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Tracheal Structure of the Moraceae Family and Its Contribution to High School Biology Learning

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ABSTRACT

This study investigates the tracheal structure of several selected Moraceae species and its potential as a medium for learning high school biology. The method used is descriptive and maceration technique, with the aim of describing in detail the structure of tracheal cells in several species of plants of the Moraceae family. The research was conducted at the Biology Education Laboratory of Sriwijaya University in September-December 2024. The samples used were jackfruit (*Artocarpus heterophyllus*), breadfruit (*Artocarpus altilis*), mulberry (*Morus nigra*), banyan (*Ficus benjamina*) and banyan beringin (*Ficus callophylla)* stems. Parameters observed included trachea type, secondary wall thickening type, perforation type, and length and diameter of tracheal cells. The results showed that the types of tracheal found were reticulate, spiral, and anular. Secondary wall thickening types are reticulate I, reticulate II, Spiral I, Spiral II, and Ring. The types of perforations found were scalariform and simple. The length of tracheal cells varied from 247.16 μm to 832.34 μm, with the longest tracheal element found in the trachea of *Artocarpus heterophyllus* and the shortest in the trachea of *Ficus benjamina*. Meanwhile, the diameter of the tracheal elements ranged from 11.06 μm to 127.69 μm, with the widest diameter in the trachea of *Artocarpus altilis* and the narrowest in the trachea of *Ficus benjamina*. in addition, based on the validation results, the booklet developed from this study scored 55 out of 60, or 91.66%, which is categorized as very valid. This indicates that the booklet is suitable for use in the field and has the potential to be an effective learning resource to support biology learning in high schools.

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INTRODUCTION

Plants are multicellular eukaryotic organisms consisting of many cells. Plant organs such as roots, stems, and leaves are complex structures composed of various types of main tissues, namely epidermal tissue, basic tissue, and vascular tissue (Ramdhini et al., 2013). Stem organs in plants are composed of several types of major tissues that work together to support the function and growth of plants as a whole. One of the tissues as the main constituent of the plant stem is the vascular tissue.

The vessel network in the stem is xylem and phloem. Both tissues are known as complex tissues, meaning that they are composed of various tissues with different structures and functions. Both networks perform their role, so that plants can grow and develop. Xylem is the main channel for transporting water and all substances dissolved in it from the roots (and also other parts of the plant body that absorb water) to other parts of the plant, especially the leaves (Kusumaningrum, 2017).

The most important function of xylem is to transport water and dissolved substances in it to all parts of the plant. Floem is a transport vascular plant tissue consisting of living cells arranged into elongated channels that transport sugar and other organic nutrients to all parts of the plant(Ai, 2016) . Floem functions in flowing the results of photosynthesis from the leaves to all parts of the plant. Phloem consists of several components, namely filter vessels formed from interconnected cells, forming channels to drain the results of photosynthesis. Companion cells provide nutrients and control the function of the vessels. Phloem fibres provide structural support to the phloem network. While the phloem parenchyma plays a role in storing various substances such as flour, crystals, and resin.

Xylem is a complex transport network that is divided into various kinds and shapes of cells. Typically, xylem cells have cells with very thick lignin walls that provide much-needed strength and structural support to the plant (Darmanti, 2015). This lignin not only provides mechanical strength but also reduces cell permeability to water, allowing for efficient transport of water from roots to leaves.

The xylem element consists of: (i) xylem fibres, (ii) xylem parenchyma and (iii) tracheal elements Nugroho (2012). Xylem fibres consist of long cells with secondary walls containing lignin. Compared to tracheids, xylem fibres have thicker walls and fewer nodes. There are two types of xylem fibres, namely tracheid fibres and libiform fibres. On the other hand, xylem parenchyma consists of living cells that function to store food reserves. The tracheal element is a component of xylem that consists of elongated cells, does not contain protoplasm, has a lignin cell wall and there are noctahs. Tracheal elements consist of tracheids and trachea (Mulyani, 2006). Tracheids are long cells with walls that have a uniform thickness and pointed ends, but do not have holes. Trachea is one of the components of xylem vessel cells which together with tracheids are known as tracheal elements (Barclay, 2015), a series of tracheal cells arranged to form tubes with thick walls that are connected to each other at the ends and base of the cell, forming long channels that can reach several meters. Tracheids are also called wood vessels and consist of rows of cells arranged lengthwise and connected at the ends and base(Hindriana, Anna, 2023).

The main difference between trachea and tracheids lies in their structure and how they are formed. Tracheid cells have single, long, slender cells with tapered ends and no large holes (only pores) on the end walls, so that the flow of water through them is slower and works as a single water transport path, while trachea cells have cell walls thickened by lignin, with holes at the top and bottom ends. While tracheid elements are cells with both ends without perforated. These cells die when mature, but the lignified cell walls remain and form channels through which water flows within the xylem vessels. Tracheal elements have wall thickening patterns in the form of annular, spiral, scalariform, and reticulate patterns (Arslan et al., 2019). The connections between the trachea cells above and below form elongated capillary tubes. The cells that form the trachea, which can reach lengths of up to 50 cells and are located in the sclerenchyma of the Cyperaceae family, are referred to as components of the xylem (Hidayat, 1995).

Some previous research results, regarding the study of tracheal type structures have been carried out by several researchers. The results of these studies using the Scanning Electron Microscope (SEM) method show differences in the shape and characteristics of the piper genus tracheal vessel network, in the form of secondary wall thickening and special structures in the trachea including the length of the vessel diameter element and the shape of the element seen in transverse slices (Kurniawati et al., 2015). In various varieties of the genus Mawar, it shows that the anatomical description of tracheal tissue in various varieties of the genus Mawar has a relatively similar shape, namely spiral 1 and spiral 2. The size of tracheal tissue, which includes secondary wall diameter and secondary wall thickness, is on average identical or similar (Chico Palam et al., 2016). Then research on lettuce and mustard plants showed differences in the characteristics of tracheal tissue observed through wholemont preparations, in lettuce plants, the protoxylem trachea has a noctah and spiral shape, while the metaxylem is noctah-shaped. Whereas in mustard plants, both protoxylem and metaxylem are both in the form of noktah (Faizul Huda et al., 2023). Xylem is the primary transport tissue in plants, consisting of tracheal elements with varying forms of secondary wall thickening, such as spiral, annular, and reticulate. Morphological variations in tracheal elements are closely related to their function in water transport and adaptation to environmental conditions, such as salinity, which can affect the size and shape of the trachea. (Novita et al., 2017) that Rosella plants growing under salinity stress conditions have xylem vessels and a widened tracheal diameter. However, from some of these studies, there has been no research that comprehensively documents the type of trachea in the Moraceae family. So to find out the characteristics of the trachea in the Moraceae family is important to do. Besides As basic data information about the characteristics of the trachea, this data can also be used as a learning resource in high school biology material.

Based on the observation results of high school Biology teaching materials, particularly on the topic of plant tissues, it was found that the textbook only provides a brief description of the xylem element without representative images of tracheary cells. This makes it difficult for students to understand the structure of tracheary cells and relate it to their function. Additionally, the examples used in textbooks are generally not found in the students' surroundings. Therefore, in this study, three subfamilies of Moraceae were used: Moreae, Artocarpeae, and Ficeae, with the species *Artocarpus heterophyllus, Artocarpus altilis, Morus nigra, Ficus benjamina,* and *Ficus callophylla.* These species are types of plants that are easily found in the students' surrounding environment. Therefore, the results of this research can bridge the limitations of existing learning resources and serve as enrichment material in high school Biology learning.

RESEARCH METHOD

This research was conducted using a descriptive method. Descriptive research aims to describe events that occur at this time, with a focus on solving actual problems as they exist at the time the research was conducted (Winarno, 2013). This method was used to examine the structure of the trachea of 5 Moraceae plants. The samples used in this study were plant stems (branches) with a diameter ranging from 3-5 cm. The branch selected was a mature part, indicated by brown bark. This is because tracheids are generally found in the part of the stem that has undergone secondary growth.

The plants used were *Artocarpus heterophyllus, Artocarpus altilis, Morus nigra), Ficus benjamina and Ficus callophylla*. The research was repeated 10 times to obtain various forms and types of trachea. The research was conducted in several stages, namely: i) material preparation; (ii) tracheal maceration process; (iii) Observations were made using a Boeco brand binocular microscope with a magnification of 400x.

The results of the tracheal structure research are used as enrichment material in high school Biology lessons in the form of a booklet. Booklets were chosen because they have several advantages, including being smaller, easier to use, and able to be designed with an attractive appearance. The stages in preparing the booklet include: (i) Collecting images of the trachea from five species of the Moraceae family. (ii) Arranging the images and descriptions into a booklet format. The research data was compiled into material that could be presented in a booklet format, considering content, language, and visual aspects. (iii) Expert Validation: The resulting booklet was validated by two lecturers from the Biology Education Department, Faculty of Teacher Training and Education, Sriwijaya University, and one high school biology teacher, who served as content and media experts. The validation results were then categorized into the following categories (Table 1).

Table 1. Validity criteria for the booklet

Skor (%)	Criteria
81-100	Very Valid
61-80	Valid
41-60	moderate
21-40	Less valid
0-20	Invalid

Material Preparation

1. Prepare plant stem (branch) samples with a diameter of (3-5 cm).
2. Plant branches that have been taken are cut with a size of (±) 2 cm, put into a jar and given FAA solution.
3. Furthermore, plant branches with a diameter of (±) 2 cm were chopped to a smaller size (the length of a).

Tracheal Maceration

Maceration is one method of separating compounds by soaking them in an organic solvent at a specific temperature. This maceration method is simpler, easier, and requires lower cost (Aryanti et al., 2025; Prihatini & Ismail 2023). The maceration process is described as follows.

1. The prepared pieces of material are put into a test tube that is containing 20% KOH.

2. Test tubes containing the ingredients and 20% KOH solution were brought to a boil for 2- 5 minutes.
3. Next, the material is washed with running water for 15 minutes, then put into a mixture of 20% chromic acid and 20% nitric acid solution in a ratio of 1:1, for 2-3 hours. To speed up the maceration process, put it in a 60°C incubator. The wood pieces are soft and can be separated using a stemmed needle.
4. The material is then washed under running water for 20 minutes.
5. All decomposed materials were dehydrated with a series of 30%, 50%, 70% 90% 100% alcohol and xylol with a time interval for each stage of 5 minutes. At the 7% stage, they were stained with 1% safranın for 24 hours.
6. At the xylol-staining stage, break down the material with two needles on a glass slide and observe using a microscope.
7. After obtaining the observation results in the form of tracheal cells, give a few drops of canada balsam, then covered with a glass lid.

RESULTS

From the observation of the tracheal structure of several plants of the Moraceae tribe, data were obtained in the form of tracheal type, type of secondary wall thickening, type of perforation, length and diameter of tracheal elements. The results of these observations are presented in Table 1.

Table 2. Tracheal cells in some stems of Moraceae plants

No	Trachea Elemen	Plants of the Moraceae Tribe				
		Jackfruit	breadfruit	Mulberry	Banyan	Banyan
1	Trachea Type	Reticulate Spiral Anular	Reticulate	Reticulate	Reticulate	Reticulate Spiral
2	Thickening type Secondary wall	Mesh I Mesh II Spiral I Spiral II Ring	Mesh I Mesh II	Mesh I Mesh II	Mesh I Mesh II	Mesh I Mesh II Spiral II
3	Perforation Type	SK S	SK S	SK S	S	SK
4	Length (µm)	595,58	646,30	650,83	581,84	454,05
5	Diameter (µm)	63,142	70,683	66,376	64,991	71,105

Description: SK: Scalariform; S: Simple

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Based on Table 1, tracheal types can be classified based on the form of secondary wall thickening they have, so the name of the tracheal type reflects the pattern of secondary wall thickening present. In other words, the secondary wall thickening on the trachea determines its type. The results of observations found 3 types of tracheas, namely reticulate type found in all five types of plants, spiral type found in the stem of Nangka (*Artocarpus heterophyllus*) and Beringin (*Ficus callophylla*) and Anular type found in the stem of Nangka (*Artocarpus heterophyllus*). The reticulate type has a secondary wall thickening shaped like a mesh pattern. This pattern consists of interconnecting lines that form a net along the tracheal wall. The spiral type has a spiral-shaped secondary wall thickening that is wrapped around the tracheal wall. While the annular type has a ring-shaped secondary wall thickening or a regular circle.

There are five types of secondary wall thickening obtained, namely: Mesh I, Mesh II, Spiral I, Spiral II and Ring. Mesh Type I with secondary wall thickening in the form of scalariforms in the form of horizontal or vertical lines that are more sparse, so that spaces such as squares and rectangles are formed. Mesh Type II has denser secondary wall thickening, forming spaces such as small squares. Spiral Type I has a wider distance between turns, resulting in a sparser spiral pattern while Spiral Type II has a more regular spiral pattern with denser spiral turns and forms a more structured circle. In addition, Ring type is the simplest secondary wall thickening pattern. The thickening layer is arranged in a ring pattern surrounding the inside of the primary wall.

Two types of perforations observed: scalariform and simple. The scalariform type is a perforated board with parallel flat holes, forming a ladder-like pattern. While the simple type is a board with only one hole. However, the hole covers the entire end wall of the cell it occupies. The length and diameter of the tracheal elements varied greatly. The results showed that the length of the tracheal elements ranged from 247.16 μm to 832.34 μm. While the diameter of the tracheal elements ranged from 11.06 μm to 127.69 μm. The results for each plant are detailed as follows.

Trachea in Jackfruit (*Artocarpus heterophyllus*) Stem

Observations of the tracheal structure of jackfruit (*Artocarpus heterophyllus*) plants show that there are variations in the types of tracheids and secondary wall thickening, namely reticulate type with thickening of secondary walls of Mesh I and Mesh II wall thickening, spiral type with thickening of secondary walls of spiral I and spiral II, and annular type with ring secondary wall thickening. Perforation types including scalariform and simple (Figure 1). While the length and diameter of tracheal elements also vary. The length of the trachea ranges from 400.54 μm to 715.00 μm, with an average length of 595.58 µm. The diameter of the tracheal elements' ranges from 86.61 µm to 101.07 µm, with an average diameter of 63.14 µm (Figure 2).

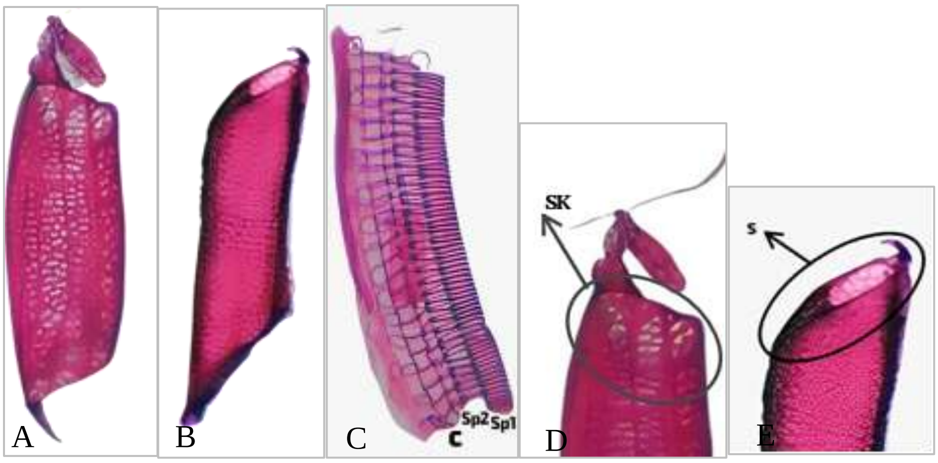

Figure 1. Tracheal structure in jackfruit (*Artocarpus heterophyllus*) stem, 400x magnification; A. Reticulate type, with thickening of secondary walls of Mesh I; B. Reticulate type, with thickening of secondary walls of Mesh II; C. Spiral 1 (sp1), Spiral 2 (sp2) and Ring (c); D. Scalarform perforation; E. Simple perforation

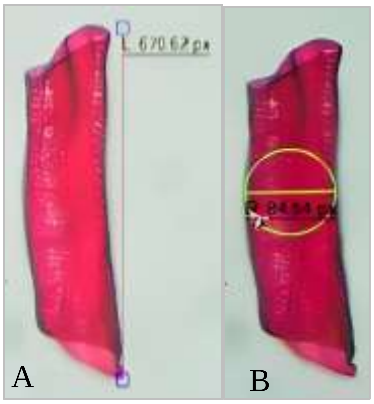

Figure 2 Tracheal cell size in Jackfruit stems (*Artocarpus heterophylus*). A. Length (670.60 µm); B. Diameter (84.54 µm).

Trachea in the breadfruit (*Artocarpus altilis*) Stem

Observations of the breadfruit (*Artocarpus altilis*) stem trachea structure show that there is variation in the type of trachea and the type of secondary wall thickening, namely reticulate type with wall thickening of mesh I and II. The perforation type also varies, namely Scalariform and Simple (Figure 3). The length and elements of the trachea also vary. The length of the trachea ranges from 459.39 µm to 764.36 µm, with an average length of 646.30 µm. The diameter of the tracheal elements ranges from 19.38 µm to 82.76 µm, with an average diameter of 70.683 µm (Figure 4).

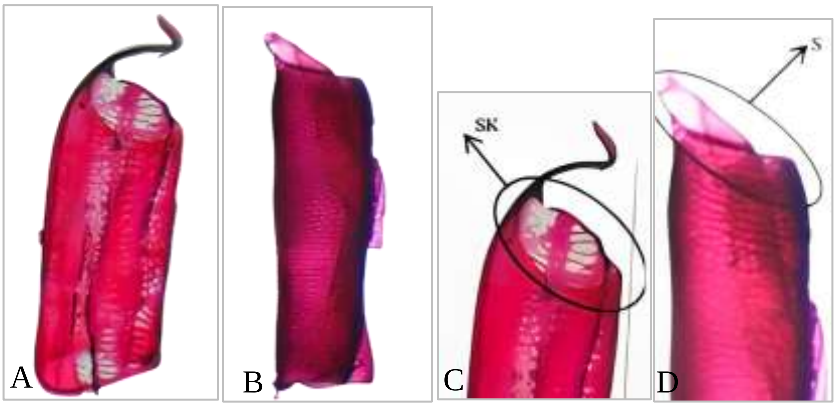

Figure 3. Tracheal structure in the breadfruit (*Artocarpus altilis*) Stem 400x magnification, A. Reticulate type, with secondary wall thickening of Mesh I; B. Reticulate type, with wall thickening secondary mesh II; C. Scalariform perforation; D. Simple perforation.

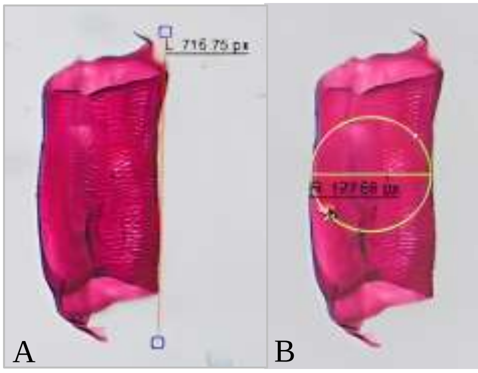

Figure 4 Tracheal cell size in breadfruit (*Artocarpus altilis*) stem A. Length (716.75 µm); B. Diamater (127.69 µm)

Trachea in the mulberry (*Morus nigra*) Stem

Observations of the tracheal structure of mulberry (*Morus nigra*) stem, showed that the type of trachea and the type of secondary wall thickening were reticulate with wall thickenings of the mesh I and II. The perforation type was scalariform (Figure 5). The length of the tracheal elements' ranges from 589.78 µm to 630.27 µm, with an average of 650.83 µm. The diameter of the tracheal elements' ranges from 54.00 µm to 56.96 µm, with an average diameter of 66.376 µm (Figure 6).

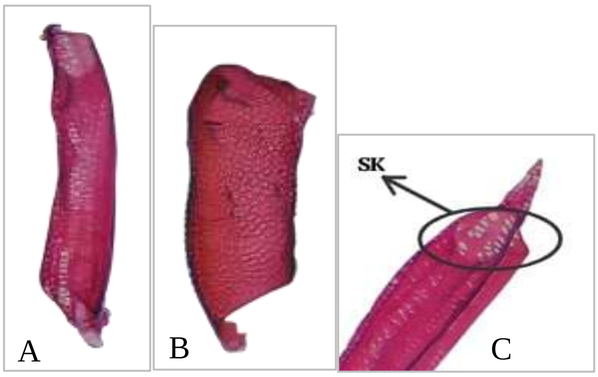

Figure 5. Tracheal structure in the mulberry (*Morus nigra*) stem 400x magnification A. Reticulate type, with thickening of the secondary wall of Mesh I; B. Reticulate type, with secondary wall thickening of Mesh II; C. Scalariform perforation.

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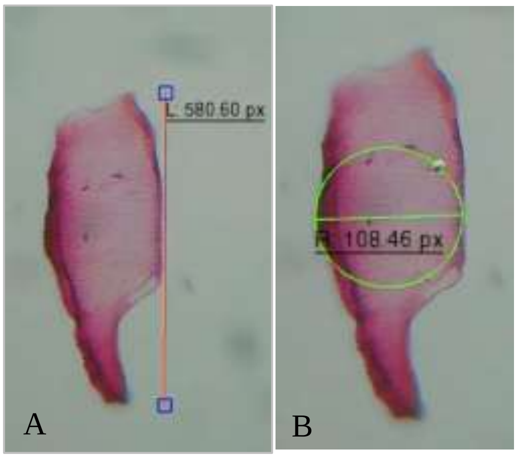

Figure 6. Tracheal cell size in mulberry stem (*Morus nigra*) A. Length (580.60 µm); B. Diamater (108.46 µm)

Trachea in the bayan (*Ficus benjamina*) Stem

Observations of the tracheal structure of the Banyan (*Ficus benjamina*) showed that the type of trachea were reticulate with secondary wall thickening of mesh I and II. The perforation type was simple (Figure 7). The length of the trachea ranges from 551.35 µm to 736.95 µm, with an average length of 581.84 µm. The diameter of the tracheal elements' ranges from 80.89 µm to 94.64 µm, with an average diameter of 64.991 µm (Figure 8).

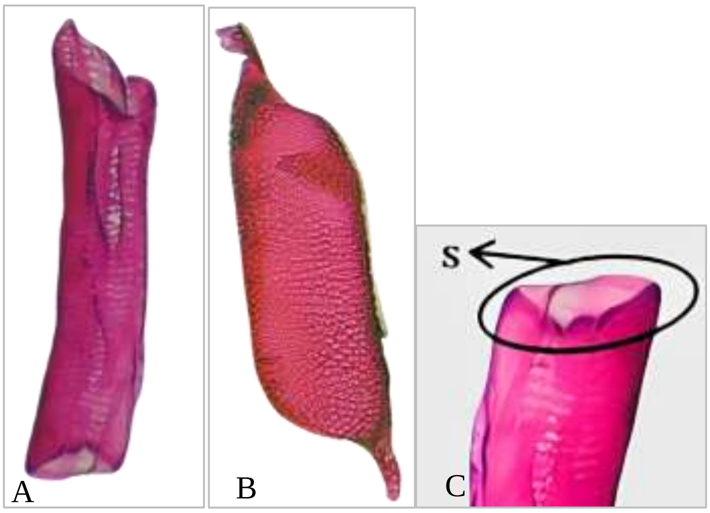

Figure 7. Tracheal structure in the banyan (*Ficus benjamina*) stem 400x magnification A. Reticulate type, with secondary wall thickening of mesh I; B. Simple perforation. Reticulate type, with secondary wall thickening of Mesh II; C. Simple perforation.

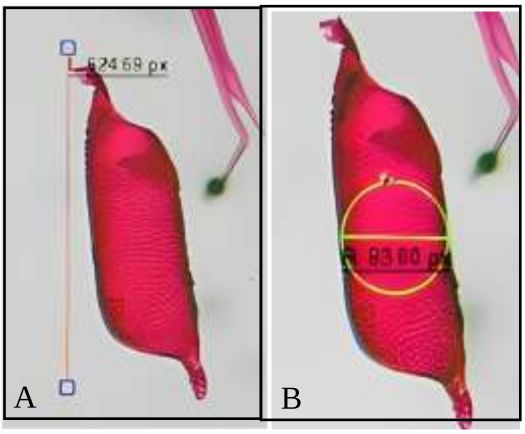

Figure 8. Tracheal cell size in banyan stems (*Ficus benjamina*) A. Length (624.69 µm); B. Diameter (83.60 µm).

Trachea in the bayan (*Ficus callophylla*) Stem

Observations on the cell structure of the banyan tree (*Ficus callophylla*) trachea show that there are 3 variations: reticulate type secondary wall thickening **mesh** I and II, and spiral type with spiral wall thickening II. The perforation type is scalariform (Figure 9). The length of the tracheal elements' ranges from 305.02 µm to 604.50 µm, with an average length of 454.05 µm. The diameter of the tracheal elements' ranges from 30.09 µm to 114.87 µm, with an average diameter of 71.105 µm (Figure 10).

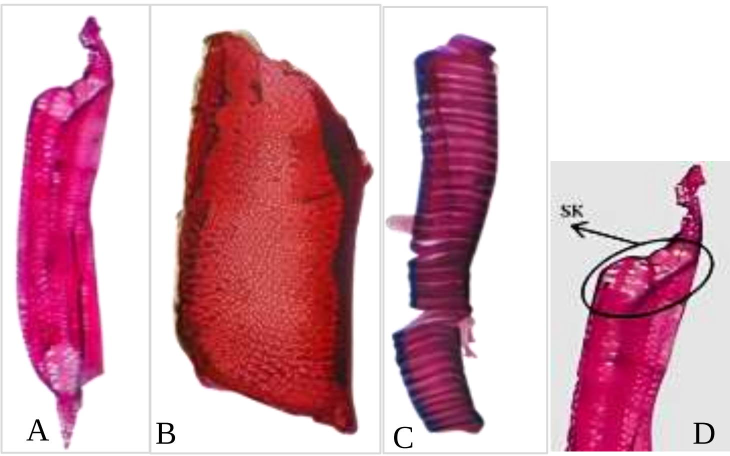

Figure 9. Tracheal structure in the banyan (*Ficus callophylla*) Stem. 400x magnification. A. Reticulate type, with secondary wall thickening Mesh I; B. Reticulate type, with secondary wall thickening Mesh II; C. Spiral type, with secondary wall thickening Spiral I; D. Scalariform Perforation.

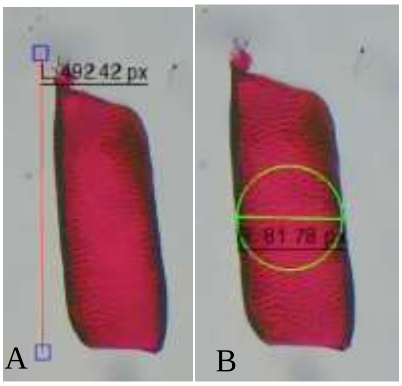

Figure 10. Tracheal cell size in banyan stems (*Ficus callophylla*) A. Length (492.42 μm); B. Diamater (81.78 μm)

Booklet validation includes several indicators: (i) language quality, (ii) booklet design and appearance, (iii) order of material presentation, and (iv) images and illustrations. Based on expert validation results, a percentage of 91.66 was obtained, consisting of: (i) language quality (85), (ii) booklet design and appearance (91), (iii) order of material presentation (100), and (iv) images and illustrations (90.5). The percentage value obtained indicates that the Booklet is rated as "very valid," making it suitable for use and contribution to biology learning in high school. However, there are several components that need improvement, namely writing and usage, the use of larger fonts and typefaces, image proportions, cover design, and adjusting the content to the booklet's objectives. The booklet's appearance after being revised is shown in Figure 11.

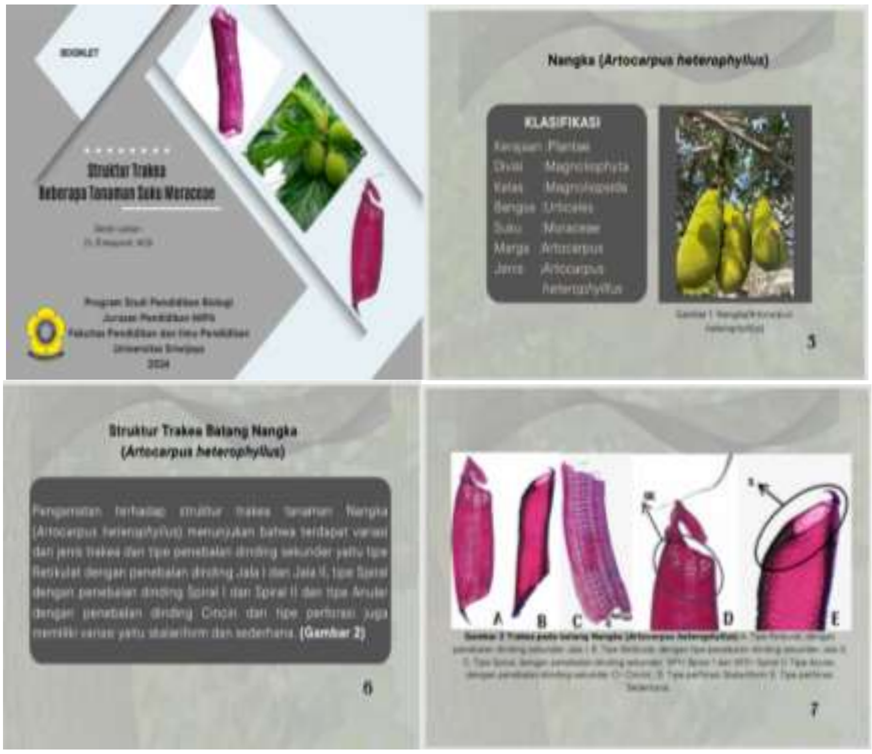

Figure 11. Booklet example

DISCUSSION

Based on the results of the tracheal element variability observed in this study has significant relevance for high school biology education. Differences in tracheal type, secondary wall thickening, and variations in length and diameter between species can be utilized as inquiry-based learning materials. Students can be trained to observe tissue slides under a microscope, note structural differences, measure the dimensions of tracheal elements, and compare them between species. Through this activity, students not only understand the theoretical concepts of vascular tissue but also develop science process skills such as observing, classifying, analyzing data, and drawing conclusions. Observations have been made on five stems, namely the stems of Jackfruit (*Artocarpus heterophyllus*), Breadfruit (*Artocarpus altilis*), Mulberry (*Morus nigra*), Banyan (*Ficus benjamina*) and (*Ficus callophylla*) all have tracheal elements (Trachea type, secondary wall thickening type, perforation type and length and diameter of tracheal elements). The tracheal elements found from each plant stem have differences that characterize the trachea elements. typical of each plant. The existence of these variations can be influenced by plant genetics and environmental condition factors. The same thing was also found in research (Qomariyah & Setiawan, 2022) on bougainvillea plants, which although derived from the same genus, have diverse epidermal forms. These differences in epidermal structure and stomatal type are also influenced by internal factors (genetic traits) and external factors such as habitat, specific adaptations to the environment, and humidity levels. This shows that variations in anatomical structures in plants are strongly influenced by a combination of genetic factors and the environment in which they grow.

The types of trachea found in a single plant vary widely, with more than two types, such as in jackfruit (Artocarpus heterophyllus) stems, which have three types: reticulate, spiral, and annular (Table 1). This finding aligns with previous research that reported that more than one type of trachea can be found in a single plant species. For example, a combination of several types of trachea was reported in white rose (Chico Palam et al., 2016).

The type of secondary wall thickening found in one plant is also more than one type such as in the trachea of Jackfruit stems (*Artocarpus heterophyllus*) has a type of secondary wall thickening in the form of Mesh I, Mesh II, Spiral I, Spiral II and Ring. Banyan (*Ficus callophylla*) stem has secondary wall thickening types in the form of Mesh I, Mesh II and Spiral II. addition, the trachea of Sukun (*Artocarpus altilis*), Mulberry (*Morus nigra*) and Banyan (*Ficus Benjamina*) stems have two types of secondary wall thickening, namely Mesh I and Mesh II types.

Forms a network in a mesh pattern, which is often caused by irregular cell division (Hidayat, 1995). Mesh type I is a structure of vertical and horizontal lines with a larger size and rarely, so that a rectangular-like space is formed. Mesh I thickening serves to provide structural strength to the stem, in this type of thickening there is a pattern of fibers or xylem elements arranged in a square that resembles a mesh (Evert et al., 2006). Mesh pattern I shows a regular pattern resembling a mesh throughout the secondary wall. In mesh type I xylem elements such as tracheids and tracheae are interconnected in a pattern that forms a repeating structure, like a net or mesh. The mesh pattern provides mechanical strength and flexibility to the stem that makes the plant resistant to external stresses such as strong winds.

The Mesh II type of secondary wall thickening is a denser horizontal line structure, forming small boxes. Mesh II type thickening serves to provide mechanical strength to the rod, in Mesh II type thickening there are elements of which are arranged in a horizontal pattern to form smaller and tighter boxes (Evert et al., 2006).

The spiral type of secondary wall thickening forms a spiral pattern wrapped around the inside of the primary wall. Spiral thickening can be one or more spirals contained within a single element. Spiral-shaped tracheal elements will unite in certain places to form a staircase-like thickening known as scalariform (Chico Palam et al., 2016). Thus, the presence of spiral-type trachea found together with the noctah indicates that the plant organ is still in the primary growth phase and has not yet reached the stage of maturity such as metaxilem or secondary xylem. Spiral tracheae have relatively weak primary cell walls and are less resistant to pressure when passing water between vessels. In , the primary wall is able to elongate or stretch in the axial direction within a certain size limit, allowing the tissue to expand more widely (Crang et al., 2012).

The observation of spiral thickening type in young cells, spiral thickening is very close to the type of thickening seen in Jackfruit (*Artocarpus heterophyllus*) stems. However, as the cell elongates due to the growth of surrounding cells, the spiral will stretch to become less tight so that this cell will tear due to the expansion of nearby cells (Hidayat, 1995) such as the spiral shape in the stem of Banyan (*Ficus benjamina*). If stem elongation is inhibited the production of spiral vessels will be reduced or stopped, while noctah vessels continue to develop. Some opinions also state that the extent of elongation of an organ affects the wall pattern of tracheal elements that develop into adults in the organ (Fahn, 1992).

Ring-type secondary wall thickening is the simplest form of secondary wall thickening. The secondary layer does not cover the entire surface of the primary wall as in sclereids, but rather forms small rings on the inside of the primary wall, with each ring separated from each other (Hidayat, 1995). Previous research also showed the same thing but not only ring thickening separated but spiral thickening also separated in organs that were experiencing elongation (Kurniawati et al., 2015). Ring-type thickening is not very strong, so cells are easily fragile. However, the advantage is that it allows the tracheal elements to extend along the length direction, so that the distance between the two rings becomes longer. Because the tracheal element can extend, it does not hinder the enlargement of the surrounding cells and remain connected to cell. As the cell elongates, the rings will separate, but this process is limited and eventually the rings will tear.

Secondary wall thickening in plant samples has a variety of patterns that are highly dependent on the species and functional needs of the plant. Based on (Table. 1) shows 5 types of secondary wall thickening patterns, differences in each type of secondary wall thickening in various plants appear as a result of specific characteristics of each species (genetic factors) and structural adaptations to physiological needs, environmental conditions.

The results also showed data on the type of perforation of tracheal elements that varied (Table 1). The type of perforation in the trachea of Jackfruit (*Artocarpus heterophyllus*), Breadfruit (*Artocarpus altilis*) and Mulberry (*Morus nigra*) stems consists of two types, namely scalariform and simple. The type of tracheal perforation of Banyan (*Ficus benjamina*) stem is simple while the type of tracheal perforation of Banyan (*Ficus callophylla*) stem is scalariform. Previous studies have also shown that within one species, two different types of perforations can be found. For example, in *Woodsia*, there are variations in perforation type between the oblique scalariform type (which is more complex) and the simple type (White, 1963).

Plant cell size, both in length and diameter, varies greatly and is influenced by external factors, particularly the environmental conditions in which the plant grows. For example, observations show that the trachea in jackfruit stems are longer than in other species. This can be explained by the physiological needs of jackfruit plants, which have relatively large stems and crowns, thus requiring higher water transport efficiency. The greater length of the tracheal elements allows for faster water flow and lower resistance. Furthermore, water availability and soil fertility in the growing environment also encourage the formation of longer trachea. Thus, differences in tracheal size not only reflect interspecies variation but also represent a structural adaptation to physiological needs and environmental conditions. Previous research also shows that the size and number of stomata are influenced by factors such as light intensity, air temperature and soil pH (Utami et al., 2018). This is also in line with previous research that changes in tracheal diameter in the roots and stems of corn plants can be influenced by differences in light intensity and water availability. The lower the light intensity, the smaller the diameter of the trachea on the roots (Akmalia, H & Suharyanto, 2017).

Table 1 also obtained data on the length and diameter of tracheal elements that varied. The longest tracheal element was found in the trachea of Nangka (*Artocarpus heterophyllus*) stem, which was 832.34 µm. The shortest tracheal element was found in the trachea of the Banyan (*Ficus benjamina*) stem, which was 247.16 µm. While the diameter of the tracheal elements from the largest number to the smallest number is Sukun (*Artocarpus altilis*) at 127.69 µm, Beringin (*Ficus callophylla*) at 114.87 µm, Jackfruit (*Artocarpus heterophyllus*) at 247.16 µm. (*Artocarpus heterophyllus*) at 101.07 µm, Mulberry (*Morus nigra*) at 85.44 µm and Banyan (*Ficus benjamina*) at 11.06 µm.

Research data shows that the length and diameter of tracheal elements vary significantly between species within the Moraceae family. This variation is not only evident in size but also in the type of tracheal elements, such as reticulate, spiral, and annular, which are distributed differently in each species. These differences are influenced by genetic factors that determine the morphological patterns of the species, as well as environmental factors that influence the growth and differentiation of xylem tissue. Environmental conditions such as water availability, temperature, and soil fertility can increase the diameter and length of tracheal elements, as seen in plants grown in fertile soil with sufficient water supply. This is in line with the findings of (Susanto & Baskorowati, 2018). Who showed that at the age of 1–3 years, growth variation is more dominantly influenced by environmental factors than genetic factors. Therefore, presenting quantitative data in the form of average length and diameter of tracheal elements (Table 1) and micrographs of tracheal types (Figure 1-10) is important to strengthen the evidence of variation found.

Furthermore, the results of this study were also developed into a booklet as a learning resource for biology in high school. The booklet contains a summary of tracheal element size data, microscopic images of each species, and learning activities that link tracheal variations to plant physiology concepts. The booklet's validation results obtained a score of 55 out of 60 (91.66%) with a very valid category, making it suitable for use as a learning medium. Thus, this booklet not only presents scientific findings but also contributes to improving students' understanding of observation skills and analysis of plant tissue structures.

CONCLUSION

The results of the study indicate that the tracheal structure in several plants of the Moraceae family varies greatly, both in terms of type (reticulate, spiral, and annular), secondary wall thickening

(Mesh I, Mesh II, Spiral I, Spiral II, and Ring), and type of perforation (simple and scalariform) with lengths and diameters that differ significantly between species. These findings highlight the uniqueness of plant anatomical structures that have great potential to be utilized in biology learning, as evidenced by the development of a Booklet that received a "Very Valid" rating. Further research can be directed to exploring other Moraceae species or developing digital learning media so that the delivery of material is more interactive and easily accessible to students.

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