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A REVIEW ON ANATOMICAL METHODS IN PLANT SYSTEMATICS

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ABSTRACT

The comparative study of plant structure, morphology, and anatomy has always been the backbone of plant systematics. Anatomical characteristics are important evidence when elucidating the relationships among higher plants. Therefore the anatomical information can be taxonomically useful without having obvious evolutionary or phylogenetic interpretation. This review is a comprehensive study of the plant anatomical methods used by various researchers using different plant sources like leaf, petiole, and stem.

Keywords: Plant anatomy, Systematics, Wood, Leaf, Petiole, Stem.

INTRODUCTION

Plant anatomy is the branch of botany dealing with the anatomical and histological structure of various parts of plant organs. Nowadays along with other branches, anatomy is also essential to validate and understand many aspects of plant biology, including the ecological and molecular ends of the spectrum. This field of biology finds application in several fields viz. systematics, forensics, and pharmacognosy. The structural variations in anatomical characteristics have enormous implications in these fields.

Systematics deals with the description, naming, classification, identification, and determination of relationships among plants by using data from many disciplines such as morphology, anatomy, molecular biology, ecology, etc. The majority of the plants have evidence according to macro-morphological features, but for accurate classification, information from diverse sources must be utilized. Anatomical features have played a very important role in determining phylogenetic relationships.

Plant Anatomy In Systematics

Wood Anatomy

Xylem and phloem are the channels for transference and communication in all vascular plants. The plant functioning such as germination, a protophloem, and protoxylem formation dependsupon the transport system. Xylem cells are formed soon after the cambium develops which helps in water transportation and the structure known as wood. Outside of cambium phloem cells develop, which plays a key role in the transport of assimilates (Schweingruber *et al*., 2011).

The anatomy of many woody species structures has been elucidated by many scientists (Wheeler *et al*., 2007). Secondary xylem (wood) is a complex biological material. In most gymnosperms and many angiosperms as a result of secondary growth, stems and roots develop from vascular cambium which is derived from secondary xylem (Butterfield & Meylan, 1980, Philipson *et al*., 1971).

Nodal Anatomy

The anatomy of the node is an important aspect of taxonomy and comparative morphology of the stem, leaf, and flower. In the angiosperms especially in the dicotyledons, the primary vascular cylinder is interrupted at each node if the exit of one or more bundles enters the leaves. The stelar bundles, which are the continuation of the bundles in the leaf bases are the leaf traces. Accordingly to the number of leaf gaps per leaf the node is termed unilacunar, trilacunar, or multilacunar (Fahn, 1989).

The trilacunar node is the primitive type in the angiosperms (Sinnott, 1914). The assumption that the trilacunar node is the primitive one has been reported by later research on nodal anatomy in the gymnosperm and angiosperm (Gunckel& Wetmore, 1946; Marsden & Bailey, 1955; Fahn & Bailey., 1957).

Leaf Anatomy

The leaf is a specialized organ in which the functions of photosynthesis is cantered. In a sense this is the most important of plant functions, since all other functions depend upon it or contribute to it either directly or indirectly. The leaf is, therefore, an exceedingly important organ (Eames, A.J; 1961).

Morpho- anatomically the most variable plant organ is the leaf. Phyllome is an aggregate term for all the types of leaves present on plants (Arber, 1950).

The stomata normally occur in the largest numbers on the dorsal surface in dicotyledonous leaves of the broadly expanded type. Some species have comparatively few on the ventral surface and some lack them on the upper surface. Floating leaves of aquatic plants have stomata on the upper exposed surface only and submersed leaves lack stomata. In general, the distribution of the stomata varies with the environment in which the plants are living; those living under the more severe condition of water loss have stomata in the more protected positions (Eames, A.J. 1961).

The stomata occur in all the plant parts above the ground, but they are large in number on leaves. Roots usually lack stomata. Crescent-shaped guard cells are common in dicot, with rounded ends and kidney-shaped (Esau, 1979).

Classification of the stomatal types is based either on their arrangement of mature subsidiary cells and their patterns of development. Types of mature stomatainclude anomocytic, anisocytic, and paracytic (Wilkinson, 1979).

The stomata are apertures in the epidermis, each bounded by two guard cells. Their main function is to allow gases such as carbon dioxide, water vapours, and oxygen to move rapidly into and out of the leaf. In green leaves, they occur either on both surfaces (amphistomatic leaf) or on one only, either the upper (epistomatic leaf) or more commonly the lower i.e., hypostomatic leaf.

The trichomes are highly variable appendages of the epidermis, including glandular (secretory) and non-glandular hairs, scales, papillae, and the absorbing hairs of roots. They occur in all parts of the plant and may persist throughout the life of a plant part or may fall off early. Although the trichomes vary widely in structure within larger and smaller groups of plants, they are sometimes remarkably uniform in a given taxon and may be used for taxonomic purposes.

Some families can be easily identified by the presence of a particular type or types of hair. In other cases, the hairs are important in the classification of genera and species and in analyzing interspecific hybrids (Metcalfe & Chalk 1950; Metcalfe and Chalk, 1979; Rollins, 1944; Carlquist, 1961). A glossary of the very rich terminology of plant trichomes has been compiled by Payne (1978).

Petiole Anatomy

The leaf blade avails the vascular supply from the stem through the petiole. The abscission zone occurs at the base of the petiole. Xylem is restricted to tracheid or narrow often discontinuous vessels which help to reduce the risk of blocking of the vessel during the leaf blade is wind damaged or eaten and also when the senescent leaf abscises. The scar formed at the time of petiole becomes disconnected was covered by a suberized protective layer of cork(Bryan & James, 2008).

The development of the petiole takes place simultaneously with the expansion of the leaf blade. Cell division occurs throughout the petiolar meristem followed by rapid elongation (O'Brien and Thiman., 1965).

Stem Anatomy

The part of the axis of a plant that bears the leave and reproductive structures and is commonly aerial and ascending in the stem. Stems and roots are alike in general structures, each possessing a stele with xylem and phloem, pericycle, endodermis, and cortex with an epidermis. Stem differ from roots in fundamental vascular structures. The difference in vascular structures lies chiefly in the arrangement of the xylem and phloem: in the roots, the strands of primary xylem and phloem lie in different radii, separated from one another; in the stem, the strands lie side by side in the same radius. Further, the xylem of the root is always exarch, whereas that of the stem is endarch (Eames, A.J.1961).

The primary vascular systems of monocotyledonous and dicotyledonous generally differ considerably. In a transverse section of the monocot stem, there are many scattered vascular bundles, while in dicots a limited number of bundles are usually arranged in a cylinder outside the pith. For the majority of dicots, the fascicular cambium separates the primary xylem and phloem of both the stem and root (Bryan & James, 2008).

Literature Study

With the huge popularity of anatomical methods, different works had been done by using different plant sources like leaf, petiole, stem, and root.

Wood Anatomy

Pathirana & Herat, (2004) studied the anatomical features of genus Garcinia grown in Srilanka. The results based on vegetative anatomy revealed that the boundaries between Sri Lankan species might be successfully established and there isa possible evolutionary relationship between the non-endemic and endemic taxa.

A detailed study had been made of several wood features that are presented in numerical codes taken from the IAWA Hardwood (1989) and Softwood (2004) Lists of microscopic features for wood identification (Gasson *et al*., 2011).

Oladipho and Illoh (2012) carried out the comparative study of wood anatomy of five species of Jatropha, found in Nigeria. The studies were carried out to shed light on the taxonomic value of the wood characters of the genus. Meylan & Butterfield (1972) made a systematic comparison of comparative leaf histology and wood anatomy more accessible. Vestured pits, the character is shown in the study done by Jansen *et al*., (1998) again with a strong phylogenetic signal at high taxonomic levels, studied in greater detail and more unambiguously. A detailed anatomical study was carried out by Pathirana & Herat, (2004) in 13 species of *Calophyllum* L. present in Sri Lanka. The result proposed is an evolutionary relationship between the non-endemic and endemic species.

A general wood anatomical description of the Bonnetiaceae (Maguire, 1972) was compared with all the tribes of the Theaceae and Guttiferae and concluded that Bonnetiaceae are wood anatomically intermediate between Theaceae and Guttiferae (*Baretta-kuipers*, 1976).

Nodal Anatomy

Bangar, 2012 studied the nodal structure of five species of Clerodendrum revealed that the leaves are mostly opposite, whorled rarely alternate, and exstipulate. The nodal anatomical characteristics such as foliar nodes, vascular strand, leaf trace, and sclerenchymatous patches are the differential traits considered under this study.

The investigation carried out by Kshiragar (2015), the vascular organization of the node in six species of Lagerstroemia that the leaves were generally opposite but except in few species with alternate phyllotaxy. The foliar nodes are unilacunar one traced reported in most of the species of Lagerstroemia but certain species are with an arc-shaped median trace. The variation in nodal characteristics can be employed in the delineation of plants.

Leaf Anatomy

The leaf anatomical characteristics of the genus *Vatica* L. in Thailand were carried out for the leaf epidermal clearing, anatomy of the lamina, and the petiole. The genus can be divided into two distinct groups based on the petiole anatomy having a different number of resin canals, which supports the grouping based on the morphological data (Anitthan & Achra.2008).

The morphological, anatomical, and micromorphological features such as in *Desmodium tortuosum* (Sw.) DC. was investigated to assist in the identification of the species as a new record for Egypt. The anatomy of leaf, petiole, stem, and seed anatomy and the leaf patterns under light and scanning electron microscopes, respectively, is the first such study on the species (Shaheen, 2008).

Ogundare & Saheed (2012), to separate the four species of *Citrus* L. based on leaf epidermal features and petiole anatomy. Leaf epidermal features include hypostomatic condition, stomata shape and type, presence of secretory cavity on the adaxial surface and polygonal shape of epidermal cells showed a close relationship among the two species from others.

Anatomical exploration of the leaf, stem bark, and fruit of *Zanthoxylum armatum* DC. (Rutaceae) which showed diagnostic features such as prominent oil cavities, nine types of stomata, and absence of trichomes. The bark and the fruit anatomy of *Z. armatum* showed different tissue arrangements. The present study was helpful in the phylogeny and taxonomic description of this important medicinal plant (Barkatullah *et al*., 2014)stem bark and fruit of this plant. Leaf of Z. armatum is bifacial, compound and punctate with glabrous surfaces having a single layer of epidermis and palisade mesophyll. The leaf has a Palisade ratio ranged from 6.00 to 9.00 (8.2±0.32. The seven varieties of *Ficus deltoidea Jack* (Moraceae) based on matured leaf character and morphological characteristic based on leaf shape, size, surface texture, margin, petiole length, and also variations in anatomical characters concerning the structures of the lamina, leaf epidermis, and midrib are also demonstrated (Nur Fatihah, *et al*., 2014).

Sreelakshmi *et al*., (2014), compared four types of stomata such as anomocytic, paracytic, diacytic, and anisocytic in dicot and monocot plants. The study helps to correlate between foliar characters and stomata in leaf.

Leaf epidermal features were studied in 10 selected species of Fabaceae (Alege & Shaibu, 2015), with the major objective of evaluating the systematic and phylogenetic relevance that could be used to resolve systematic and phylogenetic problems in this family.

Foliar epidermal features of four Nigerian species of the family Clusiaceae were studied. This was intending to exploit systematic and taxonomic values. Data acquired from this study help to resolve the taxonomic problems in this family and confirm their identity (Nnamani, 2015). Anatomical study of leaf and petiole in three species of *Rhizophora* L. occurring in the Mangrove forest of Nigeria was carried out. The results of anatomical character showed generic similarity in the taxa studied (Ta & Jayeola., 2015).

Talebi *et al*., (2017), studied and compared the anatomical traits of the genus Euphorbia collected from Kerman Province, Iran. The anatomical characters such as the absence or presence of trichomes, epidermal cell shape, and anticlinal cell wall patterns had taxonomic value and are useful in the identification of taxa.

Table 1: tabulation showing trend of work done for in plant anatomy from 1914 to 2019

Sl. No	Title	Year of publication	Ref. no.
Article references			
1.	Investigations on the phylogeny of the angiosperms. I. The Anatomy of the node as an aid in the classification of angiosperms. Shaheen, A. S. M.	1914	45
2.	Evidence for natural hybridity between Guayule (*Parthenium argentatum*) And Mariola (*Parthenium incanum*). Rollins, R.C.	1944	41
3.	Studies of development in long shoots of *Ginko biloba* L.: I, the origin and pattern of development of the cortex, pith, and procambium. Gunckel, J.E. & R.H. Wetmore.	1946	18
4.	The nodal anatomy and primary vascular cylinder of the Calycanthaceae. Fahn, A. & I.W. Bailey.	1957	15
5.	The fourth type of nodal anatomy in dicotyledons illustrated by *Cleorodendron trichotomum* thumb. Marsden, M.P.F. &I.W.Bailey.	1955	25
6.	Histological studies of the Coleoptile I. tissue and cell types in the coleoptile tip. O'Brien, T.P. &K.V.Thiman.	1965	34
7.	Bonnetiaceae.In The Botany of the Guayana Highland 9. Maguire, B.	1972	26
8.	Comparative wood anatomy of Bonnetiaceae, Theaceae, and Guttiferae. Baretta-Kuipers., T.	1976	7
9.	The plant surface. In: Anatomy of the dicotyledons. Wilkinson, H.P.	1979	52
10.	IAWA list of microscopic features for hardwood identification. IAWA Committee.	1989	20
11.	Vestures in woody plants: a review. Jansen, S., E. Smets& P. Baas.	1998	22
12.	IAWA list of microscopic features of softwood identification. IAWA Committee	2004	21
13.	Comparative vegetative anatomical study of the genus *Garcinia* L.(Clusiaceae/ Guttiferae) in Sri Lanka. Pathirana, P. S. K., & T.R. Herat, T. R.	2004	37
14.	Variations in dicot wood anatomy: a global analysis based on the Inside Wood database. Wheeler, E. A., P. Baas & S.A. Rodgers.	2007	53
15.	Leaf Anatomy of Vatica L. (Dipterocarpaceae) in Thailand. Anitthan, S. & T. Achra	2008	3
16.	Morphological and anatomical investigations in *Desmodium tortousum*. Shaheen, A. S. M.	2008	44
17.	Petiole anatomy of some Lamiaceae taxa. Akcin, O. E., O.M. Sabri&G.Senel.	2011	2
18.	Wood anatomy of CITES-listed tree species. Gasson, P., Baas, P., &E.Wheeler.	2011	17
19.	Leaf and petiole anatomical studies of the Genus Rhizophora L. in Nigeria. Ta, A., &A.A.Jayeola.	2015	49
20.	Comparative stem and petiole anatomy of West African species of *Momordica* L. (Cucurbitaceae). Aguoru, U.	2012	1
21.	Nodal Characters in Some Clerodendrum Species. Bangar, M.A.	2012	6
22.	Foliar epidermal characters and petiole anatomy of four species of Citrus L. (Rutaceae) from South-Western Nigeria. Ogundare, C. S., &S.A.Saheed.	2012	35
23.	Comparative wood anatomy of some members of the genus Jatropha (Euphorbiaceae) found in Nigeria. Oladipo, O., & Illoh, H.	2012	36
24.	Petiole anatomy of some species of Asteraceae in southwest Nigeria. Mabel, F. 2013.	2013	24
25.	Anatomical structures of vegetative and reproductive organs of *Senna occidentalis* (Caesalpiniaceae). Nassar, M. A. A. A., Ramadan, H. R. H., & Ibrahim, H. M. S.	2013	30
26.	Systematic Significance of Petiole Anatomical Characteristics in *Microcos* L. (Malvaceae: Grewioideae). Nurul-Aini, C. A. C., T. Noraini., R.C.Chung., M.N. Nurhanim&M.Ruzi.	2013	33

Continued..

27.	Leaf and stem anatomy in eight Hypericum species (Clusiaceae). Perrone, R., P.De Rosa., O.De Castro., & P. Colombo.	2013	39
28.	Leaf, stem bark, and fruit anatomy of *Zanthoxylum armatum* DC. (Rutaceae). Barkatullah, I. M., J. Ghulam&A.Imtiaz.	2014	8
29.	Leaf morphology and anatomy of 7 varieties of *Ficus deltoidea* (Moraceae). Nur-Fatihah, H. N., M.Nashriyah.,A.R.NorZaimah., M.Khairil&A.M.Ali.	2014	32
30.	Relationship between the leaf area and taxonomic importance of foliar stomata. Sreelakshmi, V. V., E.P.M.Sruthy & J.Shereena.	2014	47
31.	Phylogenetic and Systematic Value of Leaf Epidermal Characteristics in Some Members of Nigerian Fabaceae. Alege, G. O. & D.O. Shaibu.	2015	4
32.	Comparative Systematic Anatomical Studies on Stem and Root of *Stachytarpheta* Species Present in Awka, South Eastern Nigeria. Iroka, F. C., U. C. Okeke, I.A. Izundu, C.N. Okereke, I.C. Onwuasoeze&L.B.Nyananyo.	2015	19
33.	Study of nodal anatomy in some species of *Lagerstroemia* L. (Lythraceae). Kshirsagar, A. A.	2015	23
34.	Systematic Values of Foliar Anatomical Features in some Members of Nigerian Clusiaceae. Nnamani, C. V. &M.O.Nwosu.	2015	31
35.	A study of epidermal leaf anatomy of 18 Euphorbia taxa from Kerman Province, Iran. Talebi, S. M., M.Noori&H.A.Naniz.	2017	50
36.	Morphological and Anatomical Studies on *Trichosanthes cucumerina* L. (Cucurbitaceae). Ekeke, C. & J. U. Agogbua.	2018	14
37.	Comparative petiole anatomy of the tribe Sorbarieae (Rosaceae) provides new taxonomically informative characters. Song, J. H., &S.P. Hong.	2018	46
38.	Anatomy and microscopic characteristics of *Picris japonica*. Wang, Y., Y. Wen & J. Gao.	2018	51
39.	Anatomy, histochemistry, and oxalic acid content of the leaflets of *Averrhoa bilimbi* and *Averrhoa carambola*. Sa, R. D., A.L.Vasconcelos., A.V.Santos., R.J.R.Padilha., L.C.Alves., L.A.L.Soares&K.P.Randau.	2019	43
Book references			
40.	The natural philosophy of plant form. Arber, A.	1950	5
41.	Anatomy of the dicotyledons. Vol. I. Metcalfe, C.R. & L. Chalk.	1950	27
42.	Comparative plant anatomy. Carlquist, S.	1961	11
43.	Morphology of the Angiosperms. Eames, A. J.	1961	12
44.	The vascular cambium: Its development and activity. Philipson, W.R., M.W.Josephine& B.G. Butterfield.	1971	40
45.	Three-Dimensional Structure of Wood: A Scanning Electron Microscope Study. Meyland, B. A & B.G. Butterfield.	1972	29
46.	A Glossary of Plant Hair Terminology. Brittonia. Payne, W.W.	1978	38
47.	Anatomy of the seed plants. 2nd Ed. Esau, K.	1979	13
48.	Anatomy of the Dicotyledons. 2nd Ed. Metcalfe, C.R.; Chalk, L.	1979	28
49.	Three-dimensional structure of wood. An ultrastructural approach. Butterfield, B.G. & B.A. Meylan.	1980	10
50.	Plant Anatomy. Fahn, A.	1989	16
51.	Anatomy of flowering plants. An introduction to structure and development. Rudall, P.J.	2007	42
52.	Plant structure-A colour guide. Bryan, G.B. & M.D. James.	2008	9
53.	Atlas of stem anatomy in herbs, shrubs, and trees. Schweingruber. F.H., A. Borner& E.D. Schulze.	2011	48

Ekeke&Agogbua (2018) carried out the study on morphological, anatomical, and proximate characteristics of *Trichosanthes cucumerina* L. (Cucurbitaceae) using morphological observation and microtomy to determine the relationship between this species and other Cucurbits. The similarity in morphological and anatomical features of this species and other members of Cucurbits depicts the taxonomic and evolutionary relationship among them, however; the type of trichomes observed suggests that this species could be *T. cucumerina* var. anguina and not *T. cucumerina*.

A detailed Anatomical study of *Picris japonica Thunb*., (Asteraceae), a herbal medicinal plant,was helpful for species-level identification,botanical quality control, and also to detect adulterations in commercial or in laboratory samples (Wang *et al*., 2018).

The studies in species of *Averrhoa bilimbi* L. and *A. Carambola* L., (Oxalidaceae), was carried out for the anatomical and histochemical characterization, which helps in identification and localization of metabolites respectively (Sa *et al*., 2019).

Petiole Anatomy

Petiole anatomy of seven taxa of the Lamiaceae family was carried out and the variations were noticed in the petiole shape, arrangement, and several vascular bundles, hair types such as glandular and glandular hairs, and the presence of collenchyma (Akcin, SabriOzyurt and Senel, 2011).

Systematic description of seven West African species of *Momordica* L. of the family Cucurbitaceae was done based on petiole and stem anatomical characteristics for the first time by Aguoro (2012).

A detailed study of the petiole anatomy of twelve species of Asteraceae around Ile-Ife in South-Western Nigeria was done. The following distinguishing characteristics were analyzed under these study such asshapes of the petioles, variation in the number, arrangement, shapes of vascular bundles, and types of trichomes(Mabel, 2013).

The petiole anatomy of 23 *Microcos* L. (Malvaceae: Grewioideae) species was done to determine the systematic significance that may be useful in the identification and classification of the species. The petiole anatomical features observed with petiole outlines, patterns of petiole vascular bundles, presence of sclerenchyma cells, phloem sclerenchyma cells, tanniferous idioblast cells, types of crystals, presence of lignified parenchyma cells, interaxillary and intraxillary phloem, and types of trichomes. The study showed that additional data in the identification and classification of species in the genus Microcos petiole anatomical characters can be used and that these characters have some taxonomic value (Nurul-Aini *et al.,* (2013).

Iroka *et al.,* (2015) noted the anatomical features of the leaf and petiole of three species of *Stachytarpheta* in Awka, Southeast Nigeria was done with the help of a light microscope. Anatomically important features were seen in the leaf and petiole.

A comparative anatomical study of the petiole of 16 taxa belonging to the tribe Sorbarieae (Rosaceae) and the related genus *Lyonothamnus*. Based on the findings, a dichotomous key for identification at the generic/specific level was provided and also reported a structural change in the vascular bundles from the stem-leaf transitional zone to the leaf medial zone (Song & Hong, 2018).

Stem Anatomy

Rudall, 2007 reported that in the plant, the stem is mostly cylindrical, or sometimes ridged or quadrangular. The primary vascular bundle typically either presents in the form of acomplete cylinder or discrete form. The cortex is the outer region of ground tissue, lying between the surface cells and vascular tissues. Endogenous adventitious roots develop from the pericycle. The pith is the interior of the vascular tissue, but in many stems, the pith breaks down to form a central cavity. Stomata and trichomes are often present in the stem epidermis.

A detailed study on the histological features of *Senna occidentalis* (L.) Link (Coffee senna plant)was carried out by Nassar *et al*., (2013). The anatomical characteristics of different vegetative and reproductive organs were recorded and were analyzed microscopically and photomicrography.

Using light microscopy, general and histochemical staining and scanning electron microscopy by Perrone, *et al*., (2013) were carried out to study the foliar micromorphology, epicuticular wax morphology, and anatomical features of leaves and stem. The characteristic features revealed from their study considered as an additional basis for species identification.

CONCLUSION

The present review is aimed at providing a glimpse of major developments in structural plant systematics. Findings of botanists who have worked on morphology, anatomy, and development concerned with flowering plant systematics were a source of inspiration for this review.

This paper is a comprehensive approach towards plant anatomy based on the historical survey, personal experience, and observations. We hope that this review will serve as a base for further discussions and research on this topic.

CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

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