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ANATOMICAL VARIATION AMONG ARECACEAE TAXA THROUGH ROOT SECTION CUTTING BY THE IMPLEMENTATION OF LIGHT AND SCANNING ELECTRON MICROSCOPY

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Abstract

The Arecaceae family also known as Palmae, is a large group of plants belonging to the Arecales order. This research involved an anatomical study of transverse sections of roots from various species within the Arecaceae family. Anatomical studies were done through light and scanning electron microscope. Different anatomical features Epidermis cells thickness, cortex layers, cortex thickness, rhizodermis thickness, air spaces, vascular cylinder diameter, xylem, diameter of metaxylem, maximum length of phloem and pith diameter were examined. The epidermis cells thickness ranges from 17-61 µm. The cortex thickness ranges from 400-1040 µm. Rhizodermis thickness ranged between 13-35 µm. The maximum pith diameter observed was almost 820-990 µm in *Nannorrhops ritchiana* (Griff.) Aitch. Air spces ranged between 13-31 µm. Maximum length of phloem was seen in *Dypsis lutescens* (H.Wendl.) Beentje & J.Dransf. Dimeter of metaxylem ranged between 21-108 µm. In conclusion, the root transverse section cutting features exhibited significant variations, allowing for the differentiation of plants within the Arecaceae family. This is the first reported study on root section cutting of family Arecaceae species.

Keywords: Arecaceae, Light and Scanning Electron Microscope, Vascular Cylinder Diameter, Metaxylem, Rhiodermis Thickness, Pith Diameter.

INTRODUCTION

In recent times, there has been a notable increase in research focused on the vegetative organs of Arecaceae plants. However there remains a substantial knowledge gap concerning the structural and developmental aspects of vegetative organs especially the root structures in certain crucial taxa. These taxa are frequently not classified or are inadequately represented in the latest phylogenetic studies. This deficiency in understanding can be attributed, in part, to the considerable morphological diversity within

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this plant family and the challenges associated with collecting palm organs. (Govaerts & Dransfield (2015) & Tomlinson et al. 2011).

The root anatomy of plants of family Arecaceae is a fascinating and essential aspect of their biology and is a subject of profound scientific inquiry and ecological significance. Plants, belonging to the family Arecaceae, are renowned for their tall, slender trunks and distinctive fronds. However, beneath the surface, their root system plays a crucial role in anchoring these towering giants and providing them with the necessary nutrients and water for survival. Arecaceae roots play an important role, not merely as anchors in the soil, but as conduits for essential resources, facilitating the tree's growth, survival, and interaction with its surrounding environment. (Dransfield et al. 2018)

Members of the family Arecaceae, have a distinctive root anatomy that sets them apart from other types of trees and plants. Arecaceae plants roots exhibit significant differences when compared to the roots of broadleaf and coniferous trees. These distinctions primarily stem from their adventitious nature, as they emerge from a specific part of the trunk known as the root initiation zone. Arecaceae roots have their origins in the outer portion of the central cylinder, where they connect with vascular bundles within the stem. As these roots continue to grow, their sheer volume can cause the cortex and pseudobark to split and expand outward from the base of the stem. (Menezes et al. 2015). Unlike the roots of dicot plants, Arecaceae plants roots do not possess root hairs. Additionally, due to the absence of a cambium layer, it is not possible for the roots of neighboring Arecaceae trees to graft together, as is sometimes observed in dicot trees. Overall, members of Arecaceae roots are specialized for their unique growth habits and ecological niches. Their adventitious nature, connection to vascular bundles and absence of cambium are adaptations that contribute to their success in various tropical and subtropical environments. (Patrick J & Offler C. (2011).

It's important to note that Arecaceae roots vary widely among different species, and taxonomic classifications may differ based on the specific characteristics and adaptations of each species. The taxonomy of Arecaceae roots categorizes them based on various characteristics and structures. Palm roots are classified into different types and their categories are according to their functions, location, and appearance. The taxonomy of palm tree roots also considers the considerable morphological variability observed among different palm species. Some palms have slender, smooth roots, while others may have thick, textured roots with various adaptations for their specific ecological niches. Palm root taxonomy is primarily used to categorize and describe the diverse root structures and functions within the Arecaceae family. (Henderson, 2011).

MATERIALS AND METHODS

Anatomical Preparations

Root samples of the adult plants were collected and the cross sections of the root samples were cut with a rotary microtome. (Microtome model). The samples were fixed in a mixture of formaldehyde, glacial acetic acid and ethanol until lab processing. These samples were

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then dehydrated with the graded tertiary butyl alcohol series, then they were infiltered and embedded in the paraplast (58 °C melting point) and then samples were cross-sectioned. They were then stained with 1 % safranin and 1 5 with acetyl blue and then mounted with the canada oil and then fixed with the transparent nail polish. (Paiva et al. 2016). These slides were then examined under light as well as scanning electron microscope. The images were taken by the digital camera. The root characters were studied following the methods of Graciano-Ribeiro et al. (2006), with some new characteristics proposed for specific traits. The description of the anatomical data was also studied by following the terminology used by the Tomlinson (1961, 1990) and Tomlinson et al. (2011). The main quantitative studied features were number of layers, epidermal cells shapes and thickness, number of cortex layers and thickness, number of air spaces and air spaces lengths, vascular bundle diameter, and number of xylary arches. The number of metaxylem arch, inner diameter of wide metaxylem arch, maximum length of phloem strand and pith diameter, were also observed.

Light and Scanning Electron microscope

Root transverse section slides were imaged using both light and scanning electron microscopes at magnifications of 40X and 100X.

RESULTS

Archontophoenix alexandrae (F.Muell.) H.Wendl. & Drude

Root Anatomy Epidermis cells with smooth thick walls ranged from 20-32 µm. There were almost 51 cortex layers and the cortex thickness observed was 1005-1120 µm. Rhizodermis observed was single celled and the thickening of the cells varied between 18-21 µm. Air spaces observed varied in number and their number ranged from 22-29 and were varied in length from 270-310 µm. The vascular cylinder diameter is almost 1120-1210 µm. The vascular tissue observed was consisted of a number of xylem arches and the pattern of xylem arches observed was Y shaped, almost 37-41 xylem arches were observed, 2-4 metaxylem arches were also seen. The inner diameter of the widest metaxylem arch was 88 µm. The maximum length of the phloem strand observed was 145 µm. The pith diameter observed was almost 290-330 µm. Root hairs were not seen. (Fig 1a, b)

Borassus flabellifer L.

Root Anatomy Epidermis with smooth circular to semi-circular thin walls**,** epidermis thickness was 17-19 µm. There were almost 35 cortex layers and the cortex thickness observed was 840-890 µm. Air spaces were also observed in large numbers and their number ranged from 15-19 and were varied in length from 260-340 µm. The vascular cylinder diameter is almost 700-810 µm. The vascular tissue observed was consisted of a number of xylem arches, almost 17-21 xylem arches were observed, the pattern of xylem arches observed was “Y” shaped, 2-5 metaxylem arches were also seen. The inner diameter of the widest metaxylem arch was 43 µm. Short phloem strands were observed and the maximum length of the phloem strand observed was 70 µm. The pericycle

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observed showed one layered cell thickness. The pith diameter observed was almost 170-230 µm. Root hairs were not seen. (Fig 2a, b)

***Calamus rotang* L.**

Root Anatomy Epidermal cells with thick walls measured between 17.5-21 µm. The cortex consisted of nearly 30 layers, with a thickness ranging from 510-570 µm. A single-celled rhizodermis was present, with cell thickening between 13-17 µm. The number of air spaces varied from 14-20, with lengths ranging from 95-120 µm. The vascular cylinder had a diameter of approximately 510-720 µm. The vascular tissue contained numerous xylem arches, arranged in a "Y" pattern, with 17-21.5 xylem arches observed, and 2-3 metaxylem arches also noted. The widest metaxylem arch had an inner diameter of 37.5 µm, and the maximum length of the phloem strand was 52 µm. The pith diameter ranged from 260-300 µm. Root hairs were absent. (Fig 3a, b)

***Caryota urens* L.**

Root Anatomy Epidermis cells with thick walls ranged from 30.5-50.5 µm. There were almost 47 cortex layers and the cortex thickness observed was among 610-840 µm. Single celled rhizodermis was seen and the thickening of the cells varied between 19-22 µm. Air spaces observed varied in number and their number ranged from 14-21 and were varied in length from 150-270 µm. The vascular cylinder diameter is almost 970-1220 µm. The vascular tissue observed was consisted of a number of xylem arches and the pattern of xylem arches observed was Y shaped, almost 29-34 xylem arches were observed, 5-9 metaxylem arches were also seen. The inner diameter of the widest metaxylem arch was 87.5 µm. The maximum length of the phloem strand observed was 141 µm. The pith diameter observed was almost 570-810 µm. Root hairs were not seen. (fig 4a, b)

***Chamaedorea cataractrum* Mart.**

Root Anatomy Epidermis cells with smooth thin walls were observed and their thickness ranged from 18.5-22.5 µm. There were almost 40 cortex layers and the cortex thickness observed was among 920-960 µm. Single celled rhizodermis was seen and the thickening of the cells varied between 15-20 µm. Air spaces observed showed variation in number and their number ranged from 21-25 and they varied in length from 410-490 µm. The vascular cylinder diameter is almost 1090-1150 µm. The vascular tissue observed was consisted of a number of xylem arches and the pattern of xylem arches observed was Y shaped, almost 27-32 xylem arches were observed, 3-6 metaxylem arches were also seen. The inner diameter of the widest metaxylem arch was 55.5 µm. The maximum length of the phloem strand observed was 160 µm. The pith diameter observed was almost 600-690 µm. Root hairs were not seen. (Fig 5a, b)

***Chamaerops humilis* L.**

Root Anatomy Epidermis cells were smooth having thick walls and the thickness of epidermal cells ranged from 35-42 µm. There were almost 29 cortex layers and the cortex thickness observed was 810-920 µm. Single layered rhizodermis was observed and the thickening of the cells varied between 20-29 µm. Air spaces observed varied in number

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and their number ranged from 14-18 and were large in size and varied in length from 180-220 µm. The vascular cylinder diameter is almost 770-910 µm. The vascular tissue observed was consisted of a number of xylem arches and the pattern of xylem arches observed was “Y” shaped, almost 33-38 xylem arches were observed, 2-5 metaxylem arches were also seen. The inner diameter of the widest metaxylem arch was 78 µm. The maximum length of the phloem strand observed was 123 µm. The pith diameter observed was almost 420-440 µm. Root hairs were not seen. (Fig 6a, b)

***Dypsis decaryi* (Jum.) Beentje & J.Dransf.**

Root Anatomy Epidermis with mostly circular shaped cells having thin walls, thickness ranged from 23-27 µm. There were almost 50 cortex layers and the cortex thickness observed was 970-1000 µm. The endodermis seen was single layered and endodermal cells were thick walled. Air spaces observed varied in number and their number ranged from 23-31 and were varied in length from 340-370 µm. The vascular cylinder diameter is almost 990-1010 µm. The vascular tissue observed was consisted of a number of xylem arches and the pattern of xylem arches observed was “I” shaped, almost 27-29 xylem arches were observed, 3-6 metaxylem arches were also seen. The inner diameter of the widest metaxylem arch was 60 µm. The maximum length of the phloem strand observed was 105 µm. The pericycle observed showed one layered cell thickness. The pith diameter observed was almost 190-240 µm. Root hairs were not seen. (Fig 7a, b)

***Dypsis lutescens* (H.Wendl.) Beentje & J.Dransf.**

Root Anatomy Epidermis with smooth thin walls having circular to semi-circular shaped cells**,** epidermis thickness is varied between 25-30 µm. There were almost 22 cortex layers and the cortex thickness observed was almost 800-850 µm. The exodermis cells observed were with thin walls, parenchyma cells observed showed variable cell diameter from 520-840 µm. Air spaces were also observed in large numbers and their number ranged from 15-19 and were almost varied in length from 260-340 µm. The vascular cylinder diameter measured was almost 700-810 µm. The vascular tissue observed was consisted of a number of xylem arches, almost 17-21 xylem arches were observed and the pattern of xylem arches observed was “Y” shaped, 2-5 metaxylem arches were also seen. The inner diameter of the widest metaxylem arch was 43 µm. The maximum length of the phloem strand observed was 170 µm. The pericycle observed showed one layered cell thickness. The pith diameter observed was almost 170-230 µm. Root hairs were not seen. (Fig 8a, b)

***Hyophorbe lagenicaulis* (L.H.Bailey) H.E.Moore**

Root Anatomy Epidermis with smooth circular to semi-circular thin walls**,** epidermis thickness is 19-23 µm. A one layered rhizodermis was observed with rectangular to quadrangular shaped cells, the thickening of the cells varied between 15-21 µm. There were almost 10 cortex layers and the cortex thickness observed was 400-500 µm. The quadrangular cells were observed in exodermis. Parenchyma cells observed showed variable cell diameter from 520-840 µm. Air spaces were also observed in large numbers and their number ranged from 18-21 and were varied in length from 250-360 µm. The

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vascular cylinder diameter is almost 760-890 µm. The vascular tissue observed was consisted of a number of xylem arches, almost 20-30 xylem arches were observed and the pattern of xylem arches observed was “Y” shaped, 2-5 metaxylem arches were also seen. The inner diameter of the widest metaxylem arch was 55 µm. The maximum length of the phloem strand observed was 110 µm. The pericycle observed showed one layered cell thickness. The pith diameter observed was almost 200-290 µm. Root hairs were not seen. (Fig 9a, b)

***Hyphaene thebaica* (L.) Mart.**

Root Anatomy Epidermis cells were semi-circular to circular shaped having thick walls and their size ranged from 30-37 µm. There were almost 49 cortex layers and the cortex thickness observed was 1009-1120 µm. Air spaces observed varied in number and their number ranged from 20-23 and were varied in length from 360-440 µm. The vascular cylinder diameter was almost 1022-1170 µm. The vascular tissue observed was consisted of a number of xylem arches, almost 32-41 xylem arches were observed and the pattern of xylem arches observed was “I” shaped, 4-7 metaxylem arches were also seen. The inner diameter of the widest metaxylem arch was 108 µm. The maximum length of the phloem strand observed was 102 µm. The pith diameter observed was almost 600-770 µm. Root hairs were not seen. (Fig 10a, b)

***Livistonia chinensis* (Jacq.) R.Br. ex-Mart.**

Root Anatomy Epidermis cells having thick walls ranged from 50-55 µm. There were almost 42 cortex layers and the cortex thickness observed was among 690-800 µm. One celled rhizodermis was seen and the thickening of the cells varied between 14-16 µm. Air spaces observed varied in number and their number ranged from 14-20 and were varied in length from 270-340 µm. The vascular cylinder diameter is almost 770-900 µm. The vascular tissue observed was consisted of a number of xylem arches and the pattern of xylem arches observed was “I” shaped, almost 26-50 xylem arches were observed, 1-3 metaxylem arches were also seen. The inner diameter of the widest metaxylem arch was 78.5 µm. The maximum length of the phloem strand observed was 134 µm. The pith diameter observed was almost 370-520 µm. Root hairs were not seen. (Fig 11a, b)

***Nannorrhops ritchiana* (Griff.) Aitch.**

Root Anatomy Epidermis cells have smooth thick walls and their thickness ranged from 33.5-41.5 µm. There were almost 47 cortex layers and the cortex thickness observed was among 820-860 µm. Single celled rhizodermis was seen and the thickening of the cells varied between 14-17 µm. Air spaces observed were ranged in number from 19-23 and were varied in length from 370-410 µm. The vascular cylinder diameter is almost 1190-1250 µm. The vascular tissue observed was consisted of a number of xylem arches and the pattern of xylem arches observed was “I” shaped, almost 37-42 xylem arches were observed, 2-5 metaxylem arches were also seen. The inner diameter of the widest metaxylem arch was 95.5 µm. The maximum length of the phloem strand observed was 146.5 µm. The pith diameter observed was almost 820-990 µm. Root hairs were present. (Fig 12a, b)

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***Phoenix canariensis* Hort. ex Chabaud.**

Root Anatomy Epidermis cells with smooth thick walls were observed and their thickness ranged from 53.5-61 µm. There were almost 60 cortex layers and the cortex thickness observed was among 1020-1040 µm. Single celled rhizodermis was seen and the thickening of the cells varied between 13-18 µm. Air spaces observed varied in number and their number ranged from 20-23 and were varied in length from 360-380 µm. The vascular cylinder diameter is almost 1030-1050 µm. The vascular tissue observed was consisted of a number of xylem arches, almost 25.5-29 xylem arches were observed and the pattern of xylem arches observed was Y shaped, 4-6 metaxylem arches were also seen. The inner diameter of the widest metaxylem arch was 70.5 µm. The maximum length of the phloem strand observed was 129.5 µm. The pith diameter observed was almost 470-490 µm. Root hairs were not seen. (Fig 13a, b)

***Phoenix dactylifera* L.**

Root Anatomy The epidermis displayed thick walls with a thickness ranging from 35-40 µm and the epidermal cells appeared slightly elongated. A single-layered rhizodermis was observed, featuring rectangular to quadrangular cells with thickening between 20-25 µm. The cortex consisted of nearly 38 layers, with a total thickness of 970-1020 µm. Parenchyma cells were present, generally semicircular to circular in shape. Air spaces were observed, numbering 13-14 with lengths varying from 80-85 µm. The vascular cylinder had a diameter of approximately 500-550 µm and contained numerous xylem arches, specifically 15-20 arranged in a "Y" pattern, with 2-4 metaxylem arches also noted. The widest metaxylem arch had an inner diameter of 21 µm and the maximum length of the phloem strand was 70 µm. The pericycle was composed of a single cell layer and the pith diameter measured around 120-150 µm. Root hairs were absent. (Fig 14a, b)

***Phoenix sylvestris* (L.) Roxb.**

Root Anatomy Epidermis cells having thick walls ranged from 51-56 µm. There were almost 39 cortex layers and the cortex thickness observed was among 600-700 µm. One celled rhizodermis was seen and the thickening of the cells varied between 15-19 µm. Air spaces observed varied in number and their number ranged from 16-19 and were varied in length from 370-440 µm. The vascular cylinder diameter is almost 700-900 µm. The vascular tissue observed was consisted of a number of xylem arches and the pattern of xylem arches observed was “I” shaped, almost 20-35 xylem arches were observed, 1-3 metaxylem arches were also seen. The inner diameter of the widest metaxylem arch was 72 µm. The maximum length of the phloem strand observed was 129 µm. The pith diameter observed was almost 300-430 µm. Root hairs were not seen. (Fig 15a, b)

***Raphia vinifera* P. Beauv.**

Epidermis cells having thick walls ranged from 50-54 µm. There were almost 29 cortex layers and the cortex thickness observed was among 650-700 µm. One celled rhizodermis was seen and the thickening of the cells varied between 14-18 µm. Air spaces

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observed varied in number and their number ranged from 13-17 and were varied in length from 350-410 µm. The vascular cylinder diameter is almost 700-800 µm. The vascular tissue observed was consisted of a number of xylem arches and the pattern of xylem arches observed was “I” shaped, almost 25-30 xylem arches were observed, 1-2 metaxylem arches were also seen. The inner diameter of the widest metaxylem arch was 62 µm. The maximum length of the phloem strand observed was 122 µm. The pith diameter observed was almost 310-420 µm. Root hairs were not seen. (Fig16a, b)

***Raphis excelsa* (Thunb.) Henry**

Root Anatomy Epidermis cells observed were thin having circular shaped cells and their size ranged from 17-33 µm. There were almost 41 cortex layers and the cortex thickness observed was 905-1010 µm. Rhizodermis observed was single celled and the thickening of the cells varied between 17-20 µm. Air spaces observed varied in number and their number ranged from 13-18 and were varied in length from 288-410 µm. The vascular cylinder diameter is almost 1000-1110 µm. The vascular tissue observed was consisted of a number of xylem arches and the pattern of xylem arches observed was Y shaped, almost 16-24 xylem arches were observed, 1-3 metaxylem arches were also seen. The inner diameter of the widest metaxylem arch was 110 µm. The maximum length of the phloem strand observed was 95 µm. The pith diameter observed was almost 200-230 µm. Root hairs were not seen. (Fig 17a, b)

***Syagrus romanzoffiana* (Cham.) Glassman**

Root Anatomy Epidermis with thick walls was observed and the thickness observed was 45-50 µm. The epidermal cells observed were slightly elongated in shape. One layered rhizodermis was also observed with rectangular to quadrangular shaped cells, the thickening of the cells varied between 30-35 µm. There were almost 38 cortex layers and the cortex thickness observed was 980-1050 µm. Parenchyma cells were present and common semicircular to circular in shape. Air spaces observed ranged in number from 14-16 and were almost varied in length from 90-95 µm. The vascular cylinder diameter observed was almost 600--650 µm. The vascular tissue observed was consisted of a number of xylem arches, almost 15-18 xylem arches were observed and the pattern of xylem arches observed was “Y” shaped, 3-4 metaxylem arches were also seen. The inner diameter of the widest metaxylem arch was 31 µm. The maximum length of the phloem strand observed was 80 µm. The pericycle observed showed one layered cell thickness. The pith diameter observed was almost 130-170 µm. Root hairs were not seen. (Fig 18a, b)

***Washingtonia robusta* H.Wendl.**

Root Anatomy Epidermis cells have thick walls ranged from 19.5-31 µm. There were almost 31 cortex layers and the cortex thickness observed was among 520-540 µm. Single celled rhizodermis was seen and the thickening of the cells varied between 13-15 µm. Air spaces observed varied in number and their number ranged from 13-17 and were varied in length from 95-100 µm. The vascular cylinder diameter is almost 520-790 µm. The vascular tissue observed was consisted of a number of xylem arches and the pattern

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of xylem arches observed was Y shaped, almost 18-20.5 xylem arches were observed, 2-4 metaxylem arches were also seen. The inner diameter of the widest metaxylem arch was 39.5 µm. The maximum length of the phloem strand observed was 54 µm. The pith diameter observed was almost 270-310 µm. Root hairs were not seen. (Fig 19a, b)

***Wodyetia bifurcata* A.K.Irvine**

Root Anatomy Epidermal cells with thick walls measured between 50-53 µm. The cortex comprised nearly 30 layers, with a thickness ranging from 600-640 µm. A single-celled rhizodermis was present, with cell thickening varying between 15-19 µm. The number of air spaces ranged from 13-16, with lengths varying from 340-410 µm. The diameter of the vascular cylinder was approximately 500-600 µm. The vascular tissue included numerous xylem arches, arranged in an "I" pattern, with 25-30 xylem arches observed, and 2-4 metaxylem arches also noted. The widest metaxylem arch had an inner diameter of 62 µm, and the maximum length of the phloem strand was 127 µm. The pith diameter measured around 200-320 µm. Root hairs were absent. (Fig 20a, b)

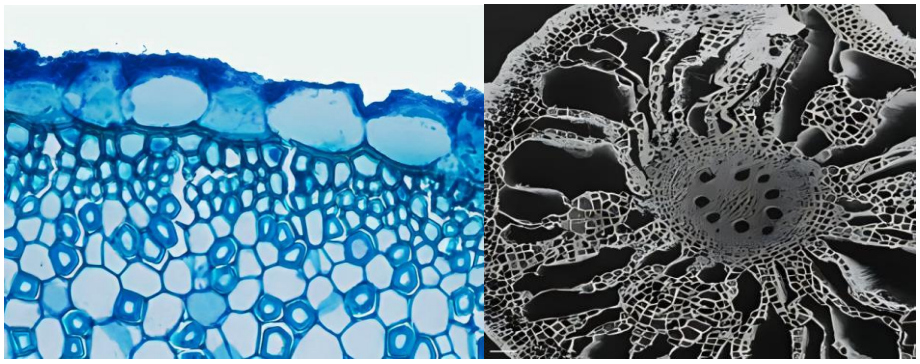

Fig 1: a. T.S of *Archontophoenix alexandrae* (F.Muell.) H.Wendl. & Drude showing thick epidermal cells
b. T.S of *Archontophoenix alexandrae* (F.Muell.) H.Wendl. & Drude showing SEM image of thick epidermal cell layer along with air channels and vascular bundles

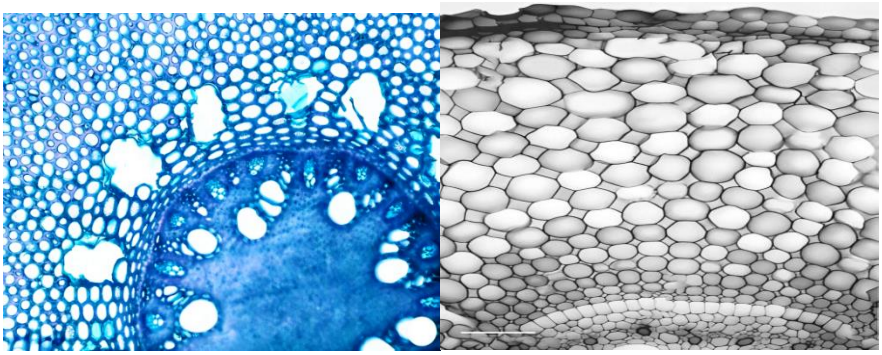

Fig 2: a. T.S of *Borassus flabellifer* L. leaf showing air channels
b. T.S of *Borassus flabellifer* L. leaf showing cortex layers

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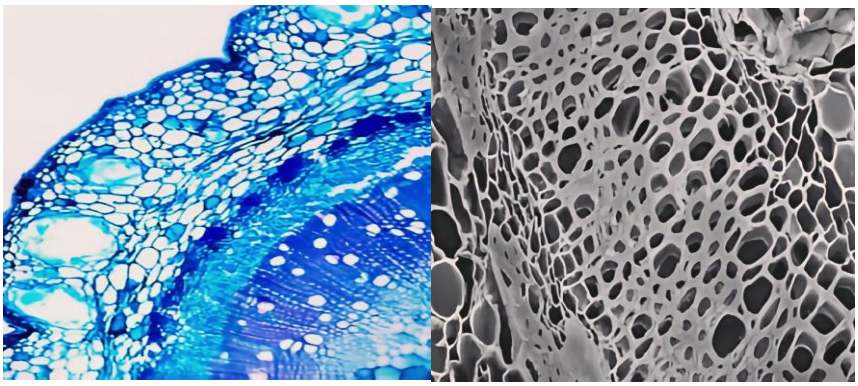

Fig 3: a. T.S of *Calamus rotang* L. *(LM)* showing exodermis, phloem and xylem vessels
b. T.S of *Calamus rotang* L. SEM of root xylem vessels

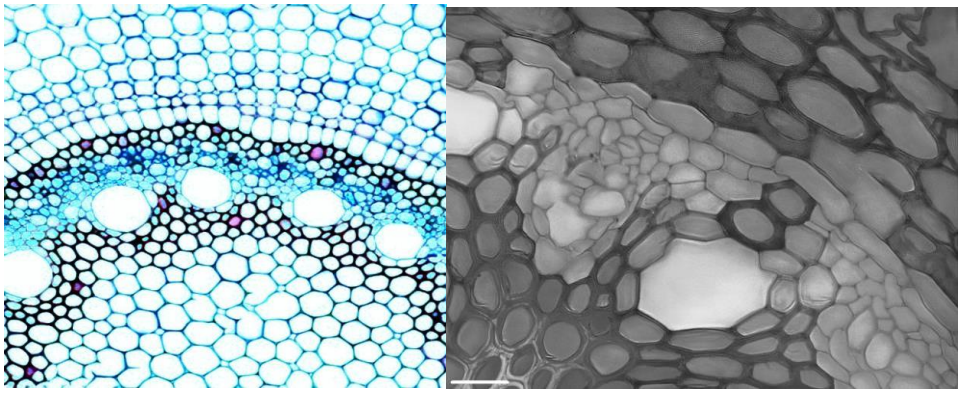

Fig 4: a. T.S of *Caryota urens* L. showing endodermis, cortex cells and pith
b. T.S of *Caryota urens* L. showing thick cortical cells

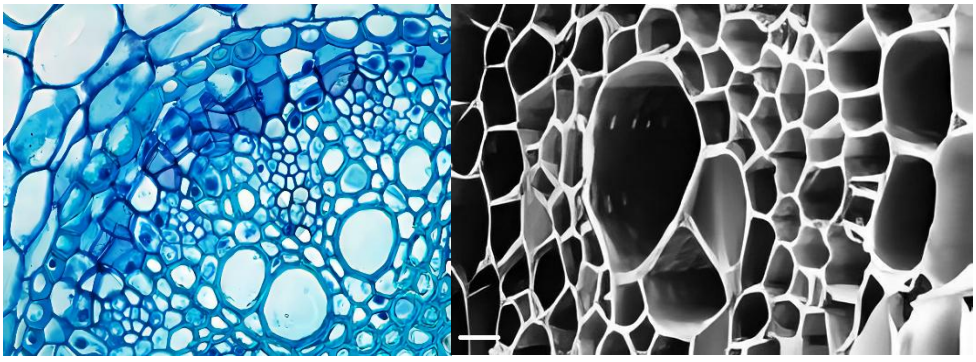

Fig 5: a. T.S of *Chamaedorea cataractrum* Mart (LM)
b. T.S of *Chamaedorea cataractrum* Mart (SEM)

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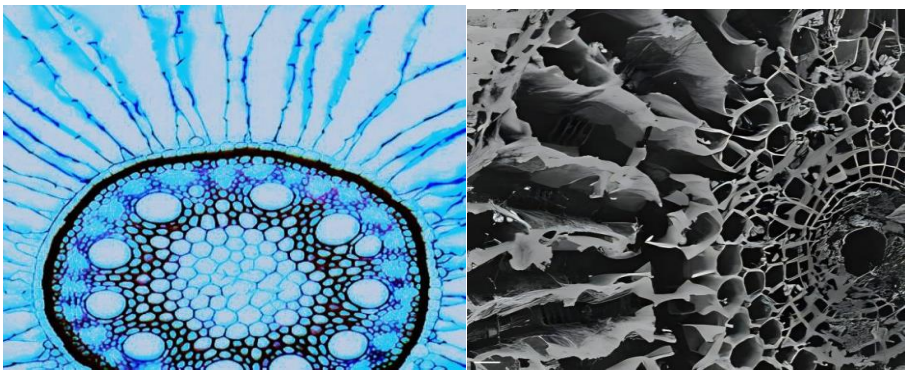

Fig 5: a. T.S of *Chamaerops humilis* L. showing large air spaces
b. T.S of *Chamaerops humilis* L. showing SEM image of large air spaces

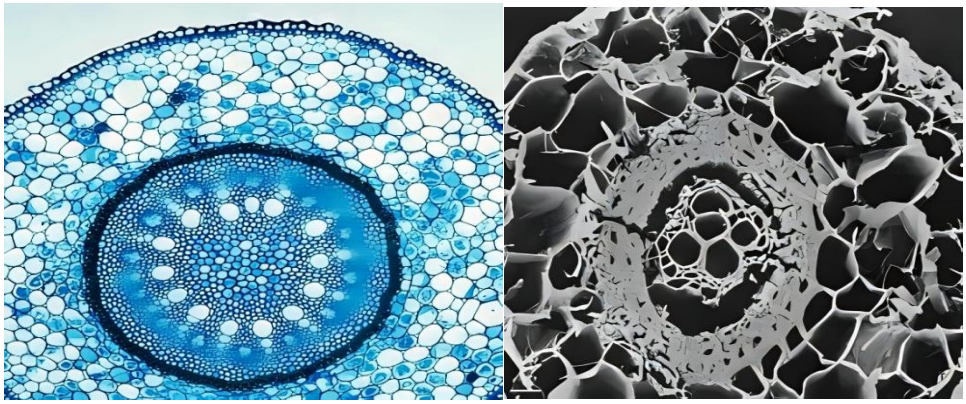

Fig 7: a. TS of *Dypsis decaryi (*Jum.) Beentje & J.Dransf. Showing
b. TS of *Dypsis decaryi (*Jum.) Beentje & J.Dransf. Showing vascular bundle and cortex cells

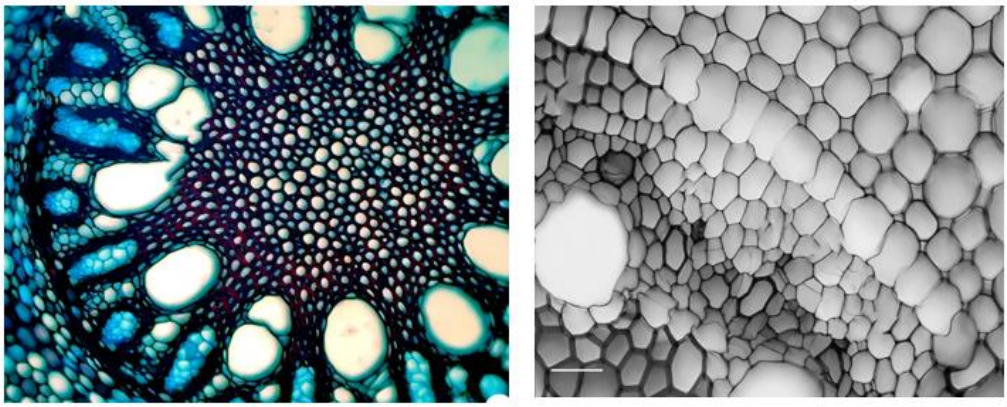

Fig 8: a. TS of *Dypsis lutescens* (H.Wendl.) Beentje & J.Dransf showing "Y" shaped xylem arches
b. TS of *Dypsis lutescens* (H.Wendl.) Beentje & J.Dransf showing thin walled endodermis

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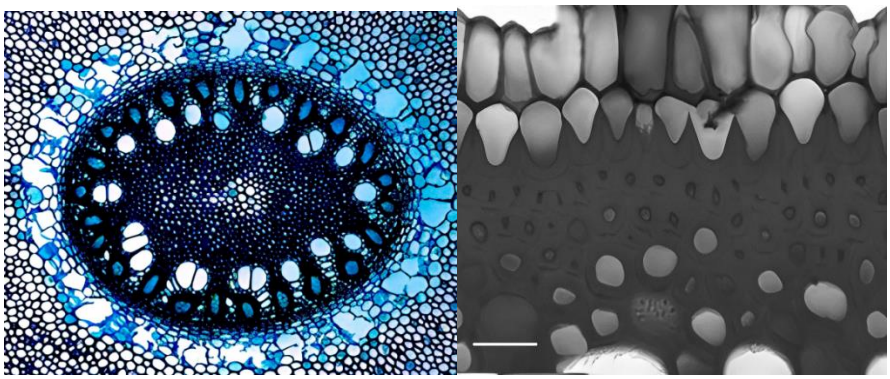

Fig 9 a. TS of *Hyophorbe lagenicaulis* (L.H.Bailey) H.E.Moore showing vascular bundles
b. TS of *Hyophorbe lagenicaulis* (L.H.Bailey) H.E.Moore showing single layered rhizodermis layer

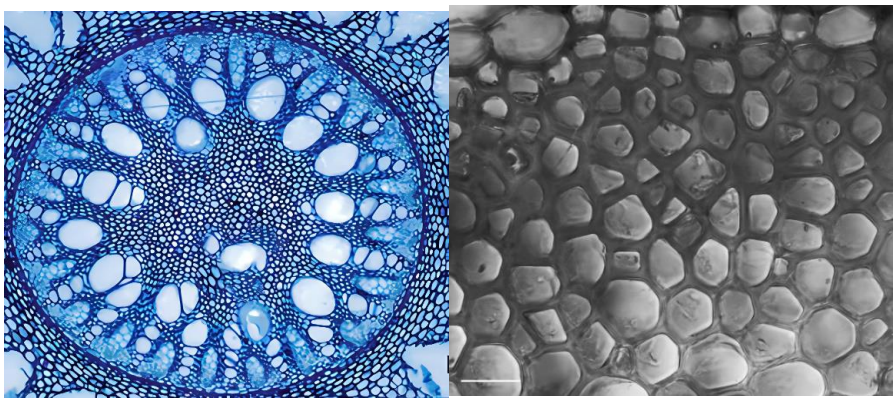

Fig 10: a. TS of *Hyphaene thebaica* (L.) Mart showing
b. TS of *Hyphaene thebaica* (L.) Mart showing cortex cells

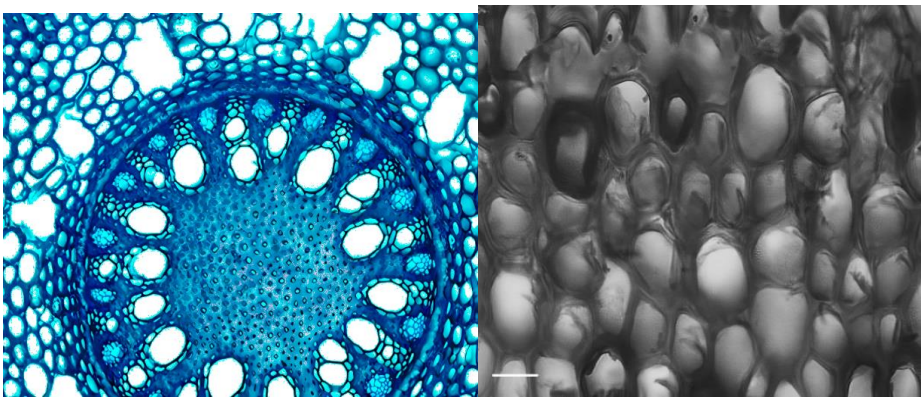

Fig 11: a. TS of *Livistonia chinensis* (Jacq.) R.Br. ex-Mart. showing air channelsand vascular bundles
b. TS of *Livistonia chinensis* (Jacq.) R.Br. ex-Mart. showing SEM image of thick-walled cortical cells

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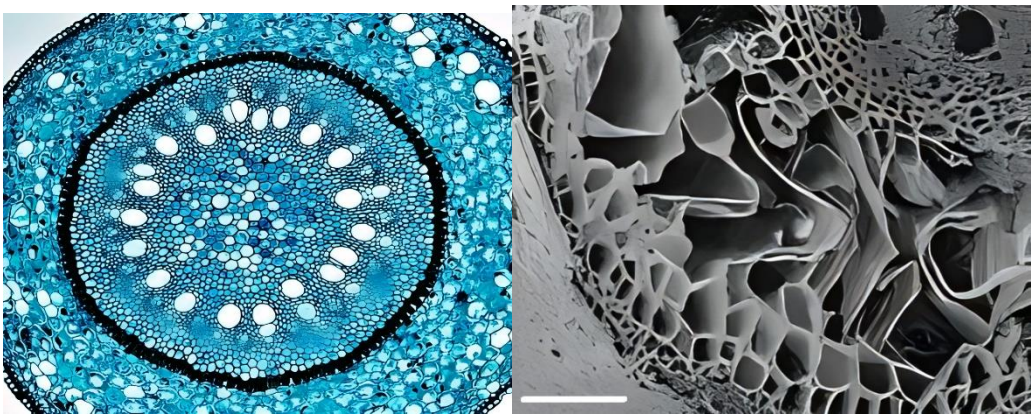

Fig 12: a. TS of *Nannorrhops ritchiana* (Griff.) Aitch. (LM)
b. TS of *Nannorrhops ritchiana* (Griff.) Aitch. (SEM)

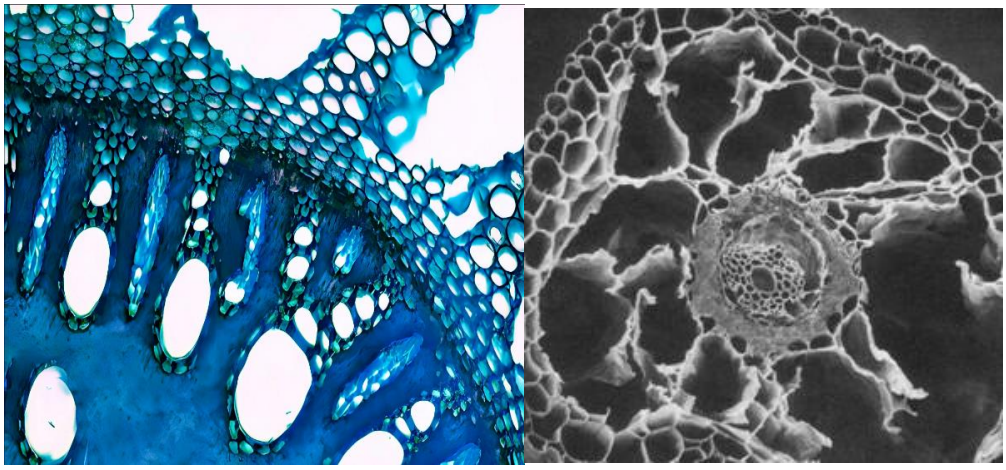

Fig 13: a. TS of *Phoenix canariensis* Hort. ex Chabaud showing I shaped xylem arches
b. TS of *Phoenix canariensis* Hort. ex Chabaud (SEM)

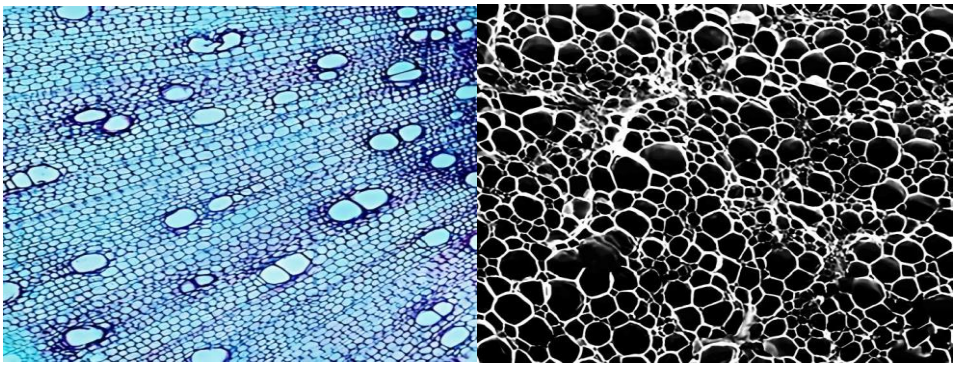

Fig 14: a. *Phoenix dactylifera* L. showing smooth xylem vessels
b. *Phoenix dactylifera* L. showng Polygonal shaped parenchyma cells

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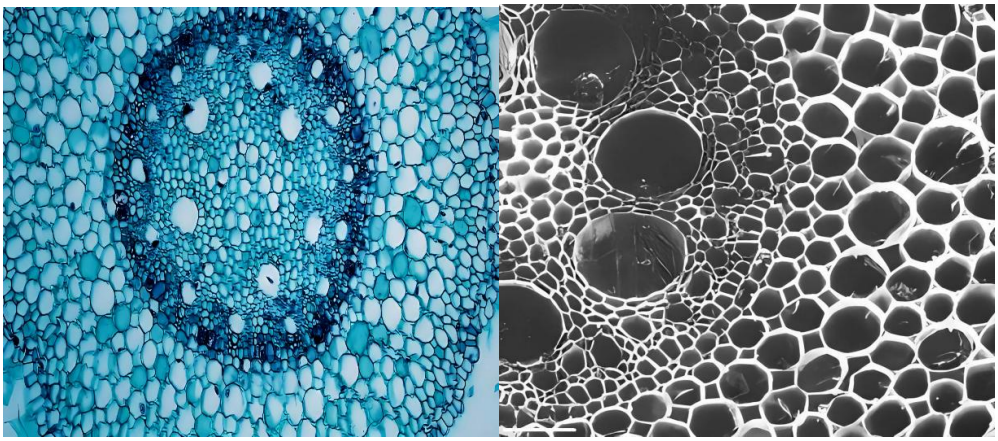

Fig 15: a. TS of *Phoenix sylvestris* (L.) Roxb. Showing cortex layers and vascular bundle
b. TS of *Phoenix sylvestris* (L.) Roxb. Showing cortex layers and endodermis

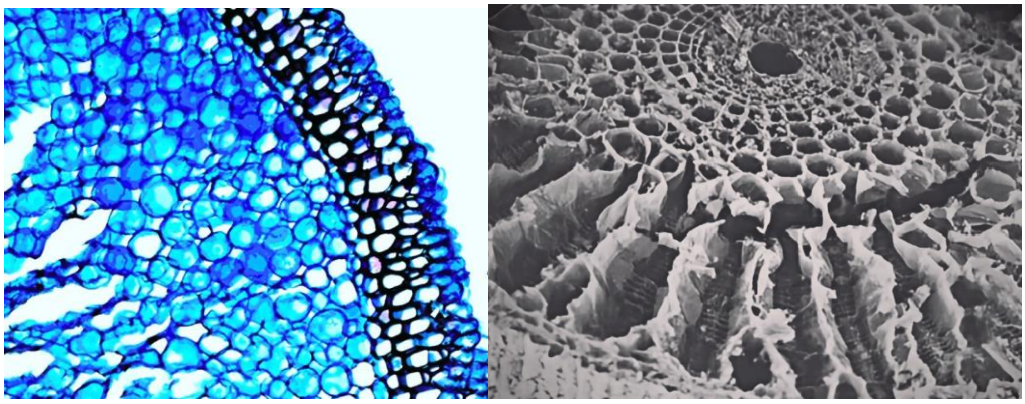

Fig 16: a. Raphia vinifera P. Beauv. Showing exodermis and xylem vessels
b. SEM. showing endodermis and medullary rays

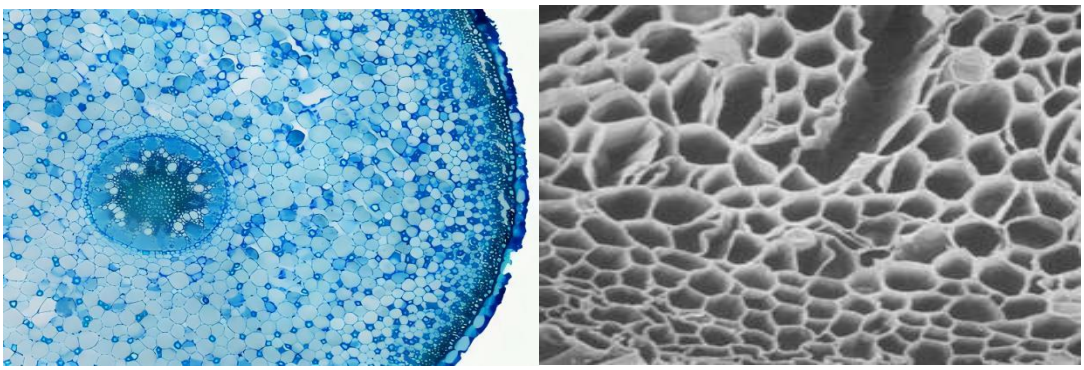

Fig 17: a. TS of *Raphis excelsa* (Thunb.) Henry showing a large number of cortex layers
b. TS of *Raphis excelsa* (Thunb.) Henry showing SEM image of cortex layers along with air channel

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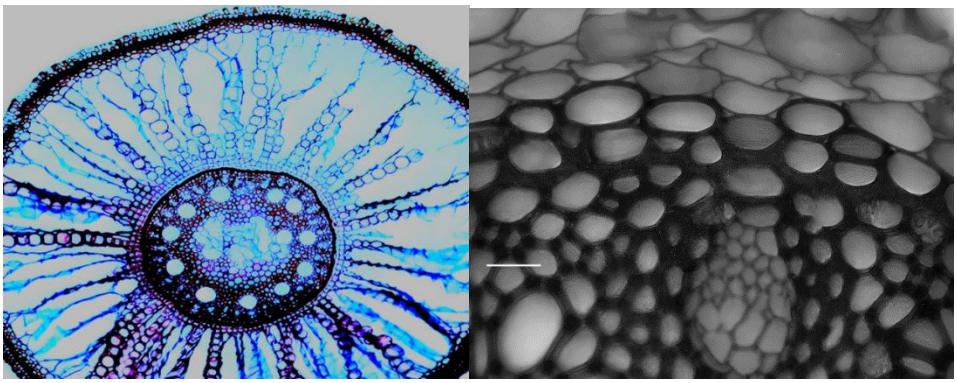

Fig 18: a.: TS of *Syagrus romanzoffiana* (Cham.) Glassman showing large air channels
b. TS of *Syagrus romanzoffiana* (Cham.) Glassman showing endodermis and phloem

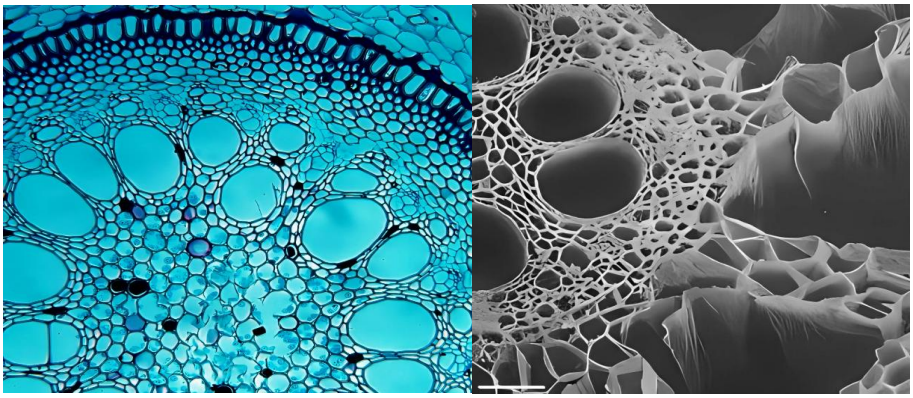

Fig 19: a. TS of *Washingtonia robusta* H.Wendl.showing vascular bundle
b. TS of *Washingtonia robusta* H.Wendl. Showing Y-shaped xylem arches

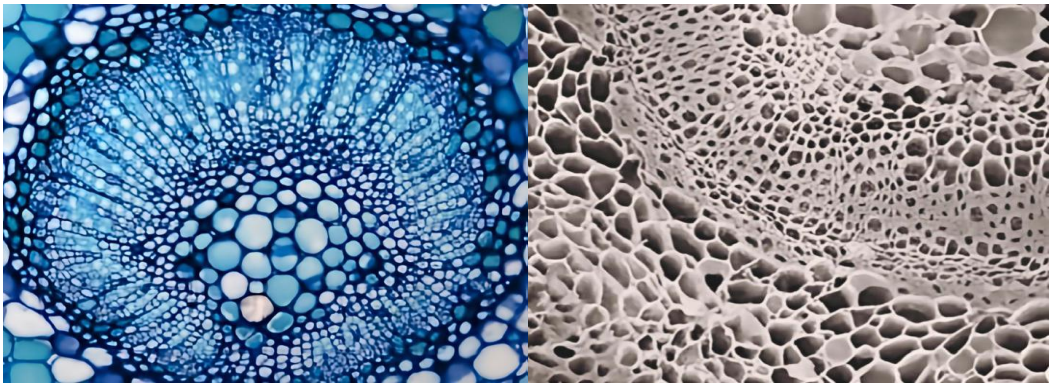

Fig 20: T. S of *Wodyetia bifurcata* A.K.Irvine (LM) showing thick endodermis and vascular bundles
b. T. S of *Wodyetia bifurcata* A.K.Irvine (SM) showing cortex parenchyma and phloem

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Table 1: Quantitative study of various parameters of root transverse section cutting of Arecaceae Species

Sr no.	Plant names	Epidermis cells thickness (µm)	Cortex layers (µm)	Cortex thickness (µm)	Rhizodermis thickness (µm)	Air spaces (µm)	Vascular cylinder diameter (µm)	Xylem arches (µm)	Metaxylem arch (µm)	Diameter of metaxylem (µm)	Maximum length of the phloem (µm)	Pith Diameter (µm)
1	***Archontophoenix alexandrae* (F.Muell.) H.Wendl. & Drude**	20-32	51	1005-1120	18-21	22-29	1120-1210	37-41	2-4	88	145	290-330
2	***Borassus flabellifer* L.**	17-19	35	840-890	-	15-19	700-810	17-21	2-5	43	70	170-230
3	***Calamus rotang* L.**	17.5-21	30	510-570	13-17	14-20	510-720	17-21.5	2-3	37.5	52	260-300
4	***Caryota urens* L.**	30.5-50.5	47	610-840	19-22	14-21	970-1220	29.5-34	5-9	87.5	141	570-810
5	***Chamaedorea cataractrum* Mart.**	18.5-22.5	40	920-960	15-20	21-25	1090-1150	27-32	3-6	55.5	160	600-690
6	***Chamaerops humilis* L.**	35-42	29	810-920	20-29	14-18	770-910	33-38	2-5	78	123	420-440
7	***Dypsis decaryi* (Jum.) Beentje & J. Dransf.**	23-27	50	970-1000	23-31	23-31	990-1010	27-29	3-6	60	105	190-240
8	***Dypsis lutescens* (H.Wendl.) Beentje & J.Dransf.**	25-30	-	800-850	-	15-19	700-810	17-21	2-5	43	170	170-230
9	***Hyophorbe lagenicaulis* (L.H.Bailey) H.E.Moore**	19-23	10	400-450	15-21	-	760-890	20-30	2-5	55	110	200-290
10	***Hyphaene thebaica (L.) Mart.***	30-37	49	1009-1120	-	20-23	1022-1170	32-41	4-7	108	102	600-770

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11	***Livistonia chinensis* (Jacq.) R.Br. ex M**	50-55	42	690-800	14-16	14-20	770-900	26-50	1-3	78.5	134	370-520
12	***Nannorrhops ritchiana*(Griff.) Aitch.**	33.5-41.5	47	820-860	14-17	19-23	1190-1250	37-42	2-5	95.5	146.5	820-990
13	***Phoenix canariensis* Hort. ex Chabaud.**	53.5-61	60	1020-1040	13-18	20-23	1030-1050	25.5-29	4-6	70.5	129.5	470-490
14	***Phoenix dactylifera* L.**	35-40	38	970-1020	20-25	13-14	500-550	15-20	2-4	21	70	120-150
15	***Phoenix sylvestris* (L.) Roxb.**	51-56	39	600-700	15-19	16-19	700-900	20-35	1-3	72	129	300-430
16	***Raphia vinifera* P. Beauv.**	50-54	29	650-700	14-18	13-17	700-800	25-30	1-2	62	122	310-420
17	***Rhapis excelsa* (Thunb.) A.Henry**	17-33		905-1010	17-20		1000-1110	16-24	1-3	110	95	200-230
18	***Syagrus romanzoffiana* (Cham.) Glassman**	45-50	38	980-1050	30-35	14-16	600--650	15-18	3-4	31	80	130-170
19	***Washingtonia robusta* H.Wendl.**	19.5-31	31	520-540	13-15	13-17	520-790	18-20.5	2-4	39.5	54	270-310
20	***Wodyetia bifurcata* A.K.Irvine**	50-53	30	600-640	15-19	13-16	500-600	25-30	2-4	62	127	200-320

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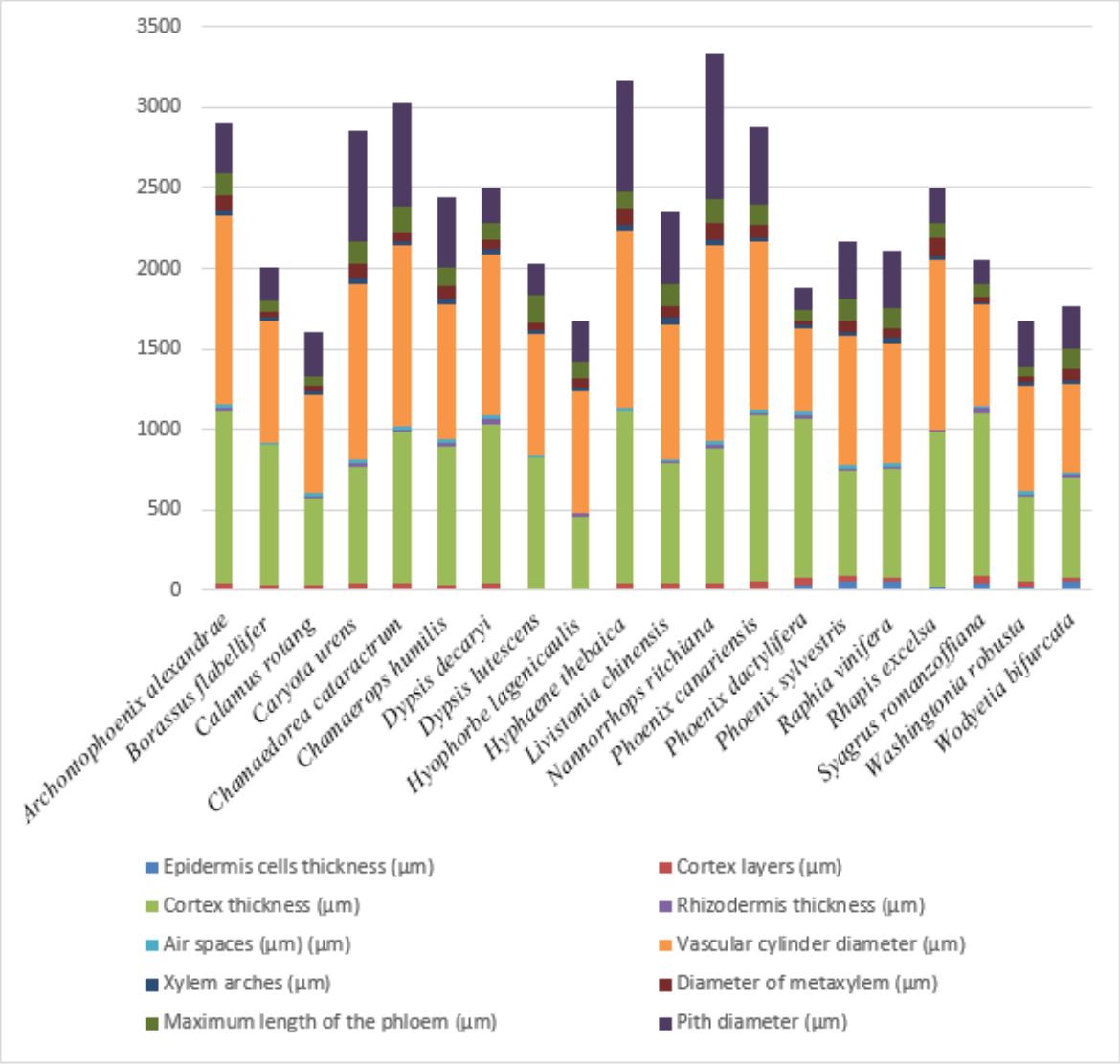

Fig 21: Comparison among various parameters of root transverse section cutting of Arecaceae species

DISCUSSION

This is the first time that the root anatomy of these species is done in Pakistan.

In the present studies the general anatomical characteristics observed in root of Arecaceae taxa were in agreement with those pointed out by the Tomlinson *et al*. (2011) and the present studies highlights some significant root anatomical parameters which can be helpful in plant species identification and differentiation.

In this research work most of the species in their transverse section of root anatomy show single layered rhizodermis having rectangular to quadrangular shape. According to a

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number of authors (Henderson *et al.* 2005, Ahmad *et al.* 2017 and Seubert, 2019) one of the main features of the rhizodermis is the root hair development however according to present studies no root hairs were seen in all the studied Arecaceae taxa. According to Tomlinson *et al.* (2011) the development of the hairy layer in Arecaceae taxa is present in very thin roots. The epidermis and epidermal cells in the present studies showed variation. Some species (*Borassus flabellifer* L., Dypsis lutescens (H.Wendl.), *Dypsis decaryi (*Jum.) Beentje & J.Dransf Beentje & J.Dransf, *Hyophorbe lagenicaulis* (L.H.Bailey) H.E.Moore and *Raphis excelsa* (Thunb.) Henry showed smooth thin walls while the remaining species showed thick smooth walls. According to Enstone *et al*. 2003 the cell walls thickening can be associated to the protection against pathogens attack and dehydration. In the present research work all the species had semicircular to circular shaped epidermal cells. Allen et al. 2013 in his studies also discussed the semi-circular to circular shaped epidermal shaped cells in the species of genus *Geonoma* of family Arecaceae which confirms the findings of the present studies.

In the present investigation the cortex showed variations among different species with respect to number of layers and thickness. The minimum number of cortex layers observed was 10 *Hyophorbe lagenicaulis* (L.H.Bailey) H.E.Moore and the maximum number of cortex layers observed was 60 in *Phoenix reobeleni* O'Brien. Variations were also observed in cortex thickenings. The minimum thickening 400-450 µm was observed in *Hyophorbe lagenicaulis* (L.H.Bailey) H.E.Moore and the maximum thickening 1020-1040 µm was observed in *Phoenix canariensis* Hort. ex Chabaud. The existence of abundant air spaces also called air channels in Arecaceae taxa is remarkable. According to Seubert 2019 these air spaces have a lysogenous origin and may be variable in size and this variability in the species depends on the intensity of the procedure that created them. According to Flores-Vindas, 2019 the presence of air spaces is common in Arecaceae taxa but it is also noted in many other monocots. The air spaces in the studied taxa showed a lot of variation in number and length. The variation was also seen in the length of the air spaces. The minimum length (90-95 µm) of air spaces was observed in *Syagrus romanzoffiana* (Cham.) Glassman whereas the maximum length (410-490 µm) of air spaces was observed in *Chamaedorea cataractrum* Mart.

The vascular cylinder is determined by the pericycle layer and the vascular bundle diameter showed a lot of variation in the studied taxa. The lowest diameter of vascular bundle (520-790 µm) was observed in *Washingtonia robusta* H.Wendl. Whereas the highest vascular bundle diameter (1190-1250 µm) was observed in *Nannorrhops ritchiana* (Griff.) Aitch. In the studied species the vascular bundle was composed of xylary arches which were variable in number in different species. All the species showed “Y” shaped pattern of xylem arches except *Dypsis decaryi (*Jum.) Beentje & J.Dransf, *Hyphaene thebaica* (L.) Mart, *Livistonia chinensis* (Jacq.) R.Br. ex-Mart, and *Nannorrhops ritchiana* (Griff.) Aitch which showed “I’ shaped xylem arches. The metaxylem vessels number per arch and their diameter was also variable in the different studied taxa. The minimum number of metaxylem arches (1-3) were seen in *Livistonia chinensis* (Jacq.) R.Br. ex-Mart. The maximum number of metaxylem arches (5-9) was seen in *Caryota urens* L. The minimum inner diameter of the widest metaxylem arch (31

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µm) was observed in *Syagrus romanzoffiana* (Cham.) Glassman. The maximum inner diameter of the widest metaxylem arch (110 µm) was observed in *Raphis excelsa* (Thunb.) Henry. Briceño *et al.* 2021 in his studies examined that the maximum number of metaxylem arches were in *G. orbignyana* and the minimum were in *G. pinnatifrons.* Similarly, the maximum inner diameter of the widest metaxylem arch was seen in *G. undata* and the minimum was observed in *G. spinescens* while studying the genus genus *Geonoma* of Arecaceae family. The phloem strands are conspicuous and their length varies in different taxa. In present studies the maximum length of the phloem strand observed was 170 µm in *Dypsis lutescens* (H.Wendl.) Beentje & J.Dransf. Whereas the minimum length of the phloem strand observed was 54 µm in *Cocothrinax argentata* (Jacq.) L.H.Bailey. Variation was also seen in pith diameter during the transverse section cutting of root in the present research work. The maximum pith diameter observed was almost 820-990 µm in *Nannorrhops ritchiana* (Griff.) Aitch. Whereas the minimum pith diameter observed was almost 130-170 µm in *Syagrus romanzoffiana* (Cham.) Glassman.

CONCLUSION

This anatomical study of root transverse section cutting was done first time by utilizing light and scanning electron microscope. The anatomical study of root transverse sections in Arecaceae species has revealed distinct morphological features that are crucial for their identification and classification. The variations in root structure among the studied species provide valuable insights into their adaptability, nutrient uptake mechanisms, and overall plant health. These findings not only enhance our understanding of the anatomical diversity within the Arecaceae family but also have practical implications for agriculture and horticulture. By improving the ability to distinguish between species, this research can aid in the development of more targeted cultivation practices, leading to better crop management and increased economic benefits. Furthermore, the study highlights the importance of detailed anatomical analysis in plant taxonomy and its potential applications in improving crop resilience and productivity.

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