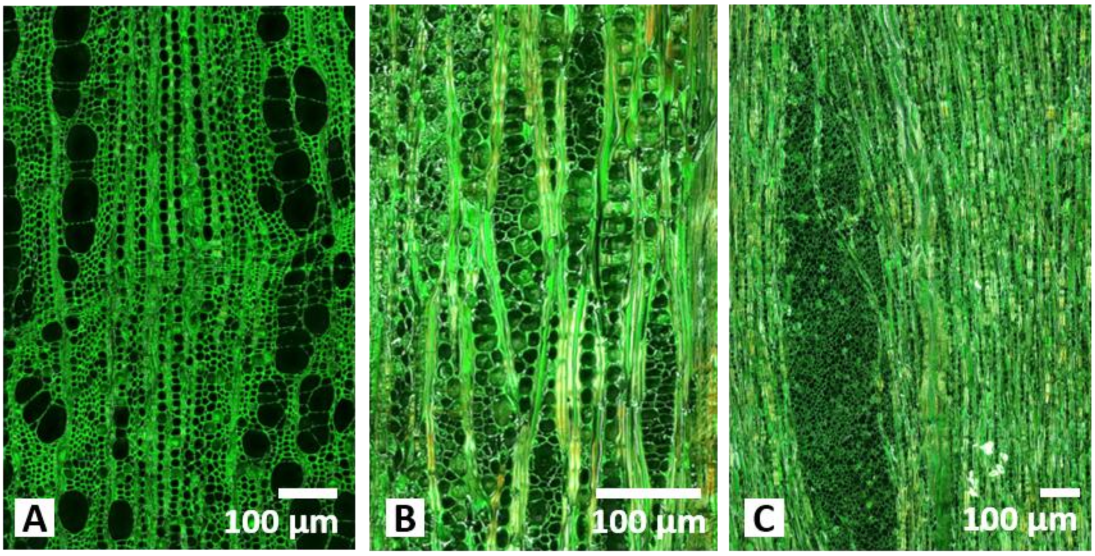
#102. Ray height > 1 mm = large rays commonly exceeding 1 mm in height.

More detailed ray height data should be given in descriptions as they may be helpful in distinguishing between taxa in some groups. Detailed Information on measuring ray height is given in Chapter 9.

#103. Rays of two distinct sizes (Fig. 17C) = when viewed in tangential section, rays form two distinct populations by their width and usually also by their height. There are no limits for the size classes – the smaller rays may be 1-, 2- or 3-seriate, the larger rays may be less than 5-seriate. Generally, to fit the feature definition, intermediate rays should not exist between the two populations or be quite rare.

If two different size classes occur in more or less equal proportions, the larger class is commonly coded in (computerized) identification keys. The sizes should differ significantly. Richter and Dallwitz (2000 onwards) give the following combinations as examples: 1-, 2- or 3-seriate rays combined with 10-seriate rays; or uniseriate rays combined with 4-seriate rays. Hence, the size classes should not be next to each other, but at least one class should be between them.

Fig. 17 **(TS) aggregate rays and (TLS) *Carpinus betulus* (A+B); rays of two distinct sizes *Quercus petraea* (C).**



Source: Thünen-Institut/ Valentina Zemke

Cellular composition of rays (Figs. 18 A-F)

Square ray cell = a ray parenchyma cell approximately square as seen in radial section.

Upright ray cell = a ray parenchyma cell with the longest dimension axial as seen in radial section.

Uniseriate and multiseriate rays composed entirely of procumbent or square/upright cells are referred to as "homocellular".

Uniseriate and multiseriate rays composed of both procumbent and square/upright cells are referred to as "heterocellular". The procumbent cells (body cells) always form the central portion of the ray, with extensions of square/upright cells at the tails.

#104. All ray cells procumbent (Fig. 18A) = as per feature descriptor.

#105. All ray cells upright and /or square (Fig. 18B) = as per feature descriptor.

#106. Body ray cells procumbent with one row of upright and /or square marginal cells (Fig. 18C) = as per feature descriptor.

#107. Body ray cells procumbent with mostly 2 – 4 rows of upright and/or square marginal cells (Fig. 18D) = as per feature descriptor.

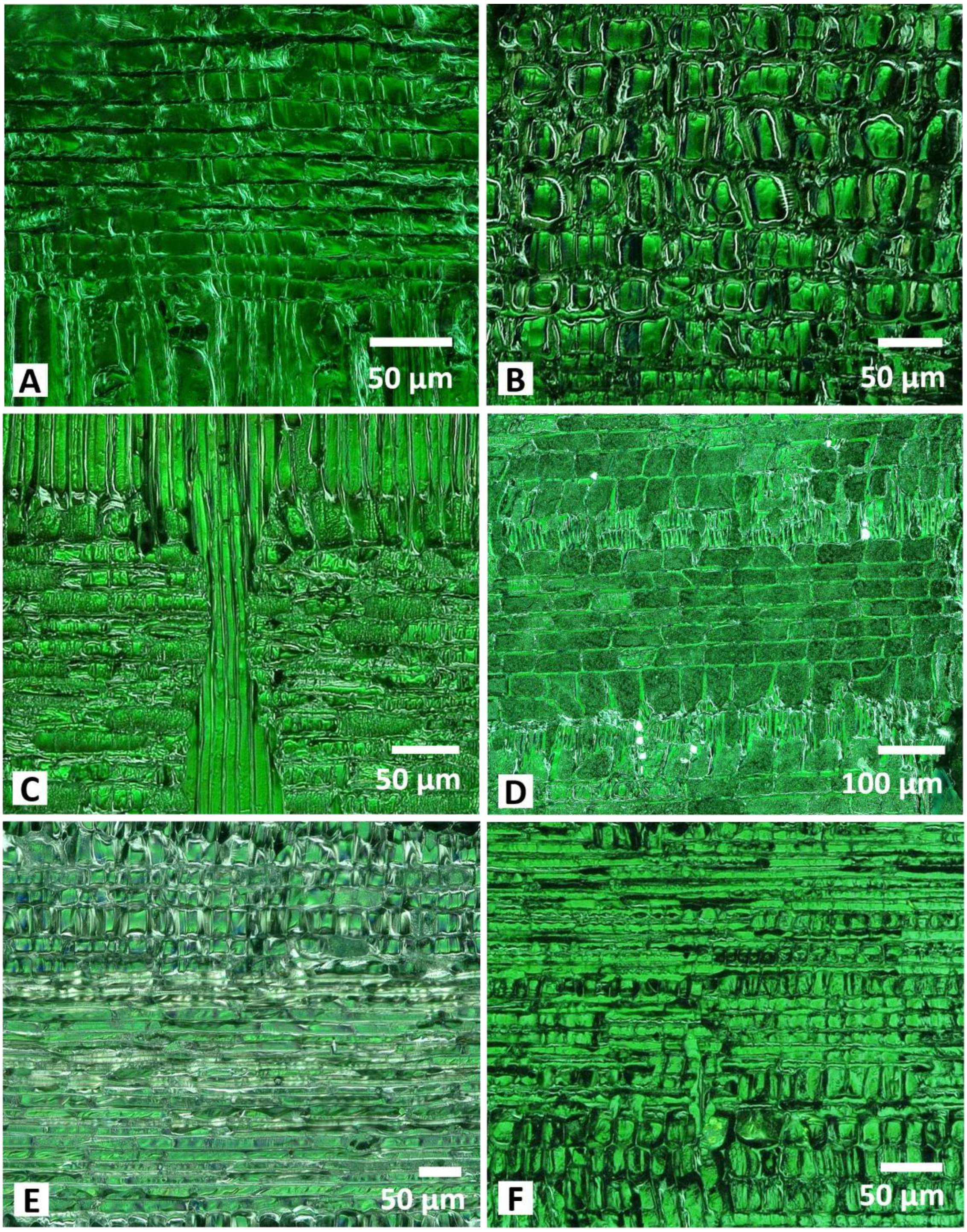
#108. Body ray cells procumbent with over 4 rows of upright and/or square marginal cells (Fig. 18E) = as per feature descriptor.

#109. Rays with procumbent, square and upright cells mixed throughout the ray (Fig. 18F) = as per feature descriptor.

The cellular composition of the uniseriate and multiseriate rays in the same wood is not necessarily the same. In some woods, their uniseriate rays are composed only of upright cells while their multiseriate rays are composed of both upright and procumbent cells. In such cases, only the multiseriate rays are described.

Caution: Although in tangential section, marginal rows of upright and/or square cells often will appear as uniseriate margins; the presence of uniseriate margins alone is not a reliable indicator of heterocellular rays. In some woods, there are uniseriate marginal rows visible in tangential section, and these cells appear larger than the body cells, but when viewed in radial section these cells are procumbent as are the cells of the multiseriate portion.

Fig. 18 **All ray cells procumbent: *Quercus petraea* (A); all ray cells upright and/or square: *Nauclea diderrichii* (B); body ray cells procumbent with one row of upright and/or square marginal cells: *Aucoumea klaineana* (C); body ray cells procumbent with mostly 2–4 rows of upright and/or square marginal cells: *Diospyros crassiflora* (D); body ray cells procumbent with over 4 rows of upright and /or square marginal cells: *Khaya* sp. (E); rays with procumbent, square and upright cells mixed throughout the ray: *Triplochitron scleroxylon* (F).**



Source: Thünen-Institut/ Valentina Zemke

Sheat cells

#110. Sheath cells (Fig. 19A) = cells that are located along the sides of broad rays (> 3-seriate) as viewed in tangential section and are larger (generally taller than broad) than the central cells.

The presence of sheath cells should be determined from tangential section. There is variability in the frequency and distinctiveness of sheath cells. In some species most, if not all, multiseriate rays have sheath cells which are much larger than the other ray cells, while in others sheath cells are not frequent and/or only slightly larger than the adjacent cells.

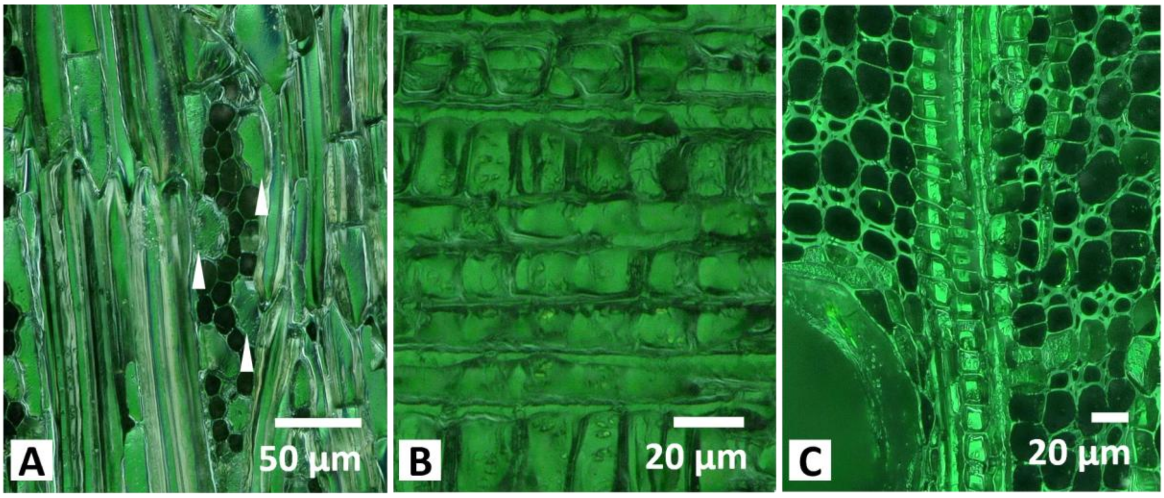
Tile cells

#111. Tile cells (Figs. 19B+C) = a special type of apparently upright (rarely square) ray cells occurring in intermediate horizontal series usually interspersed among the series of procumbent cells.

Tile cells sometimes have been classified into two groups: the "Durio type" when they have the same height as the procumbent cells, and the "Pterospermum type" when they are higher. However, this distinction is dubious because there are intergradations between the two. Tile cells are of rare occurrence and therefore highly diagnostic when identifying a wood species.

As far as is known to date, the presence of tile cells is restricted to the family of Malvaceae.

Fig. 19 **(TLS) sheath cells: *Triplochiton scleroxylon* (A); (RLS) and (TS) tile cells: *Triplochiton scleroxylon* (B+C).**



Source: Thünen-Institut/ Valentina Zemke

Perforated ray cells

#112. Perforated ray cells = ray cells of the same dimensions or larger than the adjacent cells, but with perforations, which generally are on the side walls connecting two vessels on either side of the ray.

The type of perforation in a perforated ray cell may be simple, scalariform, reticulate or foraminate, and does not necessarily coincide with the type of perforation plate occurring in the vessel elements of the same wood. Perforated ray cells have bordered pits similar to the intervessel pits.

Perforated ray cells are of rare occurrence; moreover, in species with perforated ray cells they might be present in such low frequency that they could easily be overlooked when examining a given specimen.

Disjunctive ray parenchyma cell walls

#113. Disjunctive ray parenchyma cell walls = ray parenchyma cells partially disjoined but with contacts maintained through tubular or complex wall projections. Axial parenchyma cells may also be disjunctive.

Wood rayless

#117. Wood rayless = wood with only axial elements.

According to the current state of knowledge, this is a genetically predisposed feature. Rayless woods are restricted to a small number of families, including Chenopodiaceae, Nyctaginaceae, Scrophulariaceae (Carlquist, 2001).

Storied structure (Figs. 20A-C)

Storied structure = cells arranged in tiers (horizontal series) as viewed on the tangential surface, often referred to as 'ripple marks'.

#118. All rays storied (Fig. 20A) = as per feature descriptor.

#119. Low rays storied, high rays non-storied (Fig. 20B) = as per feature descriptor.

#120. Axial parenchyma and/or vessel elements storied (Fig. 20C) = as per feature descriptor.

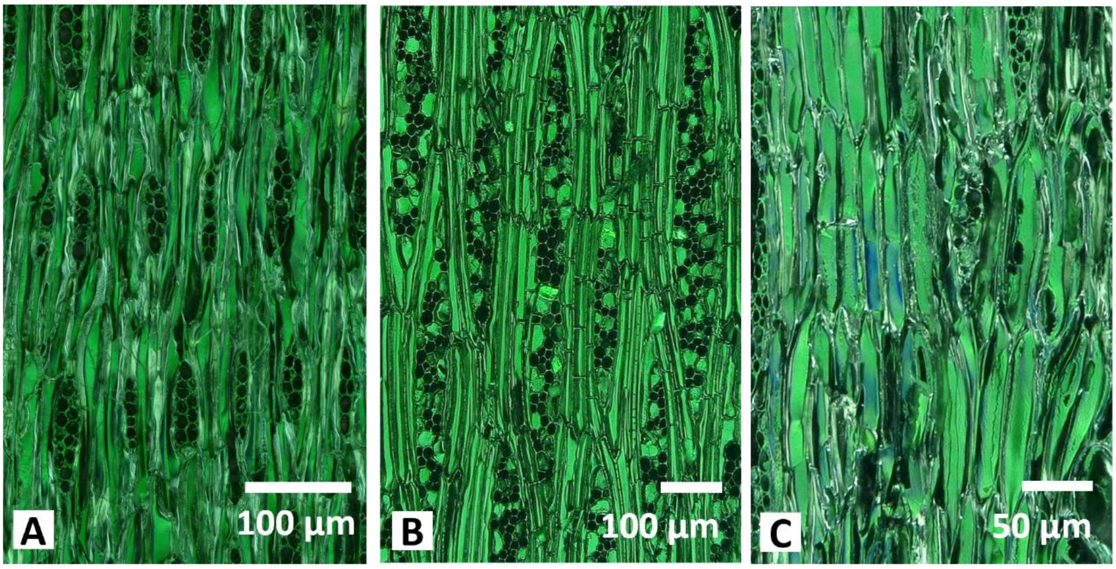
#121. Fibres storied (Fig. 20B) = as per feature descriptor.

#122. Rays and/or axial elements irregularly storied = stories of rays and/or axial elements not horizontal or straight, but wavy or oblique (synonym: 'in echelon'), or only locally present.

The presence of storied structure should be determined from the tangential section. All axial elements (axial parenchyma, vessel elements, fibres) and the rays may be storied, either singly or in various combinations as in some woods all elements are storied. Generally, if the axial parenchyma is storied, the vessel elements are also storied. In woods with rays of two distinct sizes only the low rays may be storied.

There is variability within species and also samples. For instance, in some samples of *Swietenia* and *Entandrophragma cylindricum* (Meliaceae) rays are definitely storied, in others irregularly storied, and still in others not storied.

Fig. 20 **All rays storied: *Pterocarpus angolensis* (A); only low rays and fibres storied: *Triplochiton scleroxylon* (B); axial parenchyma storied: *Robinia pseudoacacia* (C).**



Source: Thünen-Institut/ Valentina Zemke

Secretory elements and cambial variants

Oil and mucilage cells

Oil cells = parenchymatous idioblasts filled with oil.

Mucilage cells = parenchymatous idioblasts filled with mucilage.

#124. Oil and /or mucilage cells associated with ray parenchyma = as per feature descriptor.

#125. Oil and /or mucilage cells associated with axial parenchyma = as per feature descriptor.

#126. Oil and /or mucilage cells present among fibres = as per feature descriptor.

Oil cells and mucilage cells are often enlarged and oval in shape, sometimes extending considerably in axial direction.

Both oil cells and mucilage cells are commonly associated with axial and/or ray parenchyma but may also occur between fibres. They are limited to very few woody dicotyledons and are similar to each other, except for their contents which are easily removed during micro technical procedures. After charring, identification is only possible as regards presence vs. absence as the contents change their chemical composition during the charring process. The analysis of the contents proposed by Richter (1977) to differentiate between the two types is no longer possible.

Intercellular canals (Figs. 21 A-D)

Intercellular canal (Fig 21A) = tubular canal surrounded by an epithelium, generally containing resins, gums, etc. secreted by the epithelial cells. Intercellular canals may be oriented axially (axial/vertical intercellular canal), or radially (radial/horizontal intercellular canal), within a ray. In the charred state the resinous contents can no longer be identified.

#127. Axial canals in long tangential lines (Fig. 21B) = more than five canals in a line.

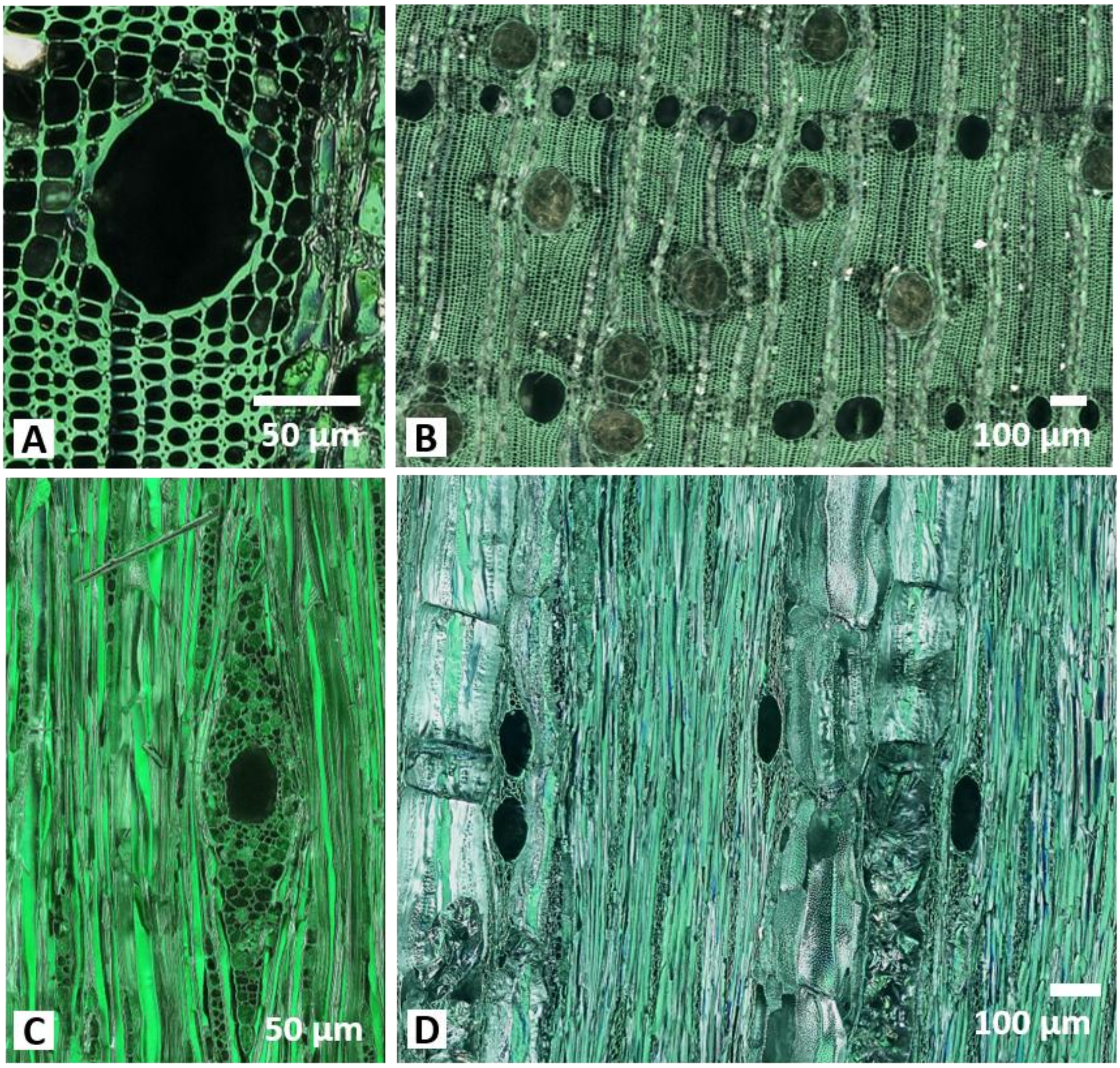
#128. Axial canals in short tangential lines = two to five canals in a line.

#129. Axial canals diffuse = randomly distributed solitary canals

#130. Radial canals (Figs. 21 C+D) = canals present in rays (synonym: horizontal canals)

#131. Intercellular canals of traumatic origin = canals formed in response to injury, arranged in tangential bands, generally irregular in outline and closely spaced.

Fig. 21 **Axial intercellular canal: botanical name unknown (A); axial canals in long tangential lines: botanical name unknown (B); radial canal: *Campnospermum* sp. (C); radial canals: *Rubroshorea leprosula* (D).**



Source: Thünen-Institut/ Volker Haag in Haag et al. 2017 (B), Valentina Zemke (A, C, D)

Cambial variants (Fig. 22)

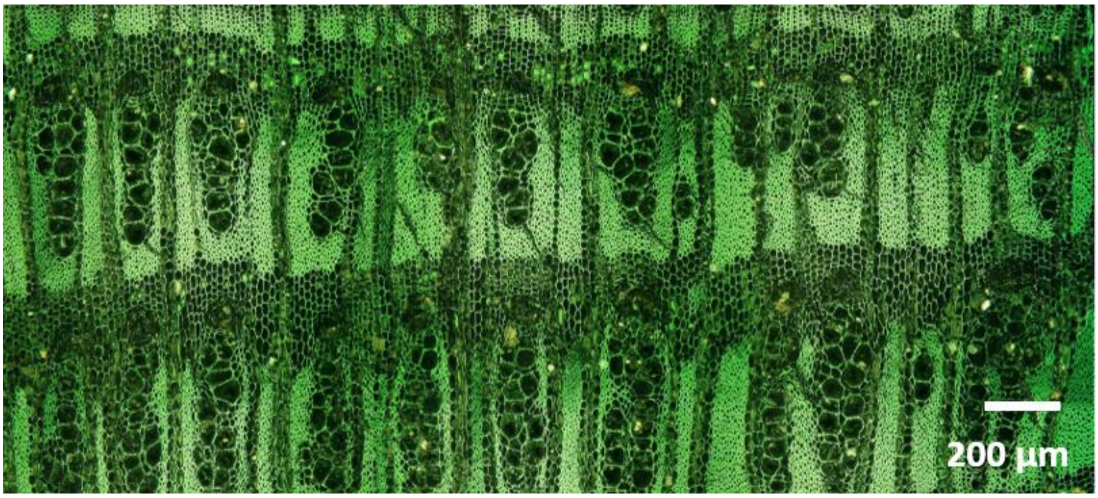
#133. Included phloem, concentric = phloem strands in tangential bands alternating with zones of xylem and/or conjunctive tissue.

#134. Included phloem, diffuse = scattered, isolated phloem strands. The phloem strands may be surrounded by parenchyma or imperforate tracheary elements.

Eichhorn (2002) states in her study that included phloem could no longer be observed after the charring process in a number of species from north-west Namibia, e.g. *Maerua* spp.

#135. Other cambial variants.

Fig. 22 Included phloem, concentric: botanical name unknown.



Source: Thünen-Institut/ Volker Haag

Mineral inclusions

Crystals

Crystals are preserved after the charring process and stand out clearly against the black charred surrounding tissue due to the colour contrast and the light reflection. They can be well identified both in normal and charred wood with the aid of polarized light. Prismatic crystals are the most common type of crystals (Chattaway, 1955; 1956). Druses are also common. All other forms are extremely rare.

When crystals are present, particular attention must be paid to their shape and to the location in the respective tissues as artefacts similar in shape and colour to crystals are also produced during the charring process. These “false” crystalline elements form mostly clusters and can be observed all over the surface. Despite a certain similarity, such artefacts are characterized by a clearly distinguishable irregular shape compared to true crystals.

Prismatic crystals (Figs. 23 A-E)

Prismatic crystals are solitary rhombohedral or octahedral crystals composed of calcium oxalate, which are birefringent under polarized light. Synonym: rhomboidal crystal.

#136. Prismatic crystals present (Figs. 23 A-E) = as per feature descriptor.

#137. Prismatic crystals in upright and /or square ray cells (Figs. 23 A-E) = as per feature descriptor.

#138. Prismatic crystals in procumbent ray cells= as per feature descriptor.

#139. Prismatic crystals in radial alignment in procumbent ray cells= as per feature descriptor.

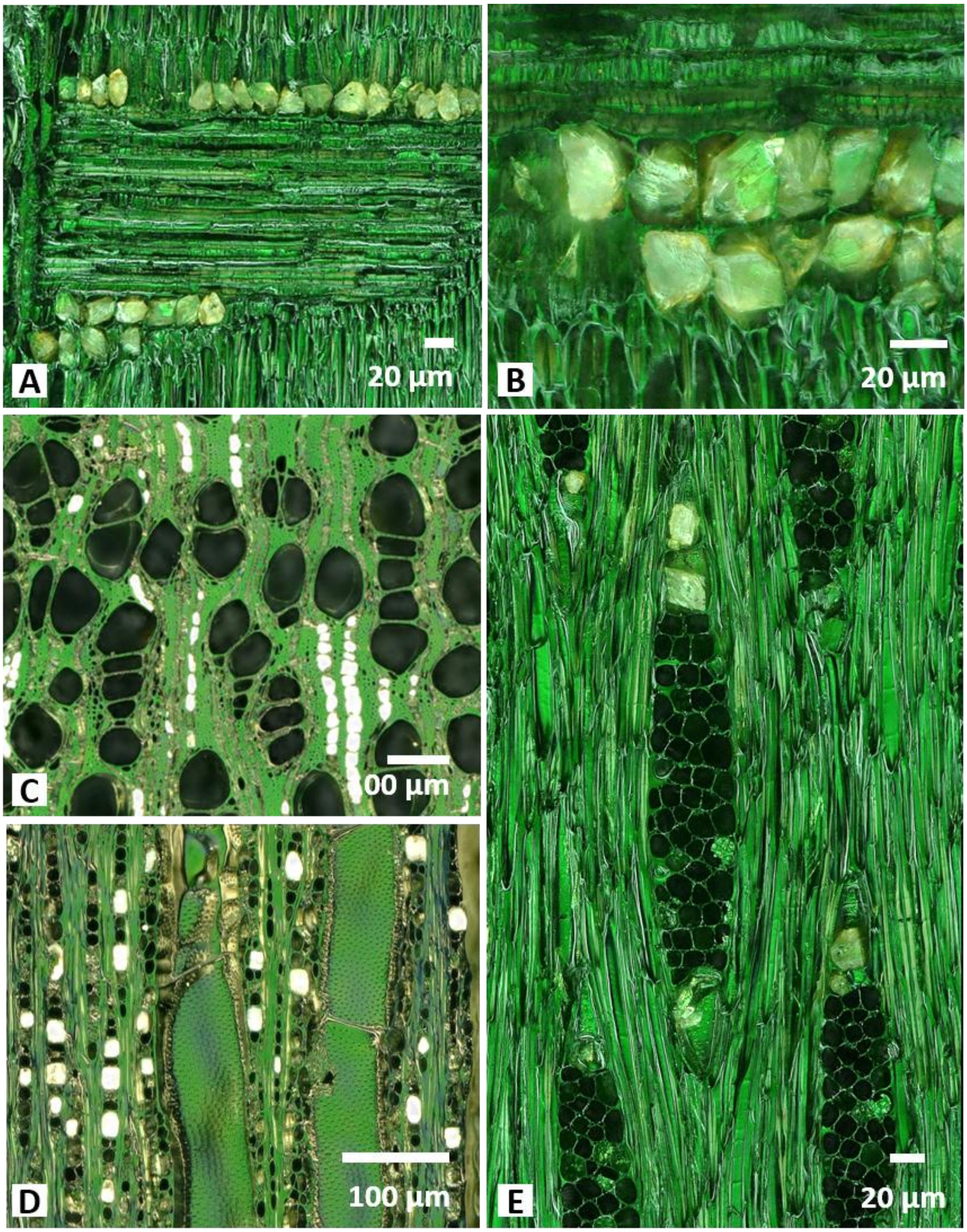
#140. Prismatic crystals in chambered upright and /or square ray cells= as per feature descriptor.

#141. Prismatic crystals in non-chambered axial parenchyma cells= as per feature descriptor.

#142. Prismatic crystals in chambered axial parenchyma cells= as per feature descriptor.

#143. Prismatic crystals in fibres= as per feature descriptor.

Fig. 23 **Prismatic crystals in upright and/or square ray cells: *Milicia excelsa* (A+B+E); botanical name unknown (C+D).**



Source: Thünen-Institut/ Sergej Kaschuro (C, D), Valentina Zemke (A, B, E)

Druses

#144. Druses present

Druses are compound crystals, more or less spherical in shape, in which the many component crystals protrude from the surface giving the whole structure a "morning star" appearance.

#145. Druses in ray parenchyma cells = as per feature descriptor.

#146. Druses in axial parenchyma cells = as per feature descriptor.

#147. Druses in fibres = as per feature descriptor.

#148. Druses in chambered cells = as per feature descriptor.

Other crystal types

#149. Raphides = bundles of long needle-like crystals, often occurring in enlarged cells.

#150. Acicular crystals = small needle-like crystals not occurring in bundles.

#151. Styloids and /or elongate crystals = large crystals at least four times as long as broad with pointed or square ends, often occurring in enlarged cells.

#152. Crystals of other shapes (mostly small) = includes all other shapes of crystals that are not covered by the other categories, such as navicular (boat-shaped), spindle-shaped, pyramidal, tabular, indented, twinned crystals, or "mega-crystals" (agglomerates composed of irregularly shaped crystals).

#153. Crystal sand = a granular mass composed of very fine crystals, often filling the entire cell. Synonym: microcrystals.

Other diagnostic crystal features

#154. More than one crystal of about the same size per cell or chamber = as per feature descriptor:

Most wood species have one crystal per cell/chamber, but some form 2 or more crystals of similar size and shape per cell/chamber.

#155. Two distinct sizes of crystals per cell or chamber = as per feature descriptor**.**

This feature is only coded when size is clearly distinguishable with no intermediates present. There are only a few wood species that develop this feature

#156. Crystals in enlarged cells = as per feature descriptor.

The crystals almost completely fill the enlarged cell and are clearly visible in a tangential section. They occur mostly in either axial parenchyma or rays, rarely in both parenchyma types in a given species. There is usually one crystal per enlarged cell. Included crystals may be prismatic, druses, raphides or other crystal types.

#157. Crystals in tyloses = as per feature descriptor; several crystals can accumulate in tyloses. The feature can already be observed in the transverse section and crystals in tyloses are formed only in the heartwood (see under feature **#56**).

#158. Cystoliths = internal stalked outgrowths of the cell wall that project into the cell lumen and are composed of cellulose impregnated with calcium carbonate. They are irregular in shape and sometimes completely fill a cell. In that case, this rather rare feature is rather difficult to recognize.

Silica (Fig. 24)

Silica consists of silicon dioxide (SiO_2) and is an important diagnostic feature among the mineral inclusions deposited in cells. It occurs as individual small particles or large irregular aggregates (silica bodies) as well as cell wall coating or solid blocks (vitreous silica).

#159. Silica bodies present = as per feature descriptor.

Whether silica occurs in aggregations often filling the entire cell, as irregularly shaped or globular bodies or whether the silica bodies have a smooth or verrucose surface may be diagnostic in certain groups and needs to be recorded in a description. Silica bodies most often are restricted to ray cells, particularly the marginal of upright cells. Sometimes they are restricted to axial parenchyma, sometimes they occur in both ray and axial parenchyma. Silica bodies occur rarely in fibres, but if they do the fibres are usually septate.

The chemical analyses for the detection of silica in normal wood cannot be transferred to the analysis of charcoal. The detection of silica in charred wood must be carried out using traditional microscopy methods. Because of its similar reflective properties in charcoal, silica can be examined using polarized light, similar to crystalline inclusions. A high magnification is best suited, as this enhances the glassy appearance.

Silica, like other mineral inclusions, is also classified according to the cell types in which it occurs:

#160. Silica bodies in ray cells = as per feature descriptor.

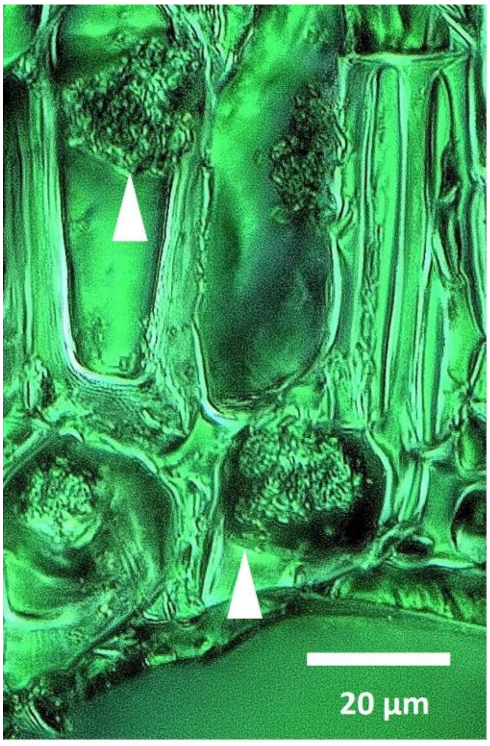
#161. Silica bodies in axial parenchyma cells = as per feature descriptor.

#162. Silica bodies in fibres= as per feature descriptor.

#163. Vitreous silica = silica that coats cell walls or forms solid blocks that completely fill the cell lumina.

Vitreous silica is deposited mostly in axial elements (vessels, axial parenchyma, fibres).

Fig. 24 Silica bodies in both ray and axial parenchyma cells: *Apuleia leiocarpa* (Zemke et al., 2020).



Source: Thünen-Institut/ Valentina Zemke

9 Quantitative Data

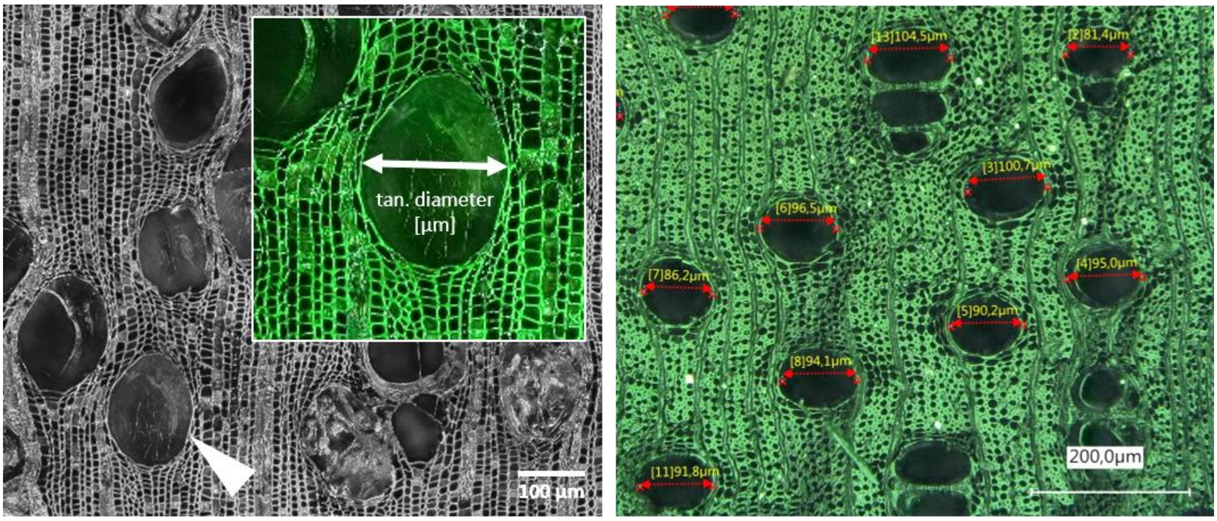
Vessels

To determine the average tangential vessel diameter, usually 25-50 (Hapla and Saborowski, 1987) measurements of values should be made on transverse section including each vessel within the field examined, irrespective of its size **(Fig. 25)**. In charcoal vessels often show a morphometric change that makes it difficult to measure the exact diameter of the vessel. For this reason, a larger number of vessels should be measured in order to obtain a more precise result.

For charcoal the size classes are currently still assigned according to the IAWA feature list categories
#40 (≤ 50 µm),
#41. Medium (50 - 100 µm),
#42. Large (100 - 200 µm),
#43. Very large (over 200 µm).

Our research has shown that a decrease in dimensions due to the charring process is significant for the majority of all studied wood species. For the feature ‘tangential vessel diameter’, the dimensional loss is on average 19% (MIN 2%, MAX 40%). If the values for solid wood are just above or below the limit of a size class, this class is often no longer attained after the charring process resulting in a shift of size class (Zemke et al., 2025).

Fig. 25 Measurement of the tangential diameter: *Aucoumea kleineana*; Measurement with 3D-reflected light microscopy of an unknown species.



Source: Thünen-Institut/ Valentina Zemke

Intervessel pits

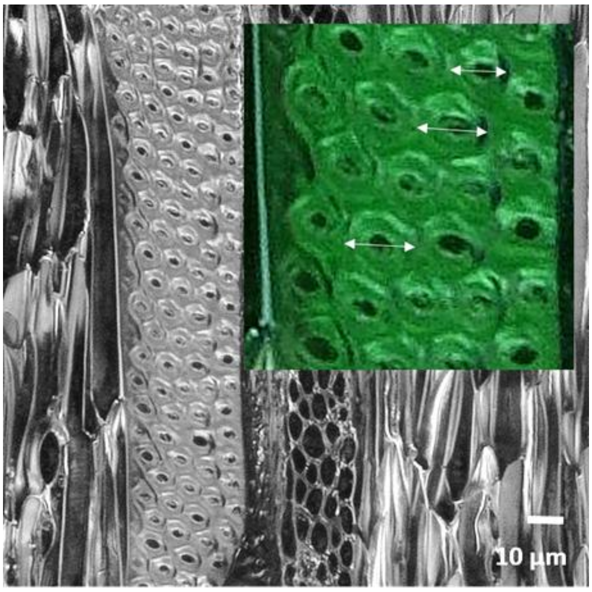
The size of the intervessel pit diameter is one component of quantitative features. Since carbonization can lead to homogenization of the cell walls, the observation of different pit components is possible only to a limited extent (Scheel-Ybert and Gonçalves, 2017; Korte et al., 2024). It becomes particularly difficult when very small (minute) pits are to be measured. Depending on the temperature during carbonization, complete fusion of the pits can occur, so that a description of the pit shape and measurements are not possible.

If the cell walls are in good condition, the pit chamber of intervessel pits can be measured **(Fig. 26).** Databases for wood identification only consider the pit chamber, which is why no reference data is available for the pit aperture. However, such data have already been collected by other disciplines, such as the identification of vessel elements in paper (Helmling et al., 2018) which focus on the pit aperture. Anthracology studies (e.g. Scheel-Ybert and Gonçalves, 2017) also works with the pit aperture if the pit chamber cannot be measured for reasons of deficient conservation. The size of intervessel pits thus may differ significantly from that reported in descriptions of normal wood in which the diameter of the pit chamber is normally measured. Our investigations have shown that with high-quality microscopy techniques, such as 3D-reflected light microscopy, artefacts of the cell walls in charcoal are mostly recognizable and the pit chamber can still be measured.

For the measurement of the horizontal intervessel pit diameter (pit chamber), it is generally recommended to collect 10 or more values, excluding extremely large or small pits in order to be able to make an accurate statement on the MIN/medium/MAX values. For charcoal the size classes are currently still assigned according to the IAWA feature list categories
#24. Minute - ≤ 4 µm,
#25. Small - 4-7 µm,
#26. Medium - 7-10 µm,
#27. Large - ≥ 10 µm.

Our investigations have shown that, depending on the wood species, pits of charred wood suffer varying dimensional losses from 2 to 53%, on average around 29%. This often leads in shifts in size class compared to the IAWA size classes (Zemke et al., 2025), emphasizing the urgent need that size classes be adapted for charcoal identification.

Fig. 26 **Measurement of the intervessel pit diameter (pit chamber) with 3D-reflected light microscopy: *Acer pseudoplatanus*.**



Source: Thünen-Institut/ Valentina Zemke

Rays

As the charring process is accompanied by structural changes, charred rays often show cracks (Rossen and Olson, 1985). These affect the exact determination of the dimensions, as additional cavities increase the measured values, primarily of ray width. This phenomenon can be observed in narrow as well as broad multiseriate rays. Some of these rays have vertical cracks in the midsection virtually separating the rays into two parts **(Fig. 27A)**.

Ray height and width **(Fig. 27B)** are measured in the tangential section. It is recommended to measure 25 or more rays in order to obtain meaningful values. Intact rays need to be selected whose mostly tapered ends serve as measuring points for determining ray height. Ray width is measured at the widest central part of a ray.

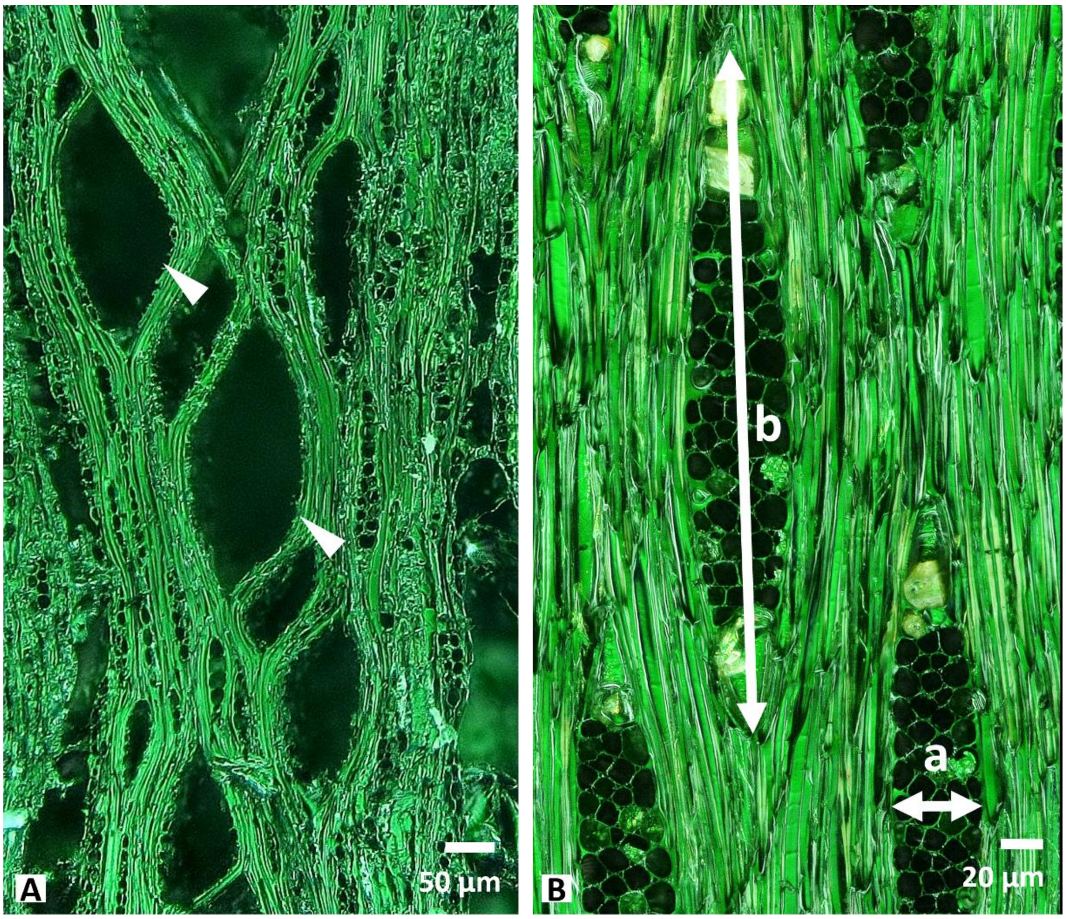
For charcoal the size class of ray height are currently still assigned according to the IAWA feature list categories

#102. Ray height > 1000.

In addition, it can be specified whether **´Rays of two distinct sizes´** are present **(#103).** Detailed Information given in Chapter 8.

Our investigations have shown that, depending on the wood species, the ray height of charred wood suffer varying dimensional losses from 2 to 55%, on average around 17%. This often leads in shifts in size class emphasizing the urgent need to adjust the feature for charcoal identification (Zemke et al., 2025).

Fig. 27 **Rays with cracks: botanical name unknown (A); measurement of ray width (a) and ray height (b) with 3D-reflected light microscopy: *Milicia excelsa* (B).**



Source: Thünen-Institut/ Valentina Zemke

Fibres

Fibre dimensions in wood are not routinely determined as the maceration process is highly time-consuming and fibre characteristics are often considered of lesser diagnostic significance than other structural features (Chattaway, 1932). However, since charred material cannot be macerated, the wall thickness of the fibres must be determined directly in transverse section using high-resolution microscopy. Due to the reduced thickness of charred fibre walls a two-stage measurement approach is recommended:

Fibre wall thickness [µ] = Tangential fibre diameter [µ] - tangential fibre diameter of lumina [µm] divided by 2.

Fibre shrinkage during charring may vary depending on the proportion of normal and gelatinous fibres, which in turn is influenced by the charring temperature. Dias Leme et al. (2010) indicate that at a charring temperature of approximately 400°C, the typical temperature in a charcoal kiln, only minor differences of dimensional changes are observed between normal and gelatinous fibres. Above 600°C, amorphous structural transformations were observed.

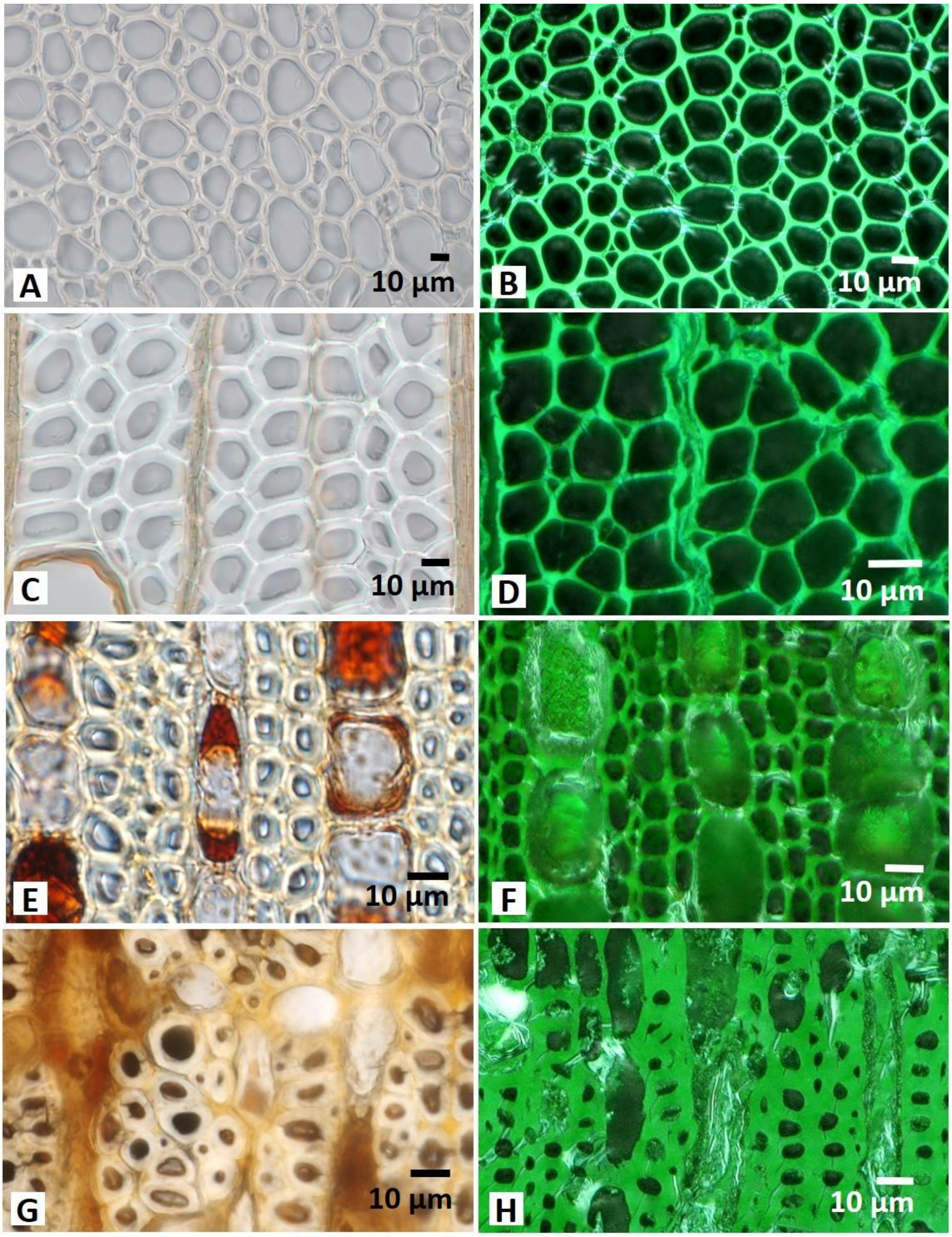
#68. Fibres very thin-walled = fibre lumina 3 or more times wider than the double wall thickness.

#69. Fibres thin- to thick-walled = fibre lumina less than 3 times the double wall thickness.

#70. Fibres very thick-walled = fibre lumina almost completely closed.

Thin-walled fibres generally retain this status even after charring **(Fig. 28 A+B)**. However, charring of thicker-walled fibres often leads to a significant reduction in wall thickness, potentially requiring reclassification in a thinner wall thickness category **(Fig. 28 C-F)**. Our study demonstrates this for most of the 34 examined wood species. Among the species originally classified in category #69 (fibres thin- to thick-walled) and/or #70 (thick-walled), 80% had to be reclassified after charring as #68 (very thin-walled). Nevertheless, individual species retained their very thick-walled fibres even after charring **(Fig. 28 G+H).**

Fig. 28 **Fibre wall thickness before (left) and after the charring process (right) of *Paulownia elongata* (A+B); *Betula pubescens* (C+D); *Ziziphus mucronata* (E+F) and *Diospyros crassiflora* (G+H).**



Source: Thünen-Institut/ Valentina Zemke

10 Features Difficult or Impossible to Use in Charcoal Identification

For the identification of charcoal, not all features used for traditional wood identification are applicable. Features from all three categories– qualitative features and quantitative features as well as and non-anatomical information are affected. Generally, the wood structure is preserved in charcoal; however, particularly high carbonization temperatures can result in significant differences between tangential and radial shrinkage, leading to distortions of the material and consequently influencing the wood structure. Such alterations become more severe with increasing carbonization temperature.

A study by Dias Leme et al. (2010) demonstrates that significant structural changes occur, especially at temperatures above 800°C, including splitting and distortion of the material. Cleavages between fibres become visible, resulting in a block-like structure, and organic substances deposited in axial parenchyma, rays and vessels may assume a globular form.

Temperatures in traditional carbonization processes are in a range of 400 to 700°C, so the aforementioned extreme changes rarely occur. Yet, even within this temperature range, initial fusion of cell walls can be detected microscopically, potentially resulting in a homogeneous appearance of cell wall layers. Generally, carbonization processes up to 700°C provide sufficient quality of tissue conservation for addressing anatomical features. However, due to the structural transformation to carbon, a number of features and corresponding information are entirely unavailable for charcoal identification:

Qualitative Features

Helical thickenings only in narrower vessel elements (#39): as per feature descriptor; they are often indistinct or not recognizable at all in charcoal. This is due to the fact that the presence of helical thickenings can only be inferred from their contact points with the vessel walls. Melting of these areas or deposits of particles that occur after the forming process of the fractures leads to a more difficult visualization. In addition, there is usually a thin mesh superimposed by adjacent cell wall components if the observed surface is not perfectly aligned.

Laticifers or tanniniferous tubes (#132) = cells or rows of cells of indeterminate length extending radially. Since laticiferous tubes and tanniniferous tubes are difficult to differentiate, they are grouped together in a common category (Fujii, 1988). In solid wood, laticiferous tubes and tanniniferous tubes can sometimes be differentiated based on the colour of the substances they contain. In charred wood this is no longer possible due to the loss of colour and change in chemical composition.

Heartwood colour (#196-201): Due to the complete conversion of the woody tissue into carbon, charcoal shows a uniform greyish to black colour and a matt to shiny surface. It is therefore difficult to distinguish between heartwood and sapwood, and streaking is also not recognisable. The lack of diversity in colour also affects the differentiation of tissue types with reflected light microscopy. Thus, it can be difficult to distinguish between axial parenchyma cells and fibres in cross section.

Solitary vessel outline (#12): The outline of solitary vessels is normally defined as circular to oval vs. angular. The irregular or curled shape that vessels can exhibit after charring limits an accurate attribution to either of the two states. In such cases, no statement can be made about the original vessel outline.

Mineral inclusions: Crystals and silica **(#136 -156)**, are normally well preserved after carbonisation, but at very high charring temperatures above 700° C other cell contents such as remnants of decay may suffer structural changes that make them appear crystalline under incident light. We repeatedly observed such crystalline debris randomly distributed on the surface of charred tissue. Such are artefacts that should not be confused with true crystals.

At high temperatures, **gums (#58)** can melt and obstruct intervessel pit fields on the vessel walls due to bubble formation. Dias Leme et al. (2010) assert that this can also lead to be misinterpreted as **tyloses (#56-57)**.

Quantitative Features

The **mean vessel element length (#52-55)** and the **mean fibre length (#71-74)** cannot be measured exactly in the cell network of charred wood. Normally, small pieces of wood are macerated followed by the measurement of individual vessels or fibres (Carlquist, 2001). As maceration of charred tissue is not possible, the determination of vessel and fibre length must be dispensed with.

Values for **vessels per square millimetre (#46-50)** and **rays per millimetre (#114-116)** generally increase due to shrinkage. Exact values are difficult to obtain owing to the frequent formation of cracks in the charred tissue and the formation of intercellular spaces; they cannot be compared with reference data from descriptions of natural wood. This constitutes a considerable restriction, and it is therefore recommended not to use this feature.

Non-anatomical information

In addition to structural features, there is general information that is also specific to a wood species and can be employed to differentiate between wood species/genera. In this group, there are particularly many limitations to their application.

Odour (#203) does not last in the wood after charring. All types of charred wood have a similar 'burnt' odour.

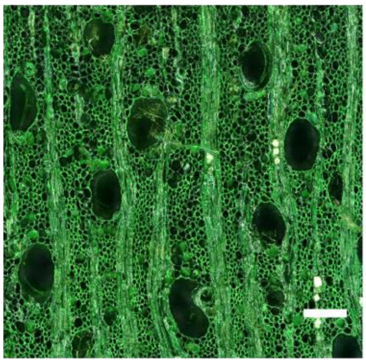
Specific gravity (#193-195) also changes due to the pyrolysis process resulting in a variable degree of shrinkage. As studies have shown an uneven change in specific gravity depending on the type of wood, this feature cannot be used for charcoal (Rossen and Olson, 1985).

Different chemical and physical tests, i.e., **Heartwood fluorescence (#204), Fluorescence and colour of aqueous and ethanol extracts: (#205-214), Froth test (#215), Chrome Azurol-S test (#216) and Burning splinter test (#217-221)** cannot be used for identifying charcoal**.**

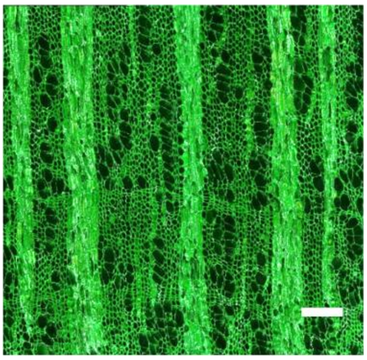
As things stand at present, there are no 'new' test methods that have been developed specifically for charcoal.

11 Overview of All Species

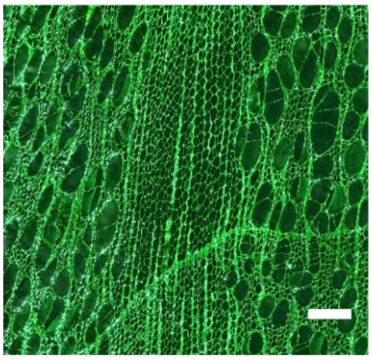
Fig. 29 Overview of all species 1 - 12 (Measuring bar of all species = 100 µm).



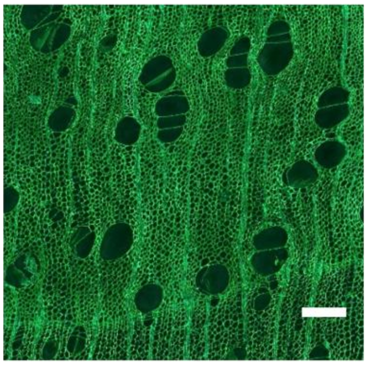
1 *Aspidosperma quebracho-blanco*



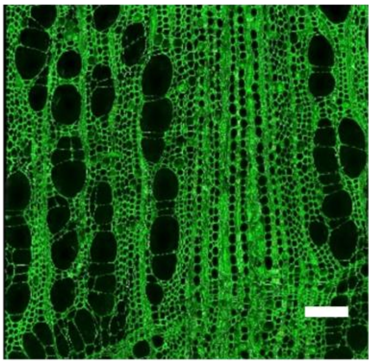
2 *Ilex aquifolium*



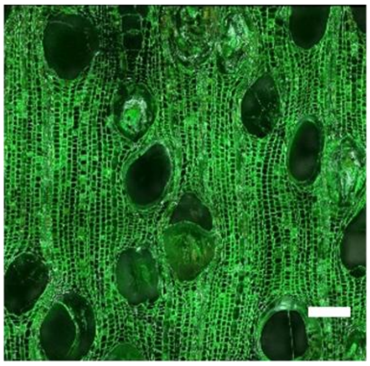
3 *Alnus glutinosa*



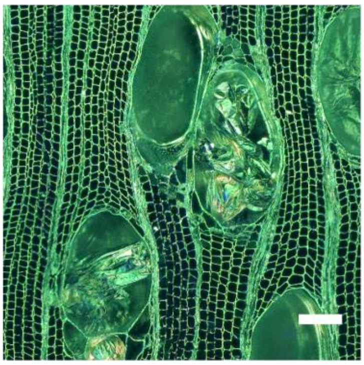
4 *Betula pubescens*



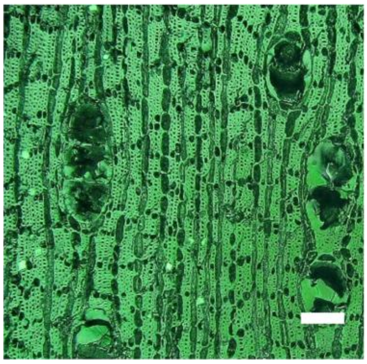
5 *Carpinus betulus*



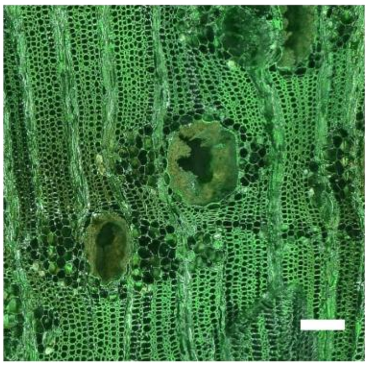
6 *Aucoumea klaineana*



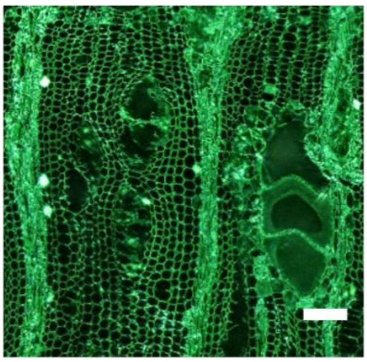
7 *Rubroshorea leprosula*



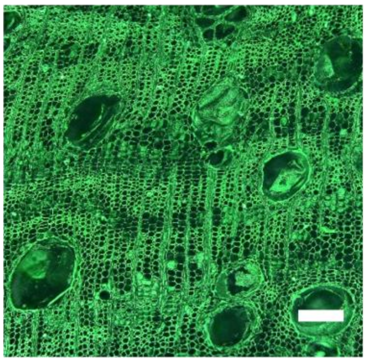
8 *Diospyros crassiflora*



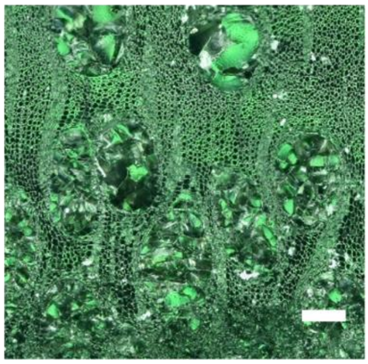
9 *Afzelia africana*



10 *Copaifera paupera*



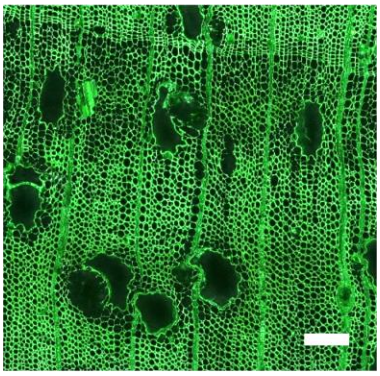
11 *Pterocarpus angolensis*



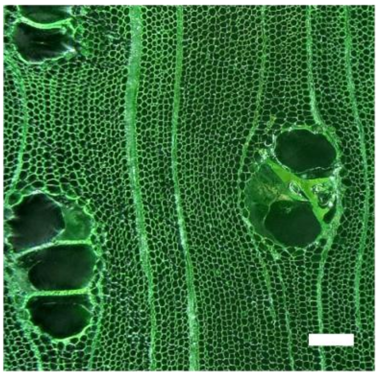
12 *Robinia pseudoacacia*

Source: Thünen-Institut/ Valentina Zemke

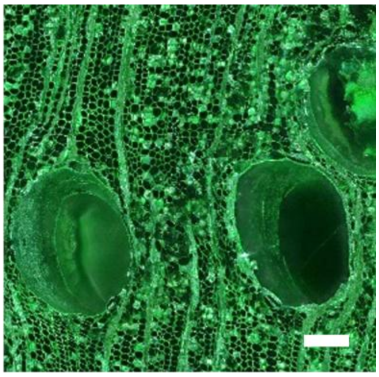
Fig. 30 Overview of all species 13 - 24 (Measuring bar of all species = 100 µm).



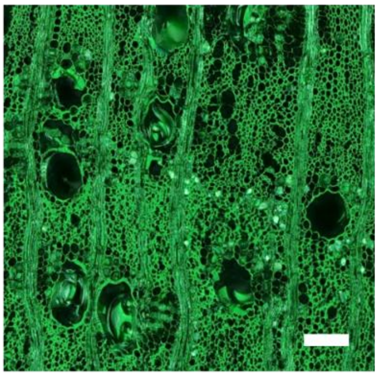
13 *Acacia dealbata*



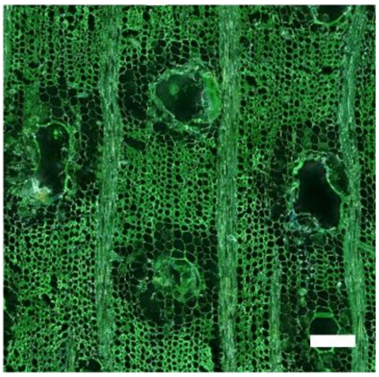
14 *Acacia melanoxylon*



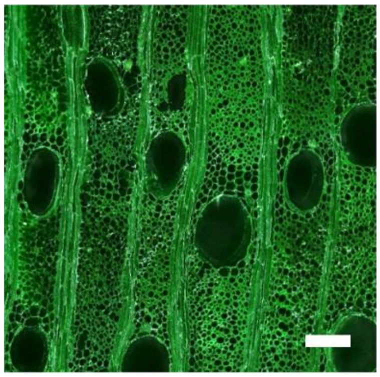
15 *Cedrelinga cateniformis*



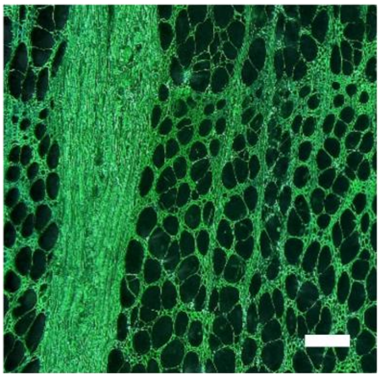
16 *Dichrostachys cinerea*



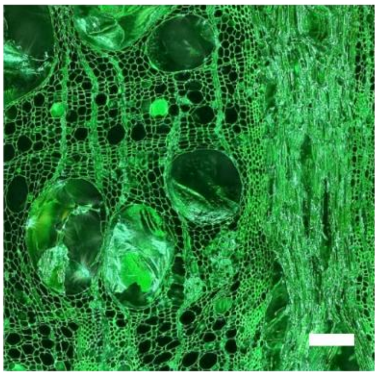
17 *Senegalia chundra*



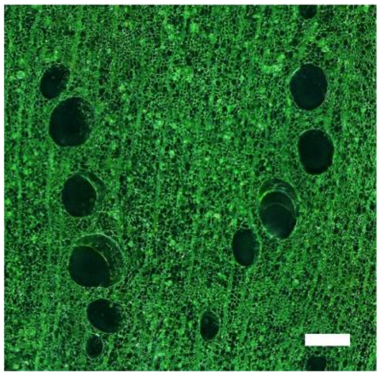
18 *Vachellia nilotica*



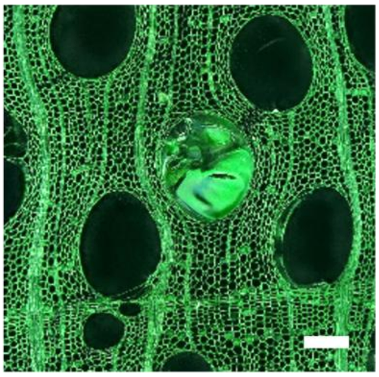
19 *Fagus sylvatica*



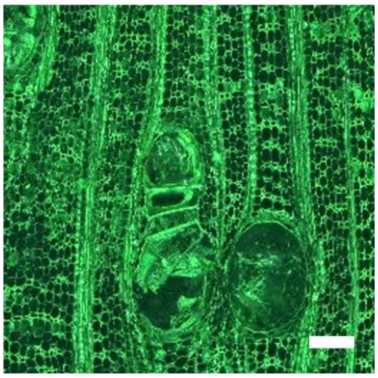
20 *Quercus petraea*



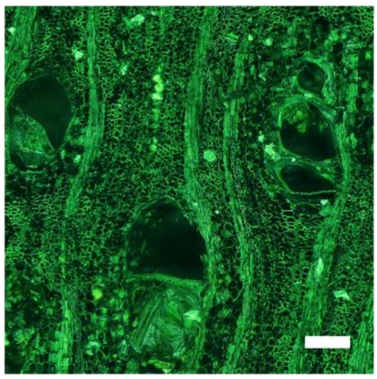
21 *Quercus suber*



22 *Juglans nigra*



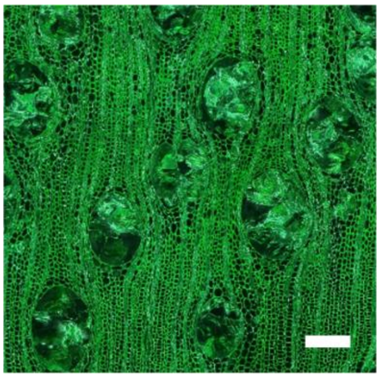
23 *Triplochiton scleroxylon*

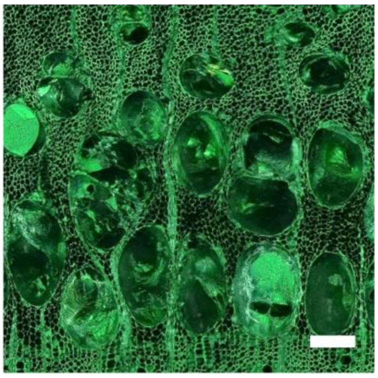


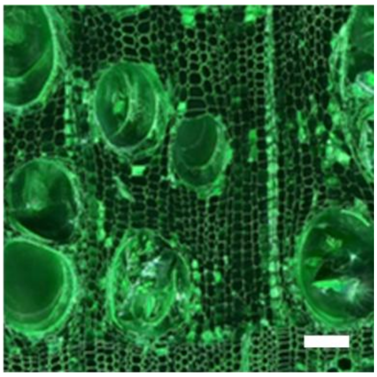
24 *Milicia excelsa*

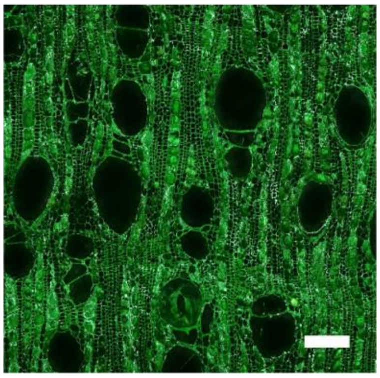
Source: Thünen-Institut/ Valentina Zemke

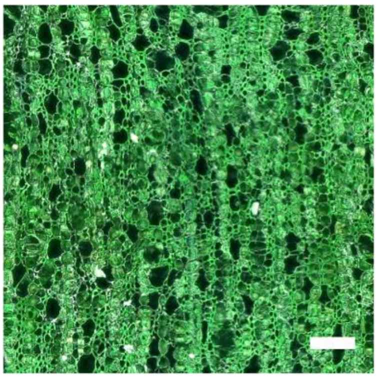
Fig. 31 Overview of all species 25 - 34 (Measuring bar of all species = 100 µm)

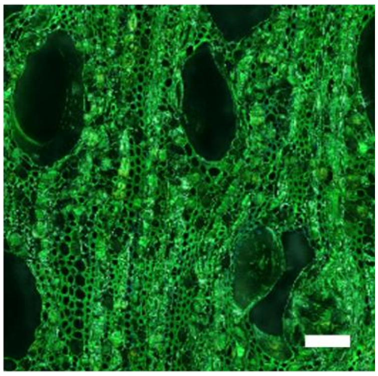

25 *Eucalyptus grandis*

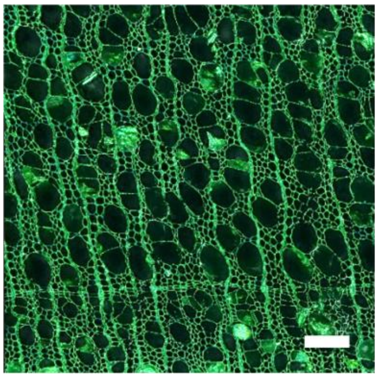

26 *Fraxinus excelsior*

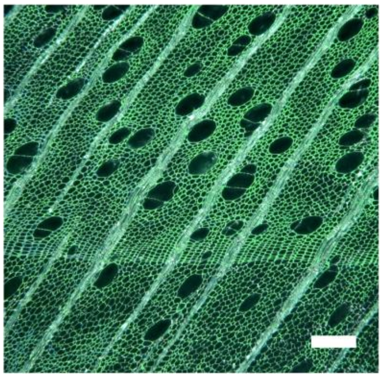

27 *Paulownia elongata*

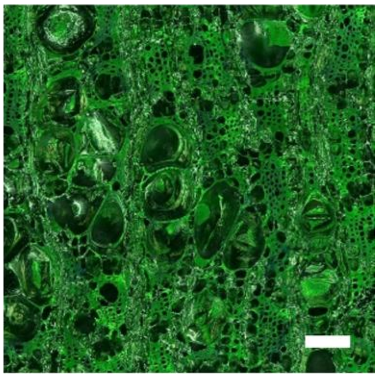

28 *Ziziphus mucronata*

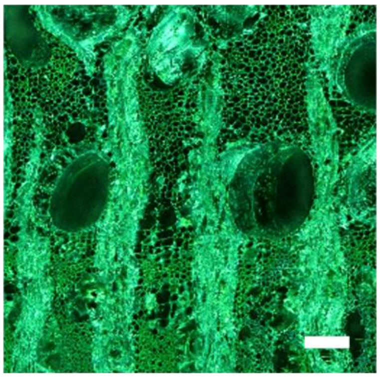

29 *Coffea arabica*


30 *Nauclea diderrichii*


31 *Populus alba*


32 *Acer pseudoplatanus*


33 *Autranella congolensis*


34 *Ulmus minor*

Source: Thünen-Institut/ Valentina Zemke

12 Microscopic Description of Species

The data sheets contain all relevant information for identifying the wood species of charcoal. Included are general data of the species (natural distribution, botanical name, family, trade names in various languages), DIN EN 13556-2003 code, CITES status, IUCN Conservation status (if any), followed by information on quantitative features for normal wood and the corresponding charcoal. A table with images of diagnostic features is included in the data sheet of all species, presenting images of the (diagnostic) structural features as observed with a 3D-Reflected Light Microscope (3D-RLM).

Acronyms used in the illustration headers

TS = Transverse section
TLS = Tangential longitudinal lection
RLS = Radial longitudinal section

Quantitative data: Data presented in the respective tables are based on the following number of measurements:

Tangential vessel diameter: n=100
Intervessel pit diameter (horizontal): n=50
Fibre wall thickness: n =50
Ray width: n=100
Ray height: n=100

ISO 3166-1:2020: Country codes used in the descriptions

AO = Angola
AR = Argentina
BE = Belgium
BO = Bolivia
BR = Brazil
CA = Canada
CD = Democratic Republic of the Congo
CF = Central African Republic
CG = Republic of the Congo
CI = Ivory Coast
CM = Cameroon
CN = China
CS = Serbia and Montenegro
CZ = Czech Republic
DE = Germany
EC = Ecuador
EN = England
ES = Spain
FR = France
GA = Gabon
GB = Great Britain
GF = French Guiana
GH = Ghana
GQ = Equatorial Guinea
HU = Hungary
ID = Indonesia
IN = India
IR = Iran
IT = Italy
JP = Japan
LR = Liberia
MD = Moldova
MY = Myanmar
MZ = Mozambique
NG = Nigeria
NL = Netherlands
PE = Peru
PK = Pakistan
PL = Poland
PT = Portugal
PY = Paraguay
RO = Romania
RU = Russia
SE = Sweden
TH = Thailand
TR = Turkey
TZ = Tanzania
UG = Uganda
US = United States
ZA = South Africa
ZW = Zimbabwe

Codes of countries are according to ISO 3166-1 (except BN)

12.1 *Aspidosperma quebracho-blanco* Schltdl. (APOCYNACEAE)

Trade names*:* Ubirá-ro-puütá (AR); cacha, quichua, chiriguano, guarirová, yviraró (BO); kebrako; white quebracho (GB, US); cachá, ebédu, yvira ji'y morotí (PY); quina (BR).

DIN EN 13556-2003 code*:* ASXX.

CITES regulations*:* Not protected.

Geographic distribution*:* NE-Brazil (Bahia); SE-Brazil (Minas Gerais, Espirito Santo, Sao Paulo, Rio de Janeiro); S-Brazil (Paraná, Santa Catarina); Bolivia (Cochabamba, La Paz, Pando, Santa Cruz).

Growth ring boundaries*:* Indistinct or absent.

Vessel elements*:* Wood diffuse-porous; vessel elements solitary; perforation plates simple.

Intervessel pits*:* Alternate.

Vessel-ray pits: with distinct borders, similar to intervessel pits.

Fibres*:* -

Axial parenchyma*:* Apotracheal diffuse and diffuse-in-aggregates; commonly 3-5 cells per parenchyma strand.

Rays*:* Multiseriate, 1-3 cells wide; all ray cells procumbent (homocellular).

Storied structure: Not observed.

Secretory structure*:* Not observed.

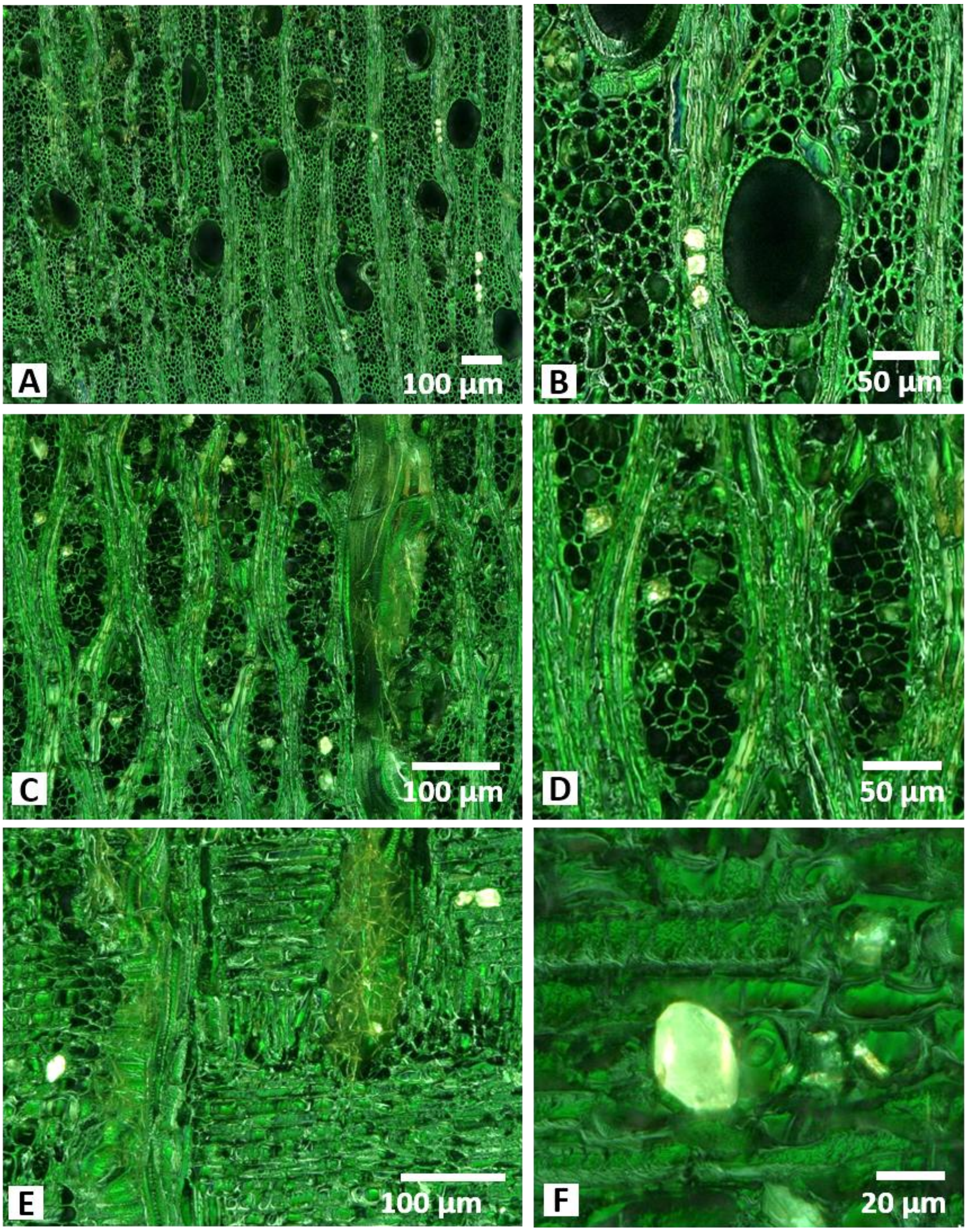
Mineral inclusions*:* Prismatic crystals located in procumbent ray cells, some in radial alignment; cells with one crystal each.

Quantitative data:

	Solid Wood (µm)	Carbonized Wood (µm)
Tangential vessel diameter	47,7 - <u>106,1</u> - 145,5	34,6 - <u>82,9</u> - 133,5
Intervessel pit diameter (horizontal)	3,7 - <u>4,2</u> - 5,2	2,4 - <u>3,1</u> - 4,0
Fibre wall thickness	<u>4,7</u>	<u>1,5</u>
Ray width	38,7 - <u>55,5</u> -75,0	19,2 – <u>48,5</u> - 72,7
Ray height	95,7 - <u>210,9</u> - 432,7	97,1 - <u>166,3</u> – 275,1

References: Catalogue of Life; Richter and Dallwitz 2000 onwards; Hassler 2004 onwards; Inside Wood 2004 onwards.

Fig. 32 **Illustration of anatomical (diagnostic) features of carbonized wood from *Aspidosperma quebracho blanco*. TS with diffuse-porous wood (A); TS with solitary vessel element (B); TLS with multiseriate rays (C+D); RLS with homocellular rays (E); RLS with prismatic crystal in ray cell (F).**



Source: Thünen-Institut/ Valentina Zemke

12.2 *Ilex aquifolium* L. (AQUIFOLIACEA)

Trade names: English holly (GB); Stechlaub, Stechpalme (DE).

DIN EN 13556-2003 code: ILAQ

CITES regulations: not protected.

Geographic distribution*:* Austria; Belgium; Luxembourg; England; Denmark; Germany; Ireland; Switzerland; Liechtenstein; Netherlands; Norway; Romania [I]; +Sweden; Portugal; Spain; Andorra; Baleares; France; Channel Isl.; Corsica; Sardinia; Sicily; Italy; Montenegro; Serbia and Kosovo; Bosnia-Herzegovina; Slovenia; Croatia; Macedonia; Albania; Bulgaria; Greece; East Aegaean Isl.; Tunisia; Algeria; Morocco; widely cultivated elsewhere.

Growth ring boundaries*:* Distinct.

Vessel elements*:* Wood semi-ring-porous or diffuse-porous; vessel elements in multiples forming a diagonal/radial pattern, and in clusters; perforation plates scalariform with up to 40 bars; helical thickenings throughout the body of vessel elements.

Intervessel pits: Scalariform, opposite, rarely alternate.

Vessel-ray pits: with distinct borders, similar to intervessel pits.

Fibres*:* Helical thickenings in ground tissue fibres; fibres with distinctly bordered pits common in both radial and tangential walls.

Axial parenchyma*:* Apotracheal diffuse; 3-8 cells per strand.

Rays*:* Rays of two distinct sizes, uniseriate and multiseriate with up to 10 or more cells wide; body cells procumbent with either one or mostly 2-4 rows of upright and/or square marginal cells (heterocellular).

Storied structure: Not observed.

Secretory structure: Not observed.

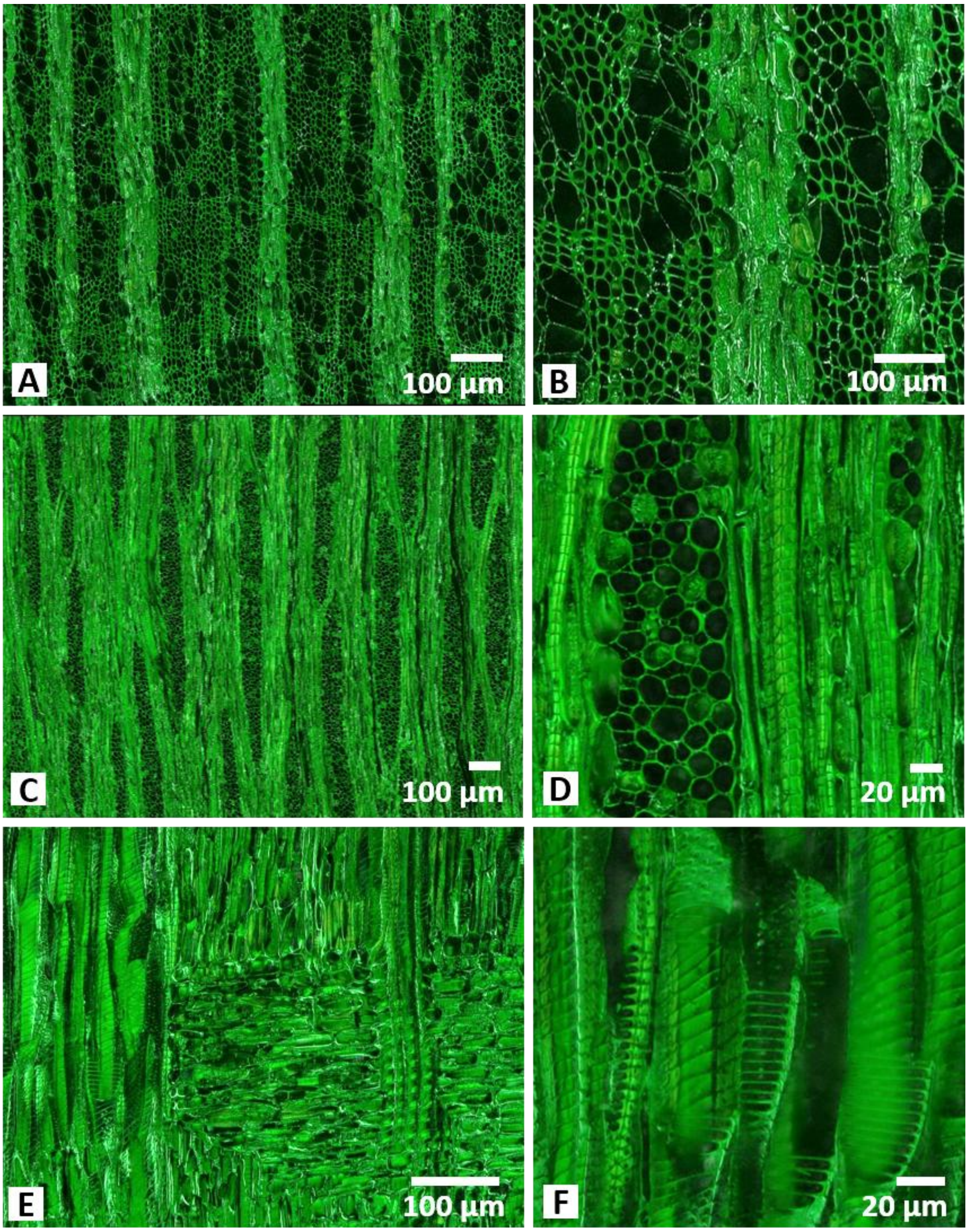
Mineral inclusions: Not observed.

Quantitative data:

	Solid Wood (µm)	Carbonized Wood (µm)
Tangential vessel diameter	13,6 - <u>27,8</u> - 41,0	14,3 - <u>26,4</u> - 41,1
Intervessel pit diameter (horizontal)	5,7 - <u>7,0</u> - 8,1	3,1 - <u>4,3</u> - 5,9
Fibre wall thickness	<u>4,6</u>	<u>0,9</u>
Ray width	54,6 - <u>90,5</u> - 133,1	45,6 - <u>68,3</u> - 113,2
Ray height	300,5 - <u>866,2</u> - 1918,6	263,0 - <u>651,0</u> - 1329,6

References: Catalogue of Life; Baas, 1973; Grosser, 1977; Schweingruber, 1990; Hather, 2000; Richter and Dallwitz, 2000 onwards; Hassler, 2004 onwards; Inside Wood 2004 onwards; Schoch et al., 2004; WCSP 2022.

Fig. 33 **Illustration of anatomical (diagnostic) features of carbonized wood of *Ilex aquifolium*. TS with semi-ring-porous to diffuse-porous wood (A); TS with vessel elements in clusters, multiples and in diagonal/radial pattern (B); TLS with uniseriate (few) and multiseriate rays (C); TLS with a large multiseriate ray and helical thickenings in fibres (D); RLS with heterocellular rays (E); TLS with scalariform perforation plates in vessel elements (F).**



Source: Thünen-Institut/ Valentina Zemke

12.3 *Alnus glutinosa* (L.) Gaertn. (BETULACEAE)

Trade names: Schwarzerle, Roterle, Gemeine Erle (DE); Common alder, Black alder, European alder (GB); aune (aulne) (FR); ontano nero (IT); elzen (NL)

DIN EN 13556-2003 code: ALGL.

CITES regulations: not protected.

Geographic distribution*:* Albania; Austria; Belgium; Luxembourg; England; Channel Isl.; Bulgaria; Corsica; Czech Republic; Slovakia; Denmark; Finland; France; Germany; Ireland; Switzerland; Liechtenstein; Netherlands; NE-Spain; Hungary; Italy; Slovenia; Croatia; Macedonia; Serbia and Kosovo; Bosnia-Herzegovina; Montenegro; Malta; Norway; Poland; Romania; Sardinia; Sicily; Sweden; Estonia; Latvia; Lithuania; E-European Russia; C-European Russia; N-European Russia; W-European Russia; Belarus; Ukraine; Kazakhstan; Tajikistan; Libya; Tunisia; Algeria; Northern Caucasus; Azerbaijan; Georgia [Caucasus]; Siberia (W-Siberia); Turkey (E-Anatolia, Inner Anatolia, N-Anatolia, NE-Anatolia, NW-Anatolia: Bithynia, S-Anatolia, SE-Anatolia, W-Anatolia, WN-Anatolia); Greece (incl. Cyclades); East Aegaean Isl.; European Turkey; Iran (N-Iran); cultivated elsewhere.

Growth ring boundaries*:* Distinct.

Vessel elements*:* Wood semi-ring-porous or diffuse-porous; vessel elements in short radial rows of 2-3 vessel elements and rows of 4 or more vessel elements; perforation plates scalariform with 15-26 bars.

Intervessel pits*:* Opposite.

Vessel-ray pits: with distinct borders, similar to intervessel pits but smaller in size. Restricted to marginal rows.

Fibres*:* -

Axial parenchyma*:* Apotracheal diffuse and diffuse-in-aggregates; mostly 4, and up to eight 8 cells per parenchyma strand.

Rays*:* Uniseriate, rarely multiseriate (up to 3-seriate); aggregate rays present; all ray cells procumbent (homocellular).

Storied structure: Not observed.

Secretory structure: Not observed.

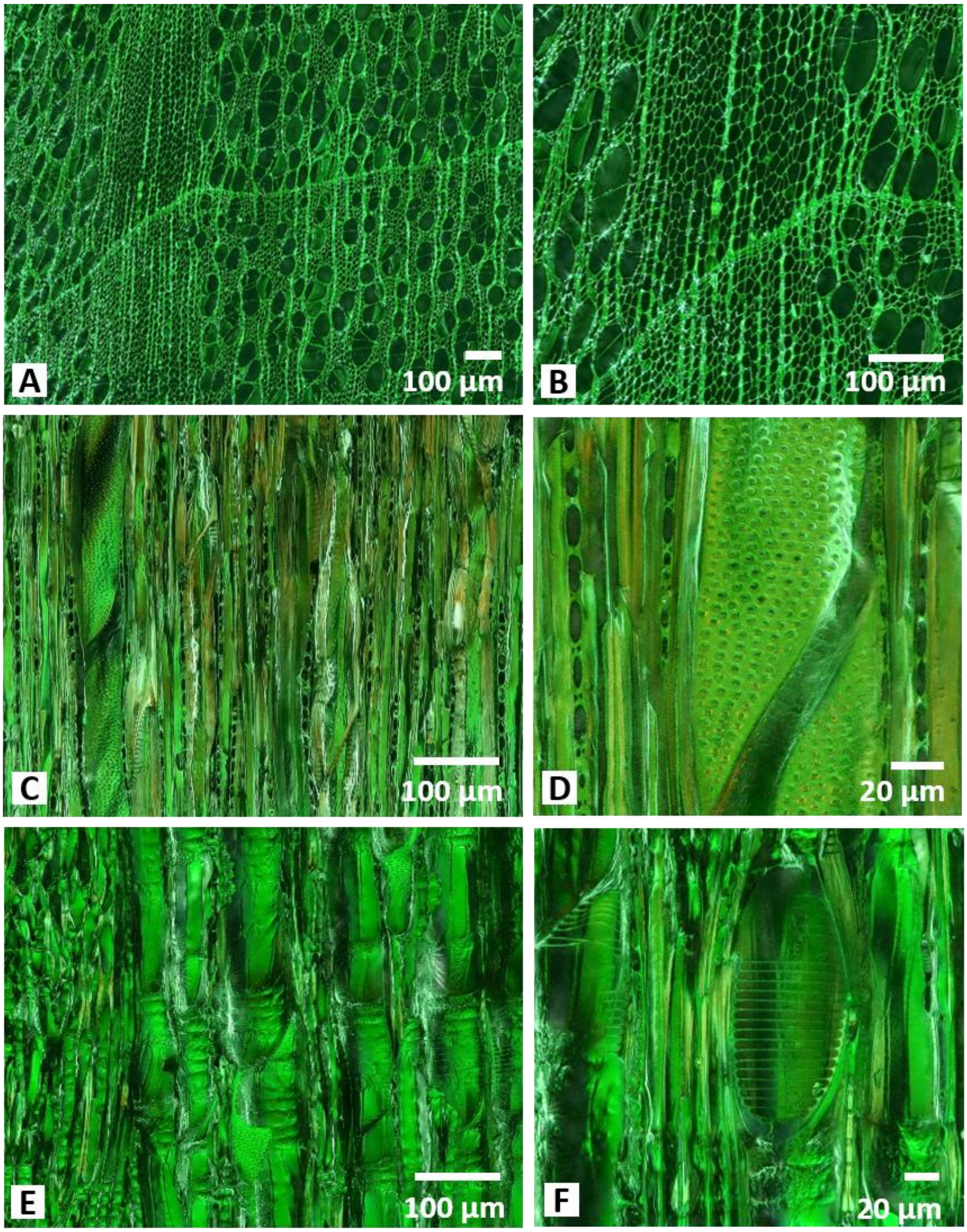
Mineral inclusions*:* Not observed.

Quantitative data:

	Solid Wood (µm)	Carbonized Wood (µm)
Tangential vessel diameter	36,4 - <u>52,1</u> - 80,2	16,1 - <u>46,0</u> - 70,1
Intervessel pit diameter (horizontal)	4,2 - <u>5,0</u> - 5,9	2,5 - <u>4,3</u> - 5,7
Fibre wall thickness	<u>3,3</u>	<u>0,8</u>
Ray width	10,0 - <u>13,9</u> - 20,1	4,0 - <u>8,8</u> - 14,4
Ray height	72,9 - <u>213,9</u> - 480,3	52,7 - <u>178,0</u> - 411,9

References: Catalogue of Life; Brazier and Franklin, 1961; Grosser, 1977; Schweingruber, 1990; Hather, 2000; Richter and Dallwitz, 2000 onwards; Hassler, 2004 onwards; Inside Wood 2004 onwards; Schoch et al., 2004.

Fig. 34 **Illustration of anatomical (diagnostic) features of carbonized wood of *Alnus glutinosa*. TS with semi-ring-porous wood (A); TS with aggregate ray (B); TLS with uniseriate rays (C); TLS with opposite to alternate intervessel pits (D); RLS with homocellular rays (E); TS with scalariform perforation plates (F).**



Source: Thünen-Institut/ Valentina Zemke

12.4 *Betula pubescens* Ehrh. (BETULACEAE)

Trade names: European birch, common birch, Downy birch (GB), berken (NL), bouleau (FR), abedul (ES), Moor-Birke (DE).

DIN EN 13556-2003 code: BTXX.

CITES regulations: not protected.

Geographic distribution: Austria; Belgium; Luxembourg; England; Channel Isl. [I]; Czech Republic; Slovakia; Denmark; Finland; France; Germany; Ireland; Switzerland; Liechtenstein; Spain; Hungary; Iceland; Italy; Serbia; Montenegro; Bosnia-Herzegovina; Slovenia; Croatia; Portugal; Norway; Poland; Romania; Sweden; Belarus; Estonia; Latvia; Lithuania; E-European Russia; C-European Russia; N-European Russia; S-European Russia; W-European Russia; Ukraine; Siberia; Siberia (S-Siberia, C-Siberia, E-Siberia, Yakutia); Kazakhstan; Northern Caucasus; Georgia [Caucasus]; Turkey (E-Anatolia, NE-Anatolia); cultivated elsewhere.

Growth ring boundaries*:* Distinct.

Vessel elements: Wood diffuse-porous; vessels solitary and in radial multiples of 2-3 elements; in latewood radial rows of more than 3 cells; perforation plates scalariform with 10–20 bars.

Intervessel pits: Alternate.

Vessel-ray pits: with distinct borders, similar to intervessel pits.

Fibres*:*

Axial parenchyma*:* Fine marginal bands; apotracheal diffuse or diffuse-in-aggregates with 5-8, rarely over eight cells per parenchyma strand.

Rays*:* Multiseriate, (1-)3 cells, up to 4 cells wide; all ray cells procumbent (homocellular).

Storied structure: Not observed.

Secretory structure: Not observed.

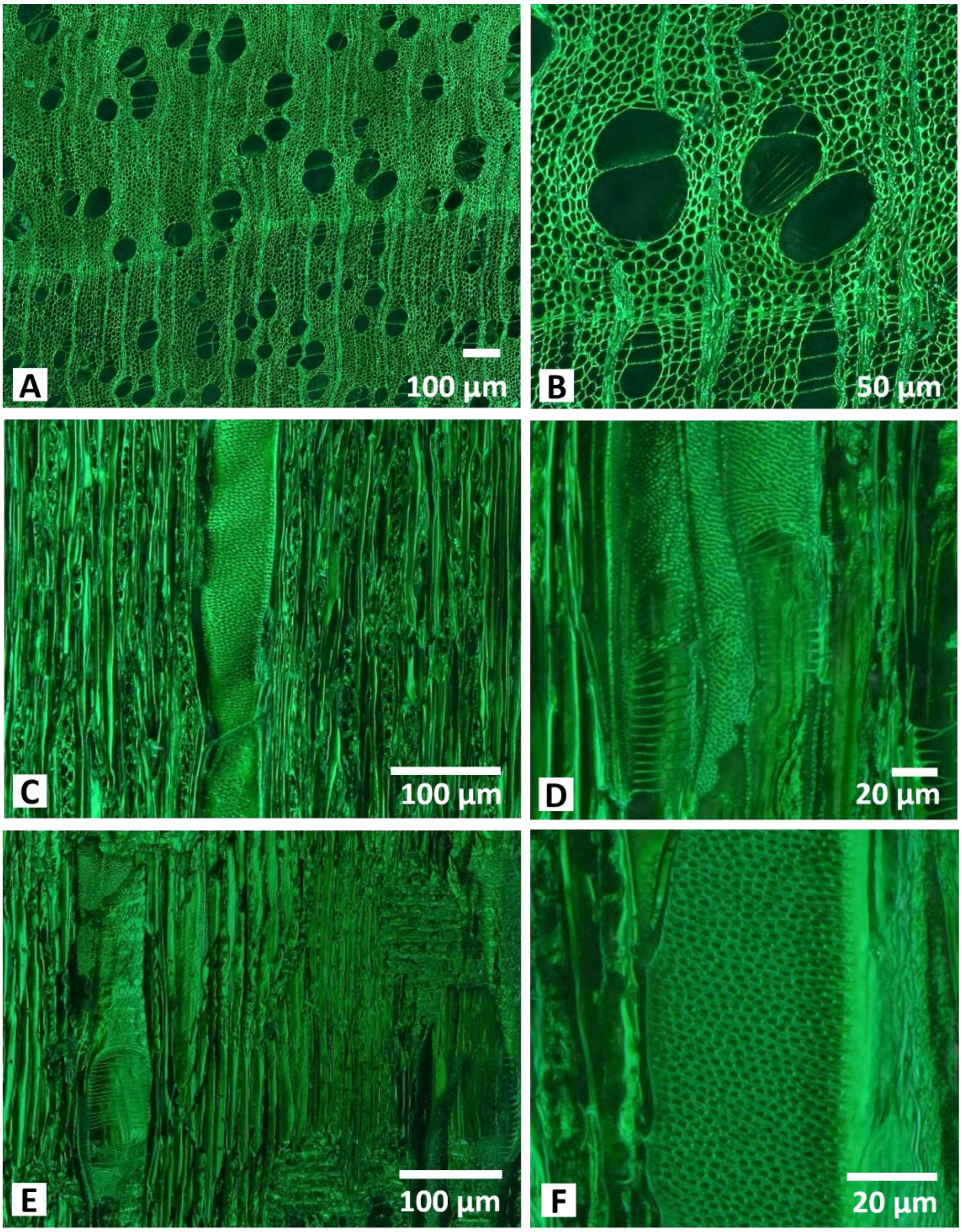
Mineral inclusions: Not observed.

Quantitative data:

	Solid Wood (µm)	Carbonized Wood (µm)
Tangential vessel diameter	34,1 - <u>59,2</u> - 85,8	16,6 - <u>57,2</u> - 94,2
Intervessel pit diameter (horizontal)	3,2 – <u>4,0</u> – 4,7	2,0 - <u>2,8</u> - 3,8
Fibre wall thickness	<u>4,2</u>	<u>0,9</u>
Ray width	11,8 - <u>27,6</u> - 44,9	5,6 - <u>10,7</u> - 17,9
Ray height	119,2 – <u>367,7</u> – 697,2	51,9 - <u>163,8</u> - 314,9

References*:* Catalogue of Life; Grosser, 1977; Miller and Cahow, 1989; Schweingruber, 1990; Hather, 2000; Richter and Dallwitz, 2000 onwards; Hassler, 2004 onwards; Inside Wood 2004 onwards.

Fig. 35 **Illustration of anatomical (diagnostic) features of carbonized wood of *Betula pubescens*. TS with diffuse-porous wood (A); TS with vessel elements in multiples and radial rows of 2-3 elements (B); TLS with multiseriate rays (C); RLM with scalariform perforation plates (D); RLS with homocellular rays (E); TLS with alternate intervessel pits (F).**



Source: Thünen-Institut/ Valentina Zemke

12.5 *Carpinus betulus* L. (BETULACEAE)

Trade names: Weißbuche, Hainbuche, Hornbaum (DE), charme commun (FR), common hornbeam (GB), haagebeuke (NL), carpino bianco (IT), habr obecny (CZ), grab (PL), carpen (RO), votbok (SE), gyertýn (HU).

DIN EN 13556-2003 code: CPBT.

CITES regulations: not protected.

Geographic distribution*:* Albania; Austria; Belgium; Luxembourg; England; Channel Isl. [I]; Bulgaria; Czech Republic; Slovakia; Denmark; France; Germany; Greece; Switzerland; Liechtenstein; Netherlands; Hungary; Italy; Slovenia; Croatia; Macedonia; Serbia and Kosovo; Montenegro; Bosnia-Herzegovina; Poland; Romania; S-Lithuania; C-European Russia; S-European Russia; Ukraine; Northern Caucasus; Georgia [Caucasus]; Tajikistan; Azerbaijan; Armenia; Sweden; Turkey (Inner Anatolia, N-Anatolia, NW-Anatolia: Bithynia,); European Turkey; Iran (NE-Iran and N-Iran, Iranian Azerbaijan).

Growth ring boundaries*:* Distinct.

Vessel elements*:* Wood semi-ring-porous or diffuse-porous; vessel elements in short to long radial rows; perforation plates simple; diameter of vessel elements gradually decreasing from earlywood-to latewood; helical thickenings present, throughout body of vessel element.

Intervessel pits*:* Alternate.

Vessel-ray pits: with reduced borders to apparently simple throughout the ray cell or restricted to marginal rows; pits rounded or angular.

Fibres*:* -

Axial parenchyma*:* Fine marginal or seemingly marginal bands; apotracheal: diffuse; commonly 3-4, rarely up to 8 cells per parenchyma strand.

Rays*:* Aggregate rays present; small rays multiseriate, up to 4 cells wide; body cells procumbent with one row of upright and/or square marginal cells (heterocellular).

Storied structure: Not observed.

Secretory structure*:* Not observed.

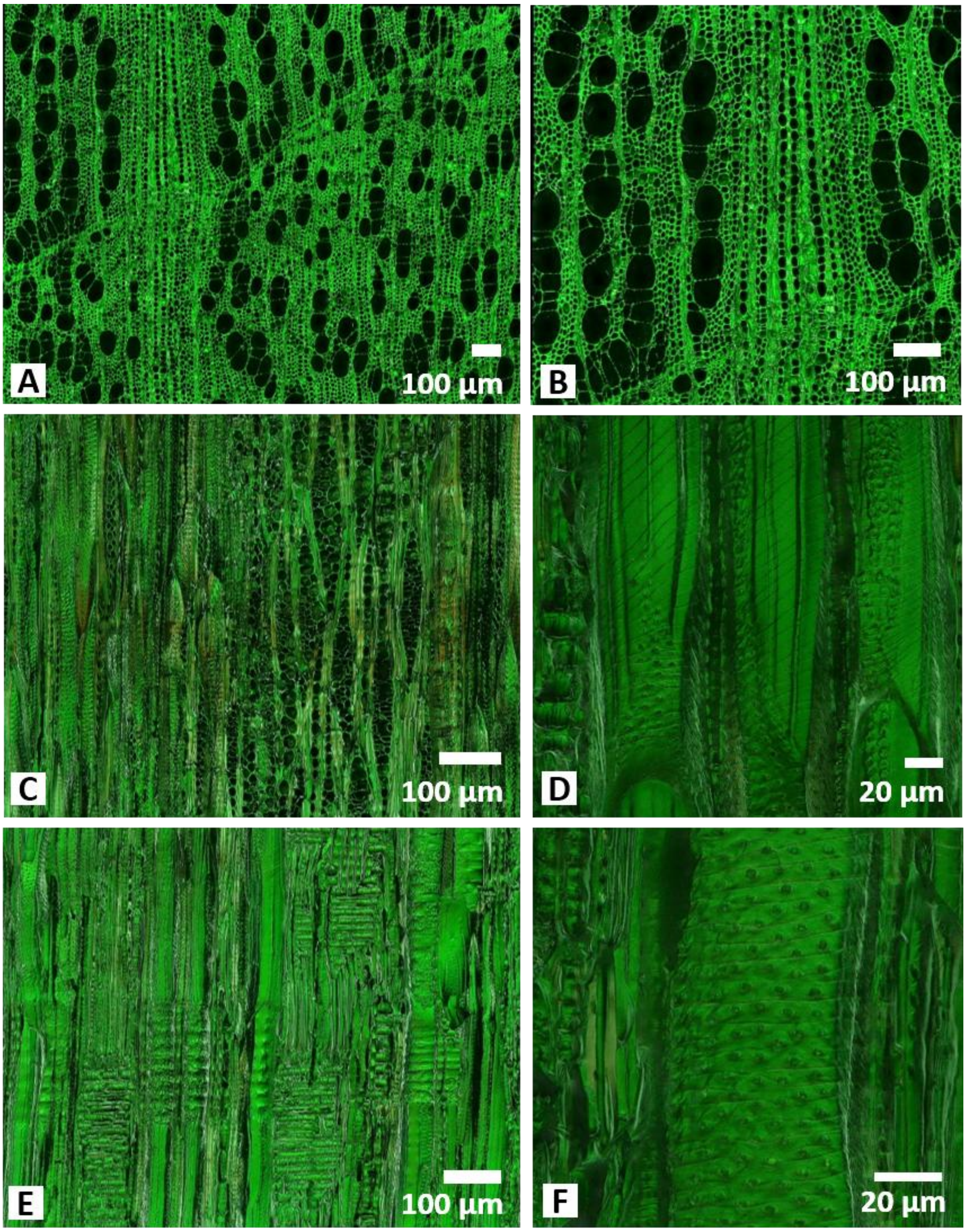
Mineral inclusions: Prismatic crystals located in procumbent ray cells; crystal bearing cells enlarged with one crystal each.

Quantitative data:

	Solid Wood (µm)	Carbonized Wood (µm)
Tangential vessel diameter	23,4 - 52,4 - 95,6	21,3 - 46,3 - 70,6
Intervessel pit diameter (horizontal)	6,1 - 9,1 - 11,6	3,5 - 5,6 - 7,9
Fibre wall thickness	4,9	1,1
Ray width	10,9 - 26,0 - 62,0	5,0 - 19,7 - 49,5
Ray height	87,9 – 312,9 – 804,2	79,7 – 261,8 - 654,9

References: Catalogue of Life; Grosser, 1977; Schweingruber, 1990; Hather, 2000; Richter and Dallwitz, 2000 onwards; Hassler, 2004 onwards; Inside Wood 2004 onwards.

Fig. 36 **Illustration of anatomical (diagnostic) features of carbonized wood of *Carpinus betulus*. TS with diffuse-porous wood (A); TS with aggregate ray (B); TLS with multiseriate rays (C); TLS with helical thickenings in vessel elements (D); RLS with heterocellular rays (E); TLS with alternate intervessel pits (F).**



Source: Thünen-Institut/ Valentina Zemke

12.6 *Aucoumea kleineana* Pierre (BURSERACEAE)

Trade names: gaboon, gabun (?), angouma, okaka (GA), angum, ongoumi, moukoumi, zonga (GQ).

DIN EN 13556-2003 code: AUKL.

CITES regulations: Listed according to annex D, is additional for the European market and to monitoring the quantitative. Conservation Status: IUCN VU (Cameroon).

Geographic distribution: Tropical West Africa **(**S-Cameroon; Equatorial Guinea; Gabon; SW-Congo [Brazzaville]).

Growth ring boundaries: Indistinct or absent.

Vessel elements: Wood diffuse-porous; vessel elements in short radial rows of 2(-3) vessels; perforation plates simple; thin-walled tyloses present.

Intervessel pits: Alternate.

Vessel-ray pits: with reduced borders to apparently simple and different to intervessel pits. Pits rounded or angular; horizontally (gash-like) or vertically (palisade).

Fibres: Septate.

Axial parenchyma: Paratracheal scanty; (4-)5(-9) cells per parenchyma strand.

Rays: Multiseriate with 1-3 cells; body ray cells procumbent with one row of upright and/or square marginal cells (heterocellular).

Storied structure: Rays sometimes irregularly storied.

Secretory structure: Not observed.

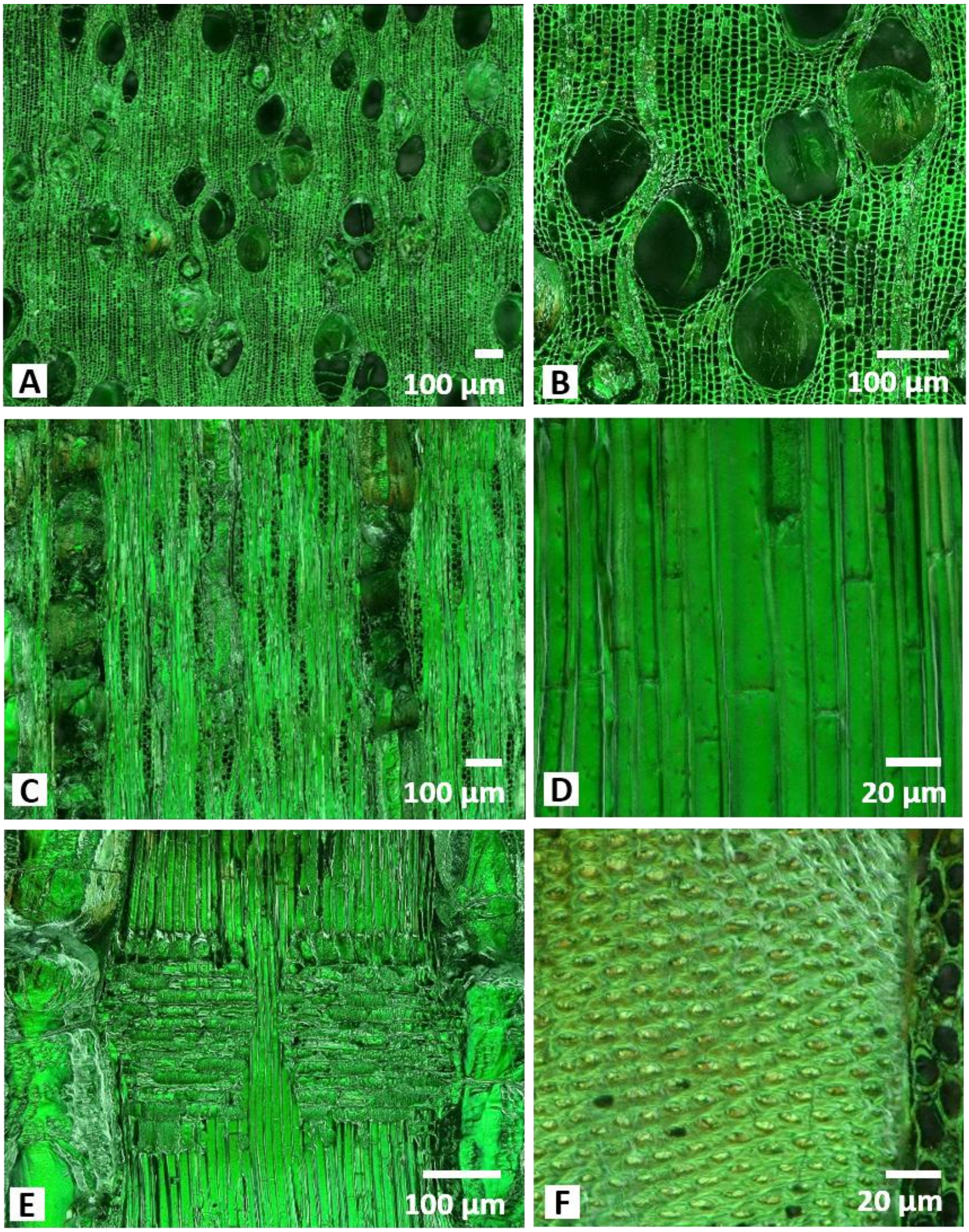
Mineral inclusions: Prismatic crystals present (infrequent), located in marginal ray cells; crystal containing cells with more than one crystal; silica grains in ray cells.

Quantitative data::

	Solid Wood (µm)	Carbonized Wood (µm)
Ø tangential vessel diameter >100	109,1 – <u>185,0</u> -265,3	105,7 - <u>150,0</u> - 199,5
Ø intervessel pit diameter (horizontal) >50	8,6 - <u>10,4</u> - 12,3	7,6 - <u>8,9</u> - 10,9
Ø tangential fibre wall thickness >50	<u>1,7</u>	<u>0,19</u>
Width of rays (µm) >100	22,7 - <u>36,5</u> -59,1	24,6 - <u>34,8</u> –-46,8
Ray heigh (µm) >100	174,2 - <u>329,2</u> – 544,4	225,3 - <u>303,3</u> – 444,4

References: Catalogue of Life; Richter and Dallwitz, 2000 onwards; Hassler, 2004 onwards; Inside Wood 2004 onwards.

Fig. 37 **Illustration of anatomical (diagnostic) features of carbonized wood of *Aucoumea klaineana*. TS with diffuse-porous wood and arranged in multiples and in radial rows of 2-3 vessel elements (A+B); TLS with multiseriate rays (C); TLS with septate fibres (D); RLS with heterocellular ray and silica bodies in ray cells (E); TLS with alternate intervessel pits (F).**



Source: Thünen-Institut/ Valentina Zemke

12.7 *Rubroshorea leprosula* Miq. P.S. Ashton & J. Heck. (DIPTEROCARPACEAE)

Trade names: meranti tembaga, tembaga, light red meranti (MY); meranti merah (ID).

DIN EN 13556-2003 code: SHLR.

CITES regulations: Not protected. Conservation Status: IUCN VU (vulnerable, Singapore).

Geographic distribution: Java; Sumatra; peninsular Malaysia (Kedah, Penang, Kelantan, Terengganu, Perak, Pahang, Selangor, Negeri Sembilan, Melaka, Johor); Singapore; Thailand; Sumatra (incl. Bangka, Belitung); Borneo; Brunei.

Growth ring boundaries: Indistinct or absent.

Vessel elements: Wood diffuse-porous; vessels elements in short radial rows of 2-3 vessels; perforation plates simple; thin-walled tyloses present.

Intervessel pits: Alternate, polygonal; vestured.

Vessel-ray pits: with distinct or with reduced borders to apparently simple and similar to intervessel pits; pits rounded and angular; horizontally (gash-like) or vertically (palisade).

Fibres: -

Axial parenchyma: Paratracheal scanty, vasicentric, aliform of the lozenge and winged type, occasionally confluent; 4-8 cells per strand.

Rays: Multiseriate, larger rays commonly 3-4 (up to 6) cells wide; body ray cells procumbent with 1-4 rows of upright and/or square marginal cells (heterocellular).

Storied structure: Axial parenchyma storied.

Secretory structure: Intercellular canals oriented axially and radially; axial canals in short to long tangential lines.

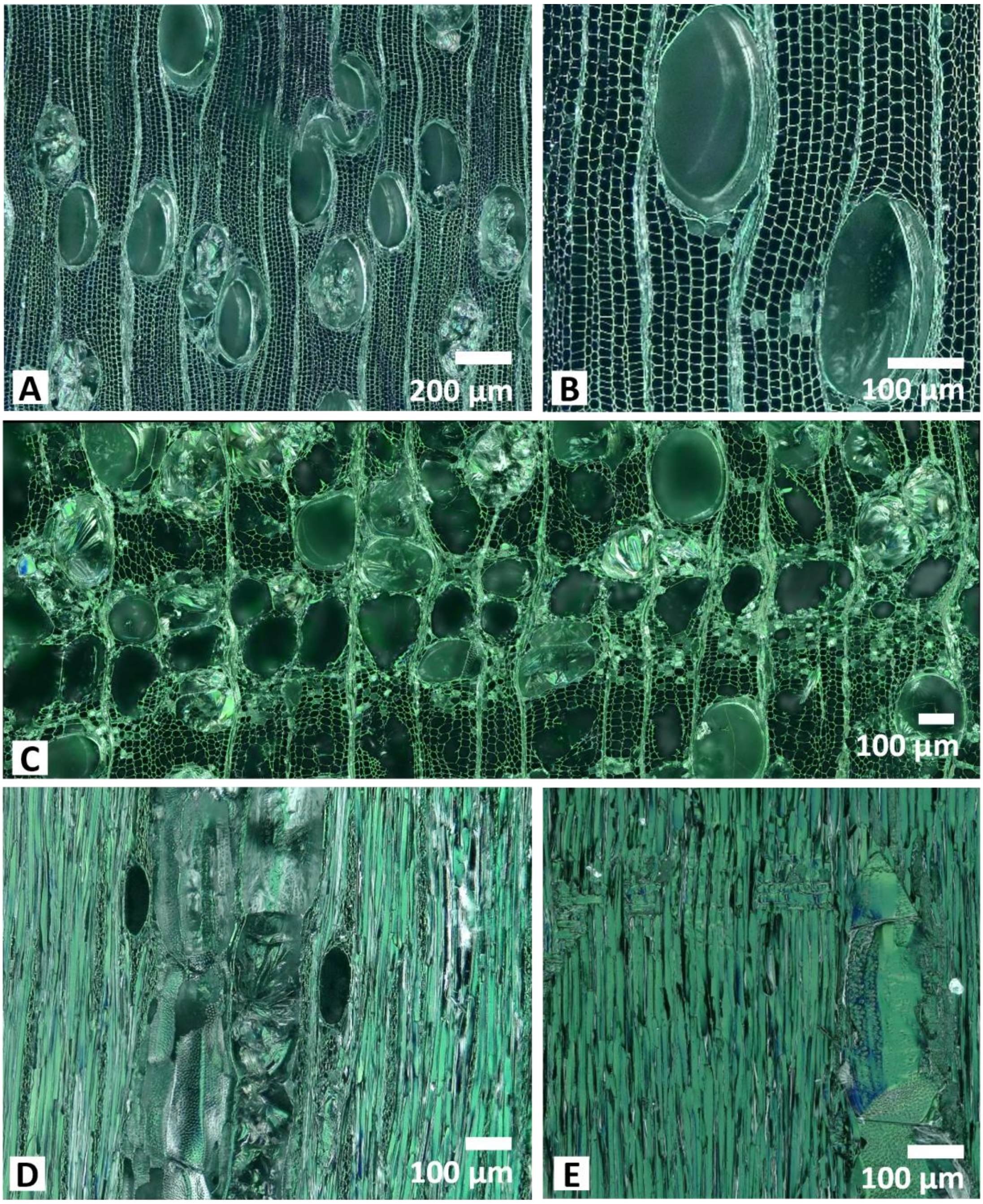
Mineral inclusions: Prismatic crystals located in non-chambered axial parenchyma cells; crystal containing cells often enlarged (idioblasts), one crystal each.

Quantitative data:

	Solid Wood (µm)	Carbonized Wood (µm)
Tangential vessel diameter	165,9 - <u>248,0</u> - 318,7	127,2 - <u>185,0</u> - 236,1
Intervessel pit diameter (horizontal)	5,9 - <u>7,3</u> - 9,7	2,9 - <u>4,1</u> - 5,3
Fibre wall thickness	<u>2,4</u>	<u>0,5</u>
Ray width	36,4 - <u>56,0</u> - 88,6	10,9 - <u>29,5</u> - 65,7
Ray height	354,1 - <u>807,8</u> - 1747,5	212,0 - <u>541,7</u> – 1130,0

References: Catalogue of Life; Richter and Dallwitz, 2000 onwards; Hassler, 2004 onwards; Inside Wood 2004 onwards.

Fig. 39 **Illustration of anatomical (diagnostic) features of carbonized wood of *Rubroshorea leprosula*. TS with diffuse-porous wood (A); TS with detail of a vessel element (B); TS with axial intercellular canals in long tangential lines (C); TLS with multiseriate rays with up to 6 cells and radial canals (D); RLS with heterocellular rays) (E).**



Source: Thünen-Institut/ Valentina Zemke

12.8 *Diospyros crassiflora* Hiern (EBENACEAE)

Trade names: African ebony (GB); afrikanisches Ebenholz (DE); ebène d'Afrique (FR, BE); ébano (PT, ES); abokpo, kanran, nyareti, osibin (NG); mevini, mavini, ndou (CM); evila (GA); ngoubou, bingo (CD).

DIN EN 13556-2003 code: DSXX.

CITES regulations: The true ebonies from Madagascar are listed to Annex II (B); but they "are easily mistaken for true ebonies from other parts of the world (currently not protected under CITES) based on macroscopic structural features" (Richter et al. 2014 onwards), Conservation Status: IUCN NT (Cameroon).

Geographic distribution*:* Gabon; Cameroon; Nigeria; Congo; Zaïre; Central African Republic; Equatorial Guinea.

Growth ring boundaries*:* Indistinct or absent.

Vessel elements*:* Wood diffuse-porous; vessels in multiples forming short radial rows of 2–3, occasionally 4 or more vessels; perforation plates simple.

Intervessel pits*:* Alternate.

Vessel-ray pits: with distinct borders, similar to intervessel pits.

Fibres*:* -

Axial parenchyma: Apotracheal diffuse-in-aggregates; in narrow bands or lines forming a reticulate pattern with the rays; paratracheal scanty, vasicentric; commonly 4, rarely up to 8 cells per strand.

Rays: Rays exclusively uniseriate; body ray cells procumbent with 1-4 rows of upright and/or square marginal cells (heterocellular).

Storied structure: Not observed.

Secretory structure: Not observed.

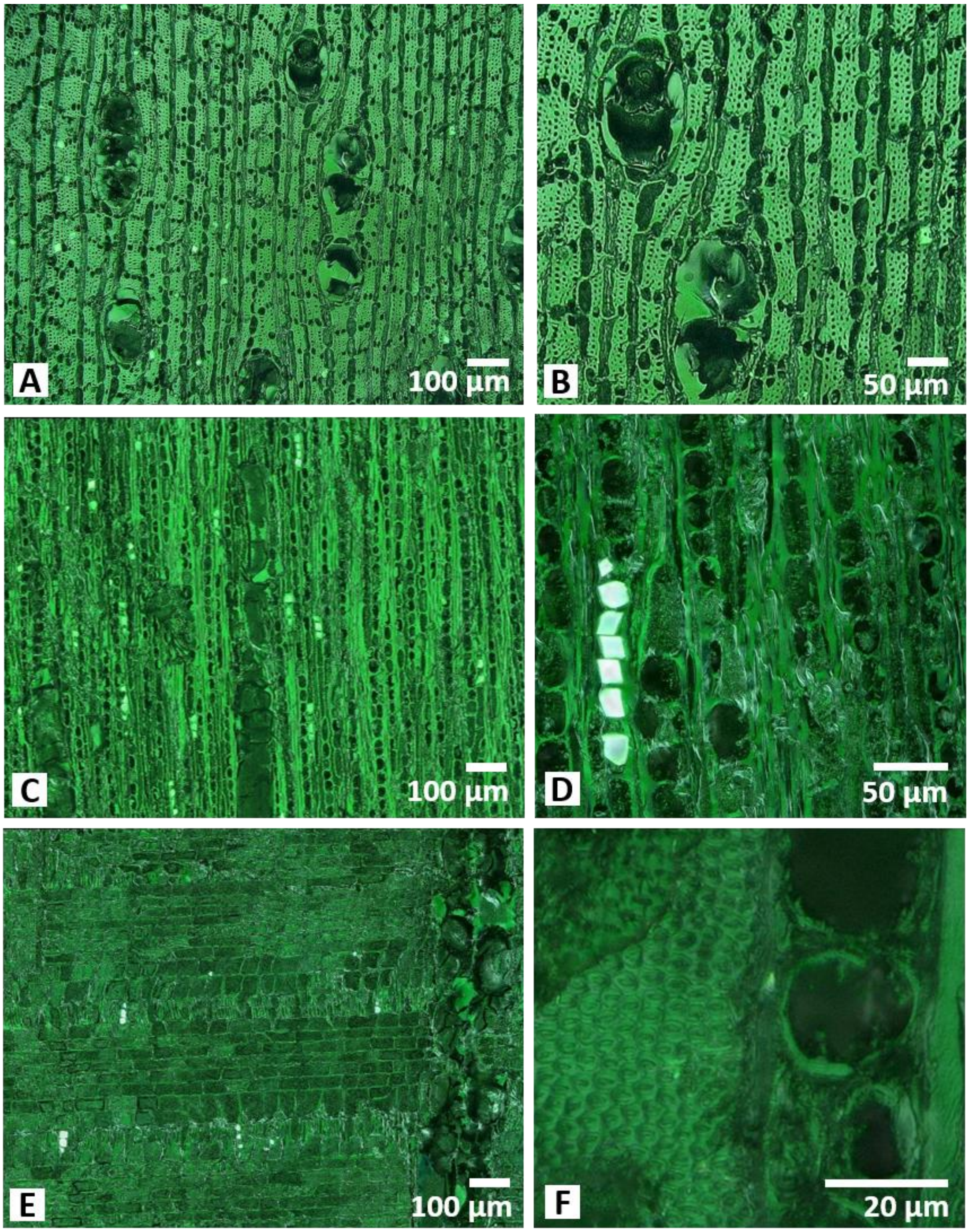
Mineral inclusions: Prismatic crystals located in chambered axial parenchyma cells, one crystal each.

Quantitative data:

	Solid Wood (µm)	Carbonized Wood (µm)
Tangential vessel diameter	68,2 - <u>117,9</u> - 169,4	50,3 - <u>96,8</u> - 139,8
Intervessel pit diameter (horizontal)	3,9 - <u>4,7</u> - 5,9	2,2 - <u>3,3</u> - 4,6
Fibre wall thickness	<u>3,9</u>	<u>1,4</u>
Ray width	13,6 - <u>22,3</u> - 34,8	16,0 - <u>19,8</u> - 24,8
Ray height	186,4 - <u>361,6</u> - 550,0	163,8 - <u>338,1</u> - 522,9

References: Catalogue of Life; Richter and Dallwitz, 2000 onwards; Hassler, 2004 onwards; Inside Wood 2004 onwards; Richter et al., 2014 onwards; WCSP 2022.

Fig. 38 **Illustration of anatomical (diagnostic) features of carbonized wood of *Diospyros crassiflora*. TS with diffuse-porous wood (A); TS with short radial rows of vessel elements and axial parenchyma diffuse-in-aggregates (B); TLS with uniseriate rays (C); TLS with crystals located in axial parenchyma cells (D); RLS with heterocellular rays (E); TLS with alternate intervessel pits (F).**



Source: Thünen-Institut/ Valentina Zemke

12.9 *Afzelia africana* Pers. (FABACEAE-CAESALPINIOIDEAE)

Trade names: Afzelia, doussié (CM, FR), apa (NG), chamfuta (MZ), lingue (CI, FR), ovala (AO), azodau (CI).

DIN EN 13556-2003 code: AFXX.

CITES regulations: All African species of the genus *Afzelia* spp. are listed to Annex II (B), indicates logs, sawn wood, veneer sheets, plywood, and transformed wood. Conservation Status: IUCN VU (Cameroon).

Geographic distribution: Benin; Central African Republic; Ivory Coast; Cameroon; Ghana; Guinea; Guinea-Bissau; Burkina Faso; Mali; Niger; Nigeria; South Sudan; Sierra Leone; Senegal; Chad; Togo; Uganda; D.R.Congo [Zaire]; Equatorial Guinea.

Growth ring boundaries: Distinct.

Vessel elements: Wood diffuse-porous; vessel elements in multiples forming short radial rows of 2-3 vessels; perforation plates simple.

Intervessel pits: Alternate, vestured.

Vessel-ray pits: with distinct borders, similar to intervessel pits.

Fibres: -

Axial parenchyma: Fine marginal bands; paratracheal aliform of the lozenge-type, sometimes confluent; apotracheal: diffuse; (2-)4 cells per parenchyma strand.

Rays: Multiseriate, 2-4 cells wide; all ray cells procumbent (homocellular).

Storied structure: Rays rarely irregularly storied.

Secretory structure: Not observed.

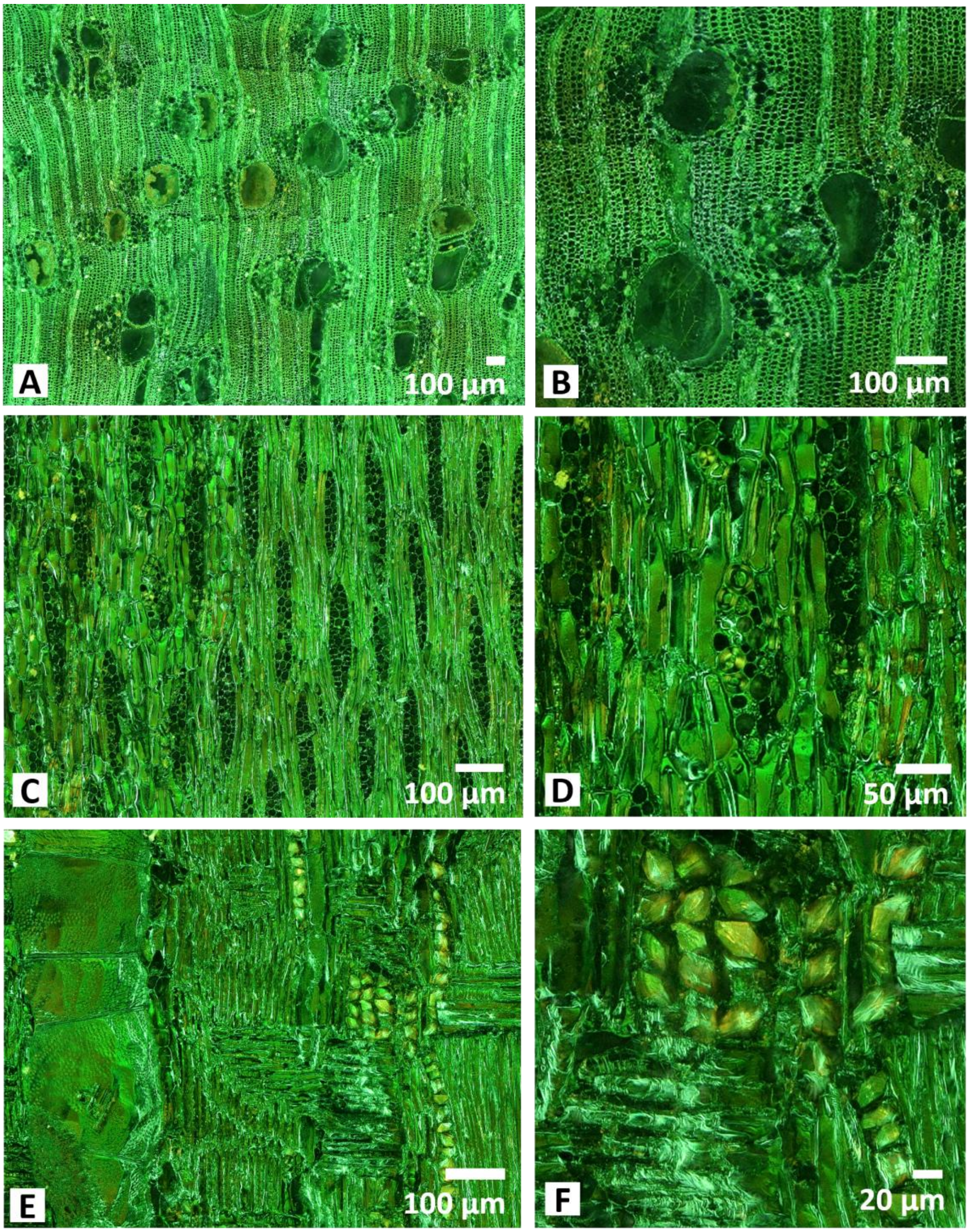
Mineral inclusions*:* Prismatic crystals located in chambered axial parenchyma cells; chambered cells with one crystal each.

Quantitative data:

	Solid Wood (µm)	Carbonized Wood (µm)
Tangential vessel diameter	109,1 - 224,6 - 332,9	69,2 - 142,1 - 252,8
Intervessel pit diameter (horizontal)	5,5 - 6,9 - 9,4	3,5 - 4,6 - 5,8
Fibre wall thickness	3,2	1,6
Ray width	28,1 - 40,8 - 61,2	25,1 - 40,7 - 59,2
Ray height	146,7 - 292,2 – 412,9	131,4 - 249,7 - 370,0

References: Catalogue of Life; PROTA4U; Höhn, 1999; Richter and Dallwitz, 2000 onwards; Hassler, 2004 onwards; Inside Wood 2004 onwards.

Fig. 40 **Illustration of anatomical (diagnostic) features of carbonized wood of *Afzelia africana*. TS with diffuse-porous wood (A); TS with aliform to confluent parenchyma (B); TLS with multiseriate rays (C); TLS with two to four cells per parenchyma strand (D); RLS with homocellular rays (E); TLS with prismatic crystals in axial parenchyma (F).**



Source: Thünen-Institut/ Valentina Zemke

12.10 *Copaifera paupera* (Herzog) Dwyer (FABACEAE-CAESALPINIOIDEAE)

Trade names: copaíba, copaúva, oleiro, óleo-de-copaíba, pau-d'oleo (BR); Diesel tree (US).

DIN EN 13556-2003 code: CFXX.

Geographic distribution: Peru; Bolivia (Cochabamba, Santa Cruz); N-Brazil.

Growth ring boundaries: Distinct.

Vessel elements: Wood diffuse-porous; vessel elements in multiples, partially forming short radial rows of up to 4 vessel elements; perforation plates simple.

Intervessel pits: Alternate, polygonal; vestured.

Vessel-ray pits: with distinct borders, similar to intervessel pits.

Fibres: -

Axial parenchyma: Axial parenchyma banded, bands more than three cells wide, seemingly marginal, including axial intercellular canals; paratracheal vasicentric and/or aliform of the lozenge type, also confluent; 4-8 eight, rarely more cells per strand.

Rays: Multiseriate, 2-3 cells wide; all cells procumbent (homocellular).

Storied structure: Not observed.

Secretory structure: Axial intercellular canals in long tangential bands.

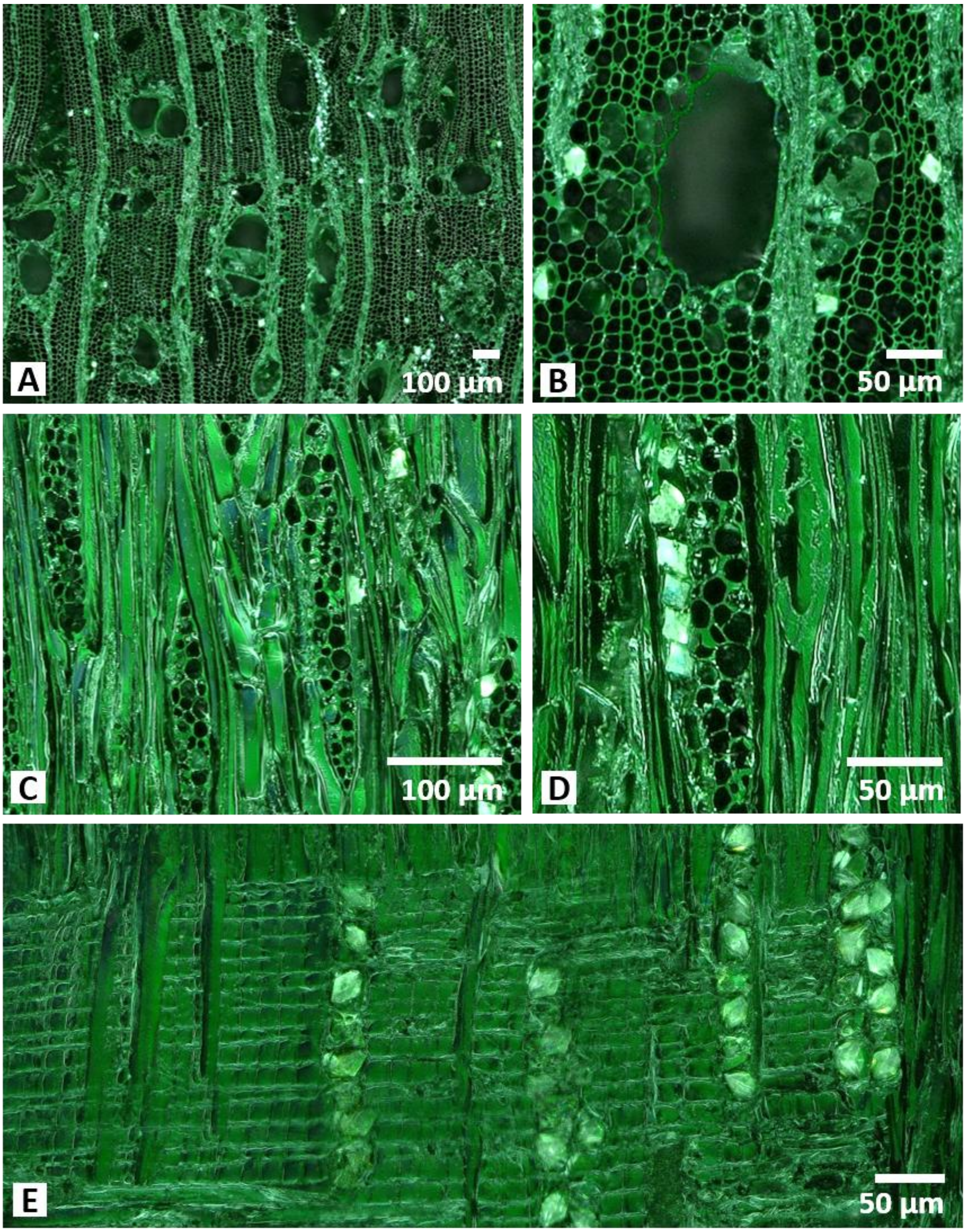
Mineral inclusions: Prismatic crystals located in chambered axial parenchyma cells, one crystal each.

Quantitative data:

	Solid Wood (µm)	Carbonized Wood (µm)
Tangential vessel diameter	102,4 - 155,7 - 209,2	74,8 - 110,9 - 166,0
Intervessel pit diameter (horizontal)	7,3 - 8,9 - 11,1	4,0 - 6,3 - 8,3
Fibre wall thickness	3,2	1,0
Ray width	22,8 - 42,9 - 66,0	14,0 - 30,7 - 47,2
Ray height	143,5 - 329,9 - 633,0	111,5 - 290,1 - 601,0

References: Catalogue of Life; Hassler, 2004 onwards; Inside Wood 2004 onwards.

Fig. 41 **Illustration of anatomical (diagnostic) features of carbonized wood of *Copaifera paupera*. TS with diffuse-porous wood (A); TS with solitary vessel element (B); TLS with multiseriate rays (C); TLS with blow-up of multiseriate ray and adjacent chambered axial parenchyma strand with prismatic crystals (D); RLS with homocellular ray and crystals in chambered axial parenchyma cells (E).**



Source: Thünen-Institut/ Valentina Zemke

12.11 *Pterocarpus angolensis* DC. (FABACEAE-FABOIDEAE)

Trade names: African teak, Transvaal teak, bloodwood (GB); muninga, mninga (TZ); girassonde (AO); mulombwa (CD); mukwa (ZW); umbila, mbila (MZ); kiaat, kajat (ZA); nkoso, lukungu nseke (CG).

DIN EN 13556-2003 code: PTAN.

CITES regulations: All African species of the genus *Pterocarpus* spp. are listed to Annex II (B), indicates logs, sawn wood, veneer sheets, plywood, and transformed wood.

Geographic distribution: Zambia; Zaire; Tanzania; Swaziland; South Africa; Namibia; Mozambique; Angola.

Growth ring boundaries: Distinct.

Vessel elements: Wood diffuse-porous; vessel elements in multiples, partially in short radial rows of 2-3 vessels; perforation plates simple; gums and other deposits in heartwood vessels.

Intervessel pits: Alternate.

Vessel-ray pits: with distinct or with reduced borders to apparently simple and similar to intervessel pits.

Fibres: -

Axial parenchyma: Fine marginal bands; paratracheal aliform with winged type, also confluent; apotracheal: diffuse-in-aggregates; 2 cells per parenchyma strand.

Rays: Uniseriate and multiseriate (2 cells wide); all cells procumbent (homocellular).

Storied structure: Rays, axial parenchyma, vessel elements and fibres storied.

Secretory structure: Not observed.

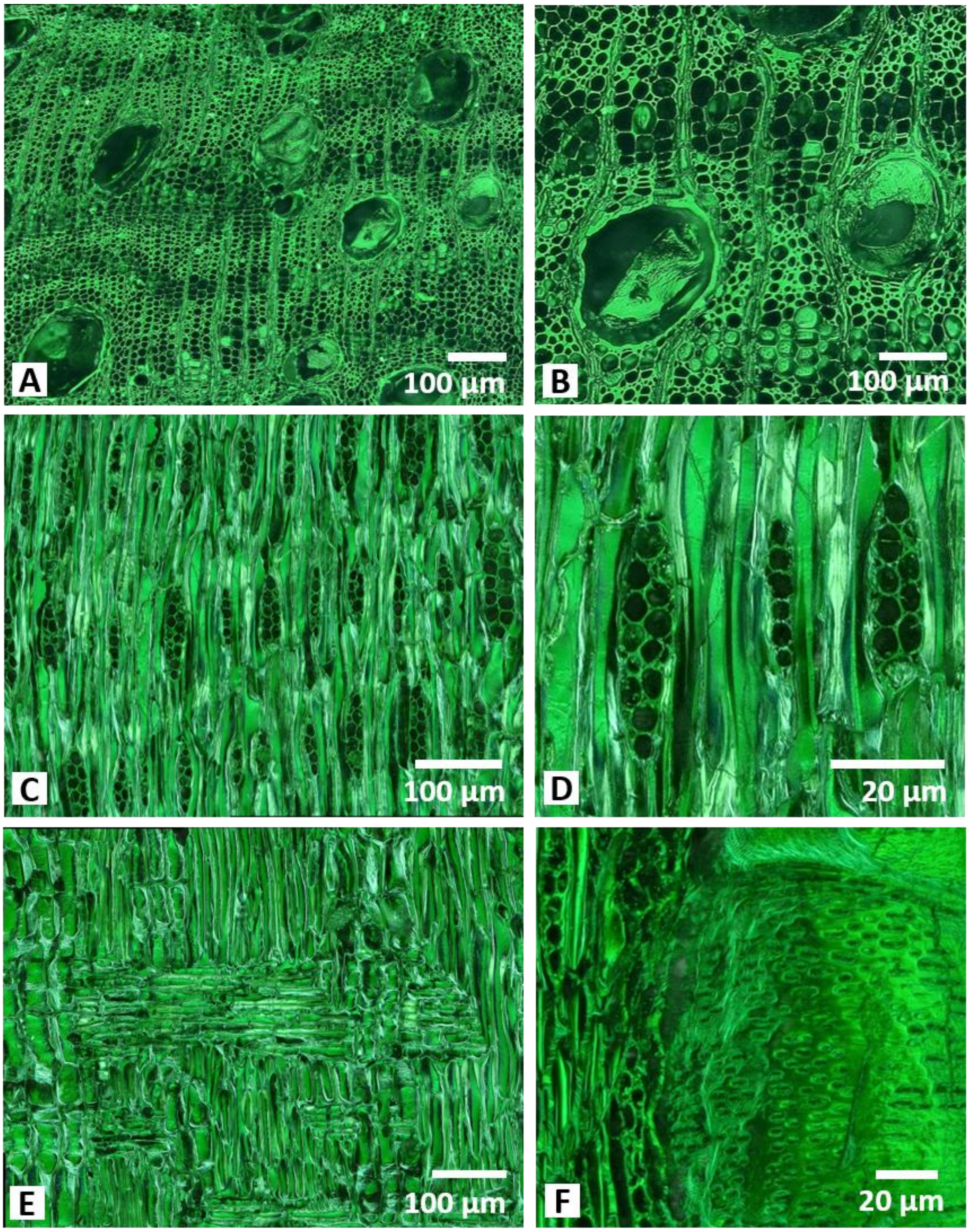
Mineral inclusions: Prismatic crystals located in chambered axial parenchyma cells; one crystal each.

Quantitative data:

	Solid Wood (µm)	Carbonized Wood (µm)
Tangential vessel diameter	98,1 - 281,0 - 459,5	76,2 - 263,2 - 450,1
Intervessel pit diameter (horizontal)	6,5 - 8,2 - 11,1	4,3 - 6,2 - 7,7
Fibre wall thickness	3,7	1,3
Ray width	14,4 - 28,6 - 47,8	7,9 - 22,3 - 34,2
Ray height	73,6 - 131,7 - 181,0	70,8 - 116,3 -150,8

References: Catalogue of Life; Richter and Dallwitz, 2000 onwards; Inside Wood 2004 onwards; Takawira-Nyenya, 2005.

Fig. 42 **Illustration of anatomical (diagnostic) features of carbonized wood of *Pterocarpus angolensis*. TS with diffuse porous wood (A); TS with confluent parenchyma (B); TLS with uniseriate and biseriate rays (C+D); RLS with homocellular rays (E); TLS with alternate intervessel pits (F).**



Source: Thünen-Institut/ Valentina Zemke

12.12 *Robinia pseudoacacia* L. (FABACEAE-FABOIDEAE)

Trade names: robinier (FR); false acacia (GB); black locust, yellow locust (US); Salkym alb (MD); robinia (NL, IT); akat (CZ); Robinia-akacia (SE); bagrem, robinija (CS); salcam (RO); akacja biala (PL); fehér akác (HU); Falsche Akazie (DE); Belaya Akatziya, Robinia Lozhno-akacia, Lzheakatziya (RU).

DIN EN 13556-2003 code: ROPS.

CITES regulations: not protected.

Geographic distribution*:* Eastern North America (USA, Canada), frequently cultivated in eastern Europe and other regions of temperate climate.

Growth ring boundaries: Distinct.

Vessel elements: Wood ring-porous; ring of earlywood vessels multiseriate; vessel elements partially in multiples of short radial rows and clusters of 2-3 vessels (in early and latewood); perforation plates simple; helical thickenings throughout narrower vessel elements; abundant thin-walled tyloses.

Intervessel pits: Alternate, vestured.

Vessel-ray pits: with reduced borders to apparently simple; pits rounded or angular.

Fibres: -

Axial parenchyma: Broad marginal bands partially enclosing the first formed earlywood vessels; in latewood paratracheal scanty, vasicentric and aliform of the lozenge type and confluent; apotracheal: diffuse-in-aggregates; fusiform and as strands of 2-4 cells.

Rays: Multiseriate, commonly 1-3 cells, larger rays up to 6 cells wide; all ray cells procumbent (homocellular).

Storied structure: Axial parenchyma and/or vessel elements.

Secretory structure: Not observed.

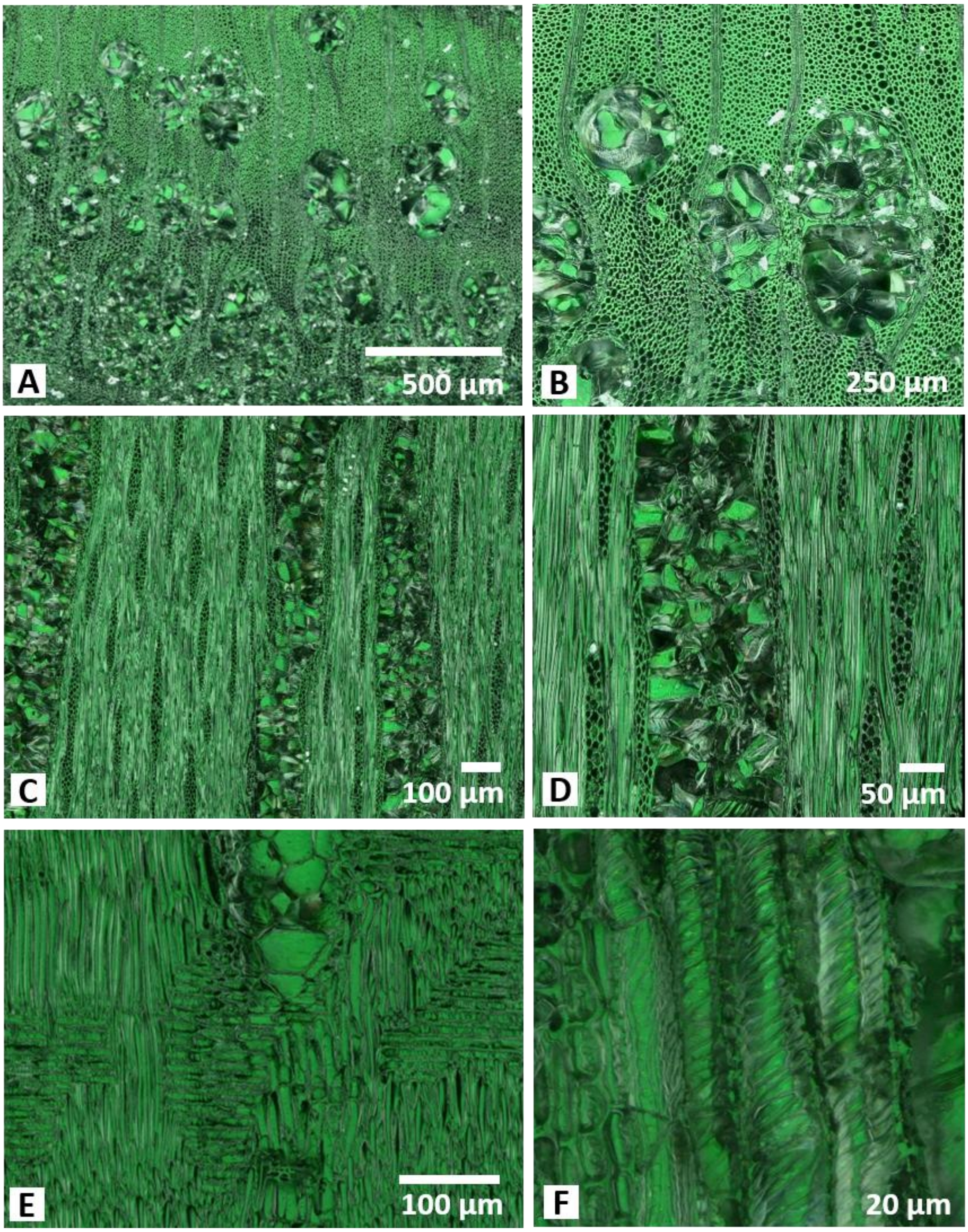
Mineral inclusions: Prismatic crystals located in procumbent ray cells and in chambered axial parenchyma cells, one crystal each.

Quantitative data:

	Solid Wood (µm)	Carbonized Wood (µm)
Tangential vessel diameter	100,4 - 186,1 - 345,5	79,1 - 183,2 - 290,5
Intervessel pit diameter (horizontal)	7,3 - 8,9 - 11,4	5,1 - 8,7 -11,4
Fibre wall thickness	3,8	1,2
Ray width	21,6 - 48,7 - 75,0	19,6 - 37,4 - 75,4
Ray height	134,6 - 339,0 - 708,1	108,3 - 286,9 - 592,2

References: Catalogue of Life; Grosser, 1977; Richter and Dallwitz, 2000 onwards; Hassler, 2004; onwards Inside Wood 2004 onwards; Roskov et al., 2014.

Fig. 43 **Illustration of anatomical (diagnostic) features of carbonized wood of *Robinia pseudoacacia*. TS with ring porous wood (A); TS with tyloses in vessel elements (B); TLS with large multiseriate rays (C); TLS with tyloses in vessels (D); RLS with homocellular rays (E); RLS with helical thickenings in narrow vessel elements (F).**



Source: Thünen-Institut/ Valentina Zemke

12.13 *Acacia dealbata* Link (FABACEAE-MIMOSOIDEAE)

Trade names: Silver Wattle (EN); Silberakazie (DE)

DIN EN 13556-2003 code: -

CITES regulations: not protected.

Geographic distribution: Australia (N-New South Wales to W-Victoria, Tasmania); cultivated worldwide.

Growth ring boundaries: Distinct or indistinct/absent, depending on growth conditions.

Vessel elements: Wood diffuse-porous; some vessel elements in radial multiples of 2-3 vessels; perforation plates simple.

Intervessel pits: Alternate, vestured.

Vessel-ray pits: with distinct borders, similar to intervessel pits.

Fibres: -

Axial parenchyma: Paratracheal vasicentric; 2-4 cells per parenchyma strand.

Rays: Multiseriate (1-)3 cells wide; all ray cells procumbent (homocellular).

Storied structure: Not observed.

Secretory structure: Not observed.

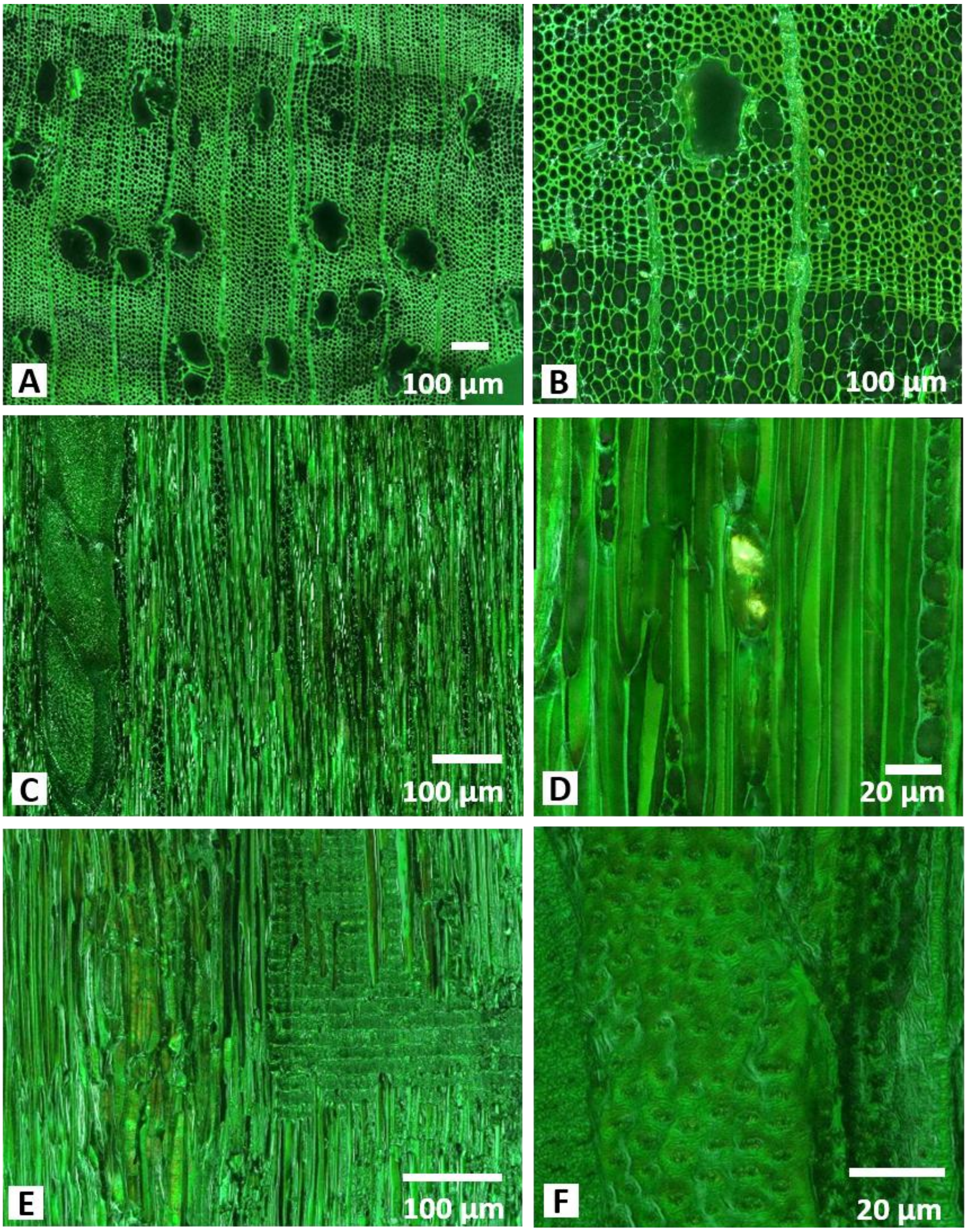
Mineral inclusions: Prismatic crystals located in chambered axial parenchyma cells and in fibres; chambered cells with one crystal each.

Quantitative data:

	Solid Wood (µm)	Carbonized Wood (µm)
Tangential vessel diameter	45,7 - <u>116,8</u> - 174,9	36,8 - <u>70,3</u> - 117,8
Intervessel pit diameter (horizontal)	5,9 - <u>7,9</u> - 9,6	3,4 - <u>5,1</u> - 6,5
Fibre wall thickness	<u>1,5</u>	<u>0,9</u>
Ray width	9,1 - <u>19,0</u> - 29,6	4,8 - <u>11,6</u> - 26,9
Ray height	102,7 - <u>245,7</u> - 563,6	78,5 - <u>238,4</u> - 555,8

References: Catalogue of Life; Hassler, 2004 onwards; Inside Wood 2004 onwards; Evans et al., 2006; Whinder et al., 2013.

Fig. 44 **Illustration of anatomical (diagnostic) features of carbonized wood of *Acacia dealbata*. TS with diffuse-porous wood (A); TS with vasicentric parenchyma (B); TLS with multiseriate rays of 1-3 cells (C); TLS with crystals in axial parenchyma cells (D); RLS with homocellular cells (E); TLS with alternate intervessel pits and vestured (F).**



Source: Thünen-Institut/ Valentina Zemke

12.14 *Acacia melanoxylon* R.Br. (FABACEAE-MIMOSOIDEAE)

Trade names: Blackwood (EN); mudgerabah (AU); Acacia à bois noir (FR); pão das cabras (PT)

DIN EN 13556-2003 code: -

CITES regulations: Not protected.

Geographic distribution: Australia (South Australia, Queensland, New South Wales, Victoria, Tasmania; cultivated elsewhere.

Growth ring boundaries: Distinct.

Vessel elements: Wood diffuse-porous; some vessel elements in short radial of 2-3 vessels; perforation plates simple; gums and other deposits in heartwood vessels

Intervessel pits: Alternate, vestured.

Vessel-ray pits: with distinct borders, similar to intervessel pits.

Fibres: -

Axial parenchyma: Paratracheal: vasicentric and/or aliform; 3-4 cells per parenchyma strand.

Rays: Multiseriate, 1-3 cells wide; all ray cells procumbent (homocellular).

Storied structure: Not observed.

Secretory structure: not observed.

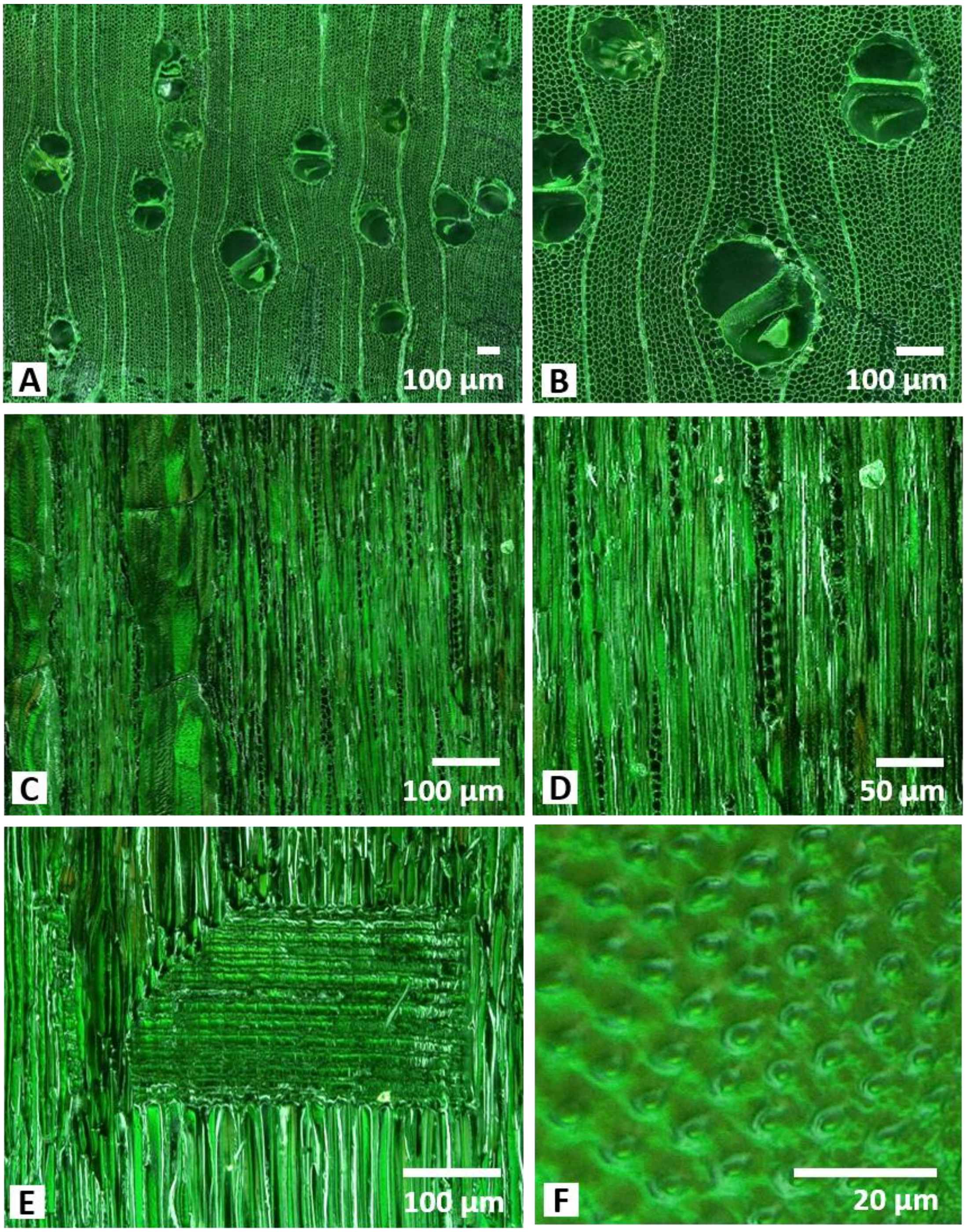
Mineral inclusions*:* Not observed.

Quantitative data:

	Solid Wood (µm)	Carbonized Wood (µm)
Tangential vessel diameter	72,7 - 160,6 - 236,5	58,9 - 127,5 - 200,3
Intervessel pit diameter (horizontal)	5,8 - 7,8 - 10,0	3,7 - 4,9 - 6,2
Fibre wall thickness	1,7	1,5
Ray width	9,1 - 17,1 - 31,8	5,6 - 12,1 - 30,7
Ray height	75,1 - 235,8 - 515,9	61,3 - 228,3 - 501,9

References: Catalogue of Life; Kribs, 1968; Olvera et al., 1980; Quirk et al., 1983; Hassler, 2004 onwards; Inside Wood 2004 onwards; Evans et al., 2006; Whinder et al., 2013; Tian et al., 2021.

Fig. 45 **Illustration of anatomical (diagnostic) features of carbonized wood of *Acacia melanoxylon*. TS with diffuse-porous wood (A+B); TS with vasicentric parenchyma (B); TLS with multiseriate rays of 1-3-seriate cells (C+D); RLS with procumbent cells (E); TLS with alternate intervessel pits and vestured (F).**



Source: Thünen-Institut/ Valentina Zemke

12.15 *Cedrelinga cateniformis* (Ducke) Ducke (FABACEAE-MIMOSOIDEAE)

Trade names: Iacaica, paricá, yacayac (BR); chuncho, mara macho, seique, tsaik (EC), achapo (CO), huayra caspi (PE), don cede (GF).

DIN EN 13556-2003 code: CGCT.

CITES regulations: not protected.

Geographic distribution: Venezuela (Amazonas, Bolívar); N-Brazil (Pará, Amazonas, Acre); WC-Brazil (Mato Grosso do Sul); Peru; Ecuador; Surinam; French Guiana; Colombia (Amazonas, Caquetá, Putumayo, Vaupés, Vichada); Bolivia (Beni, La Paz, Pando, Santa Cruz).

Growth ring boundaries: Indistinct or absent.

Vessel elements: Wood diffuse-porous; vessel elements in multiples, some in short radial rows of 2-3 vessels; perforation plates simple.

Intervessel pits: Alternate, vestured.

Vessel-ray pits: with distinct borders, similar to intervessel pits.

Fibres: -

Axial parenchyma: Apotracheal diffuse (chambered cells without any contents) and diffuse-in-aggregates; paratracheal vasicentric and/or aliform lozenge-type and confluent.

Rays: Multiseriate, 1-2 cells wide; all ray cells procumbent (homocellular).

Storied structure: Rays (mostly) irregular storied.

Secretory structure: Not observed.

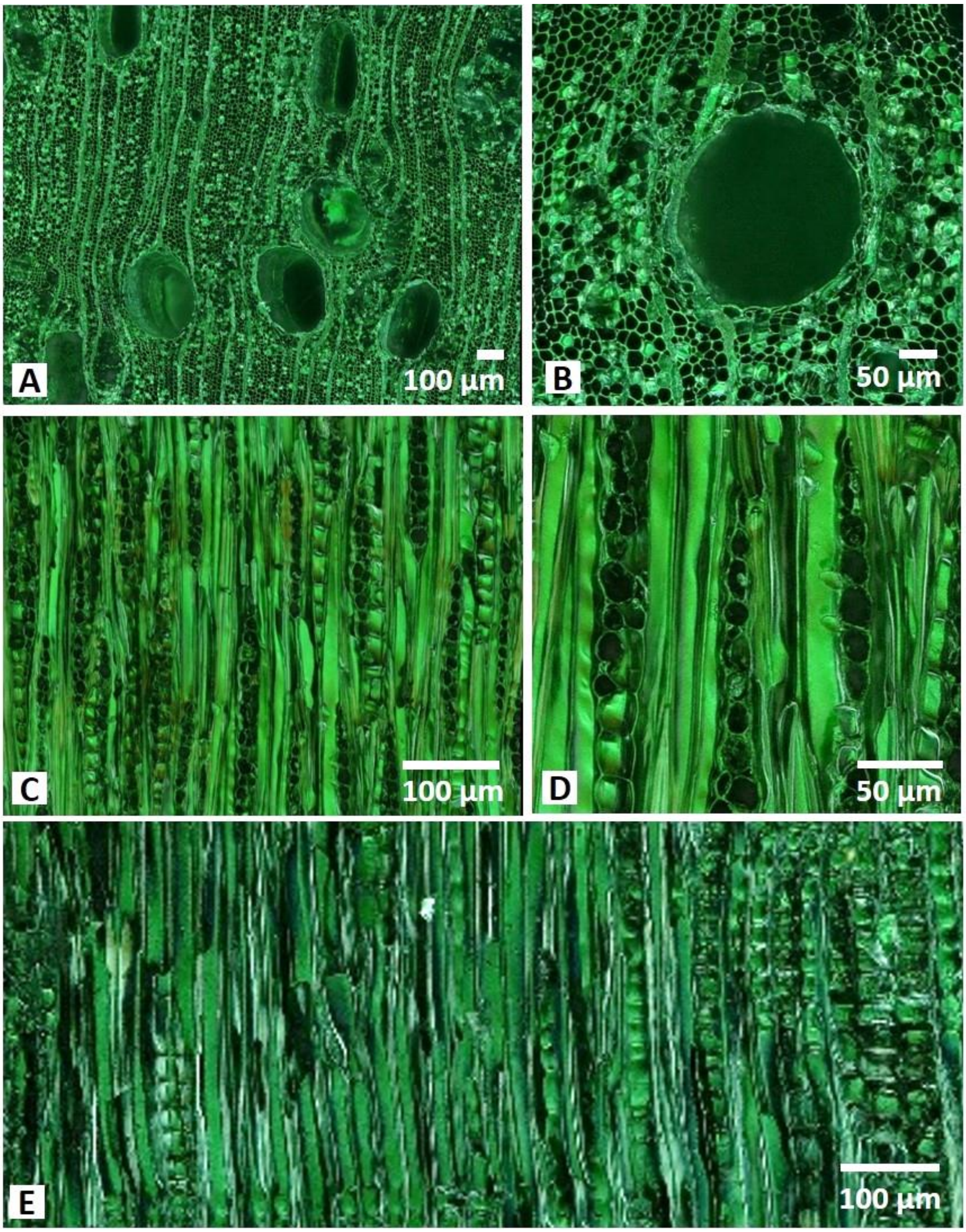
Mineral inclusions: Not observed.

Quantitative data:

	Solid Wood (µm)	Carbonized Wood (µm)
Tangential vessel diameter	100,4 - 244,1 - 323,2	62,6 - 198,9 - 315,5
Intervessel pit diameter (horizontal)	4,5 - 6,4 - 9,1	4,7 - 6,2 - 7,4
Fibre wall thickness	3,1	1,2
Ray width	10,9 - 18,3 - 32,5	7,5 - 14,2 - 29,7
Ray height	89,3 - 192,3 - 569,7	62,1 – 142,7 - 350

References: Catalogue of Life; Richter and Dallwitz, 2000 onwards; Hassler, 2004 onwards; Inside Wood 2004 onwards.

Fig. 46 **Illustration of anatomical (diagnostic) features of carbonized wood of *Cedrelinga cateniformis*. TS with diffuse-porous wood and vessel elements in radial multiples (A); TS with solitary vessel and paratracheal vasicentric axial parenchyma (B); TLS with uniseriate and multiseriate rays (C+D); RLS with homocellular rays (E).**



Source: Thünen-Institut/ Valentina Zemke

12.16 *Dichrostachys cinerea* (L.) Wight & Arn. (FABACEAE-MIMOSOIDEAE)

Common names: Acacia Saint Dominique (FR); Chinese lantern, sickle bush, Kalahari christmas tree, bell mimosa (GB,ZA); aroma (NA); ndebele (ZA); marabú (CU); mpangara (ZW); Sichelbusch, Farbkätzchenstrauch (DE).

DIN EN 13556-2003 code: -

CITES regulations: not protected.

Geographic distribution: Zimbabwe; Zambia; Zaire; Yemen; United States; Uganda; Togo; Thailand; Tanzania; Swaziland; Sumatera; Sudan; Sri Lanka; South Africa; Somalia; Sierra Leone; Senegal; Saudi Arabia; Rwanda; Reunion; Pakistan; Nigeria; Niger; Namibia; Myanmar; Mozambique; Mauritius; Martinique; Mali; Malawi; Madagascar; Liberia; Lesser Sunda Is; Kenya; Java; Indonesia; India; Guinea Bissau; Guinea; Guadeloupe; Ghana; Gambia The; Ethiopia; Egypt; East Timor; Cuba; Comoro Is; China; Chad; Central African Rep.; Cape Verde; Cameroon; Burundi; Botswana; Benin; Australia; Angola.

Growth ring boundaries: Distinct or indistinct or absent.

Vessel elements: Wood diffuse-porous; perforation plates simple; gums or other deposits in hardwood vessels.

Intervessel pits: Alternate, vestured.

Vessel-ray pits: with distinct borders, similar to intervessel pits.

Fibres: -

Axial parenchyma: Paratracheal vasicentric and/or aliform of the lozenge type and/or unilateral; occasionally confluent; 2-4 cells per parenchyma strand.

Rays: Multiseriate, 2-5 cells wide; all ray cells procumbent (homocellular).

Storied structure: Not observed.

Secretory structure: Not observed.

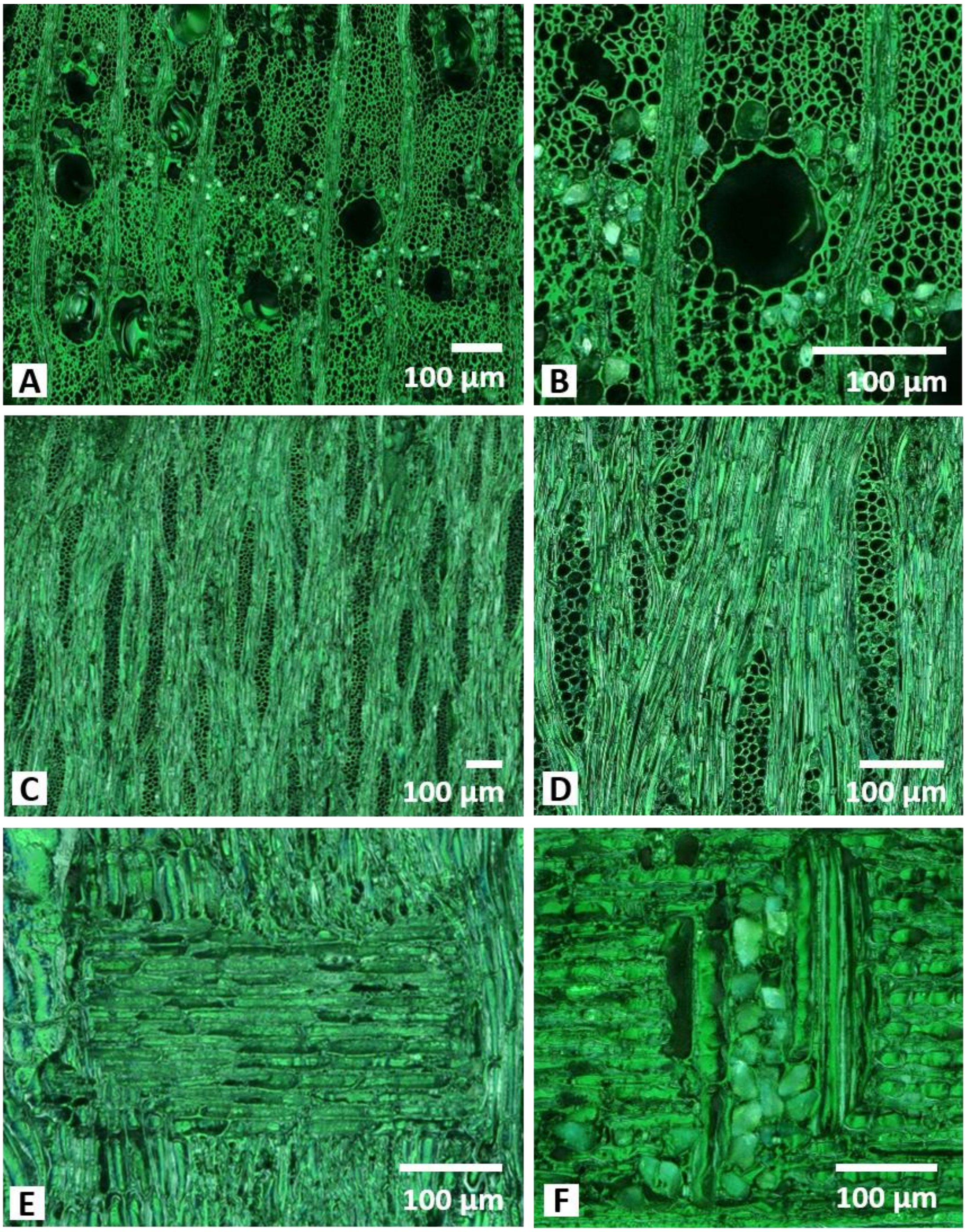
Mineral inclusions: Prismatic crystals located in chambered axial parenchyma cells, one crystal each.

Quantitative data:

	Solid Wood (µm)	Carbonized Wood (µm)
Tangential vessel diameter	79,6 - 138,6 - 211,4	58,9 - 110,9 - 196,6
Intervessel pit diameter (horizontal)	5,0 - 6,6 - 8,4	2,7 - 4,5 - 6,8
Fibre wall thickness	5,8	1,2
Ray width	30,3 - 48,2 - 68,5	32,2 - 45,6 - 68,0
Ray height	125,7 - 384,0 - 822,8	86,2 – 369,6 – 677,3

References: Catalogue of Life; Sosef et al., 1998; Hassler, 2004 onwards; Inside Wood 2004 onwards; Evans et al., 2006; Roskov et al., 2014.

Fig. 47 **Illustration of anatomical (diagnostic) features of carbonized wood of *Dichrostachys cinerea*. TS with diffuse-porous wood and aliform parenchyma of the lozenge-type and confluent(A+B); TLS with multiseriate rays (C+D); RLS with homocellular ray (E); TLS with prismatic crystals, located in chambered axial parenchyma cells (F).**



Source: Thünen-Institut/ Valentina Zemke

12.17 *Senegalia chundra* (Roxb. Ex Rottler) Maslin (FABACEAE-MIMOSOIDEAE)

Synonyms: Acacia catechu Willd., Acacia chundra (Roxb. ex Rottler) Willd., Acacia suma (Roxb.) Buch.-Ham. ex Wall., Acacia sundra (Roxb.) DC., Mimosa chundra Roxb. ex Rottler, Mimosa sundra Roxb.

Trade names: Cutch, kath, wattle.

DIN EN 13556-2003 code: -

CITES regulations: Not protected.

Geographic distribution: India (Andhra Pradesh, Goa, Gujarat, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Orissa, Pondicherry, Rajasthan, Tamil Nadu, West Bengal); Myanmar; Sri Lanka.

Growth ring boundaries: Distinct.

Vessel elements: Wood diffuse-porous; solitary; perforation plates simple; gums and other deposits in heartwood vessels.

Intervessel pits: Alternate (polygonal), vestured.

Vessel-ray pits: with distinct borders, similar to intervessel pits.

Fibres: -

Axial parenchyma: Marginal bands; paratracheal vasicentric, aliform of the lozenge type, confluent; 4-5(-8) cells per parenchyma strand.

Rays: Multiseriate, commonly 3-5, larger rays up to 10 cells wide; all ray cells procumbent (homocellular).

Storied structure: Not observed.

Secretory structure: Not observed.

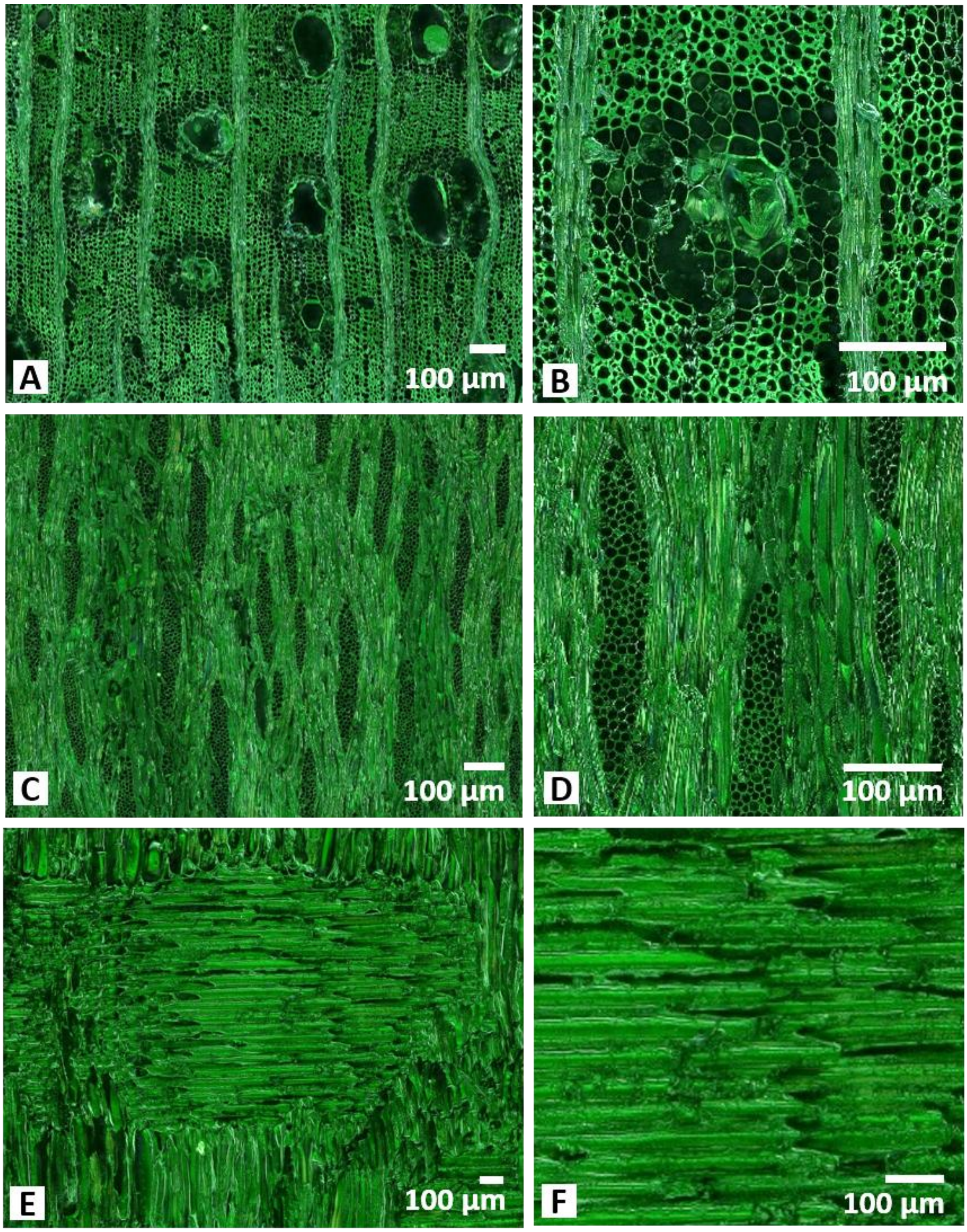
Mineral inclusions: Prismatic crystals located in procumbent ray cells and in chambered axial parenchyma cells, one crystal each.

Quantitative data:

	Solid Wood (µm)	Carbonized Wood (µm)
Tangential vessel diameter	95,9 - <u>176,5</u> - 304,7	59,0 - <u>120,0</u> - 187,7
Intervessel pit diameter (horizontal)	4,5 - <u>6,1</u> - 7,9	4,0 - <u>5,4</u> - 7,3
Fibre wall thickness	<u>3,6</u>	<u>1,2</u>
Ray width	22,7 - <u>61,5</u> - 86,5	18,0 - <u>43,4</u> - 63,2
Ray height	162,7 - <u>356,5</u> - 654,1	103,3 - <u>279,7</u> - 640,0

References: Catalogue of Life; Hassler 2004 onwards.

Fig. 48 **Illustration of anatomical (diagnostic) features of carbonized wood of *Senegalia chundra*. TS with diffuse-porous wood (A); TS with aliform parenchyma of the lozenge-type to confluent (B); TLS with multiseriate rays with up to 10 cells (C-D); RLS with homocellular rays (E+F).**



Source: Thünen-Institut/ Valentina Zemke

12.18 *Vachellia nilotica* (L.) P.J.H. Hurter & Mabb. (FABACEAE-MIMOSOIDEAE)

Synonyms: Acacia arabica var. nilotica (L.) Benth.; Acacia nilotica (L.) Delile

Trade names: Babul acacia, Scented-pop acacia (US).

DIN EN 13556-2003 code: -

CITES regulations: Not protected.

Geographic distribution: Africa, Asia, Caribbean, Central America, North America, South America, Indian Ocean, Indian subcontinent, Australia.

Growth ring boundaries: Indistinct or absent.

Vessel elements: Wood diffuse-porous; perforation plates simple; gums and other deposits in heartwood vessels

Intervessel pits: Alternate (polygonal), vestured.

Vessel-ray pits: with distinct borders, similar to intervessel pits.

Fibres: -

Axial parenchyma: Fine marginal bands; paratracheal vasicentric, aliform of the lozenge type, also confluent; 2-4 cells per strand.

Rays: Multiseriate, commonly 3-4, larger rays up to 10 cells wide; all ray cells procumbent (homocellular).

Storied structure: Not observed.

Secretory structure: Not observed.

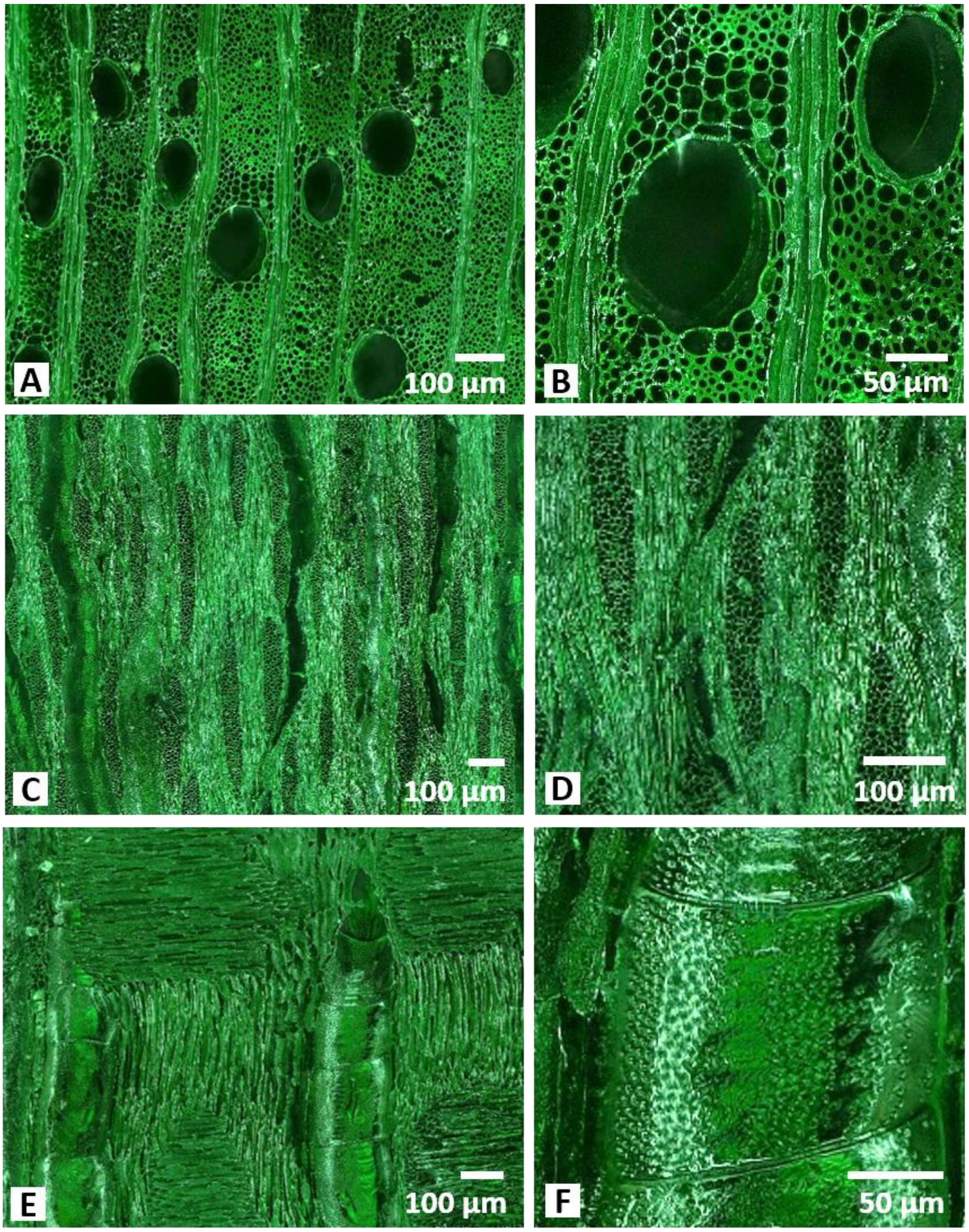
Mineral inclusions: Prismatic crystals located in chambered axial parenchyma cells, one crystal each.

Quantitative data:

	Solid Wood (µm)	Carbonized Wood (µm)
Tangential vessel diameter	75,1 - 163,4 - 235,7	59,9 - 124,5 - 219,8
Intervessel pit diameter (horizontal)	5,7 - 7,4 - 8,6	2,4 - 4,3 - 5,3
Fibre wall thickness	3,1	1,2
Ray width	31,8 - 61,7 - 100,0	33,7 - 57,9 - 83,9
Ray height	192,3 - 506,3 - 1033,3	161,7 - 422,4 - 797,3

References: Catalogue of Life; Pearson and Brown, 1932; Kribs, 1968; Inside Wood 2004 onwards; Fagg et al., 2005; Evans et al., 2006.

Fig. 49 **Illustration of anatomical (diagnostic) features of carbonized wood of *Vachellia nilotica*. TS with diffuse porous wood (A); TS with aliform to confluent parenchyma (B); TLS with multiseriate rays (C+D); RLS with homocellular ray cells (E); RLS with alternate intervessel pits (F).**



Source: Thünen-Institut/ Valentina Zemke

12.19 *Fagus sylvatica* L. (FAGACEAE)

Trade names: European beech (GB), hêtre, fayard (FR), faggio (IT), beuken (NL), kaym (TR), rödbok (SE), buk (CZ, PL, RO), bökk (HU), Rotbuche, gemeine Buche (DE).

DIN EN 13556-2003 code: FASY.

CITES regulations: Not protected.

Geographic distribution: Albania; Austria; Belgium; Luxembourg; England; Channel Isl. [I]; Bulgaria; Corse; Czech Republic; Slovakia; Denmark; France; Germany; Greece; Switzerland; Liechtenstein; Netherlands; Spain; Hungary; Italy; Slovenia; Croatia; Serbia and Kosovo; Montenegro; Bosnia and Hercegovina; Norway; Poland; Romania; W-European Russia; S-European Russia; Ukraine; Crimea; Belarus [I]; Estonia [I]; Sicily; Sweden; Ireland [I]; Java [I]; European Turkey; Haiti [I]; USA [I] (Massachusetts [I], Maryland [I], Maine [I], New York [I], Ohio [I], Rhode Island [I], Utah [I]); Canada [I] (Ontario [I]).

Geographic distribution: Albania; Austria; Belgium; Luxembourg; England; Channel Isl. [I]; Bulgaria; Corse; Czech Republic; Slovakia; Denmark; France; Germany; Greece; Switzerland; Liechtenstein; Netherlands; Spain; Hungary; Italy; Slovenia; Croatia; Serbia and Kosovo; Montenegro; Bosnia-Herzegovina; Norway; Poland; Romania; W-European Russia; S-European Russia; Ukraine; Crimea; cultivated elsewhere in regions of temperate climate.

Growth ring boundaries: Distinct.

Vessel elements: Wood semi-ring-porous to diffuse-porous; vessels in multiples, in clusters and in short radial rows of 2-3 elements; perforation plates simple, in latewood vessels also scalariform with 8 to 20 bars.

Intervessel pits: Opposite, scalariform (rare).

Vessel-ray pits: with much reduced borders to apparently simple; pits rounded or angular. Pits extended horizontally (gash-like) and vertically (palisade).

Axial parenchyma: Paratracheal scanty and apotracheal diffuse; 4-8 cells per parenchyma strand.

Rays: Rays of two distinct sizes, small rays 2-5 cells, large rays 10 or more cells wide; large rays distended at the growth ring boundary; all ray cells procumbent (homocellular).

Storied structure: Not observed.

Secretory structure: Not observed.

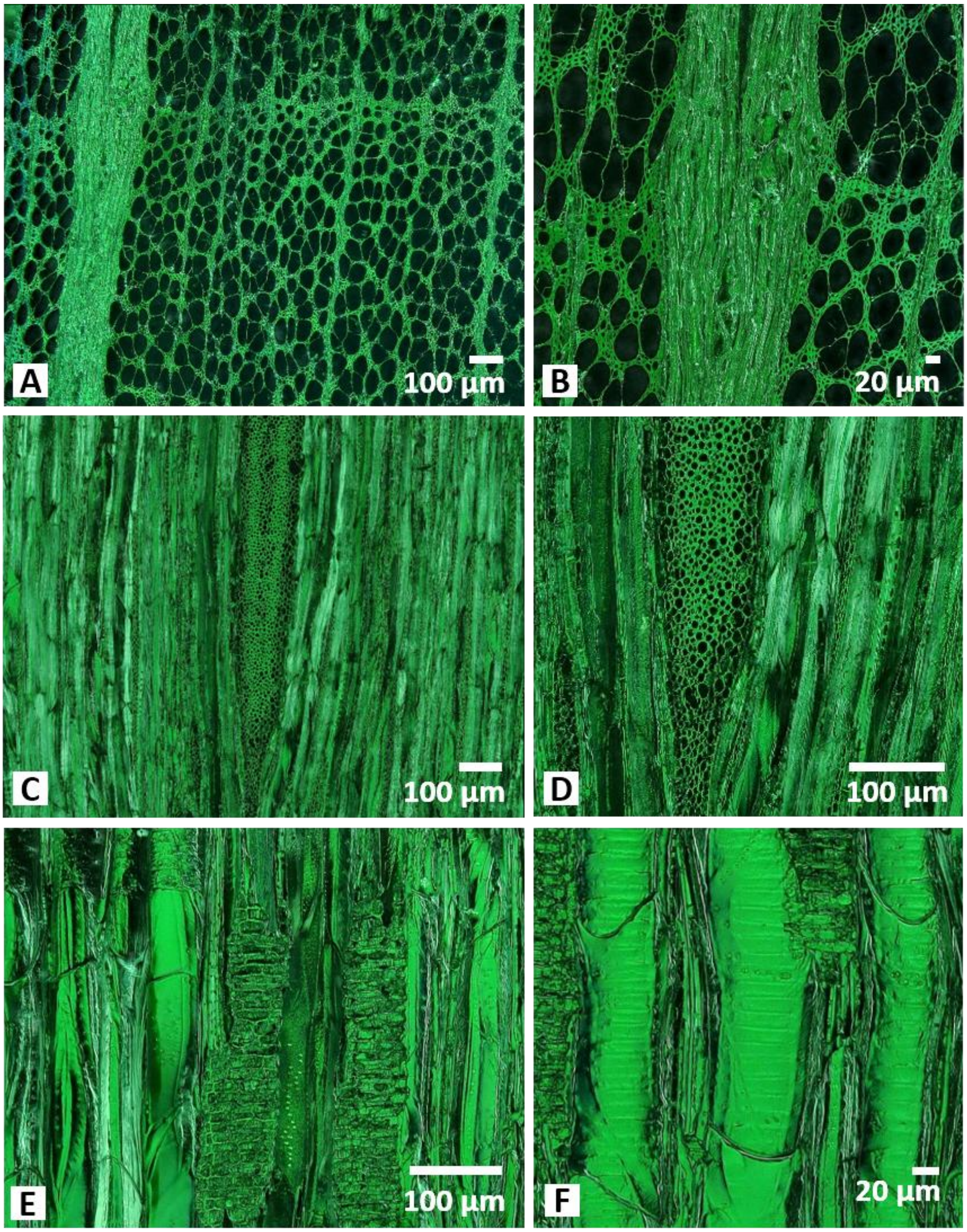
Mineral inclusions: Prismatic crystals in procumbent ray cells (very rarely).

Quantitative data:

	Solid Wood (µm)	Carbonized Wood (µm)
Tangential vessel diameter	31,9 - 56,5 - 79,2	25,4 - 49,0 - 80,3
Intervessel pit diameter (horizontal)	5,5 - 6,9 - 8,6	3,3 - 5,6 - 9,3
Fibre wall thickness	5,0	1,6
Ray width (small rays)	11,4 - 33,5 - 79,8	7,5 - 25,0 - 71,1
Ray width (large rays)	101,3 - 160,1 - 203,3	104,6 - 146,0 - 191,4
Ray height(small rays)	193,5 - 410,8 - 859,1	170,4 – 519,7 -747
Ray height (large rays)	1070,7 - 1416,7 - 2413,8	1082,2 – 1414 – 1847

References: Catalogue of Life; Brazier and Franklin, 1961; Grosser 1977; Schweingruber, 1990; Hather, 2000; Richter and Dallwitz, 2000 onwards; Hassler, 2004 onwards; Inside Wood 2004 onwards; WCSP, 2022.

Fig. 50 **Illustration of anatomical (diagnostic) features of carbonized wood of *Fagus sylvatica*. TS with semi-ring-porous wood (A); TS with large rays distended at the growth ring boundary (B); TLS with rays in two different sizes (C); TLS with large multiseriate ray (D); RLS with homocellular rays (E); RLS with scalariform intervessel pits (F).**



Source: Thünen-Institut/ Valentina Zemke

12.20 *Quercus petraea* (Matt.) Liebl. (FAGACEAE)

Trade names: European oak (GB); European white oak (US); Weißeiche (DE); roble (ES).

DIN EN 13556-2003 code: QCXE.

CITES regulations: Not protected.

Geographic distribution: Albania; Austria; Belgium; Luxembourg; England; Channel Isl. [I]; Bulgaria; Corsica; Czech Republic; Slovakia; Denmark; France; Germany; Ireland; Switzerland; Liechtenstein; Netherlands; Spain; Andorra; Hungary; Italy; Slovenia; Croatia; Serbia and Kosovo; Macedonia; Montenegro; Bosnia and Herzegovina; Norway; Greece; Poland; Romania; Latvia [I]; Estonia [I]; Lithuania; W-European Russia; C-European Russia; Belarus; Ukraine; Moldova; Crimea; Sicily; Sweden; Northern Caucasus; Georgia [Caucasus]; Turkey (E-Anatolia, Inner Anatolia, N-Anatolia, NE-Anatolia, NW-Anatolia: Bithynia, S-Anatolia, SE-Anatolia, WN-Anatolia); European Turkey; Iran (NE-Iran: Mts., N-Iran, Iranian Aserbaijan); Lebanon (C-Lebanon).

Growth ring boundaries*:* Distinct.

Vessel elements: Wood ring-porous; earlywood vessels solitary; latewood vessels in short radial rows of 2-3 vessels arranged in a diagonal and/or radial („flame-like") pattern; perforation plates simple; thin-walled tyloses present.

Intervessel pits: Alternate.

Vessel-ray pits: with reduced borders to apparently simple; circular or angular to horizontal (gash-like) to mostly vertical (palisade).

Axial parenchyma: Paratracheal scanty; apotracheal: diffuse and/or diffuse-in-aggregates; with 4-8 cells per strand.

Rays: Rays of two distinct sizes, uniseriate and multiseriate with up to 10 and more (up to 30) cells; all ray cells procumbent (homocellular).

Storied structure: Not observed.

Secretory structure: Not observed.

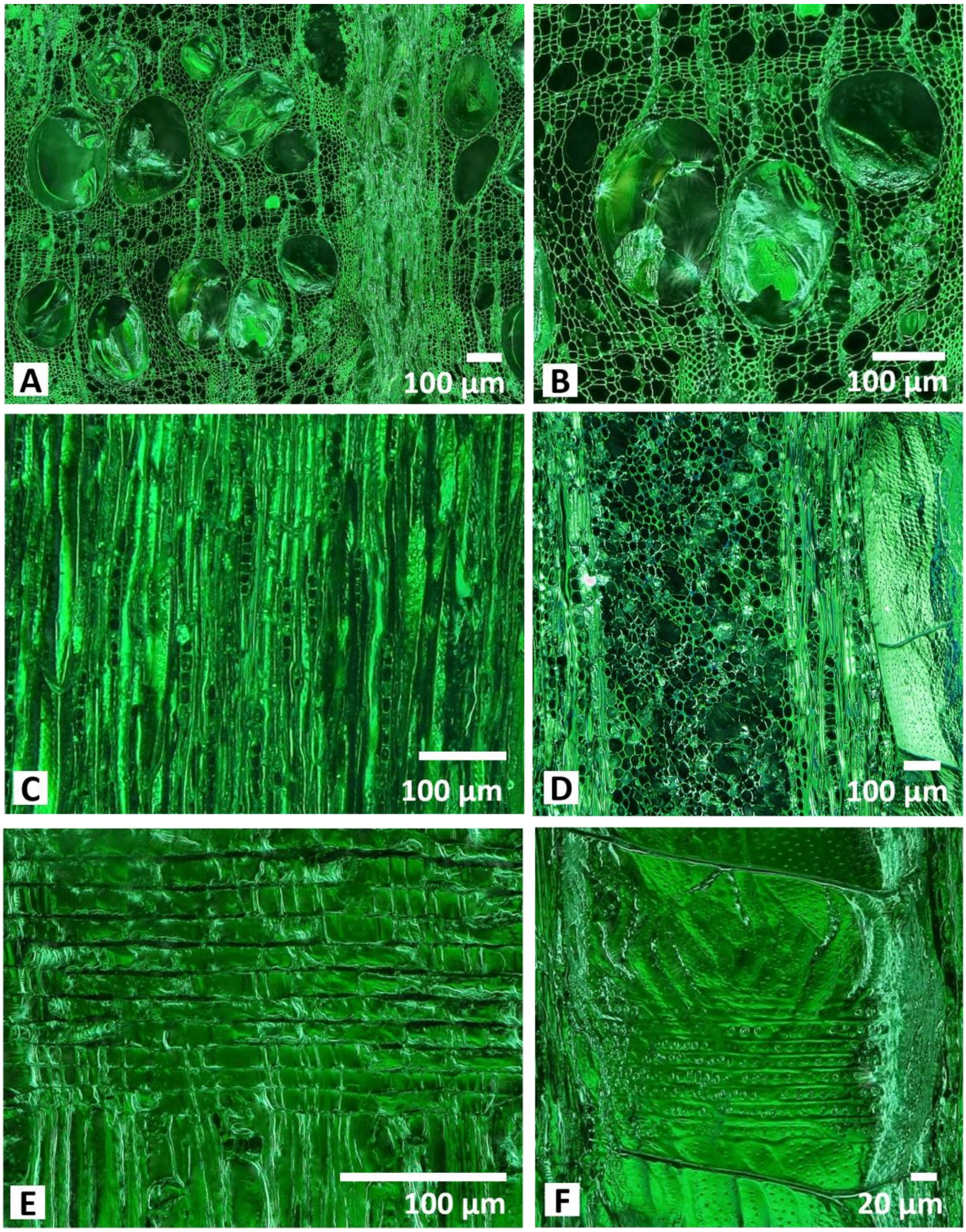
Mineral inclusions: Prismatic crystals located in procumbent ray cells and in chambered axial parenchyma cells, one crystal each.

Quantitative data:

	Solid Wood (µm)	Carbonized Wood (µm)
Tangential vessel diameter	113,6 - <u>232,6</u> - 357,5	88,7 - <u>186,6</u> - 310,9
Intervessel pit diameter (horizontal)	5,8 - <u>6,9</u> - 8,5	4,9 - <u>6,2</u> - 7,3
Fibre wall thickness	<u>3,6</u>	<u>0,9</u>
Ray width (small rays)	8,4 - <u>14,3</u> - 21,9	5,0 - <u>11,6</u> - 19,2
Ray width (large rays)	172,7 - <u>227,5</u> - 409,2	112,4 - <u>159,67</u> – 277,4
Ray height (small rays)	76,3 - <u>179,4</u> - 332,9	73,9 - <u>152,1</u> - 284,4
Ray height (large rays)	6803,0 - <u>25472,2</u> - 50060,3	4113,70 - <u>17413,73</u> - 43011,2

References: Catalogue of Life; Grosser, 1977; Hather, 2000; Richter and Dallwitz, 2000 onwards; Hassler, 2004 onwards; Inside Wood 2004 onwards; WCSP, 2022.

Fig. 51 **Illustration of anatomical (diagnostic) features of carbonized wood of *Quercus petraea*. TS with ring porous wood and latewood vessels in short radial rows of 2-3 vessels arranged in a diagonal and/or radial („flame-like“) pattern; large ray (A); TS with thin-walled tyloses in earlywood vessels (B); TLS with uniseriate rays (C); TLS with a large multiseriate ray (D); RLS with homocellular rays (E); RLS with alternate intervessel pits and vessel-ray pits (F).**



Source: Thünen-Institut/ Valentina Zemke

12.21 *Quercus suber* L. (FAGACEAE)

Trade names: *Quercus suber*: Cork oak (GB); sobreiro (PT); alcornoque (ES); *chêne-liège (FR); Korkeiche (DE); Quercus* spp.: Live oak, evergreen oak (GB,US): Sunda oak (Asia); pasang (MY,ID); ko (TH); roble, encino (MX, Central America).

DIN EN 13556-2003 code: -

CITES regulations: Not protected.

Geographic distribution: *Quercus suber*: Southern Europe, North Africa. Other species: temperate and tropical Asia (India, Pakistan, Sri Lanka, Myanmar, Thailand, Laos, Vietnam, Cambodia, Malaysia, Indonesia); western North America (California), Mexico and Central America and northern South America.

Growth ring boundaries: Distinct.

Vessel elements: Wood semi-ring-porous to diffuse porous; vessel elements exclusively solitary, arranged in diagonal and/or radial pattern; perforation plates simple.

Intervessel pits: Alternate.

Vessel-ray pits: with much reduced borders to apparently simple; pits rounded or angular, horizontal (gash-like) or vertical (palisade).

Fibres: -

Axial parenchyma: Paratracheal scanty, apotracheal: diffuse and/or diffuse-in-aggregates; commonly with 4-8 cells per strand.

Rays: Rays of two distinct sizes, uniseriate and multiseriate, 10 or more cells wide; all ray cells procumbent (homocellular).

Storied structure: Not observed.

Secretory structure: Not observed.

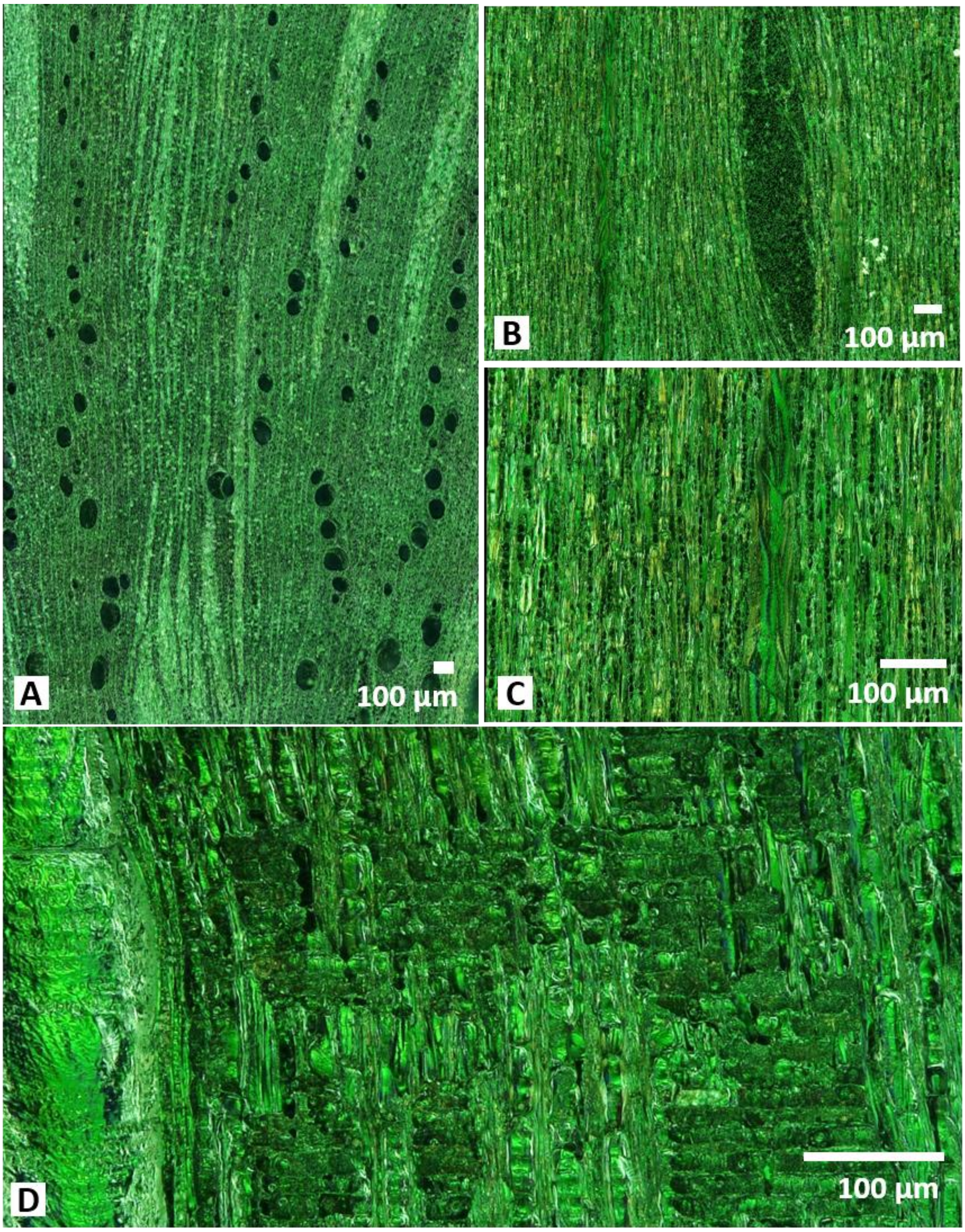
Mineral inclusions: Prismatic crystals located in procumbent ray cells and in chambered axial parenchyma cells, one crystal each.

Quantitative data:

	Solid Wood (µm)	Carbonized Wood (µm)
Tangential vessel diameter	36,4 - 115,9 - 259,1	28,6 - 85,1 - 175,3
Intervessel pit diameter (horizontal)	4,3 - 6,4 - 8,5	3,7 - 5,2 - 6,9
Fibre wall thickness	3,0	0,7
Ray width (small rays)	8,6 - 16,2 - 33,5	4,1 - 10,9 - 21,5
Ray width (large rays)	100,4 - 343,3 - 590,0	47,8 - 178,4 - 357,9
Ray height (small rays)	77,6 - 235,7 - 591,1	61,9 - 184,8 - 373,3
Ray height (large rays)	2466,0 - 3535,2 - 5104,2	1056,4 - 2338,6 - 4659,9

References: Catalogue of Life; Richter and Dallwitz, 2000 onwards; Hassler, 2004 onwards; Inside Wood 2004 onwards; Sousa et al., 2009; WCSP, 2022.

Fig. 52 **Illustration of anatomical (diagnostic) features of carbonized wood of *Quercus suber*. TS with diffuse porous wood, vessels mostly solitary and arranged in diagonal and/or radial pattern (A); TLS with large multiseriate ray (B); TLS with small rays (C); RLS with vessel element and uniseriate homocellular rays (D).**



Source: Thünen-Institut/ Valentina Zemke

12.22 *Juglans nigra* L. (JUGLANDACEAE)

Trade names: Black walnut, American walnut (GB); American black walnut, eastern black walnut (US); oresák cerny (CZ); noyer noir (FR); noce nero (IT); oreh crni, oreh crni (CS); Amerikaans noten (NL); nuc negru (RO); orech tschornyi (RU); fekete diá (HU); Amerikanischer Nussbaum, Schwarznuss (DE).

DIN EN 13556-2003 code: JGNG.

CITES regulations: Not protected.

Geographic distribution: Eastern North America (USA, Canada); widely cultivated.

Growth ring boundaries: Distinct.

Vessel elements: Wood semi-ring-porous to rarely diffuse-porous; vessel elements in multiples, short radial rows of 2-3 vessels; perforation plates simple; thin-walled tyloses present.

Intervessel pits: Alternate

Vessel-ray pits: with distinct borders; similar to intervessel pits in size and shape throughout the ray cell.

Fibres: -

Axial parenchyma: Fine marginal bands; apotracheal diffuse in aggregates to irregularly banded, forming a reticulate pattern with rays; 3-8 cells per axial parenchyma strand.

Rays: Multiseriate, commonly 1-3, larger rays 4(-10) cells wide; all ray cells procumbent (homocellular), some with one row of upright/square cells (heterocellular).

Storied structure: Not observed.

Secretory structures: Not observed.

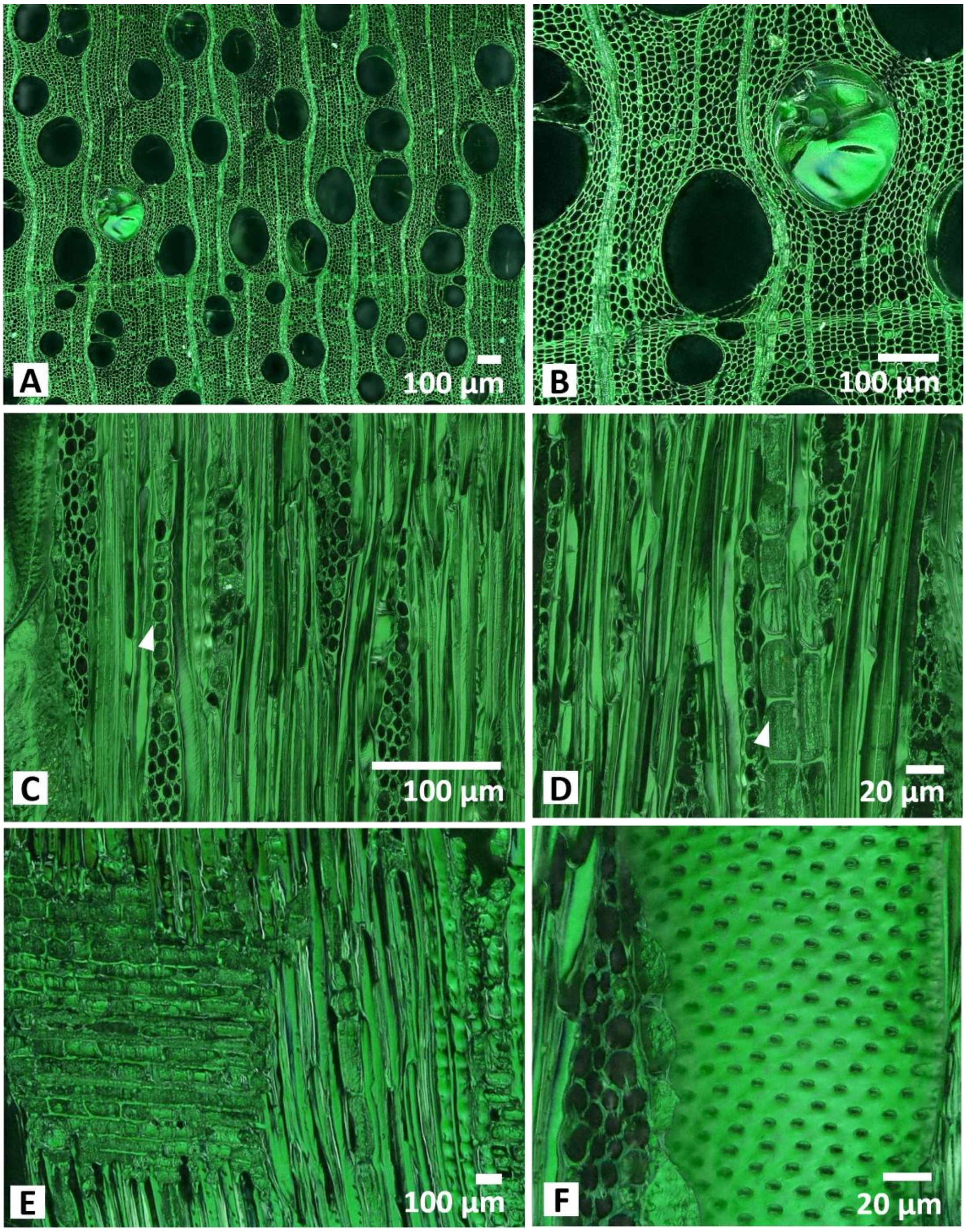
Mineral inclusions: Prismatic crystals located in non-chambered axial parenchyma cells; crystal containing cells of normal size or enlarged (idioblasts), one crystal each.

Value data of anatomical features:

	Solid Wood (µm)	Carbonized Wood (µm)
Tangential vessel diameter	77,3 - 186,0 - 254,6	85,3 - 160,4 - 219,8
Intervessel pit diameter (horizontal)	9,1 - 11,4 - 12,9	3,5 - 5,3 - 8,8
Fibre wall thickness	3,8	0,9
Ray width	13,6 - 46,8 - 68,3	15,7 - 29,2 - 49,4
Ray height	200,0 - 409,0 - 830,0	182,8 - 351,0 - 777,9

References: Catalogue of Life; Miller, 1976; Richter and Dallwitz, 2000 onwards; Hassler, 2004 onwards; Inside Wood 2004 onwards.

Fig. 53 **Illustration of anatomical (diagnostic) features of carbonized wood of *Juglans nigra*. TS with semi-ring-porous wood, axial parenchyma in fine bands forming a reticulate pattern with rays (A); TS of vessel with thin-walled tyloses (B); TLS with multiseriate rays and with uniseriate portions (C); TLS with parenchyma strand (D); RLS with heterocellular ray (E); TLS with alternate intervessel pits (F).**



Source: Thünen-Institut/ Valentina Zemke

12.23 *Triplochiton scleroxylon* K. Schum. (MALVACEAE)

Trade names: Abachi (DE); obeche (NG, BE); wawa (GH, GB); ayous (FR, GH, CM); samba (CI, FR).

DIN EN 13556-2003 code: TRSC.

CITES regulations: Not protected.

Geographic distribution: Guinea; Sierra Leone; Ivory Coast; Ghana; Togo; Benin; Nigeria; Cameroon; Equatorial Guinea; Gabon; Central African Republic; D.R.Congo [Zaire]; Congo [Brazzaville].

Growth ring boundaries: Distinct or indistinct or absent.

Vessel elements: Wood diffuse-porous; vessel elements in multiples, short radial rows of 2-3 vessels; perforation plates simple; thin-walled tyloses present.

Intervessel pits: Alternate (polygonal)

Vessel-ray pits: with distinct borders, similar to intervessel pits in size and shape throughout the ray cell.

Fibres: -

Axial parenchyma: Apotracheal diffuse and diffuse-in-aggregates; paratracheal scanty or vasicentric; fusiform and with 2-4 cells per parenchyma strand.

Rays: Rays of two distinct sizes, few uniseriate and large multiseriate rays up to 5 cells wide; body ray cells procumbent with 1-4 rows of upright and/or square marginal cells (heterocellular); both sheath cells and tile cells present.

Storied structure: Low rays storied; axial parenchyma, fibres and vessel elements storied.

Secretory structure: Not observed.

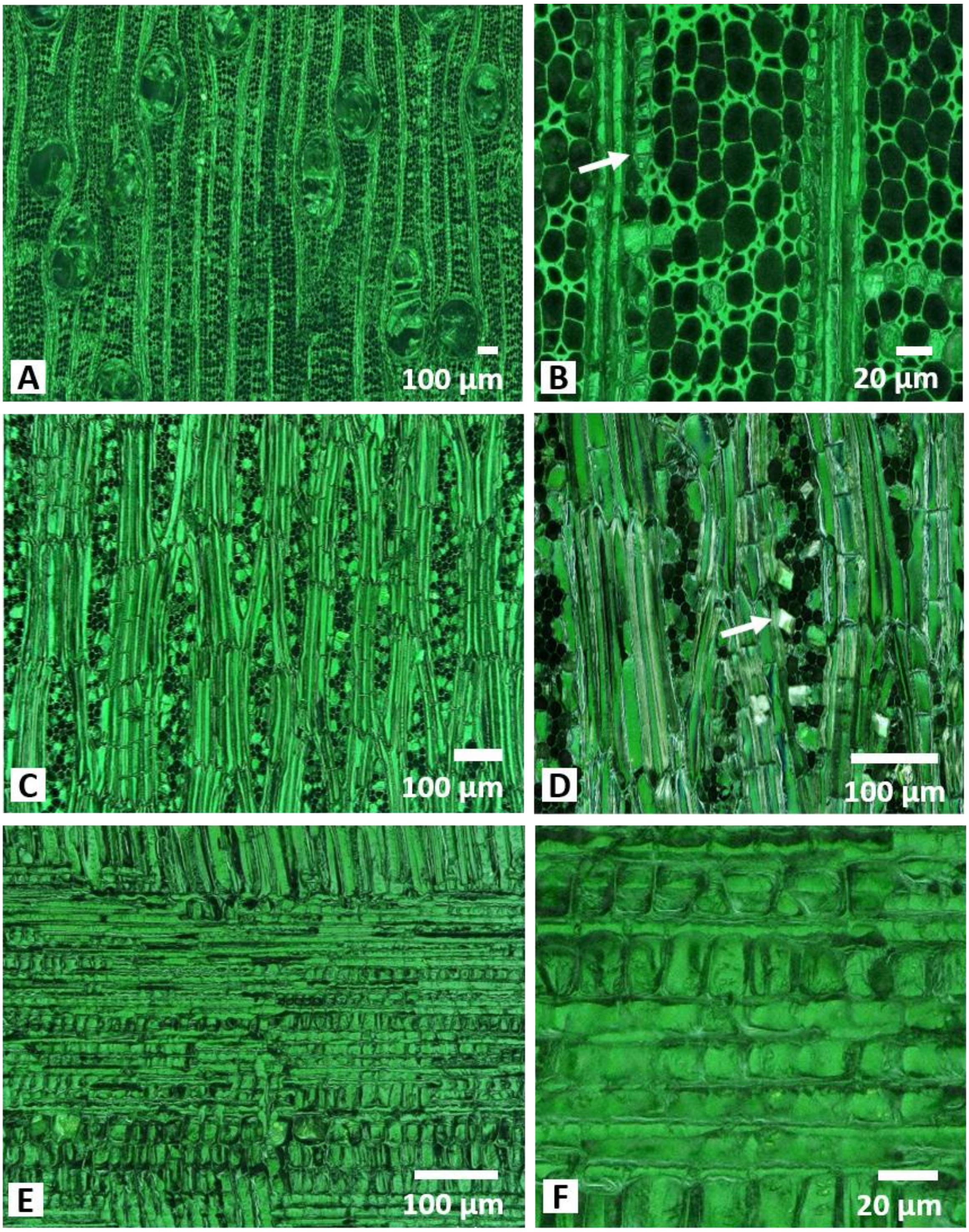
Mineral inclusions: Prismatic crystals located in upright and/or square ray cells and in non-chambered axial parenchyma cells, one crystal each.

Quantitative data:

	Solid Wood (µm)	Carbonized Wood (µm)
Tangential vessel diameter	115,1 - 196,2 - 272,7	128,5 - 191,2 - 271,7
Intervessel pit diameter (horizontal)	5,2 - 7,7 - 10,5	3,6 - 4,7 - 6,8
Fibre wall thickness	3,2	0,6
Ray width	25,4 - 62,2 - 100,1	21,5 - 57,0 - 81,2
Ray height	109,5 - 458,3 - 863,9	107,5 - 377,6 - 795,5

References: Catalogue of Life; Richter and Dallwitz, 2000 onwards; Inside Wood 2004 onwards.

Fig. 54 **Illustration of anatomical (diagnostic) features of carbonized wood of *Triplochitron scleroxylon*. TS with diffuse porous wood (A); TS with crystals in ray cells (B); TLS with multiseriate and storied small rays, axial parenchyma and fibres (C); TLS with crystals in ray cells (D); RLS with heterocellular ray and tile cells (E+F).**



Source: Thünen-Institut/ Valentina Zemke

12.24 *Milicia excelsa* (Welw.) C.C. Berg (MORACEAE)

Trade names: Iroko, african teak, nkambala (GB), odum (GH, CI), abang, bang (CM), amoreira (AO), chamfuta (MZ), semli (LR), rokko (NG), lusanga (CD); Nkamba (CD).

DIN EN 13556-2003 code: MIXX.

CITES regulations: Not protected.

Geographic distribution: Guinea-Bissau; Guinea; Burkina Faso; Sierra Leone; Ivory Coast; Ghana; Togo; Benin; Nigeria; Cameroon; Central African Republic; South Sudan; Ethiopia; Gabon; Congo [Brazzaville]; Equatorial Guinea; Bioko Isl. [Fernando Po]; São Tomé; Principe Isl.; D.R.Congo [Zaire]; Angola; Uganda; Kenya; Tanzania; Malawi; Mozambique; Zambia; Zimbabwe.

Growth ring boundaries: Indistinct or absent.

Vessel elements: Wood diffuse-porous; vessel elements in multiples forming short radial rows of 2-3 vessel elements; perforation plates simple; thin-walled tyloses present.

Intervessel pits: Alternate

Vessel-ray pits: with much reduced borders to apparently simple; pits circular or angular, rarely extended horizontally (gash-like) or vertically (palisade).

Fibres: -

Axial parenchyma: Fine marginal bands at irregular intervals; paratracheal vasicentric and aliform to confluent; 2-4 cells per parenchyma strand.

Rays: Multiseriate, larger rays commonly 3-4 cells wide; body ray cells procumbent with one row of upright and/or square marginal cells (heterocellular).

Storied structure: Not observed.

Secretory structure: Laticifers sporadically present.

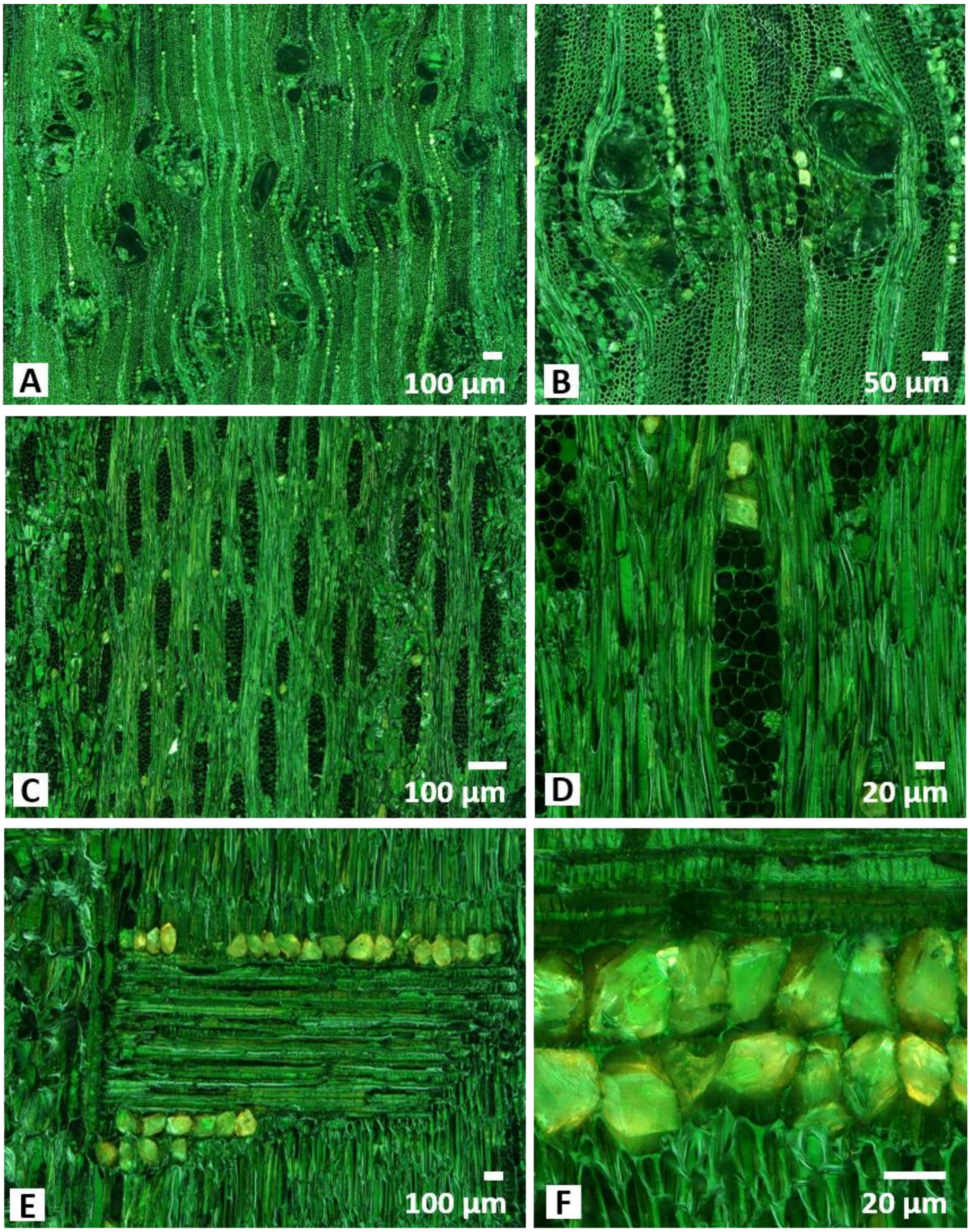
Mineral inclusions: Prismatic crystals located in chambered upright and/or square ray cells (occasionally in radial alignment) and non-chambered axial parenchyma cells, with one or more crystals each; crystals in one cell or chamber of the same size, or of two distinct sizes.

Quantitative data:

	Solid Wood (µm)	Carbonized Wood (µm)
Tangential vessel diameter	91,6 - 221,7 – 336,6	56,6 - 173,0 - 254,9
Intervessel pit diameter (horizontal)	9,8 - 12,3 - 15,9	6,0 - 8,8 - 12,4
Fibre wall thickness	3,3	1,0
Ray width	22,7 - 53,5 - 95,5	19,6 - 43,8 - 61,5
Ray height	219,4 - 373,7 - 769,0	102,1 - 286,6 - 442,8

References: Catalogue of Life; Kribs 1968; Richter and Dallwitz 2000, onwards; Hassler 2004 onwards; Inside Wood 2004 onwards; Takawira-Nyenya 2005.

Fig. 55 **Illustration of anatomical (diagnostic) features of carbonized wood of *Milicia excelsa*. TS with diffuse-porous wood (A); TS with aliform parenchyma of the lozenge type (B); TLS with multiseriate rays (C+D); RLS with heterocellular rays (E); RLS with crystals in ray cells in radial alignment (F).**



Source: Thünen-Institut/ Valentina Zemke

12.25 *Eucalyptus grandis* W. Hill ex Maid. (MYRTACEAE)

Trade names: Flooded gum, Rose gum (GB).

DIN EN 13556-2003 code: EUSL.

CITES regulations: Not protected.

Geographic distribution: Australia; cultivated worldwide: Taiwan; tropical Africa; Peru; South Africa; China (Guangdong, Guangxi); Ecuador; Mauritius; La Réunion; Thailand; Bangladesh; Vietnam; Myanmar; Sri Lanka; Colombia; USA (Florida); Argentina; Morocco; Zimbabwe; Mozambique; Honduras; New Zealand.

Growth ring boundaries: Indistinct or absent.

Vessel elements: Wood diffuse-porous; vessel elements solitary, arranged in diagonal and/or radial pattern; perforation plates simple; thin-walled tyloses common.

Intervessel pits: Alternate, vestured.

Vessel-ray pits: with much reduced borders to apparently simple; pits rounded or angular.

Tracheids and fibres: Vascular/vasicentric tracheids (in cross section easily confused with vasicentric axial parenchyma).

Axial parenchyma: Paratracheal scanty, vasicentric, and confluent; apotracheal diffuse; 3-8 cells per parenchyma strand.

Rays: Uniseriate and multiseriate rays 2-3 cells wide; body cells either all procumbent (homocellular) or with one row of upright and/or square marginal cells (heterocellular).

Storied structure: Not observed.

Secretory structure*:* Not observed.

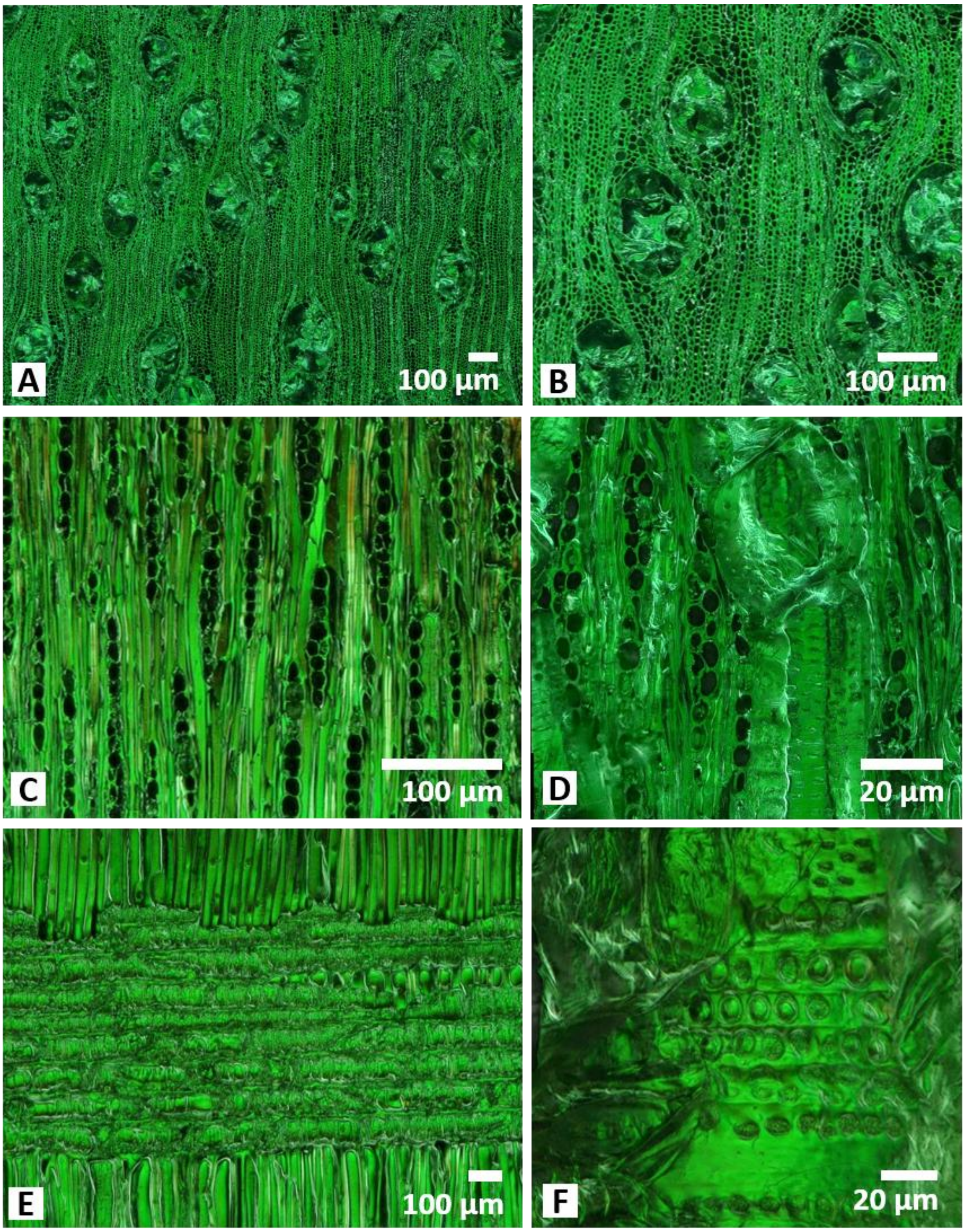
Mineral inclusions: Prismatic crystals located in non-chambered and chambered axial parenchyma cells, one crystal each.

Quantitative data:

	Solid Wood (µm)	Carbonized Wood (µm)
Tangential vessel diameter	45,5 - 149,2 - 204,6	35,9 - 121,1 - 201,6
Intervessel pit diameter (horizontal)	6,8 - 8,8 - 11,1	3,0 - 7,1 - 9,8
Fibre wall thickness	1,8	1,0
Ray width	9,1 - 16,0 - 29,9	4,4 - 15,0 - 29,6
Ray height	119,0 - 273,4 - 450,0	64,9 - 157,5 - 251,2

References: Catalogue of Life; PROTA4U; Hassler, 2004 onwards; Inside Wood 2004 onwards.

Fig. 56 **Illustration of anatomical (diagnostic) features of carbonized wood from *Eucalyptus grandis* by 3D-reflected light microscopy (RLM). (A-B) TS with diffuse-porous-wood and solitary vessel elements in diagonal and radial pattern (C) TLS with uniseriate (D) and multiseriate rays (E) RLS with homocellular rays (F) TLS with much reduced borders. Pits rounded and horizontal to vertical.**



Source: Thünen-Institut/ Valentina Zemke

12.26 *Fraxinus excelsior* L. (OLEACEAE)

Trade names: Common ash (GB), Europees essen (NL), frêne commun (FR), frassino maggiore (IT), fresno comun (ES), dischbudak (TR), daban gondjeschk (IR), sum (PK), hum (IN). Europäische Esche, einheimische Esche, gemeine Esche (DE).

DIN EN 13556-2003 code: FXEX.

CITES regulations: Not protected.

Geographic distribution: Albania; Austria; Belgium; Luxembourg; England; Channel Isl.; Czech Republic; Slovakia; Denmark; Germany; Greece; Switzerland; Liechtenstein; Switzerland; Netherlands; Hungary; Norway; Poland; Romania; Sweden; Spain; Andorra; France; Italy; Montenegro; Serbia and Kosovo; Slovenia; Croatia; Bosnia and Hercegovina; Macedonia; Bulgaria; Belarus; Estonia; Latvia; Lithuania; Crimea; C-European Russia; S-European Russia; Ukraine; Armenia; Georgia [Caucasus]; cultivated elsewhere in regions of temperate climate.

Growth ring boundaries: Distinct.

Vessel elements: Wood ring-porous; vessel elements in multiples and partially in short radial rows of 2-3; perforation plates simple; ingrowths of an undetermined nature from adjacent parenchymatous cells into the vessels, resembling thin-walled tyloses.

Intervessel pits: Alternate.

Vessel-ray pits: with distinct borders, similar to intervessel pits in size and shape throughout the ray cell.

Fibres: -

Axial parenchyma: Marginal bands along the growth ring boundary; in latewood paratracheal vasicentric and aliform of the winged type to confluent; 4 to 8 cells per parenchyma strand.

Rays: Multiseriate with 1-3, rarely up to 4 cells wide; all ray cells procumbent (homocellular).

Storied structure: Not observed.

Secretory structure: Not observed.

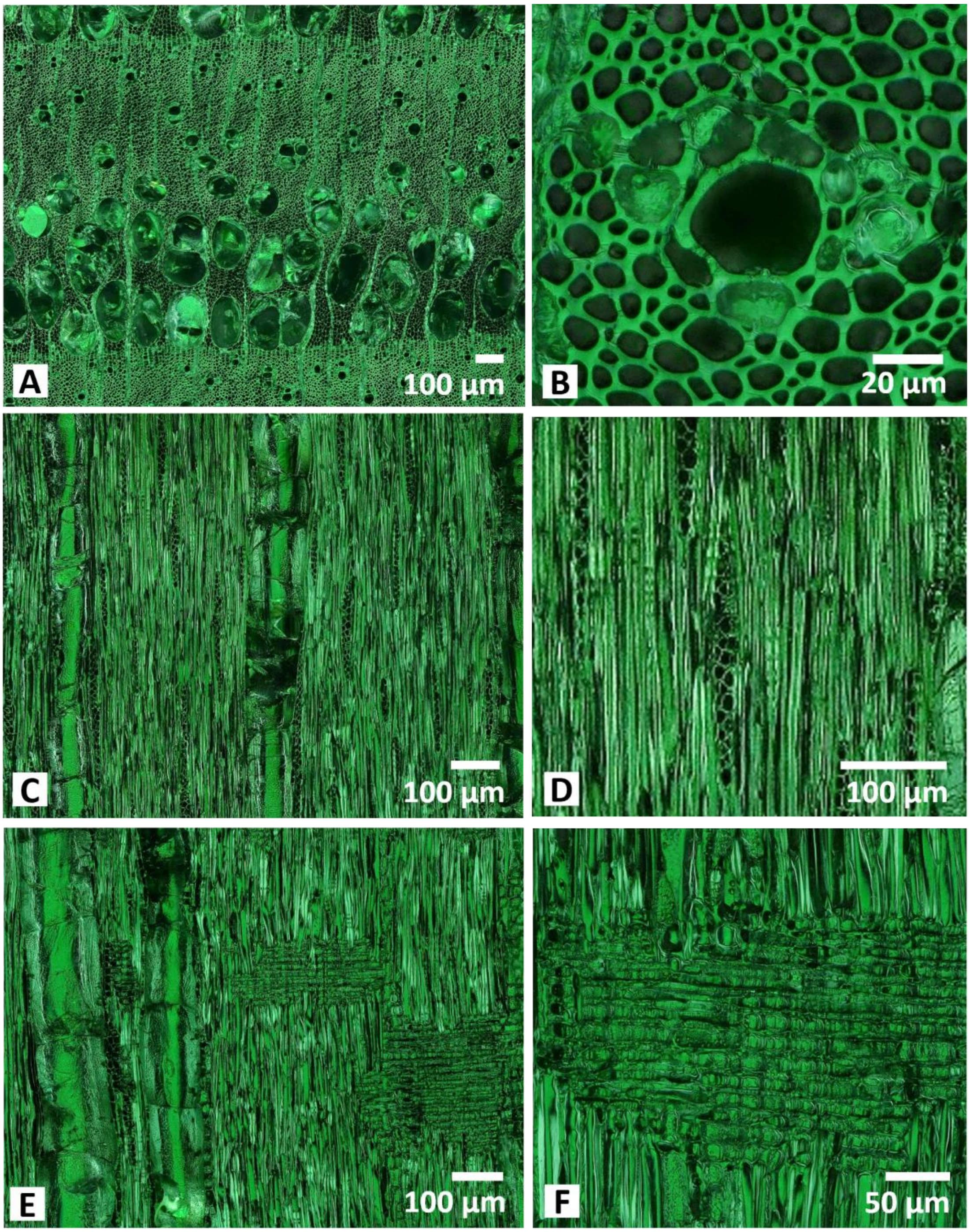
Mineral inclusions: Not observed.

Quantitaive data:

	Solid Wood (µm)	Carbonized Wood (µm)
Tangential vessel diameter	31,8 - 142,1 - 309,1	25,0 - 106,3 - 200,0
Intervessel pit diameter (horizontal)	3,0 - 3,7 - 4,6	2,2 - 3,6 - 4,4
Fibre wall thickness	3,0	1,1
Ray width	11,4 - 22,6 - 34,2	8,5 - 16,7 - 26,2
Ray height	111,4 - 252,1 - 639,3	64,8 - 189,9 - 453,1

References: Catalogue of Life; Brazier and Franklin, 1961; Grosser 1977; Schweingruber, 1990; Hather, 2000; Richter and Dallwitz, 2000 onwards, Hassler, 2004 onwards; Inside Wood 2004 onwards; WCSP, 2022.

Fig. 57 **Illustration of anatomical (diagnostic) features of carbonized wood of *Fraxinus excelsior*. TS with ring-porous wood (A); TS with latewood vessel and paratracheal vasicentric parenchyma (B); TLS with multiseriate rays (C+D); RLS with homocellular rays composed of procumbent cells (E+F).**



Source: Thünen-Institut/ Valentina Zemke

12.27 *Paulownia elongata* S. Y. Hu (PAULOWNIACEAE)

Trade names: Kiri, shima-giri (JP); Paulownia (trade); mao pao tong (CN); Paulownia impérial (FR); empresstree (GB, US); chinesischer Blauglockenbaum (DE).

DIN EN 13556-2003 code: not listed.

CITES regulations: Not protected.

Geographic distribution: China (Anhui, Hebei, Henan, Hubei, Jiangsu, Shaanxi, Shandong, Shanxi); cultivated worldwide.

Growth ring boundaries: Distinct.

Vessel elements: Wood ring-porous; vessel elements arranged in short radial rows of 2-3 vessel elements (earlywood) or in clusters (latewood); perforation plates simple; late wood vessels with helical thickenings throughout the body of the vessel; thin-walled tyloses common.

Intervessel pits: Alternate.

Fibres: -

Axial parenchyma: Fine marginal bands; paratracheal vasicentric and aliform of the lozenge type and confluent; apotracheal diffuse-in-aggregates; 2-5 cells per strand.

Rays: Multiseriate, small rays (1-)3, larger rays up to 5 cells wide; all ray cells procumbent (homocellular).

Storied structure: Not observed.

Secretory structure: Not observed.

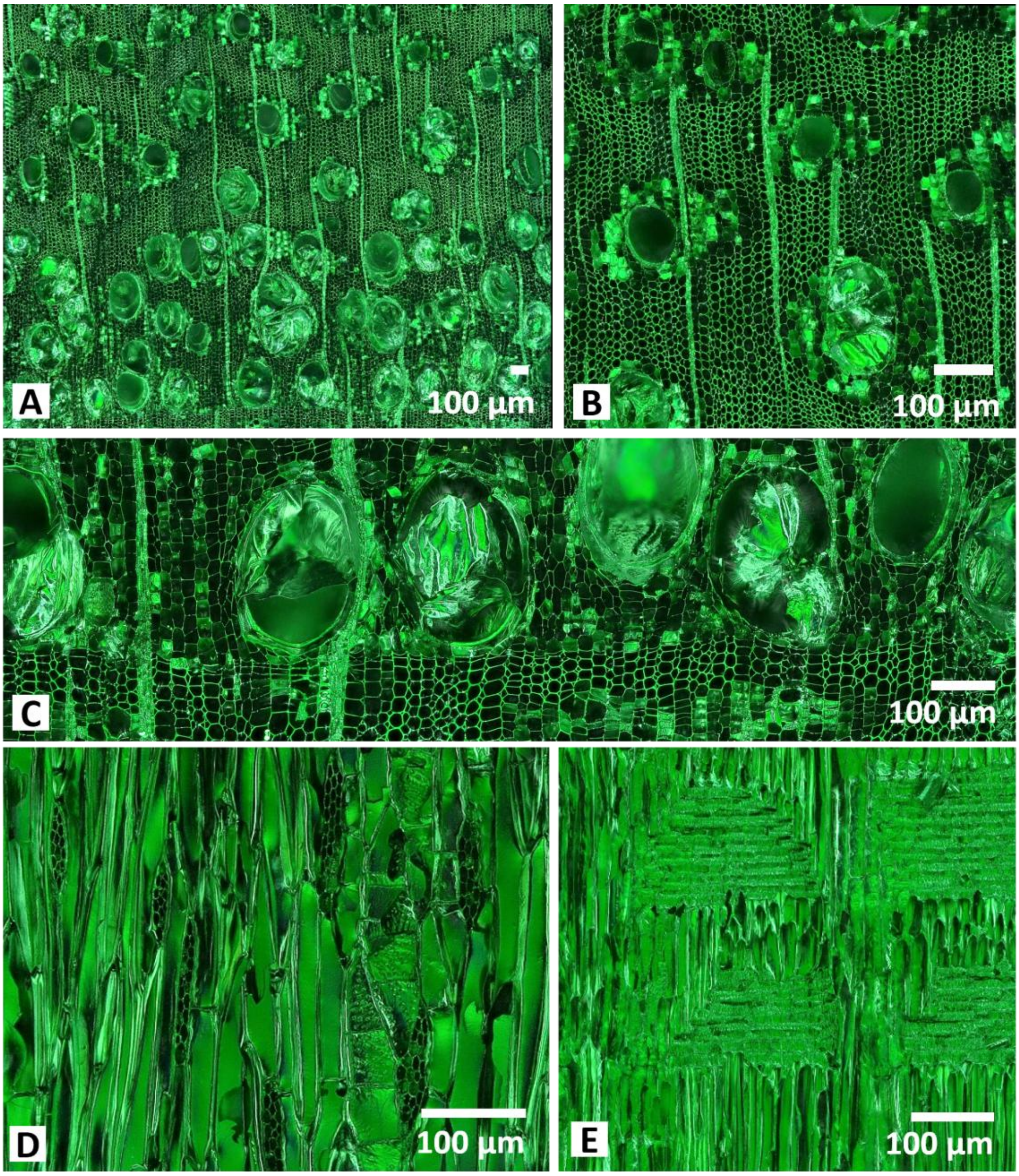
Mineral inclusions: Not observed.

Quantitative data:

	Solid Wood (µm)	Carbonized Wood (µm)
Tangential vessel diameter	118,2 - 215,6 - 341,7	95,4 - 179,2 - 308,8
Intervessel pit diameter (horizontal)	5,9 - 7,5 - 9,8	4,0 - 5,3 - 7,2
Fibre wall thickness	2,7	1,0
Ray width	21,0 - 30,2 - 44,8	14,1 - 24,0 - 40,9
Ray height	120,5 - 204,9 - 413,3	105,0 - 177,0 - 339,7

References: Catalogue of Life; Richter and Dallwitz, 2000 onwards; Hassler, 2004 onwards.

Fig. 58 **Illustration of anatomical (diagnostic) features of carbonized wood of *Paulownia elongata*. TS with ring porous wood (A); TS with aliform parenchyma of the lozenge type arranged around late wood vessel elements (B); TS with a distinct growth ring boundary and axial parenchyma diffuse-in-aggregates arranged in the early wood (C); TLS with multiseriate rays of 2-5 cells (D); RLS with homocellular rays (E).**



Source: Thünen-Institut/ Valentina Zemke

12.28 *Ziziphus mucronata* Willd. (RHAMNACEAE)

Trade names: Buffalo thorn (GB, ZA); blinkblaar-wagn-'n-bietjie (ZA); Jujube (DE)

DIN EN 13556-2003 code: -

CITES regulations: Not protected.

Geographic distribution: Yemen, South Africa, West Africa, Central Africa, Madagascar.

Growth ring boundaries: Indistinct or absent.

Vessel elements: Wood diffuse-porous; perforation plates simple and scalariform with up to 20 bars.

Intervessel pits: Alternate, polygonal.

Vessel-ray pits: with distinct borders, similar to intervessel pits in size and shape throughout the ray cell.

Fibres: -

Axial parenchyma: Fine marginal bands; paratracheal vasicentric, aliform of the lozenge and winged type; with 3-8 cells per strand.

Rays: Exclusively uniseriate, composed mostly of upright/square cells (homocellular), some with procumbent, square and upright cells mixed throughout the ray.

Storied structure: Not observed.

Secretory structure: Not observed.

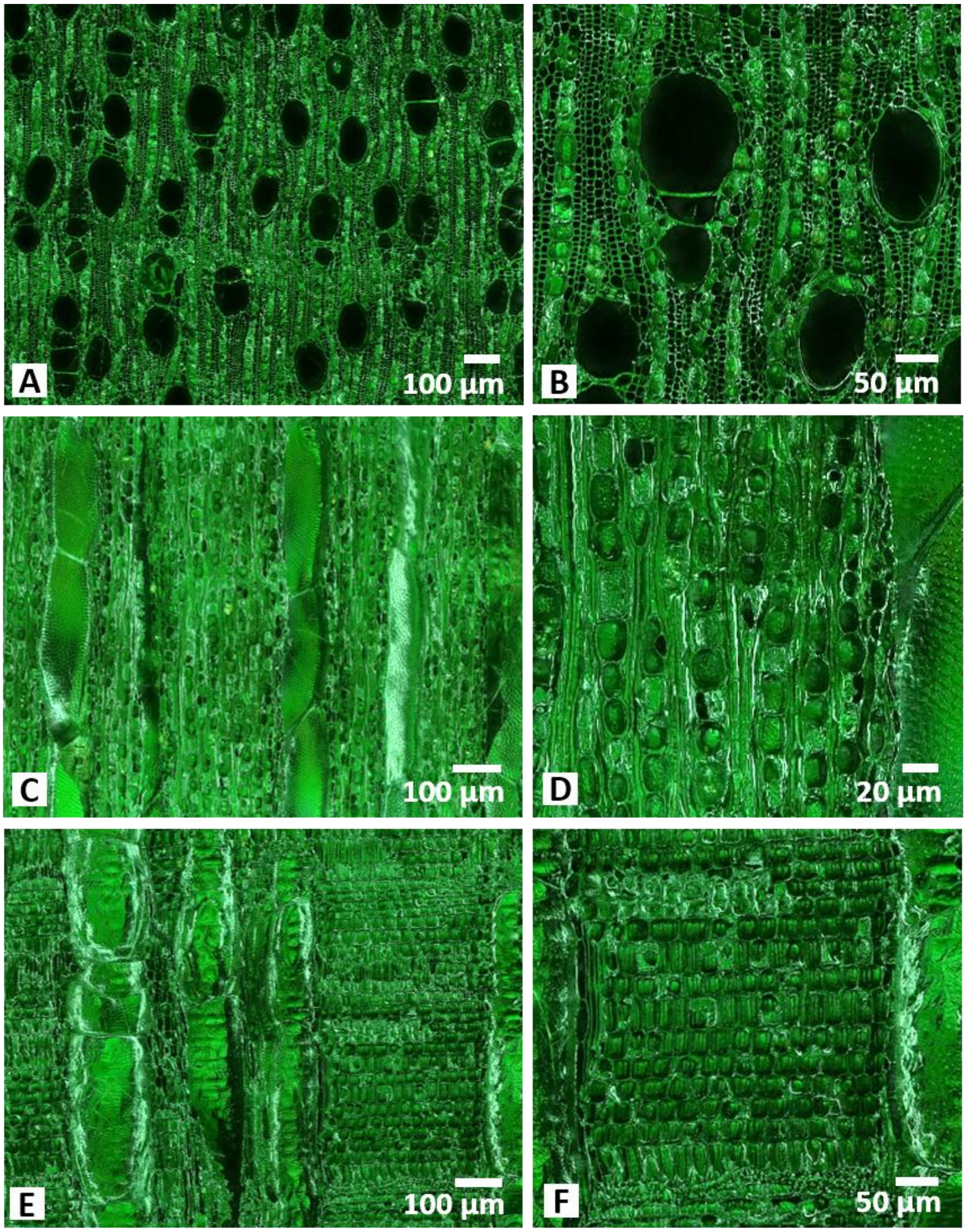
Mineral inclusions: Prismatic crystals located in upright and/or square ray cells and in non-chambered axial parenchyma cells, one crystal each.

Quantitative data:

	Solid Wood (µm)	Carbonized Wood (µm)
Tangential vessel diameter	61,5 - 97,5 - 145,5	61,6 - 92,1 - 124,7
Intervessel pit diameter (horizontal)	7,0 - 8,8 - 10,7	3,1 - 4,6 - 5,9
Fibre wall thickness	2,2	0,9
Ray width	13,6 - 23,4 - 41,2	10,7 - 20,3 - 32,5
Ray height	114,0 - 334,2 - 682,7	128,7 - 300,4 - 636,4

References: Catalogue of Life; Inside Wood 2004 onwards.

Fig. 59 **Illustration of anatomical (diagnostic) features of carbonized wood of *Ziziphus mucronata*. TS with diffuse porous wood (A); TS with paratracheal vasicentric parenchyma (B); TLS with uniseriate rays (C+D); RLS of homocellular rays with upright/square cells (E+F).**



Source: Thünen-Institut/ Valentina Zemke

12.29 *Coffea arabica* L. (RUBIACEAE)

Trade names: Arabian Coffee (GB); Kaffeestrauch (DE).

DIN EN 13556-2003 code: -

CITES regulations: not protected.

Geographic distribution: Ethiopia; South Sudan; N-Kenya, cultivated worldwide.

Growth ring boundaries: Distinct or indistinct to absent.

Vessel elements: Wood diffuse-porous; vessel elements solitary; perforation plates simple.

Intervessel pits: Alternate, vestured.

Vessel-ray pits: with distinct borders, similar to intervessel pits in size and shape throughout the ray cell.

Fibres: -

Axial parenchyma: Apotracheal diffuse and diffuse-in-aggregates; 3-5 (occasionally up to 8 cells) per parenchyma strand.

Rays: Multiseriate, 1-3 cells wide; body ray cells procumbent with 4 or more rows of upright and/or square marginal cells (heterocellular); some rays with procumbent, square and upright cells mixed throughout the ray; perforated ray cells present.

Storied structure: Not observed.

Secretory structure: Not observed.

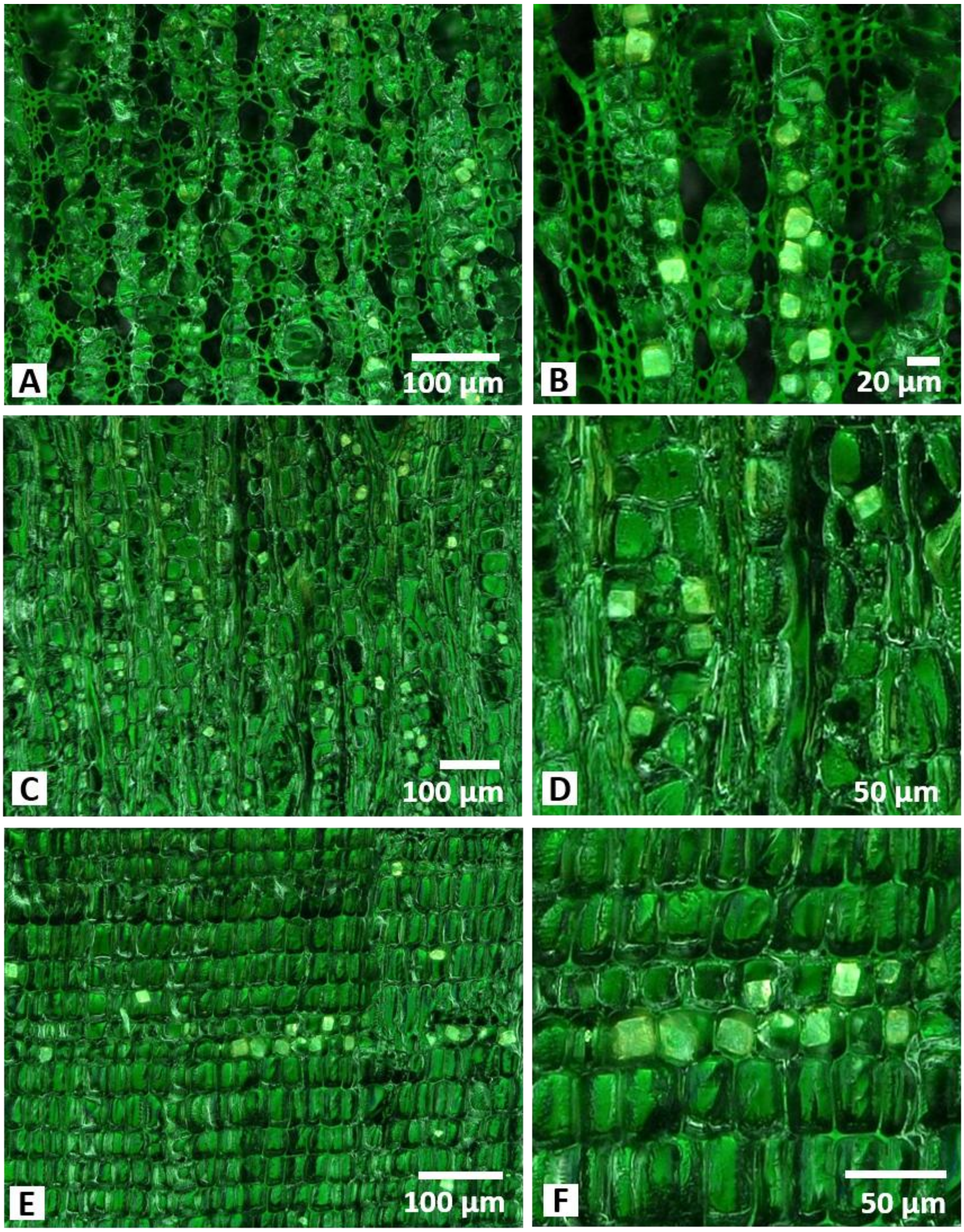
Mineral inclusions: Prismatic crystals located in procumbent, single and chambered ray cells; one crystal each.

Quantitative data:

	Solid Wood (µm)	Carbonized Wood (µm)
Tangential vessel diameter	26,5 - 44,2 - 63,8	19,1 - 31,5 - 53,5
Intervessel pit diameter (horizontal)	3,6 - 4,1 - 4,8	2,1 - 2,7 - 3,5
Fibre wall thickness	7,2	1,4
Ray width	18,2 - 38,6 - 71,1	14,3 - 30,4 - 53,2
Ray height	332,3 - 1046,8 - 2718,3	263,0 - 1014,8 - 2230,5

References: Catalogue of Life; Jansen et al., 1997; Hassler, 2004 onwards; Inside Wood 2004 onwards.

Fig. 60 **Illustration of anatomical (diagnostic) features of carbonized wood of *Coffea arabica*. TS with diffuse-porous wood (A); TS with solitary (deformed) vessel elements (B) and crystals in rays; TLS with multiseriate rays (C+D); RLS with heterocellular rays and prismatic crystals in procumbent ray cells (E+F).**



Source: Thünen-Institut/ Valentina Zemke

12.30 *Nauclea diderrichii* (De Wild.) Merr. (RUBIACEAE)

Trade names: Bilinga, boxwood, brimstone tree (DE, GA, FR, NL, GQ); opepe (NG, GB, BE); badi, sibo, bedo, ekusamba (CI); kusia (GH); akondok, eke, aloma (CM); bonkangu, gulu maza (AO, CD); mokese, kilingi (UG); kienga ki masa, ngulu masa (CD).

DIN EN 13556-2003 code: NADD.

CITES regulations: Not protected. **Conservation Status:** IUCN VU (vulnerable, Cameroon).

Geographic distribution: Benin; Guinea; Ghana; Ivory Coast; Liberia; Nigeria; Sierra Leone; Togo; Angola [Cabinda]; Central African Republic; Cameroon; Congo [Brazzaville]; Equatorial Guinea; Gabon; D.R. Congo [Zaire]; Uganda.

Growth ring boundaries: Indistinct or absent.

Vessel elements: Wood diffuse-porous; vessel elements solitary, often arranged in diagonal (or radial) pattern; perforation plates simple.

Intervessel pits: Rare, alternate (polygonal); vestured.

Vessel-ray pits: with distinct borders, similar to intervessel pits in size and shape throughout the ray cell.

Fibres: Rarely septate; distinctly bordered pits common in both radial and tangential walls.

Axial parenchyma: Apotracheal diffuse and/or diffuse-in-aggregates; paratracheal scanty; (4–)6–8–10 cells per parenchyma strand.

Rays: Uniseriate (few) and multiseriate; uniseriate rays mostly composed of square or upright cells (homocellular); multiseriate rays 2-4 cells wide, body cells procumbent with 2-4 or more marginal rows of upright and/or square cells (heterocellular); rays with multiseriate portion as wide as uniseriate portion; perforated ray cells present.

Storied structure: Not observed.

Secretory structure*:* Not observed.

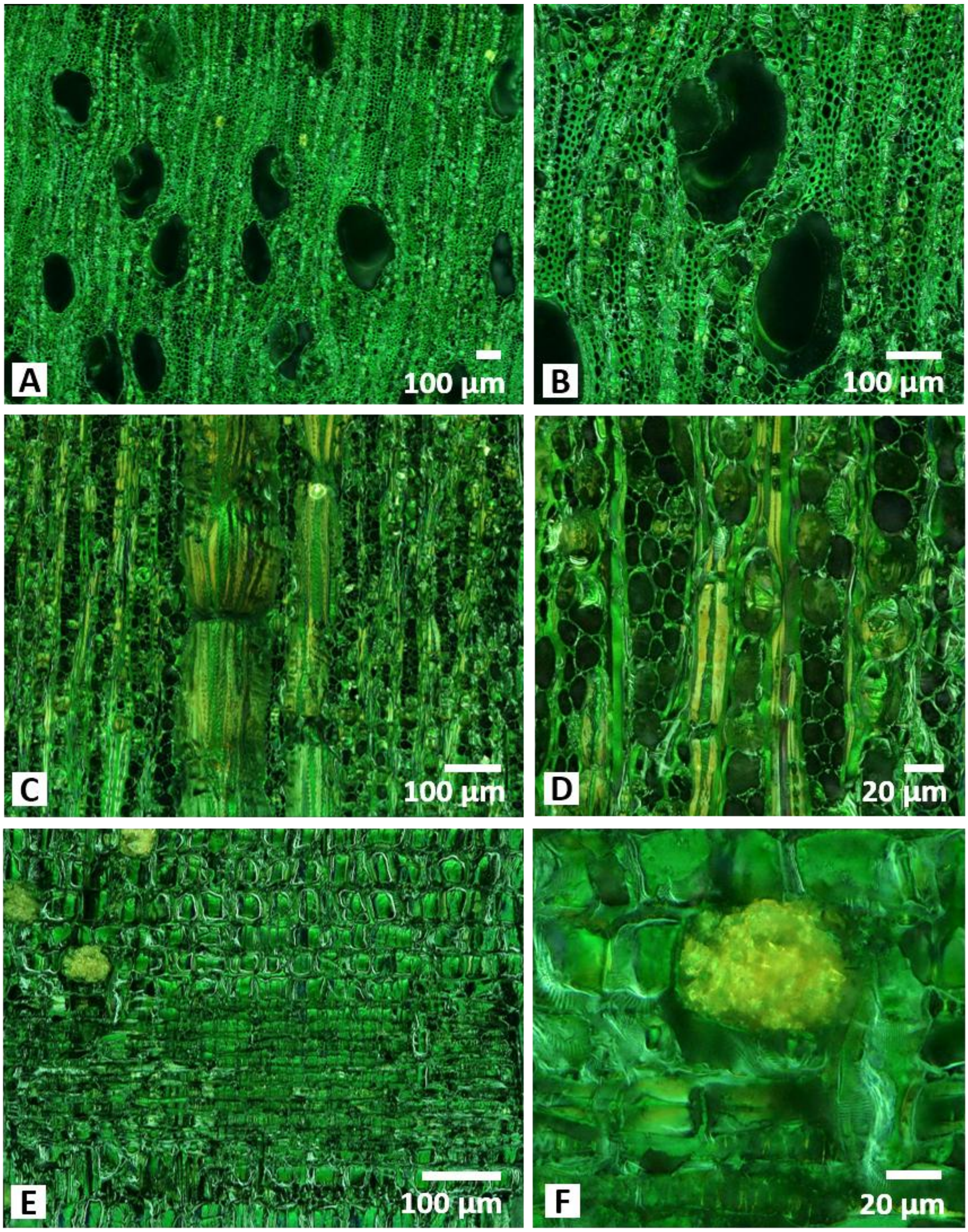
Mineral inclusions: Small prismatic crystals or crystal sand located in upright, square or procumbent ray cells.

Quantitative data:

	Solid Wood (µm)	Carbonized Wood (µm)
Tangential vessel diameter	72,9 - <u>233,9</u> - 304,9	72,8 - <u>142,3</u> - 260,1
Intervessel pit diameter (horizontal)	6,5 - <u>8,5</u> - 10,7	3,5 - <u>5,1</u> - 6,5
Fibre wall thickness	<u>8,7</u>	<u>1,9</u>
Ray width	18,2 - <u>43,5</u> - 72,8	20,0 - <u>36,4</u> - 57,9
Ray height	257,1 - <u>795,9</u> - 2397,8	229,8 - <u>697,8</u> – 1555,0

References: Catalogue of Life; PROTA4U; Ayensu and Bentum, 1974; Richter and Dallwitz, 2000 onwards, Hassler, 2004 onwards; Inside Wood 2004 onwards; Takawira-Nyenya 2005; WCSP, 2022.

Fig. 61 **Illustration of anatomical (diagnostic) features of carbonized wood of *Nauclea diderrichii*. TS with diffuse porous wood (A); TS with solitary vessel elements (B); TLS with multiseriate rays (C+D); RLS with heterocellular rays (E); RLS with crystal sand in ray cells (F).**



Source: Thünen-Institut/ Valentina Zemke

12.31 *Populus alba* L. (SALICACEAE)

Trade names*:* White poplar, silver poplar, silverleaf poplar (GB); abeel espen, populieren (NL); peuplier blanc (FR); beyaz kavak (TR); pioppo blanco (IT); álamo blanco, álamo común, chopo blanco (ES); *topol černý* (CZ); plop alb (RO); *fehér nyár* (HU); Silberpappel, Weißpappel (DE).

DIN EN 13556-2003 code: POAL.

CITES regulations: Not protected.

Geographic distribution: Europe, excl. Mediterranean, Mediterranean incl. North Africa and Middle East, temperate Asia; cultivated elsewhere.

Growth ring boundaries: Distinct.

Vessel elements: Wood diffuse-porous; vessel elements in multiples of short radial rows of 2-3; perforation plates simple; thin-walled tyloses (rarely) present.

Intervessel pits: Alternate.

Vessel-ray pits: with much reduced borders to apparently simple; pits rounded or angular, restricted to marginal cell rows.

Fibres: -

Axial parenchyma: Fine marginal bands; commonly 3(-4) cells per parenchyma strand.

Rays: Uniseriate; all ray cells procumbent (homocellular).

Storied structure: Not observed.

Secretory structure: Not observed.

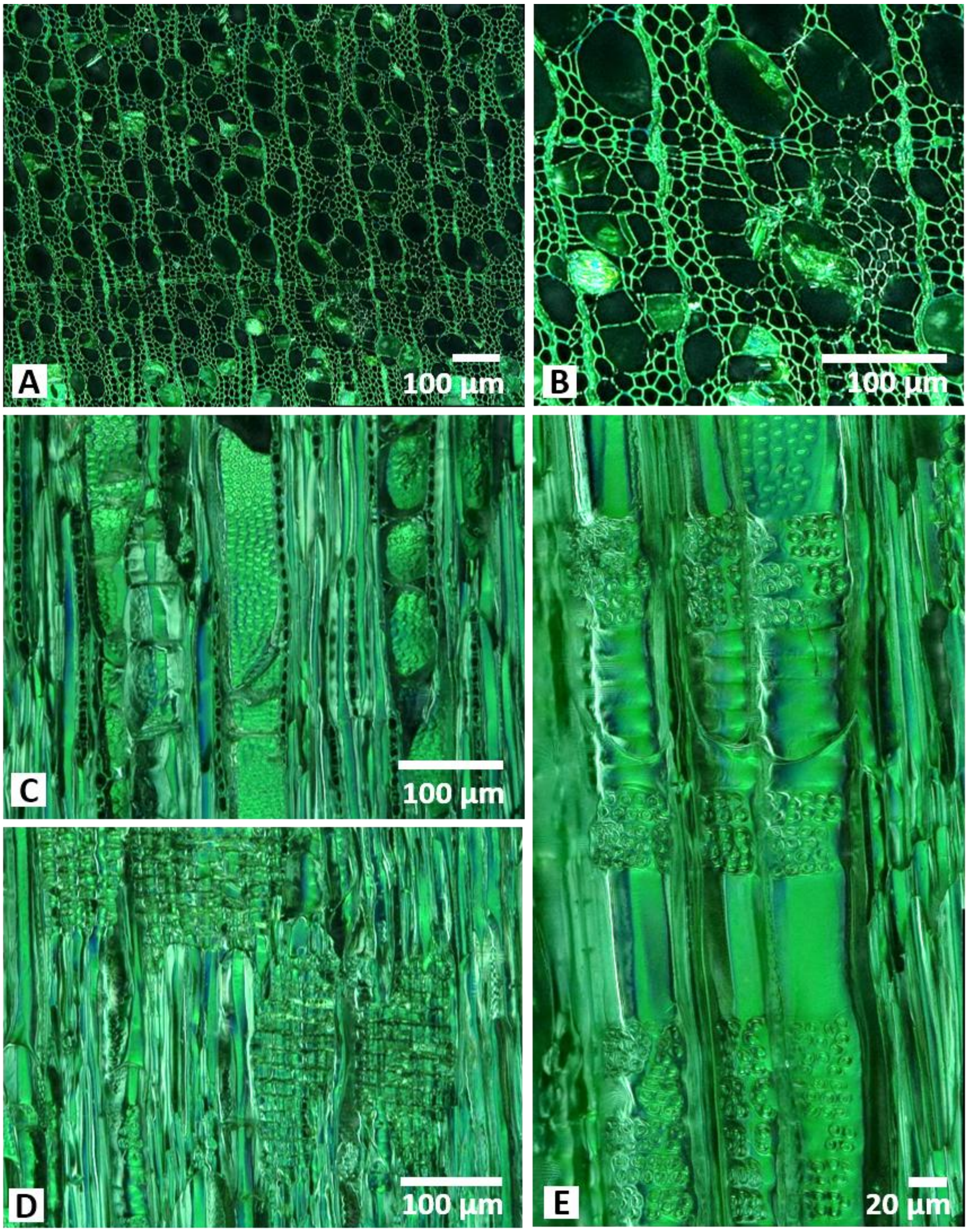
Mineral inclusions: Not observed.

Quantitative data:

	Solid Wood (µm)	Carbonized Wood (µm)
Tangential vessel diameter	31,0 - 49,4 - 63,0	30,1 – 50,9 - 65,6
Intervessel pit diameter (horizontal)	8,1 - 9,7 - 11,3	7,0 - 8,6 - 10,9
Fibre wall thickness	2,8	0,6
Ray width	15,9 - 27,0 - 41,0	2,3 - 7,9 - 16,6
Ray height	113,1 - 624,8 - 1227,4	75,0 - 213,8 - 496,1

References: Catalogue of Life; Brazier 1961; Schweingruber, 1990; Hather 2000; Richter and Dallwitz, 2000 onwards; Hassler, 2004 onwards; Inside Wood 2004 onwards; Schoch et al., 2004.

Fig. 62 **Illustration of anatomical (diagnostic) features of carbonized wood from *Populus alba*. TS with diffuse porous wood and fine marginal parenchyma band (A); TS with Vessel elements in multiples, partially in short radial rows (B); TLS with uniseriate rays and alternate intervessel pits (C); RLS with homocellular rays (D); RLS of vessel ray pits with reduced or apparently simple borders in marginal cell rows (E).**



Source: Thünen-Institut/ Valentina Zemke

12.32 *Acer pseudoplatanus* L. (SAPINDACEAE, formerly ACERACEAE)

Trade names: Sycamore maple (GB); érable (FR); acero (IT); falso plátano, arce blanco (ES); Bergahorn (DE).

DIN EN 13556-2003 code: ACPS.

CITES regulations: Not protected.

Geographic distribution: Austria; Belgium; Luxembourg; Czech Republic; Slovakia; Germany; Switzerland; Liechtenstein; Netherlands; Hungary; Poland; Romania; England [I]; cultivated elsewhere in regions of temperate climate.

Growth ring boundaries: Distinct.

Vessel elements: Wood diffuse-porous; in short radial multiples of 2-3 cells (few); perforation plates simple; helical thickenings throughout body of the vessel element.

Intervessel pits: Alternate

Vessel-ray pits: with reduced borders or apparently simple; pits rounded or angular.

Fibres: -

Axial parenchyma: Marginal bands; paratracheal scanty; rarely apotracheal diffuse and diffuse-in-aggregates.

Rays: Multiseriate, of two distinct sizes; small rays mostly 1-2, large rays 4-7 cells wide, all ray cells procumbent (homocellular).

Storied structure: Not observed.

Secretory structure: Not observed.

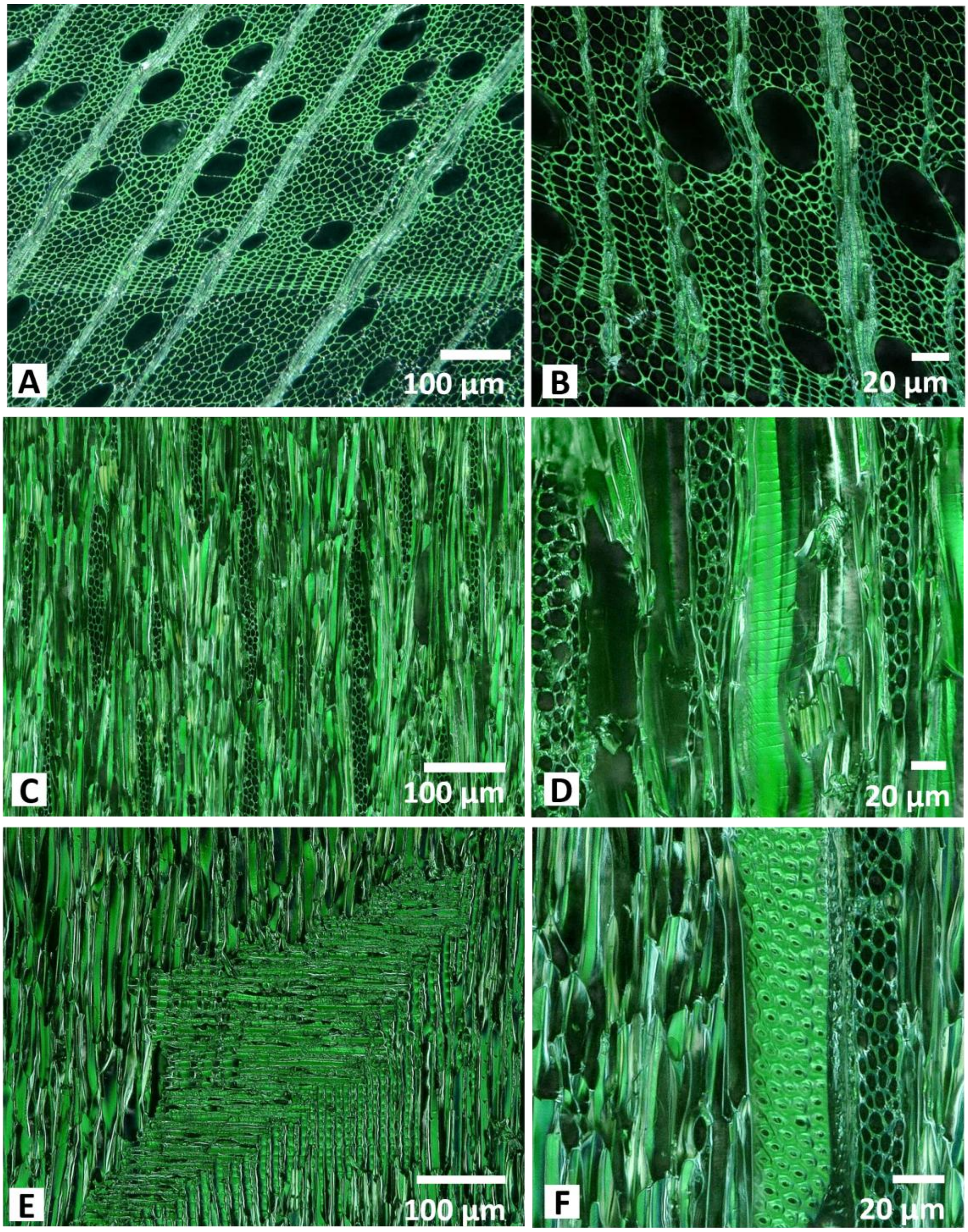
Mineral inclusions: Prismatic crystals not observed.

Quantitative data:

	Solid Wood (µm)	Carbonized Wood (µm)
Tangential vessel diameter	38,3 - 57,7 - 85,1	32,4 - 52,7 - 79,7
Intervessel pit diameter (horizontal)	7,5 - 9,3 - 10,8	4,3 - 7,0 - 9,5
Fibre wall thickness	2,1	0,7
Ray width	15,9 - 39,7 - 65,9	10,3 - 20,7 - 35,5
Ray height	100,1 - 273,3 - 788,6	79,2 - 268,5 - 611,4

References: Catalogue of Life; Brazier and Franklin, 1961; Grosser, 1977; Schweingruber, 1990; Hather, 2000; Richter and Dallwitz, 2000 onwards*;* Hassler, 2004 onwards; Inside Wood 2004 onwards; Schoch et al., 2004.

Fig. 63 **Illustration anatomical (diagnostic) features of carbonized wood of *Acer pseudoplatanus*. TS with diffuse-porous wood (A); TS with short radial rows of vessel elements (B); TLS with multiseriate rays (C); TLS with helical thickenings in vessel elements (D); RLS with homocellular rays (E); TLS with alternate intervessel pits (F).**



Source: Thünen-Institut/ Valentina Zemke

12.33 *Autranella congolensis* (De Wild.) A.Chev. (SAPOTACEAE)

Trade names: Afrikulu (DE); kungulu (AO); elang, elanzok (CM); akola (GA); bouanga (CQ); mfua (CG); autracon, kabulungu, mukungolo (CD); uku (NG); m'banga, ovanga (CF).

DIN EN 13556-2003 code: AWCO.

CITES regulations: Not protected. **Conservation status**: IUCN EN (endangered)

Geographic distribution: D.R. Congo [Zaire]; Congo [Brazzaville]; Cameroon; Nigeria; Gabon; Central African Republic; Angola.

Growth ring boundaries: Indistinct or absent.

Vessel elements: Wood diffuse-porous; vessel elements in multiples in radial rows of 2 to 4 or more cells forming a radial and/or diagonal pattern; perforation plates simple; thin-walled tyloses.

Intervessel pits: Alternate.

Vessel-ray pits: with much reduced borders to apparently simple; pits rounded or angular; rarely extended horizontally (gash-like) or vertically (palisade).

Fibres: -

Axial parenchyma: Fine marginal bands; apotracheal diffuse or diffuse-in-aggregates, the latter often extending into wavy lines forming a reticulate pattern with rays; 6-9 cells per parenchyma strand.

Rays: Multiseriate with 1-3 cells; body ray cells procumbent with mostly 2-4 rows of upright and/or square marginal cells (heterocellular).

Storied structure: Not observed.

Secretory structure: Not observed.

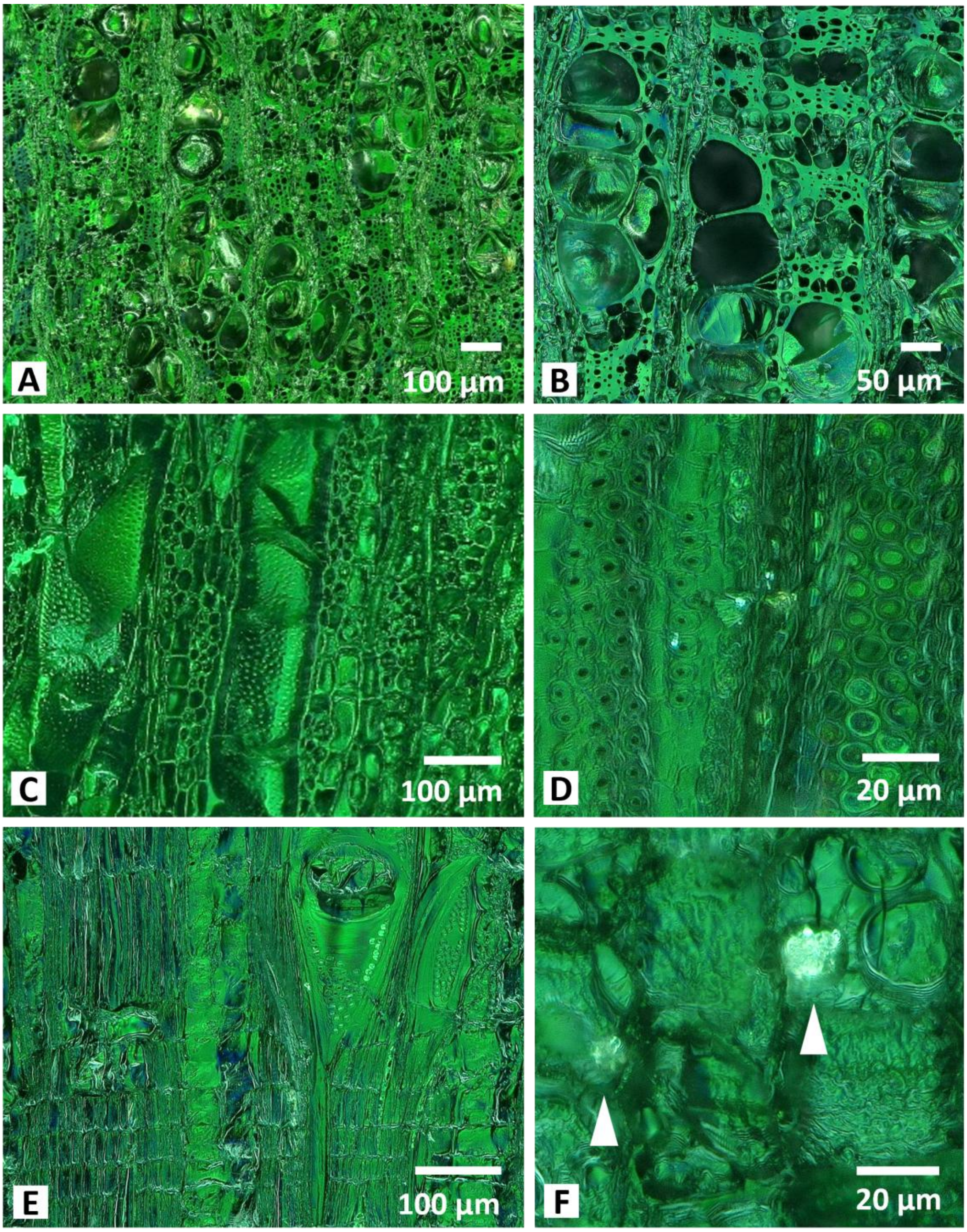
Mineral inclusions: Prismatic crystals located in chambered axial parenchyma cells, one crystal each; silica bodies in ray and axial parenchyma cells.

Quantitative data:

	Solid Wood (µm)	Carbonized Wood (µm)
Tangential vessel diameter	66,0 - 118,8 - 167,6	50,7 - 105,5 - 160,6
Intervessel pit diameter (horizontal)	6,6 - 9,3 - 11,9	3,3 - 6,2 - 8,2
Fibre wall thickness	8,7	1,9
Ray width	27,4 - 54,7 - 84,9	21,6 - 48,5 - 85,1
Ray height	173,8 - 481,4 - 1261,6	139,1 - 404,6 -705,9

References: Catalogue of Life; Richter and Dallwitz, 2000 onwards; Hassler, 2004 onwards; Inside Wood 2004 onwards; WCSP 2022.

Fig. 64 **Illustration of anatomical (diagnostic) features of carbonized wood of *Autranella congolensis*. TS with diffuse-porous wood and vessel elements arranged in multiples and radial rows of up to more than 4 vessel elements (A); TS with fine axial parenchyma lines (B); TLS with multiseriate rays 1-3 cells wide (C); RLS with alternate intervessel pits (D); RLS with heterocellular rays (E); TLS with silica bodies in ray cells (F).**



Source: Thünen-Institut/ Valentina Zemke

12.34 *Ulmus minor* (ULMACEAE)

Trade names: Feldulme, Rüster (DE); Dutch elm (GB,US); Europees iepen (NL); orme champetre (FR); olmo campestre (IT); olmo comune; (ES) jilm polni; (CZ) wiaz (PL); ulm de camp (RO); mezei szil (HU.

DIN EN 13556-2003 code: ULMI

CITES regulations: Not protected.

Geographic distribution: Europe: southern Sweden to the Mediterranean; towards the east to Caucasus.

Growth ring boundaries: Distinct.

Vessel elements: Wood ring-porous; ring of earlywood vessels multiseriate; latewood vessel elements in wavy tangential bands often forming a diagonal pattern; earlywood vessels in radial multiples of 2-3; latewood vessel elements exclusively in clusters; perforation plates simple; helical thickenings throughout the body of narrow vessel elements; thin-walled tyloses present.

Intervessel pits: Alternate.

Vessel-ray pits: with distinct borders, similar to intervessel pits in size and shape throughout the ray cell.

Fibres: -

Axial parenchyma: Paratracheal scanty or vasicentric; apotracheal: diffuse-in-aggregates; parenchyma strands with 2-4 cells.

Rays: Mostly multiseriate, commonly 3-5, very large rays up to 10 cells wide; all cells procumbent (homocellular).

Storied structure: Not observed.

Secretory structure: Not observed.

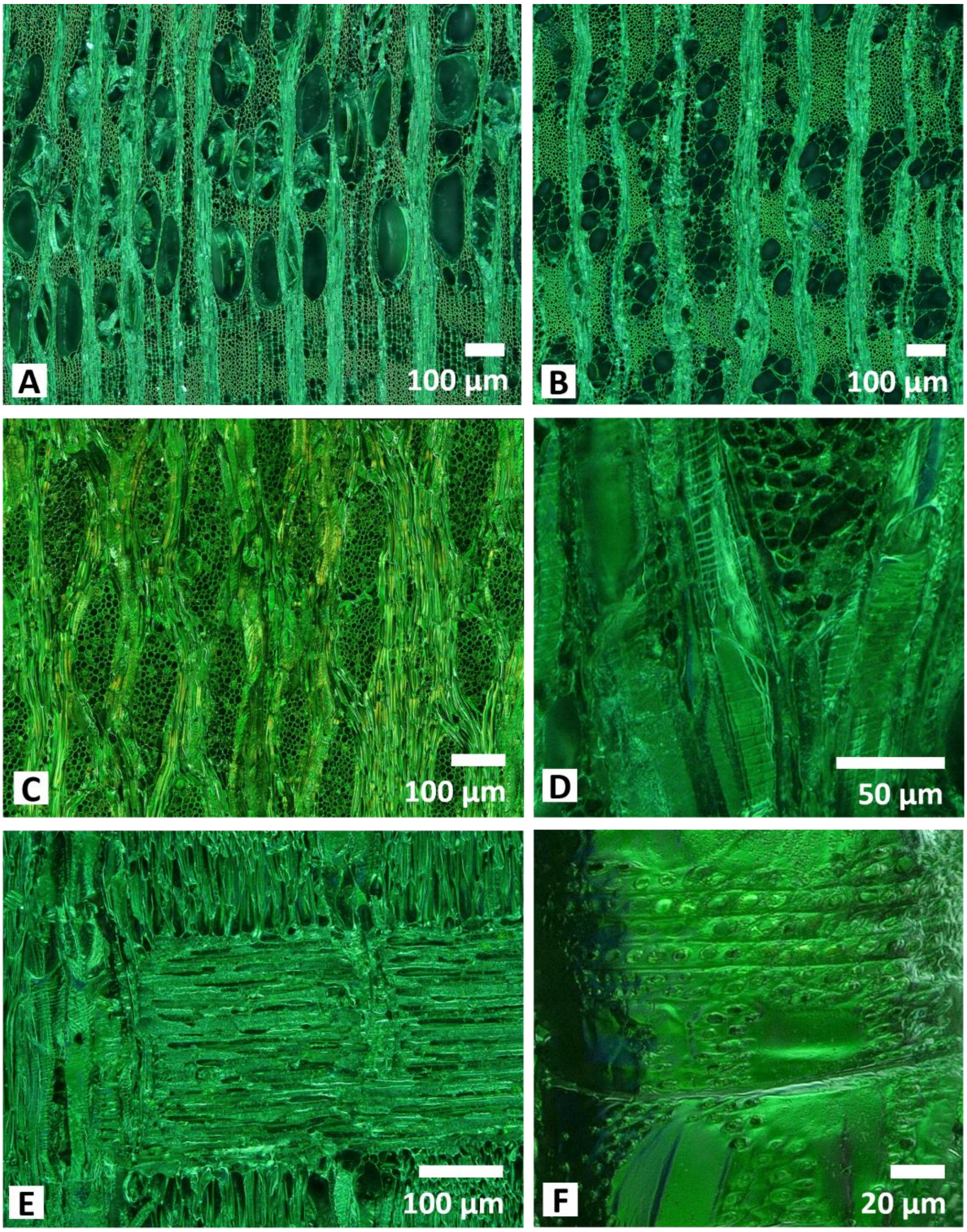
Mineral inclusions: Not observed.

Quantitative data:

	Solid Wood (µm)	Carbonized Wood (µm)
Tangential vessel diameter	66,1 - 147,2 - 212,6	48,0 - 113,0 - 198,9
Intervessel pit diameter (horizontal)	6,2 - 8,7 - 10,1	4,9 - 6,7 - 8,3
Fibre wall thickness	2,4	0,3
Ray width	34,8 - 80,5 - 102,9	32,7 - 60,5 - 98,7
Ray height	132,1 - 291,2 - 526,2	134,8 - 233,3 - 419,1

References: Catalogue of Life; Grosser, 1977; Hather, 2000; Richter and Dallwitz, 2000 onwards; Hassler, 2004 onwards; Inside Wood 2004 onwards.

Fig. 65 **Illustration of anatomical (diagnostic) features of carbonized wood from *Ulmus minor*. TS with ring-porous wood (A); TS with latewood-vessels in tangential bands (B); TLS with multiseriate rays (C); TLS with helical thickenings in small vessel element (D); RLS with homocellular rays (E); RLS with intervessel and ray-vessel pits (F).**



Source: Thünen-Institut/ Valentina Zemke

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