Analysing the effect of bending process on microstructure of Grevillea robusta wood

Priyank Maithani
pmaith.2010@gmail.com

Jackhammer India (Pvt.) Limited

Kamal Mishra
ICFRE- Institute of Wood Science and Technology

Atul Kumar
Veer Chandra Singh Garhwali Uttarakhand University of Horticulture & Forestry

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Research Article

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Abstract

Photomicroscopy allows for a detailed analysis of the cellular composition of wood, providing invaluable insights into the cellular structure, with remarkable spatial resolution. The present study was carried out on a bentwood sample of *Grevillea robusta*, to assess the impact of wood bending process on the microstructure of wood at various bending positions using photomicrography. It was observed that the bentwood exhibited a higher incidence of defects in terms of curvature length, particularly evident between block numbers 11 and 15 in the form of splits. Interestingly, a greater number of splits were observed on the curvature side in comparison to the arm sections. Notably, block numbers 11, 13, and 15 displayed 16, 15, and 14 splits per mm^2respectively. The study provides insights on the influence of bending forces on various hardwood structural elements. It was observed that, when subjected to bending, thick walled cells are evidently more susceptible to developing splits or fractures in contrast to their thin-walled counterparts, such as ray parenchyma or axial parenchyma. This indicates that different cell types react differently under stress conditions, emphasizing the necessity of assessing detailed structure of wood species before subjecting them to such stress, particularly in the context of bending. In summary, this study underscores the importance of understanding how various wood species respond to stress conditions, ultimately informing best practices for their utilization.

1. Introduction

Wood has been utilised as a key natural resource by mankind since long for diverse uses such as crafting furniture and constructional purpose. The art of shaping wood through bending has been an integral part of various industries throughout history and continues to play a significant role in today's manufacturing processes. From crafting boats and ships to producing furniture, agricultural tools, and sports equipment, wood bending remains a vital technique. Among the array of methods employed for creating curved wooden components, bending stands out as a cost-effective solution ideal for a wide range of applications (Peck 1957).

Wood bending is a traditional technique that has evolved through various treatments to achieve different effects. Treatments such as ammonia fumigation, steam treatment, high-frequency heating, kerf bending, and laminate bending have been employed for wood bending. Each treatment method differs from each other in their mechanism. For instance, ammonia fumigation softens wood fibres, while steam bending uses moisture and heat to make wood flexible. High-frequency bending employs electromagnetic energy for heating and bending, and kerf bending involves making a series of cuts on one side of the wood to aid bending. Laminate bending involves gluing multiple thin layers of wood to form curved shapes (Kang 2010).

These different methods utilized for wood bending process, offers woodworkers and designers a broader range of creative possibilities and enhanced flexibility. Factors, such as the radius of bending, species, moisture content, thickness and width of wood, steaming time, fiber direction and defects are of profound importance in the wood bending process (Büyüksarı & As 2013; Niemiec & Brown 1995).

However, when a piece of wood is bent, the outer side of the bend undergoes stretching or tension due to fiber elongation, while inner side being under compressive stress due to fiber contraction (Stevens & Turner 1970). This bending creates internal stresses that work to revert the wood to its original straight shape (Peck 1957).

The microstructure, along with the variety and distribution of various cell types, plays a key role in influencing the physical and mechanical characteristics of wood. When wood undergoes bending, it experiences tension and compression forces that can influence the bonding between its structural elements. The stronger the bond between the wood elements, the better the wood can withstand these tensile and compressive forces. On the other hand, if the binding force is weak, it can lead to fractures or splits, ultimately reducing the strength of wood and potentially causing it to fail. Relative proportion of the wood elements (fibres, vessels, rays and axial parenchyma) have a crucial role in determining the bending ability of wood and degree of curvature up to which any wood can be bent. Thus, knowledge of the anatomy of wood is important to determine its uses as engineering material, because these characteristics influence its durability, physical and mechanical properties (Tsoumis 1991; Winandy & Rowell 1984).

A considerable amount of research has been conducted on changes occurring in the anatomy of wood modified at various temperature ranges have been explored in detail by many scholars (Awoyemi & Jones, 2010; Boonstraet al. 2006, Terziev & Daniel 2002, Fengel & Wegener 1989). However, there is scarcity of information regarding changes occurring in the wood at microscopic level as a consequence of bending process. Study of wood microstructure could assist in understanding the response of wood to applied external stress during wood bending process. Therefore it becomes imperative to analyse the anatomical structure of wood affected by such modification processes, since these changes are very crucial and likely to influence the strength and mechanical behaviour of wood products in end use applications (Dogu et al. 2010).

Grevillea robusta, also known as 'Silver oak,' is a fast growing agro-forestry tree belonging to the Proteaceae family. Originating from the eastern coastal regions of Australia, it has expanded its presence to various countries including India and Africa. In India, this tree species holds great significance as a valuable timber resource and is extensively cultivated as a shade tree in coffee and tea plantations (Nagaveni et al. 2011). The wood is notable for its distinctive mechanical and anatomical properties, making it suitable for a variety of uses. The wood has a basic density of 0.478 g/cm^3 (Shanavas & Kumar 2007). The timber is utilized for variety of purposes such as in the production of railroad ties, plywood, paneling, air-freight cases, furniture (Orwa et al. 2009).

Our knowledge regarding the morphology of silver oak bentwood remains limited. In this endeavour, this study represents a unique effort to explore the effects of bending on the microstructure of wood. The primary objective of this study is to conduct a detailed microscopic examination of the defects that develop within bentwood, such as splits or fractures with an aim to gain insights into the specific roles played by fundamental wood elements in maintaining the structural integrity of bentwood. Consequently, the study will address specific inquiries pertaining to the suitability of wood species for bending based on the proportions of different wood elements. This research will enable the prioritization of wood species suitable for bending, thus ensuring that only appropriate species are utilized for this purpose.

2. Material and methods

2.1. Wood Sample

A bentwood specimen of *Grevillea robusta* (silver oak) was obtained for the present study, from the wood anatomy laboratory of the institute (Fig. 1a). The bentwood sample was divided into 20 sections, each representing distinct stress levels evident in the wood sample after undergoing bending (Fig. 1b).

Upon initial examination, it was noted that most consecutive blocks displayed similar patterns. Consequently, for the sake of simplifying the study, alternate blocks were selected for further analysis. Microscopic studies were then conducted on these alternate sections. True blocks were prepared and soaked in water for a minimum of 24 hours to achieve optimal softening. Subsequently, sections of the wood sample were obtained from the blocks of the respective sections using the Reichert microtome, ensuring a uniform thickness of 60–80 micrometer (μm). Finally, these sections were permanently mounted using internationally acclaimed process (Gärtner & Schweingruber 2013), and is described in the subsequent section.

2.2. Sectioning and staining procedures

The sections were soaked in iron alum, so as to remove the impurities present in the sections and later were washed 5–6 times. The sections were soaked in haematoxylin (2–3 drops) till the sections turned blue. Haematoxylin acts as a moderator and help bind the stain to the sections properly. The sections were then soaked in water for about half an hour. 4–6 drops of safranin stain were used with 30% alcohol and sections were soaked overnight. The sections were run through alcohol dehydration series. The concentrations of 30%, 50%, 70%, 90% and absolute were used for the complete dehydration of the sections.

The sections were later soaked in a mixture of xylene: clove oil (50: 50). Xylene is used to ensure that the section does not contain any moisture anymore and clove oil is used to prevent the rolling of the sections respectively. The sections were then mounted in Canada balsam to prepare the permanent Blocks.

2.3. Data Collection

The collection of data was done in accordance to the list of microscopic features given by International Association of Wood Anatomists (IAWA 1989) for Hardwood Identification. The photographs of the sections were taken by the Carl Zeiss compound light microscope on the top of which Carl Zeiss camera was fitted with photographic attachments. Digital Software was used to capture the microscopic images with 100x magnification.

3. Results and Discussions

3.1. Wood anatomy of *Grevillea robusta*

Wood is diffuse porous with tangential arrangement. Vessels size ranging from large to medium and moderately numerous (3–9 per mm^2). Vessels are usually crammed with tangential rows filled with deposits and distinct apart by fibrous tissue in alternate fashion, usually in irregular clusters or tangential multiples, few solitary, round to oval, mostly open and vessel lines distinct. Growth ring boundaries are clearly distinct. Thick to thin-walled fibres are evident, both septate and non-septate, with simple to minutely bordered pits.

Parenchyma paratracheal-vasicentric and aliform to aliform-confluent, just visible to the naked eye, distinct under hand lens in closely spaced lines enclosing or connecting the vessels tangentially. Rays of two types viz. broad to very broad and fine to very fine are observed, the previous prominent to the oculus, widely spaced and the later rarely visible under the hand lens. Prominent silvery radial flecks are present. Gum canals of traumatic type occasionally present in tangential row. The wood microstructure of each block was further observed to ascertain the level of damage caused as a consequence of bending process.

3.2. Microscopic study of the wood blocks

The anatomical structure of hardwoods is more complex than that of softwoods due to the presence of various cell types, mainly vessels, fibers, parenchyma, and rays and exhibit significant variability among these cells (Wiedenhoeft 2010). The structural integrity of these elements has a profound effect on the different wood properties. These structural elements of wood get influenced, when wood is subjected to bending process. In this study, it was evident that the structural components of wood were intact in the initial blocks (block numbers 1 and 3). As we move towards the areas having higher stress concentration (block numbers 5, 7, 9, 13 and 15), the number of splits or fractures get increased due to comparatively more stress in comparison to other block number.

Cross section of block number 1 (Fig. 2a.) served as a control sample for the study as this portion was from unbent area of the wood sample. As evident from figure, there is no splitting of wood elements (fibre, vessel, ray and parenchyma). There was no stress development due to which all elements were intact and no splitting was observed. Similar pattern was observed for block number 3 and 5 (Fig. 2b and 3a respectively) as there was no splitting between wood elements.

Block 7 (Fig. 3b) showed damage in vessel walls whereas block 9 (Fig. 4a) showed radial splitting of fibres with damage in vessel walls.

Block 11 (Fig. 4b) showed radial splitting of fibres with maximum in number of splits per unit area (Fig. 6), while Block 13 (Fig. 5a) showed tangential splitting of fibres with less number of splits.

A decreasing trend in number of splits per mm^2 can be observed from Block number 13. Block number 11, 13 and 15 showed maximum splitting per unit area i.e. 16, 15, 14 splits per mm^2 respectively as evident from Fig. 6. This area of wood sample was subjected to maximum stress due to which forces got increase between cells and resulted in splitting and stretching of fibres.

Block 15 (Fig. 5b) showed radial splitting of fibres with decrease in number of splits per mm^2 and block 17 (Fig. 6a) showed similar splitting of fibres but less in numbers and damage of vessel walls were observed in both blocks.

Block 19 (Fig. 6b) depicted very less damage to fibres and vessel walls with a decrease in number of splits per mm^2.

Figure 7 shows that the number of splits per unit area started increasing with block numbers indicating that the blocks sampled from the points near maximum curvature were under maximum stress. In higher stress conditions a splitting force is developed between different wood elements (vessels, fibre, parenchyma and rays) and radial splits also get developed whereas in lower stress conditions, tangential splitting between fibres only was observed.

Vessels and fibres are comparatively thick walled cells compared to rays and parenchyma, which are thin walled cells. This study suggests that wood having higher proportion of thin walled cells would be less susceptible to splitting, hence, more suitable for bending. Although, fibres are crucial element as far as strength properties of wood are concerned, however, this study shows that the binding forces between fibres is not so strong as compared to other wood elements. Hence, when wood is subjected to higher stress conditions, it results in weakening of binding forces leading to splitting between the fibres. It suggests that wood species having more proportion of thin walled tissues (parenchyma and rays) are suitable for industrial application of bending and making curved structures.

Dogu et al. (2010) evaluated the effect of temperature and pressure on anatomical features of *Pinus sylvestris L.* (Scotch pine) solid wood panels. The panels were hot pressed at temperatures of 120°C or 150°C and pressure of either 5 or 7 MPa for 1 hour. The findings indicated that the highest level of damage occurred in the early wood regions. Additionally, the study highlighted that a consistent growth ring structure, with uniform earlywood and latewood widths across the samples, significantly helps prevent cell collapse. Furthermore, the processing parameters (temperature and pressure) were observed to be correlate with the anatomy of the wood samples.

Similarly, Dogu et al. (2016) also reported the extent of damages in the thick walled cells like fibres and parenchyma after thermal modification of wood. In thermal modification of wood, the wood undergoes extreme pressure and temperature which tends to rupture cell walls in wood. The results of present study is in cognizance with the works carried out by Dogu et al. (2010) and Dogu et al. (2016). Although, the samples used in this study did not underwent any thermal treatments, but the wood underwent bending process and these processes might have generated enough amount of stress to damage thick walled cells like vessels and fibres. The thin walled cells like parenchyma and rays have shown enough flexibility that they undergo extreme bending pressure without being severely damaged.

4. Conclusions

The research indicates that a high concentration of thick-walled cells reduces the flexibility of wood and makes it more prone to damage on applying bending forces, while a higher proportion of thin-walled cells enhances flexibility and bending potential. However, it’s important to note that thick walled cells have a significant contribution on the overall strength of wood. Therefore, the proportion of thick and thin-walled cells in wood have a key role to play in determining the potential applications and usage, considering wood structure and its intended use. This approach ensures that wood resources are used judiciously and sustainably, especially in the context of limited availability of timber resources.

Declarations

PM : Conceptualization, methodology, investigation, validation, writing-original draft

KM: Writing- review and editing

AK : Investigation, writing- review and editing

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Author Contribution

Statements and Declarations:Priyank Maithani: Methodology, investigation, validation, writing – original draftKamal Mishra: Conceptualization, writing – review and editing.Atul Kumar: Data Analysis and writing – Review and editing.

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Figures

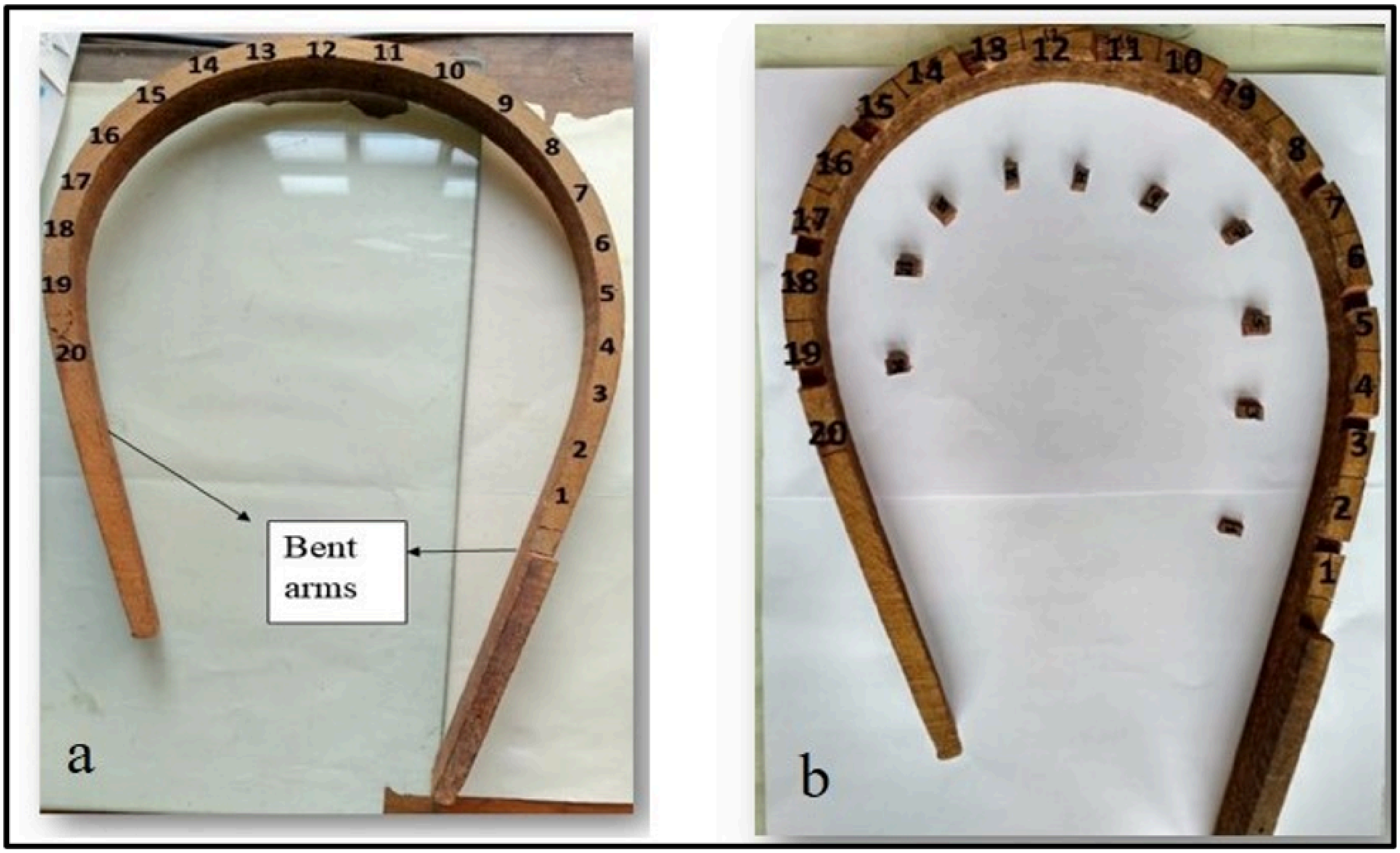

Figure 1

a) Bentwood sample of *G. robusta* **b)** Block preparation for microscopic study

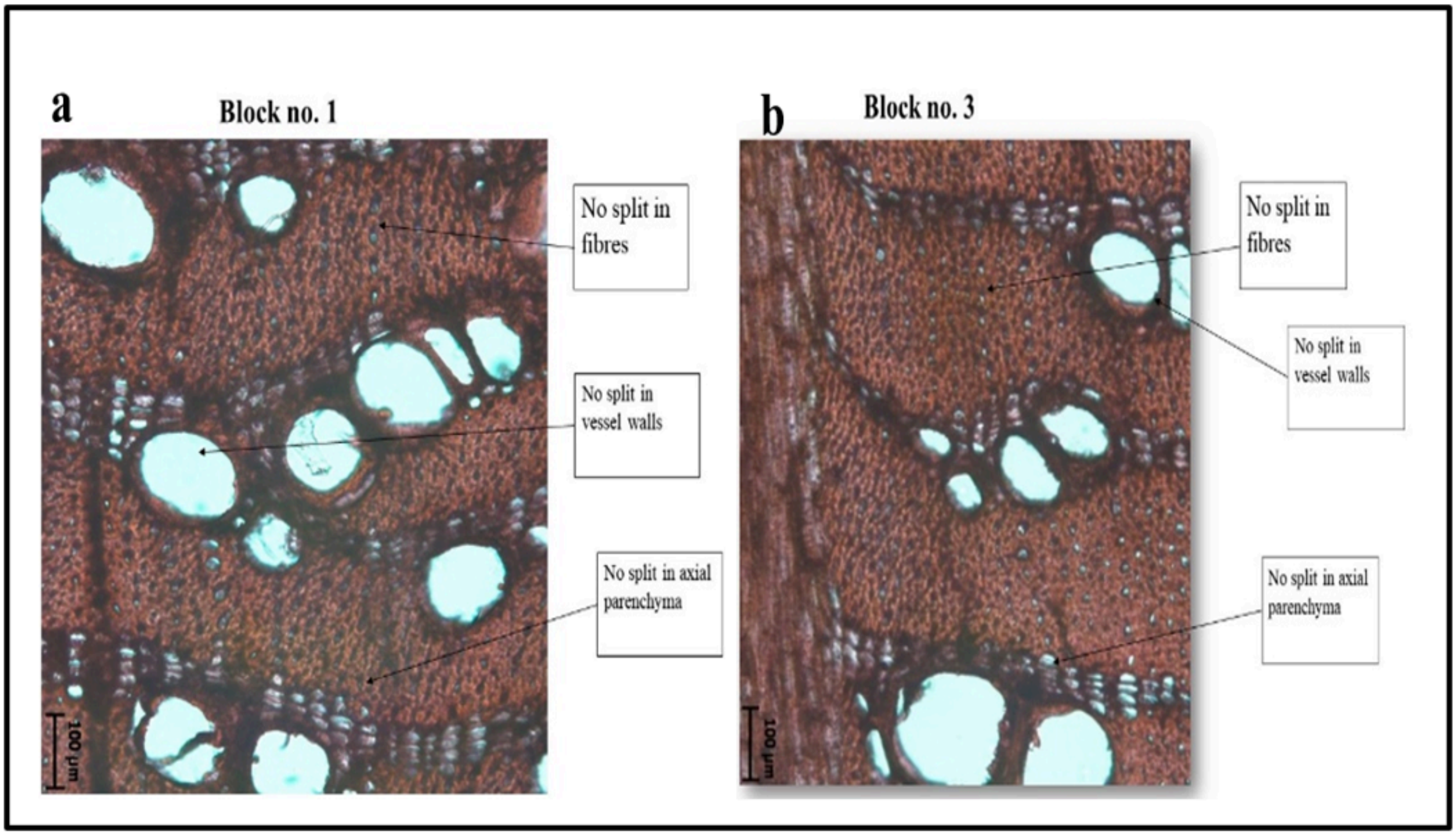

Figure 2

Cross section of a) Block number 1 and b) Block number 3

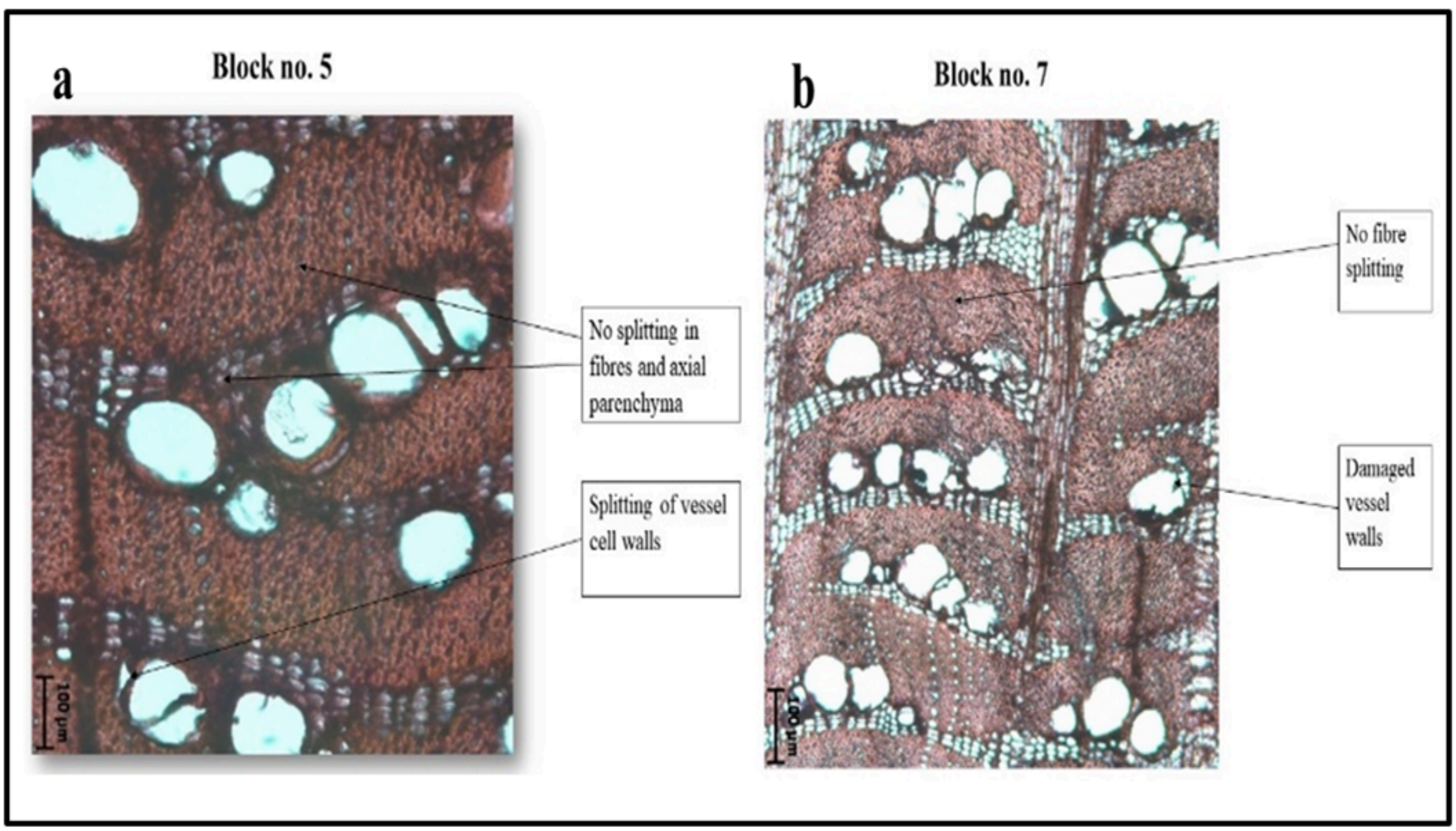

Figure 3

Cross section of a) Block number 5 and b) Block number 7

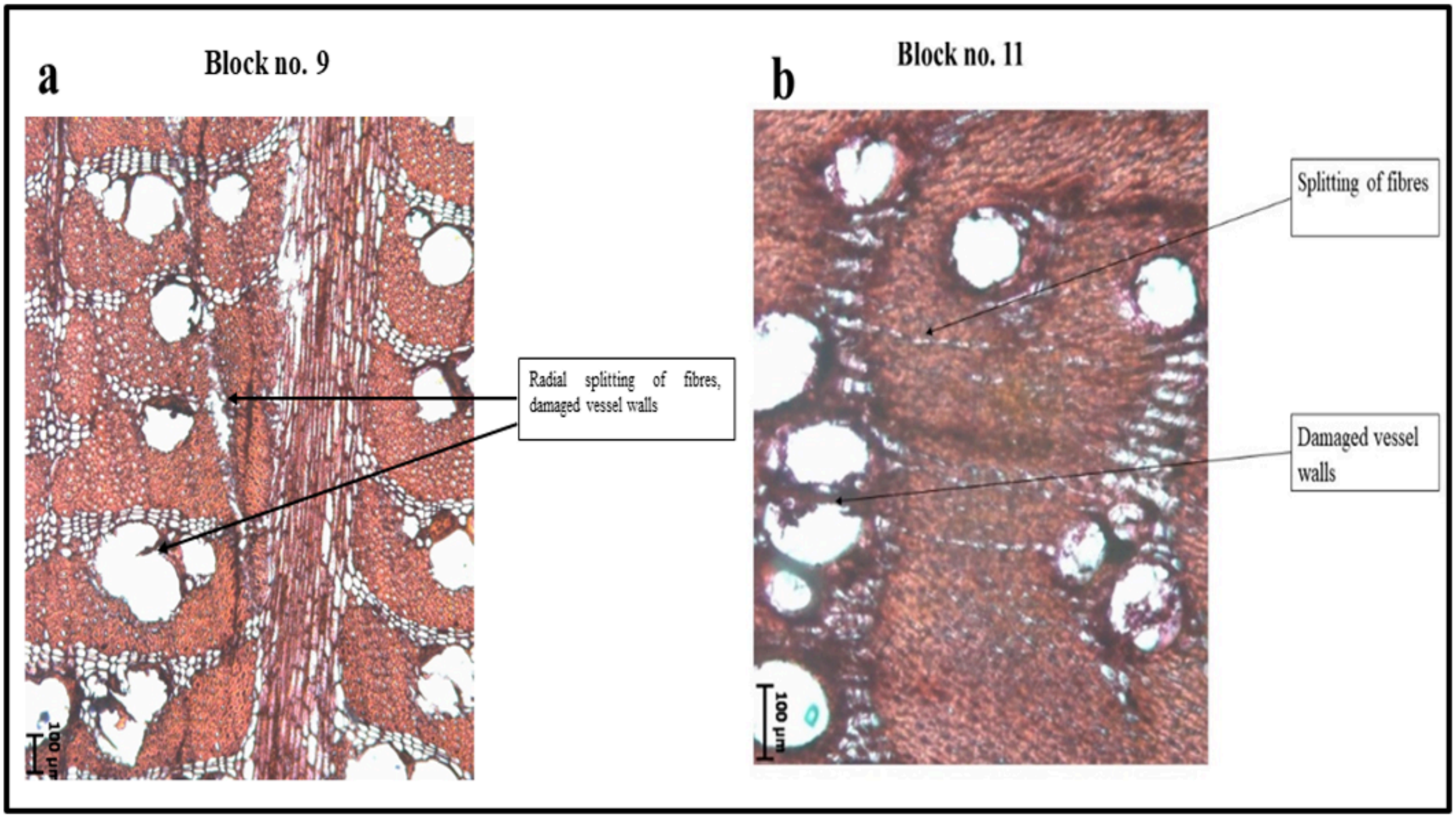

Figure 4

Cross section of a) Block number 9 and b) Block number 11

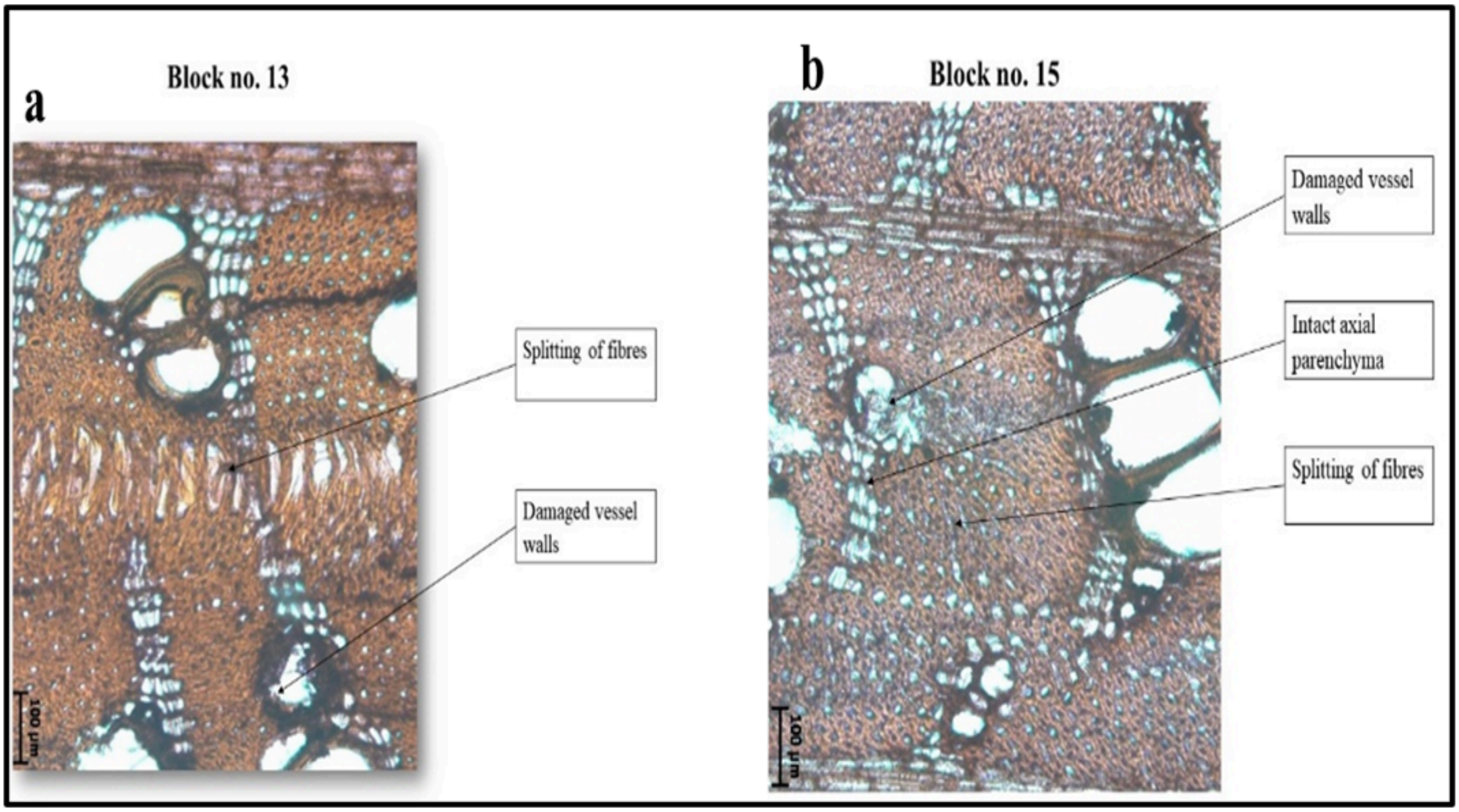

Figure 5

Cross section of a) Block number 15 and b) Block number 17

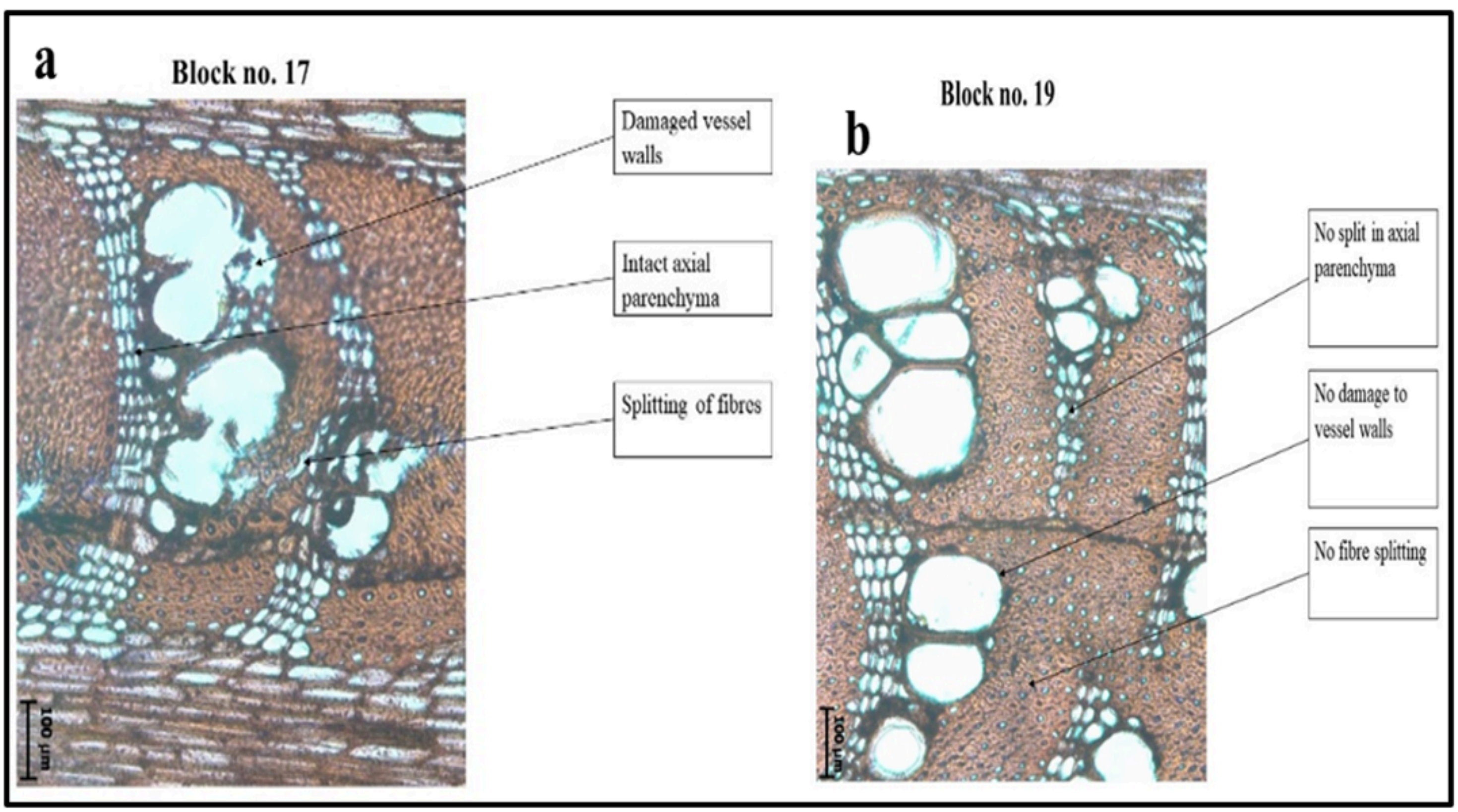

Figure 6

Cross section of a) Block number 17 and b) Block number 19

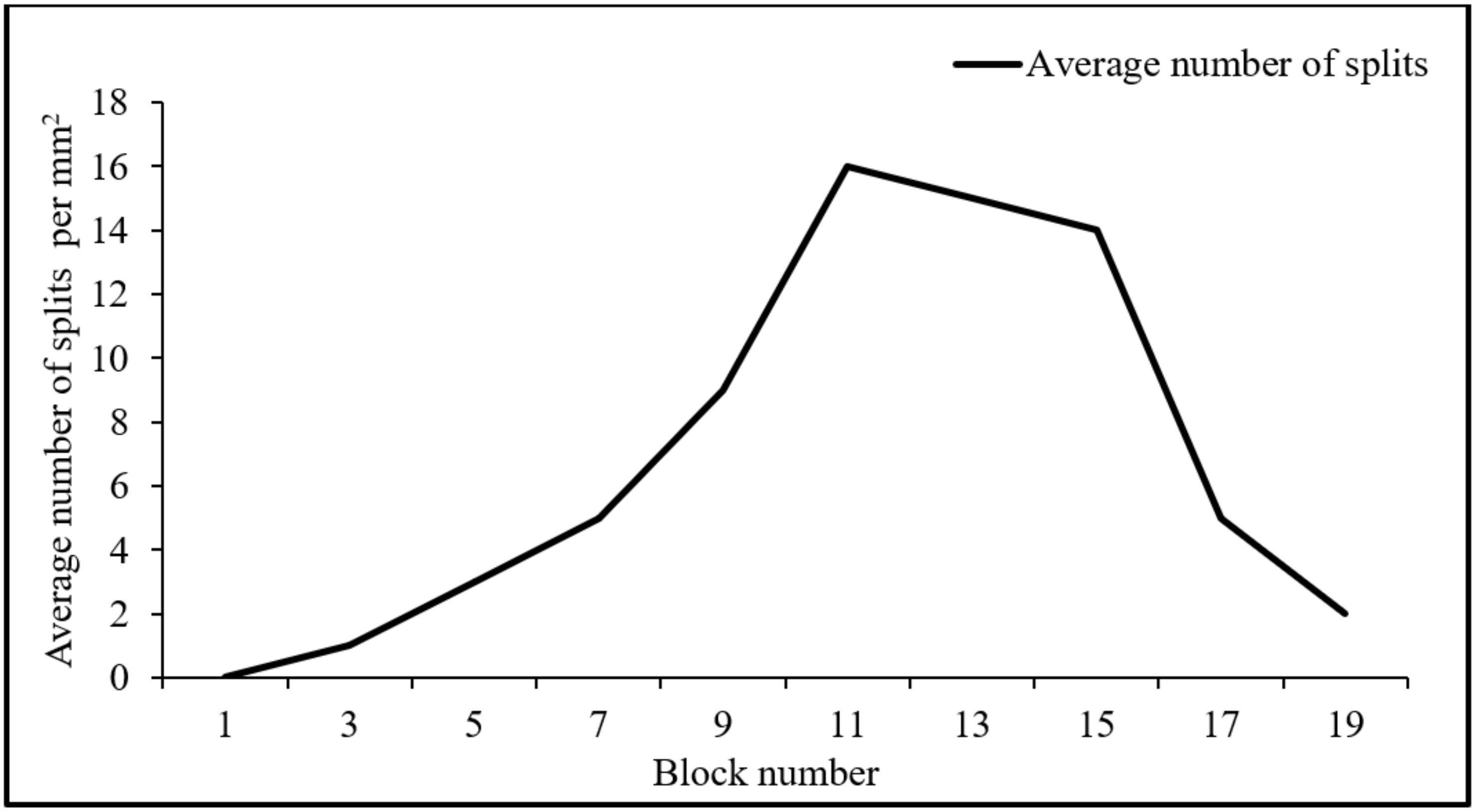

Figure 7

Average number of splits observed (per mm^2)