Cey. J. Sci. (Bio.Sci.) Vol. 32, 2004, 39-66

COMPARATIVE VEGETATIVE ANATOMICAL STUDY OF THE GENUS *GARCINIA* L. (CLUSIACEAE / GUTTIFERAE) IN SRI LANKA.

P. S. K. Pathirana and Tissa R. Herat*

Department of Botany, The Open University of Sri Lanka, Nawala, Nugegoda, Sri Lanka.

*Faculty of Applied Sciences, The Rajarata University of Sri Lanka, Polgolla, Sri Lanka.

ABSTRACT

Vegetative anatomical studies of 10 species of *Garcinia* L., described by earlier workers to be present in Sri Lanka were carried out. A detailed anatomical investigation of lamina, petiole, young stem and wood, was carried out and the results were analyzed by statistical methods. The study agrees with previous workers in that there are 10 *Garcinia* species in Sri Lanka. Further, it also revealed that the boundaries between the Sri Lankan species could be successfully established based on vegetative anatomy. With the results of anatomical, morphological and ecological studies combined with statistical analysis, possible evolutionary relationships between the non- endemic and endemic taxa has been suggested. On this basis, the non-endemic species, *G. mangostana* L., *G. spicata* (W. & A.) Hook. f. and *G. xanthochymus* Hook. f. centering *G. morella* (Gaertn.) Desr., form the basic stock from which two lines of specialization have arisen. The doubtful endemic *G. echinocarpa* Thw. could be considered as the most specialized species and the two endemics, *G. quaesita* Pierre and *G. terpnophyla* (Thw.) Thw. could be the coupling group between the basic group and *G.echinocarpa* Thw.. The endemic *G. zeylanica* Roxb. is observed to be an off shoot of *G. quaesita* Pierre. The exotic species *G. xanthochymus* Hook. f. could be interpolated between the basic group and the group which includes the two endemics *G. thwaitesii* Pierre and *G. hermonii* Kosterm. Further, based on the overall anatomical data, results of statistical analysis, ecological distribution and the findings with respect to the degree of specialization, it could be suggested that the most specialised species, *G. echinocarpa* Thw., is endemic to Sri Lanka.

Key words

Garcinia, comparative anatomy, principle component analysis and cluster analysis.

INTRODUCTION

Pre-Linnaen history of the Sri Lankan *Garcinia* species could be traced way back to the period of Dutch occupation in Sri Lanka. Hermann (1717) described two species as belonging to the genus *Garcinia* and named them using latin descriptive clauses such as *"Arbor indica quam Gummi Guttae fundit Fructu sulcato aurieo mati magnitudine"* (now known as *Garcinia zeylanica* Roxb.) and "Kanawa Koraka, Kaepnaji Koraka, Gohkatu or Ghoraka" {now known as *G. morella* (Gaertn.) Desr.}. Subsequantly, Burmann (1737), recognized only one species and named it using the latin descriptive clause" *Arbor indica gummi gutam fundens fructi dulci rotundoceraci magnitudine"* which is now known as *G. morella* (Gaertn.) Desr..

Linnaeus (1747) in his Flora Zeylanica mentioned the genus *Cambogia* within which no species were incorporated. However, Jussieau in 1789 recognized the genus as *Mangostana* and named the then known plant as *M. cambogia.* Subsequantly the species *M. cambogia* of Jussieau was renamed as *Garcinia cambogia* by Desroussaux (1792).

Moon (1824), recognized three differant kinds of Gamboge or goraka (S*) *viz.* sudu goraka, ratu goraka and ela goraka growing in Colombo area and incorporated them into *Garcinia cambogia* Desr. Moon in the same publication referred to the plants growing in [Jaffna as *G. celebica* and incorporated the commonly known Gamboge or Kana goraka (S) [also known as Gokatu (S) used for

* S = Sinhala name

Flavouring food, within the genus *Stalagmitis* Willd. *(=Cambogioides* L.). However, Kostermans (1980) is of the opinion that the Ratu goraka (S) is distinct and is nothing but *G. quaesita* of Pierre.

Roxburgh (1832) dealing with the Indian fraction of the genus recognized and incorporated ten species within the genus *Garcinia* which included a new species from Sri Lanka *G. zeylanica.* Subsequently, Thwaites (1864), with the assistance of J. D. Hooker, recognized three species of *Garcinia* L., namely *G. cambogia* Desr., *G. morella* Desr. and *G. echinocarpa* Thw.. In addition, he recognized the two genera *Terpnophyllum* Thw. and *Xanthochymus* Roxb., along with *Garcinia* L. as three separate genera within the family. However, as an addendum in the same publication, he corrected the misidentified species *Terpnophyllum zeylanicum* Thw., as G. *(Discostigma) terpnophylla* Thw. Then, in 1885, Pierre described and illustrated the then known members of the genus, which included *G. quaesita* Pierre and *G. thwaitesii* of his own.

Trimen (1893) recognized five species of *Garcinia* growing in Sri Lanka, namely *G. cambogia* Desr., *G. morella* (Gaertn.) Desr., *G. echinocarpa* Thw., *G. terpnophylla* (Thw.) Thw. and *G. spicata* (W. & A.) Hook f. Accordingly, *G. terpnophylla* (Thw.) Thw. and *G. echinocarpa* Thw. are endemic to Sri Lanka. Further, Alston (1931), providing a supplement to the Trimen's Flora of Ceylon (now known as Sri Lanka) incorporated the introduced and naturalized species *G. xanthochymus* Hook. f. into the Sri Lankan fraction of the genus.

Kostermans (1976) in his preliminary treatment of the genus recognized only nine species of *Garcinia* in Sri Lanka. However, in his treatment of the Revised Flora of Ceylon (1980), he recognized a total of ten species on the basis of morphological characters. According to him, five species out of the ten are endemic to Sri Lanka namely, *G. zeylanica* Roxb., *G. quesita* Pierre, *G. terpnophylla* (Thw.) Thw., *G. thwaitesii* Pierre and his new species *G. hermonii* while three are indigenous [*G. morella* (Gaertn.) Desr., *G. echinocarpa* Thw. and G. *spicata* (W. & A.) Hook. f.], one naturalized (*G. xanthochymus* Hook.f.) and the other cultivated *(G. mangostana* L.) (Table 1). The species *G. echinocarpa* Thw. which was considered as endemic to Sri Lanka by Trimen (1893), has been considered as an indigenous species by Kostermans (1980). However, he was in doubt of its occurance in the closest land mass India and whether the taxon is the same as the taxon he believed which was present in South India. On this basis, 50% of the total number of *Garcinia* represented in Sri Lanka are endemic while the endemicity of one species is doubtful, thus making the genus one of the most important taxa relatively old and well established in Sri Lanka.

The ten species described by Kostermans (1980), are represented in all the four natural climatic zones recognized by Muller-Dombois (1968) *viz.* Arid, Dry, Intermediate and Wet zones (Table 1, Fig. 1). Except for the work of Kostermans (1980) based on morphological studies enhanced by typification, no major study has been under taken to enumerate the species limits to gain a better understanding of the Sri Lankan fraction of the genus.

From the above discussion it is evident that the species limits of the genus *Garcinia* in Sri Lanka are yet to be known. In the present study, an attempt has been made to understand the limits of the taxa concerned, by investigating morphological and anatomical features together with ecological influences. The observations and the results have been analyzed to elucidate the relationships between the taxa and an attempt has been made to trace evolutionary trends within the genus. In addition, these observations have been compared with those of other relevant works, for a broader understanding of the genus.

MATERIALS AND METHODS

Fresh material of the representative members of the genus in Sri Lanka reported by Kostermans (1980) were collected along with voucher herbarium specimens in triplicate. The specimens collected were identified by consulting Kostermans (1980), Trimen (1893) and by comparing with plant specimens deposited in the National Herbarium, Royal Botanical Garden, Peradeniya (PDA). A set of herbarium specimens, wood samples were deposited at the PDA and another at the Herbarium of the Botany Division, The Open University of Sri Lanka, Nawala, Nugegoda. It should be noted that during the present study, *G. terpnophylla* Var. *terpnophylla* which Kostermans (1980) has reported to be rare and not seen under natural conditions but seen only one herbarium specimen, was not encountered under natural conditions. Data such as mean annual rainfall and mean annual temperature covering the ecological regions concerned, were obtained from the Meteorological Department, Bauddhaloka Mawatha, Colombo. Altitudes of sites where samples were collected were measured in the field with one inch topographic maps of the Survey Department (1992).

For the purpose of comparative anatomical studies, fresh material of leaf, petiole and young stem were collected and preserved in FAA (40% Formalin: 95% Ethanol: Glacial Acetic Acid and water based on the ratio 2:10:1:7 respectively) in the field. Wood samples were collected from straight branches to avoid the inclusion of tension and compressed wood as much as possible.

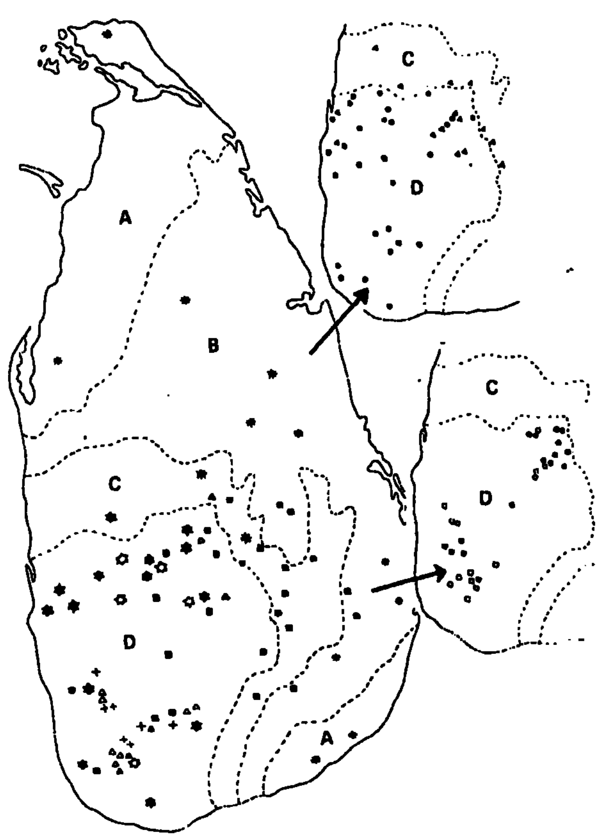

Figure 1. Distribution of *Garcinia* species in Sri Lanka [Modified after Kostermans (1980)]

G. echinocarpa (open circle) ∘
G. hermonii (open square) ▫
G. mangostana (solid star) ✸
G. morella (solid square) ■
G. quaesita (solid triangle) ▲
G. spicata(star) ✱
G. terpnophylla var acuminata (open triangle) △
G. terpnophylla var terpnophylla (dotted triangle) ▲
G. thwaitesii (cross) +
G. xanthochymus (open star) ✡
G. zeylanica (solid circle) •
A = arid zone; B = dry zone, C = intermediate zone; D = wetzone
[Based on Muller - Dombois (1968)].

Comparative anatomical studies of vegetative structures were carried out by preparing stained, permanent microscopic slides in the laboratory. For this purpose, the specimens of lamina, petiole and young stem were washed in running water for 24 hours to remove any traces of FAA from the tissues. Based on preliminary studies, parts of leaves (10 mm x 10 mm) including midrib from half the length of the leaf blade were removed for comparative cross sectional studies. Similarly, portions of the lamina were taken for paradermal sections from the middle of the lamina. Portions of petioles were taken from the distal end immediately below the lamina by following Metcalfe & Chalk (1950) for comparative cross sectional studies. Portions of young stems were taken from the middle of the first internode and the second node was selected for nodal anatomical studies. By following the method described by Johanson (1940), the specimens of lamina, petiole and young stem thus selected were passed through a tertiary butyl alcohol dehydration series followed by embedding in wax.

Table 1
***Garcinia* species reported from Sri Lanka by Kostermans (1980).**

Species	Distribution.	Endemicity
G. echinocarpa Thw.	W + +	E?
G. hermonii Kosterm.	WL	E
G. mangostana L.	WL, IL	NE
G. morella (Gaertn). Desr.	WL, IL & D	NE
G. quaesita Pierre.	WL & IL	E
G. spicata (W & A). Hook f.	I L & D	NE
G. terpnophylla (Thw). Thw.	WL, W +	E
G. thwaitesii pierre.	WL	E
G. xanthochymus Hook f.	WL	NE
G. zeylanica Roxb.	WL	E

D - dry zone, A - arid zone, IL - intermediate zone – lowlands, WL - wet zone – lowlands, W + - wet zone – lowlands to 1000 m. altitude, W + + - wet zone – above 1000 m., E - endemic species, E? - doubtful endemic species, NE - non-endemic species. [The division of climatic zones within Sri Lanka is based on Muller - Dombois (1968)].

Approximately 2 cm^3 blocks of wood were cut and preserved in 70% Ethyl Alcohol. Transverse, tangential and radial longitudinal sections of 10-20μm thick were cut by using a sliding microtome. The sections were then stained in a Safranin - Fast Green series and mounted in Canada Balsam according to Sass (1958). Macerations were made by cutting pieces of wood into small strips and softening them in a mixture of 30% Hydrogen Peroxide, Glacial Acetic acid and Distilled water mixed in the ratio 1:5: 4 respectively. Slides of macerated tissues were prepared by staining in a weak aqueous solution of Safranin followed by an alcohol dehydration series and mounting in Canada Balsm following Johanson's method (1940).

Anatomical characters of lamina, petiole and young stem to be studied and quantified were selected according to Metcalfe & Chalk (1950) and Solereder (1908). All the data on quantitative characters were based on 15 measurements of each sample. Further, quantitative data of lamina, petiole and young stem anatomical characters were obtained from cross sections except for lengths and breadths of epidermal cells which were measured from the paradermal sections of lamina. The maximum diameter parallel to the flattened adaxial side of the petiole was taken as petiolar diameter measurements. The maximum and minimum diameters of the young stem were measured and the average values were used for statistical analysis.

Anatomical characters of wood to be studied were selected according to Record & Chattaway (1937); Metcalfe & Chalk (1950). Lengths of vessel elements and fibres and the diameters of fibres were measured from wood maceration slides prepared. Lengths of vessel elements were measured from tips to tails, according to Chattaway (1932), Chalk & Chattaway (1934). Measurements of vessel diameter and vessel frequency were taken from cross sections. Vessel frequency measurements were based on 15 counts within an area of 19.7 sq.mm field of view. Individual pores were counted according to Wheeler (1986). Ray widths, ray heights and ray frequencies were measured using tangential longitudinal sections. The descriptions, terminology and the classes of wood are according to the IAWA Committee (1964). Height and width classes of rays are according to Chattaway (1932). Descriptions of ray types are based on the classification put forward by Kribs (1935) and the Committee on Nomenclature of Wood Anatomists (1957). All the anatomical observations were made using an Olympus, PM-1 DAD Light Microscope.

METHOD OF STATISTICAL ANALYSIS

Simple statistical analysis was carried out by following Siegel (1988). The sample means of quantitative wood, lamina, petiole, and young stem anatomical characters were calculated and tabulated along with the species descriptions. The mean ranges of species with minimum and maximum confidence intervals are noted within parenthesis. Preliminary statistical analysis of variants within the taxa was carried out. Pearson Product Movement Correlation Coefficients (*r*) were calculated for the data matrix of quantitative characters. Simple regression analyses were carried out with ecological parameters and quantitative anatomical characters to detect any dependencies between the two. Univariate statistical techniques such as Histograms, High-Low graphs, bivariate scatter diagrams and correlation matrices were constructed. In addition, multivariate statistical techniques adopted by Sneath & Sokal (1973), were employed to confirm the findings thus made. Consequently, Cluster Analysis (CA) and Principal Component Analysis (PCA) were carried out to examine the taxonomic patterns of the data and to generate a classification system.

During statistical analysis each species was coded by a number and an acronym. The code numbers and the acronyms assigned to each species are listed in Table 2. Similarly, the anatomical characters quantified were also coded during statistical analysis and the code words so given are listed in Table 3. Raw data obtained were converted to standard scores, i.e. Z-values, before analysis. Phenetic similarity / dissimilarity was used to obtain phenograms, following Bass et al. (1988) and Hederen (1990 b).

All the statistical computations were carried out using a Commodore PC – 10 III (Model PC 10C / PC 20 C) with the aid of the statistical program package SPSS/PC +TM, Version 4.0 (SPSS Inc., 1990).

Table 2
Species, Code numbers and acronyms used in the study.

Species	Code No.	Acronym
G. echinocarpa	1	GE
G. hermonii	2	GH
G. mangostana	3	GMA
G. morella	4	GMO
G. quaesita	5	GQ
G. spicata	6	GS
G. terpnophylla var. *acuminata*	7	GTE
G. thwaitesii	8	GTH
G. xanthochymus	9	GX
G. zeylanica	1 0	GZ

DISCUSSION

The anatomy of the lamina, petiole, young stem and wood is discussed in relation to its taxonomic significance in establishing boundaries between the Sri Lankan species of the genus *Garcinia*.

Leaf and Young stem

Vesque (1893) pointed out that the shape of the stomates, crystals in the epidermis, presence of hypodermis, number of palisade layers and the thickness of mesophyll in lamina are important in the identification of taxa within the genus *Garcinia*. Solereder (1908), reviewing the anatomical features of the family Guttiferae, emphasized that the laminal characters such as the distribution of secretory canals, diverse nature of the mesophyll, varying forms of epidermal cells, type of stomatal apparatus, papilose or strongly striate subsidiary cells in the stomatal apparatus, presence of hypodermis, nature of crystals and the presence of sclerosed cells and terminal tracheids in the veins are of diagnostic value in the delimitation of taxa within the genus. Further, Metcalfe and Chalk (1950) pointed out that the thickness of cuticle, height of epidermal cells, degree of undulation of anticlinal walls of epidermal cells, nature, size and distribution of secretory canals and cavities and the type of midrib vascular bundle in leaf are valuable for the identification of species within the family Clusiaceae.

According to the present study, the leaves of all the species considered are dorsi-ventral. Abaxial and adaxial epidermises of all the taxa considered are uniseriate and comprise of rectangular to square cells in cross section. The outer cell walls of the epidermal cells are well cuticularised with cuticular ridges extending between anticlinal walls. These features which are common to all the species considered, could be used to characterize the Sri Lankan fraction of the genus concerned.

Even though there is a possibility of grouping certain taxa based on varying thickness of lamina, cuticle and the epidermis of leaf, separation or identifying individual species is not possible.Based on the shapes of the anticlinal walls of the epidermal cells in paradermal sections of lamina, 3 groups of taxa could be recognised. Viz:-

1. both adaxial and abaxial epidermises undulated or sinuous to a varying degree in *G. terpnophyla, G. zeylanica, G. morella, G. quaesita* and *G. xanthochymus* . (Plate 1 A).

2. both adaxial and abaxial epidermises not undulated in *G. echinocarpa, G. thwaitesii* and *G. hermonii* (Plate 1 B).

3. abaxial epidermises slightly undulated and adaxial epidermises not undulated in *G. mangostana* and *G. spicata* (Plate 1 C).

However, as emphasized by Metcalfe & Chalk (1950), the value of this character in the identification of individual species, seems to be doubtful.

According to Abu – Asab & Cantino (1987), stomata have been classified on the basis of the configurations of neighbouring and subsidiary cells by Vesque in 1889; Metcalfe & Chalk (1950); and Payne (1970). Including the anomocytic, anisocytic, diacytic and paracytic types of Metcalfe & Chalk (1950), Baranova (1987) recognized 14 morphological types of stomates with several sub types within the plant kingdom. Solereder (1908) has observed only the Rubiaceous type of stomates of Vesque in 1889 to be present in the taxa of Guttiferae. Further, Metcalfe & Chalk (1950) working on the same taxa, also had observed only paracytic type which they believe is the same as the Rubiaceous type of Vesque in 1889. According to the present study, modifications and sub-types of paracytic type of stomates recognized by Baranova (1987) were observed in the species described below.

- Hemiparacytic stomatal type described by Van Cotthem (1970) in which the two guard cells are accompanied by a single subsidiary cell parallel to the long axis of the pore, longer or shorter than the guard cells in *G. morella, G. terpnophyla, G. thwaitesii* and *G. zeylanica* (Fig. 2b). According to Baranova (1987), this is a modification of the paracytic type of Metcalfe & Chalk (1950).

- Brachyparacytic type of stomata of Dilcher (1974) in which two subsidiary cells lie on each side of the guard cells but do not fully surround, and ordinary epidermal cells occupy both polar ends as observed in *G. hermoniii, G. quaesita, G. terpnophylla, G. xanthochymus* and *G. zeylanica* (Fig. 2c). According to Baranova (1987), this is a sub-type of the paracytic type of Metcalfe & Chalk (1950).

In anomocytic type of stomates in the sense of Metcalfe & Chalk (1950) (Fig 2a) the cells directly surrounding the guard cells are not distinguishable from the rest of the epidermal cells. According to Baranova (1987), this is the same as Rannanculaceous type described by Vesque in 1889. The results of the present study however, can not fully agree with Solereder (1908) and Metcalfe & Chalk (1950), for reasons that anomocytic type of stomates were observed in all the species concerned and various other sub types of stomates were found within the same species.

Various sub-types of stomates observed within the genus are as follows.

❖ ·Encyclocytic type of stomates as described by Stomberg in 1956 (Baranova, 1987) where the guard cells are surrounded by a narrow ring of four or more subsidiary cells as observed only in the exotic species *G. mangostana* (Fig. 2d). According to Baranova (1987), this is a simple modification of the anomocytic type of Metcalfe & Chalk (1950).

❖ Stephenocytic type of stomates as described by Baranova (1987) where five or more (usually 5-7) feebly differentiated subsidiary cells forming a more or less distinct rosette around the guard cells. These were observed in *G. echinocarpa* and *G. spicata* (Fig. 2e). As stated by Baranova (1987), this is a modification of the anomocytic type of Metcalfe & Chalk (1950).

❖ Tetracytic type of stomates where the guard cells are surrounded by two polar subsidiary cells described by Metcalfe in 1961 observed in *G. hermonii* , *G. mangostana* and *G. spicata* (Fig. 2f).

❖ Special type of stomata in which the guard cells were surrounded by two polar subsidiary cells and more than two normal epidermal cells observed in *G. mangostana* and *G. xanthochymus* (Fig. 2g). Based on the descriptions and illustrations of Baranova (1987), this type would fall very close to the tetracytic type of Metcalfe in 1961.

Vesque (1893) and Solereder (1908) emphasized the fact that the presence or absence of hypodermis in the leaf could be used to delimit taxa within the genus. As such, the doubtful endemic *Garcinia echinocarpa* and the endemics *G. quaesita* and *G. zeylanica* could be separated from the rest of the Sri Lankan taxa on the presence of hypodermis made up of rectangular to barrel- shaped cells in cross section of lamina (Plate 2).

The mesophylls of all the taxa concerned were well developed into palisade and loosely arranged spongy cell layers (Plate 2). The number of palisade layers varied from 1-2 except in *G. mangostana* which was 2-3 - layered.

D'Arcy and Keating (1979) pointed out that the shape of the vascular bundles and their associated structures have been used as an important feature in the delimitation of taxa within the genus *Calophyllum* (Clusiaceae). Further, Somaratne & Heart (2001) has observed this to be true with respect to the taxa of the genus *Calophyllum* of Sri Lanka. On these lines the present study clearly shows that the type of the mid rib vascular bundle and the extra xylary fibres surrounding it (here after referred to as the bundle sheath) could be used to separate the Sri Lankan taxa of the genus into 6 main groups as follows :-

Group 1: two adaxial curls of the arc-shaped vascular bundle almost fused. The bundle sheath surrounding the incurved arc fused adaxially as seen in *G. quaesita* and *G. zeyalnica* (Fig. 3a).

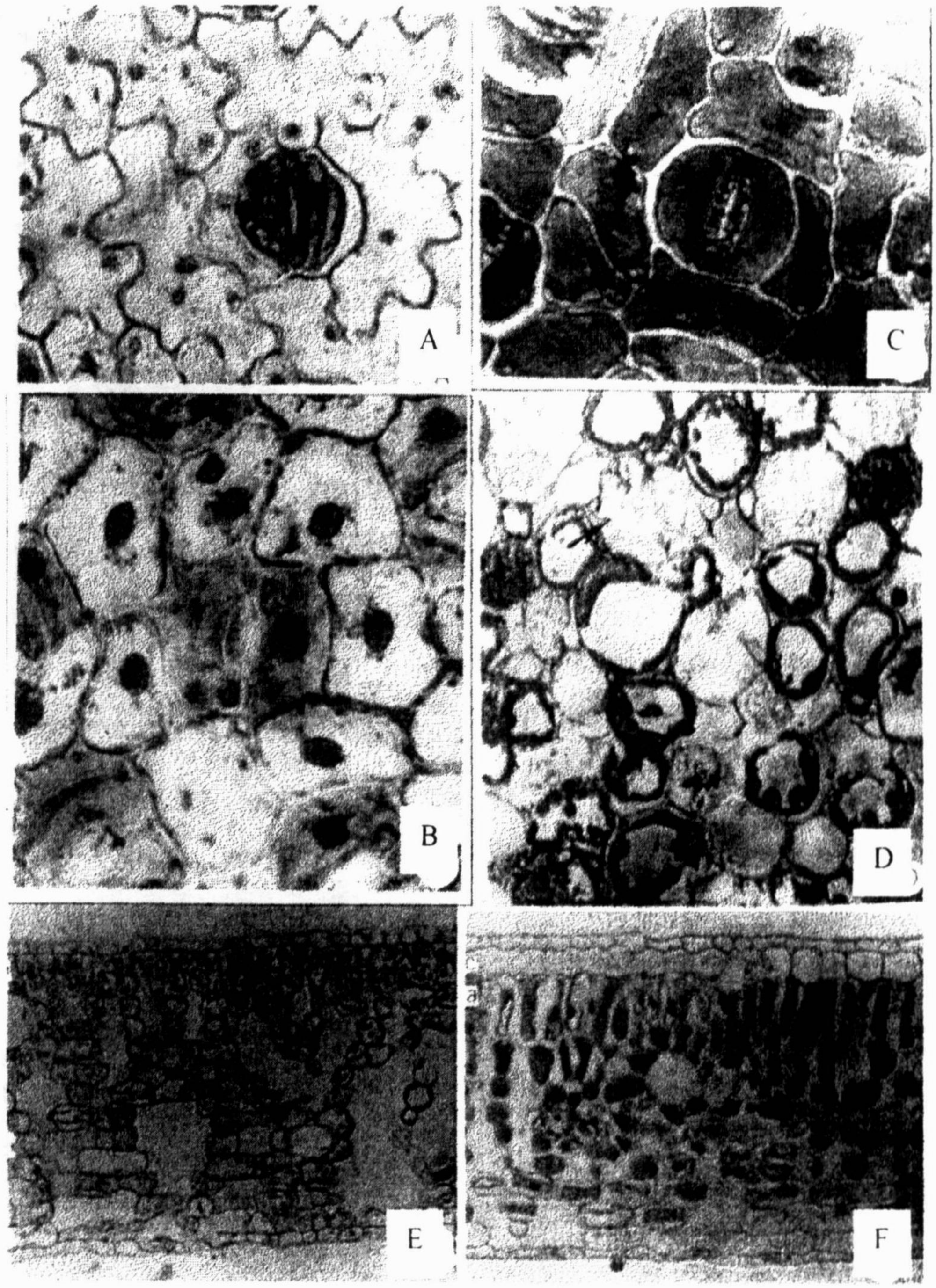

Plate 1 Lamina anatomical features of the genus *Garcinia* A). Paradermal section of *G. morella* showing undulated anticlinal walls of abaxial epidermal cells and hemiparacytic type of stomates x 1320. B). Paradermal section of *G. echinocarpa* showing anticlinal walls of abaxial epidermal cells without undulation and stephenocytic type of stomata x 1320. C). Paradermal section of *G. magostana* showing slightly undulated anticlinal walls of abaxial epidermal cells and special type of stomata x 1320. D). Paradermal section of lamina of *G. morella* showing druse crystals in the mesophyll cells x 1320. E). Cross section of lamina of *G. morella* showing single layered epidermis, cuticular ridges running between epidermal cells, well developed palisade and loosely arranged spongy cell layers x 660. F). Cross section of lamina of *G. quaesita* showing hypodermis made up of rectangular to barrel shaped cells x 660.

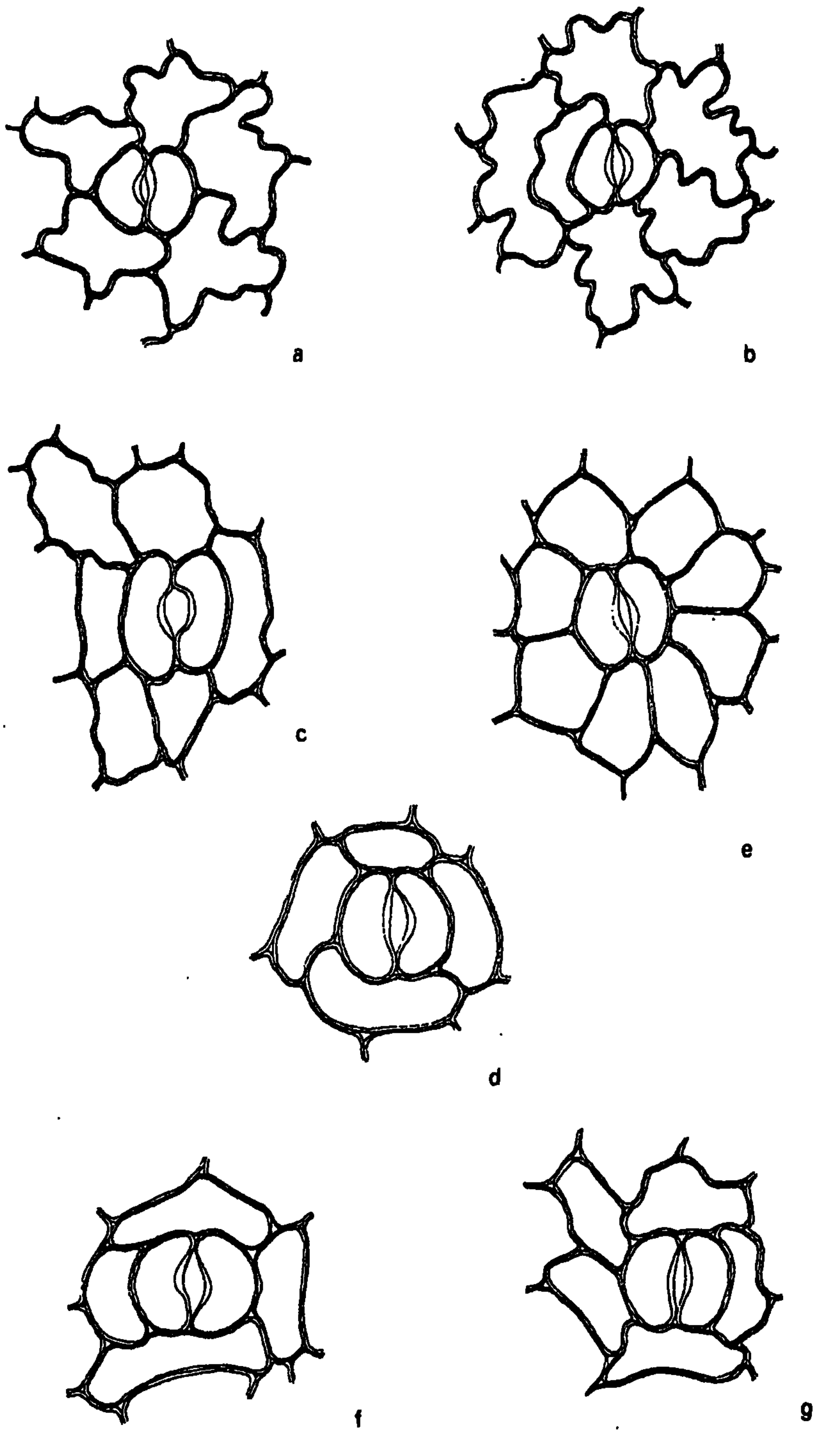

Figure 2 Stomatal types observed in *Garcinia*. a) Anomocytic type in *G. morella*. b) Hemiparacytic type in *G. morella* c) Brachyparacytic type in *G. xanthochymus* d) Encyclocytic type in *G. mangostana*. e) Stephenocytic type in *G. echinocarpa* f) Tetracytic type in *G. mangostana* g) Special type in *G. mangostana*.

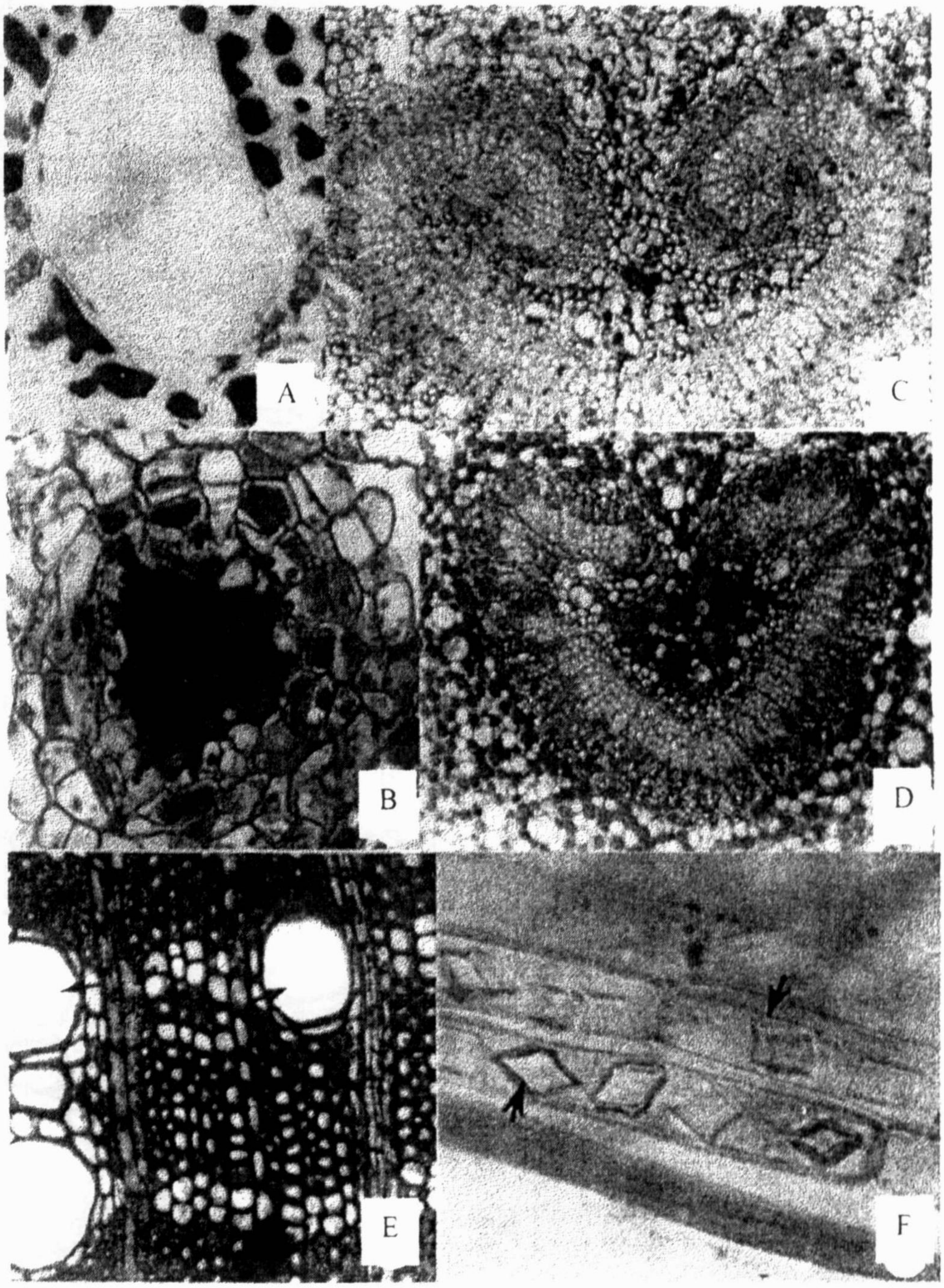

Plate 2 **Lamina petiole and wood anatomical features of the genus Gaicinia A). Paradermal section of lamina of G. Morella showing schizogenous secretory spaces within the palisade tissue x 1320. B). Paradermal section of lamina of G. Morella showing lysigenous secretory spaces within the palisade tissue x 1320. C) Cross section of petiole of G. mangostana showing incurved, open vascular strand x 330. D). Cross section of petiole of G. echinocarpa showing incurved, open vascular strand x 330. E). Cross section of wood of G. quaesita showing angularity of solitary pores x 1320. F) Maceration of wood showing chambered crystalliferous cells (arrows) in the axial parenchyma of wood x 1320.**

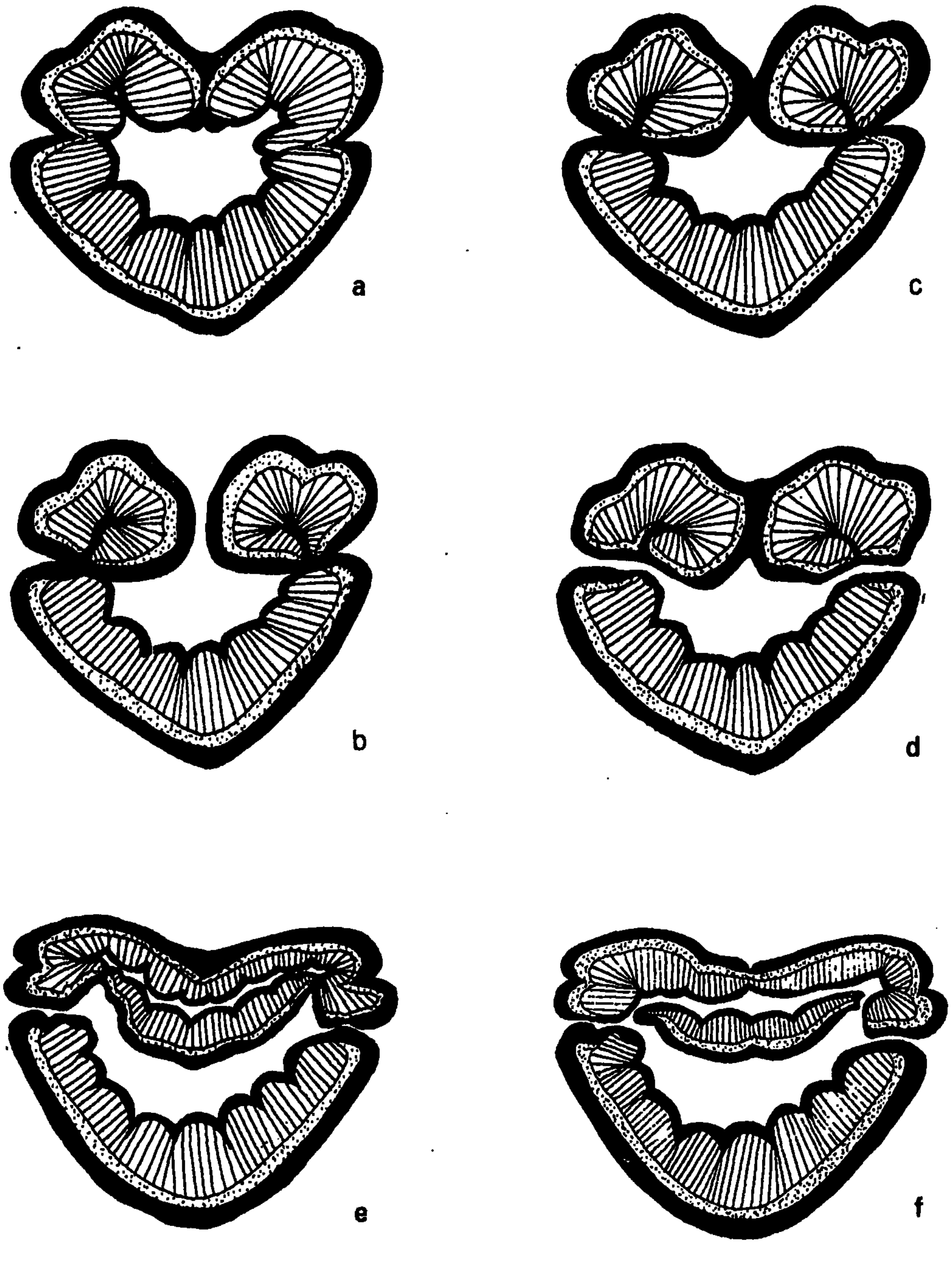

Figure 3 Mid rib vascular bundles in *Garcinia* a) Vascular bundle in *G. zeylanica* and *G. quaesita* with two adaxial curls of the main vascular strand almost fused. b) Vascular bundle in *G. echinocarpa* and *G. terpnophyla* with distal ends of the adaxial curls incurved. c) Vascular bundle in *G. spicata* in which two distal strands separated from the main strand. d). Vascular bundle in *G. morella* in which two distal strands fused by the bundle sheath. e) Vascular bundle in *G. xanthochymus* and *G. hermonii* with two adaxial arcs and the main abaxial arc facing each other with a middle vascular plate, and altogether surrounded by a continuous bundle sheath. f) Vascular bundle in *G. mangostana* and *G. thwaitesii* with adaxial and abaxial vascular arcs facing each other with a middle plate, each separately surrounded by bundle sheaths.

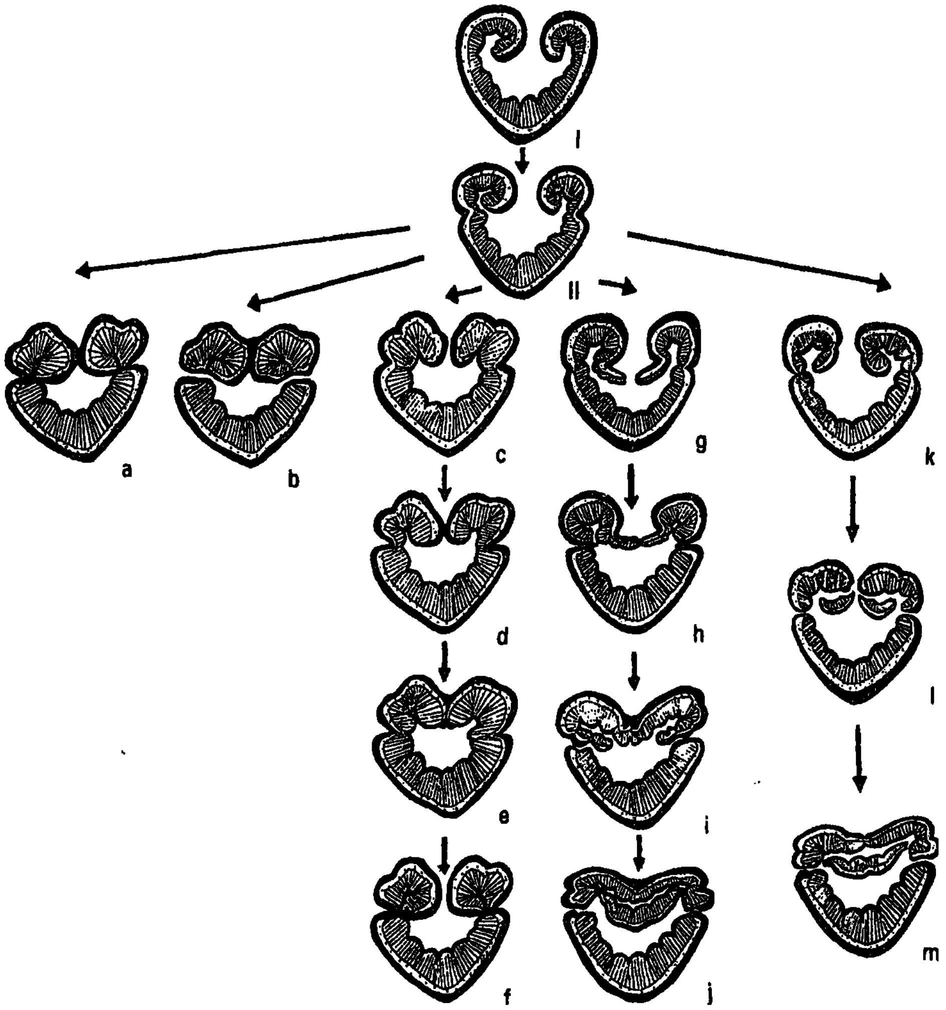

Figure 4 **Diagrammatic representation of the vascular changes from petiole along the mid vein, up to the mid way of lamina within the genus *Garcinia* I - Common petiolar vascular structure II - Common mid-vein vascular structure a - *G. spicata*. b - *G. morella*. c–> d - Intermediate stages of *G. zeylanica* and *G. quaesita*. e - *G. zeylanica* and *G. quaesita*. f - *G. terpnophyla* and *G. echinocarpa*. g –> i - Intermediate stages of *G. xanthochymus* and *G. hermonii*. j - *G. xanthochymus* and *G. hermonii*. k –> l - Intermediate stages of *G. mangostana* and *G. thwaitesii*. m - *G. mangostana* and *G. thwaitesii*.**

Xylem **Phloem** **Bundle sheath**

Group 2: arc-shaped vascular bundle with incurved distal ends. Two sides of the vascular bundle broken, entire vascular structure is well surrounded by a bundle sheath and the two distal ends do not meet as seen in *G. echinocarpa*, and *G. terpnophylla* (Fig. 3b).

Group 3: similar to group 2, however the bundle sheath surrounding the incurred distal ends fused as seen in *G. spicata* (Fig. 3c).

Group 4: Similar to group 3 however, adaxial vascular strands together with the bundle sheath ,separated from the main vascular bundle as seen in *G. morella* (Fig.3d).

Group 5: Two adaxial and abaxial vascular arcs facing each other with a middle vascular plate altogether surrounded by a continuous bundle sheath as seen in *G. hermonii* and *G. xanthochymus* (Fig. 3e).

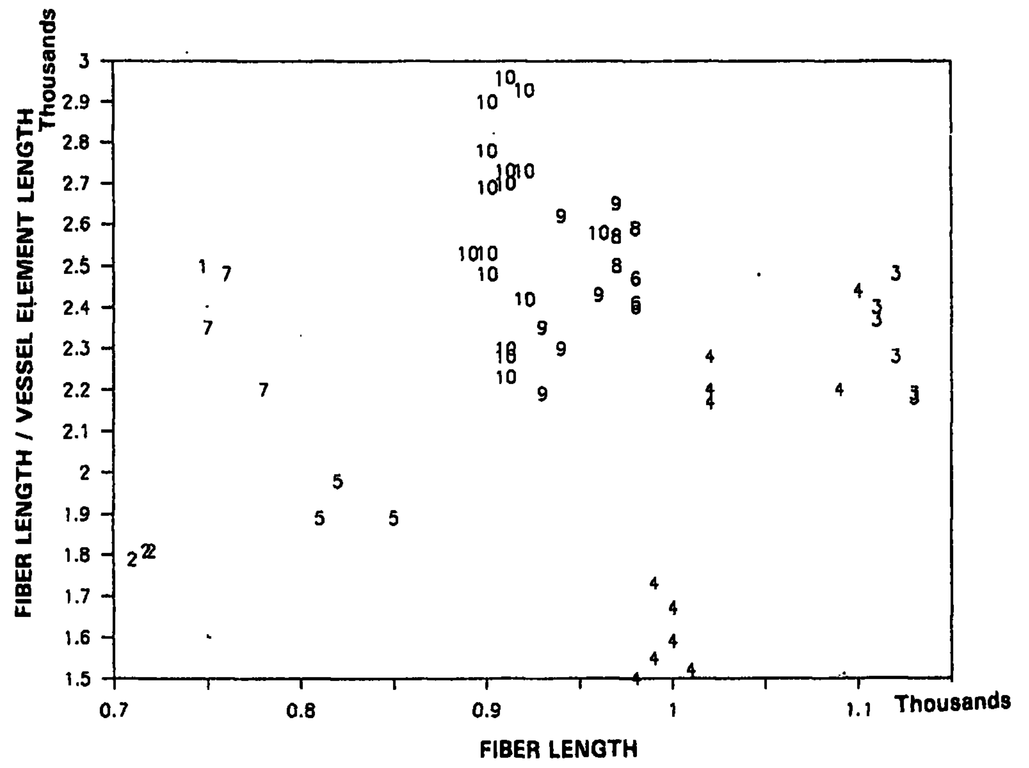

Figure 5 Scatter plot produced by plotting vessel length against fibre length for the Sri Lankan *Garcinia sp.* For species codes follow Table 2.

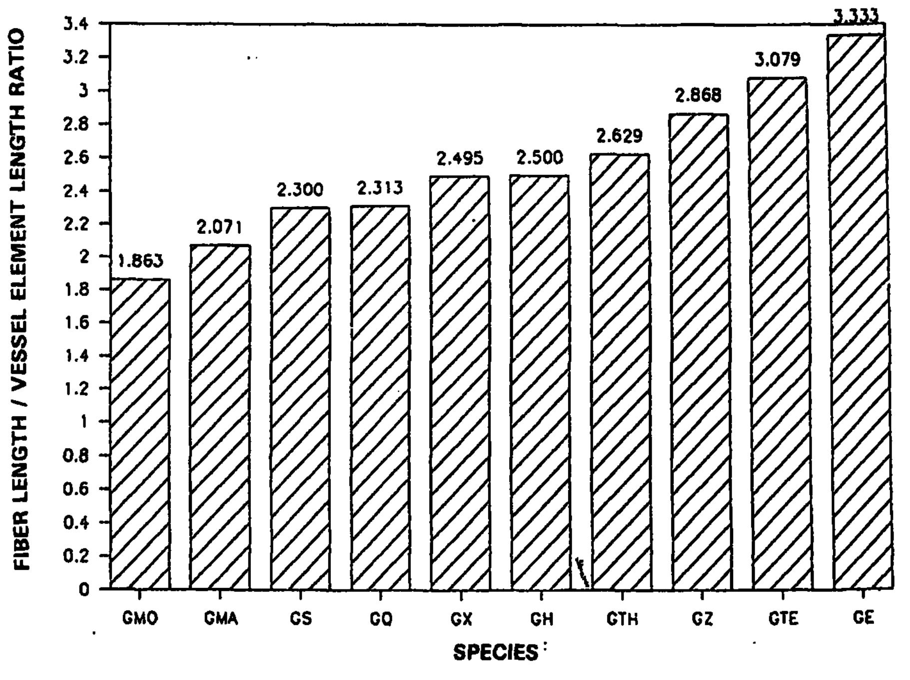

Figure 6 Variation of fibre length / vessel length ratio among the Sri Lankan *Garcinia* sp. For species codes follow Table 2.

Table 4

Principle component analysis of 29 quantitative anatomical features of lamina, petiole, young stem and wood of *Garcinia* species. Table entries are coefficients for each character for the first 5 principle components. For abbreviations follow Table 2.

Variable	PC 1	PC 2	PC 3	PC 4	PC 5
DP	.95726	.04158	-.01345	-.00251	.00122
DY	.94055	-.06280	-.02560	-.05558	-.03918
CTY	.91400	-.24423	.27212	-.00417	-.09113
CT	.88621	-.30016	.24281	-.01148	-.12925
VD	.84086	.12739	-.02366	-.11913	-.10276
TL	.67638	.51041	.33713	-.11161	-.00892
PFID	.63380	.41960	-.15519	-.01539	-.12953
ET	.59993	-.44831	.36565	-.03820	.03930
ELAD	.05262	.82916	-.10710	.05066	.05412
EBAD	-.17893	.77311	-.08420	.14919	.04354
PAL1H	-.32000	.70757	-.13675	.09356	.03193
VL	.41534	-.69542	-.30846	-.38104	-.19928
EBAB	.01512	.65216	-.42037	.34981	.32164
ELAB	.01475	.62047	-.47413	.39684	.18591
VF	-.03874	-.23760	.86105	.14490	-.03824
CTAD	.33770	.23203	.80292	.22571	-.12324
ET	.29502	-.46579	.70279	-.09236	-.18725
CTAB	.49829	.14954	.69785	.29518	-.12061
PAL2H	-.45813	.24965	-.51428	.21394	-.07724
EHAD	-.07364	.13722	.05026	.96659	-.08915
EHAB	-.16238	.11549	.05122	.95979	-.08506
CCDIN	.10320	.41783	.12910	.73726	.08127
RH	-.18158	.06961	-.14809	-.09635	.89745
RHC	-.45376	.00292	-.10377	-.15097	.73152
CCDOU	.41358	.22142	.04584	.15685	.43232
FD	.15380	.33542	.01591	.06664	-.03082
FL	.06601	.25871	-.56169	.04772	-.12541
PFLUD	-.49224	.46882	-.22421	-.15502	-.01188
VD	.19481	-.11502	-.32959	.21138	.03168
% variability explained	33.4	19.4	11.4	10.3	8.5
Cumulative%	33.4	52.4	63.8	74.1	82.6

Group 6: Two adaxial and abaxial vascular arcs facing each other with a middle vascular plate, each separately surrounded by bundle sheath as seen in *G. mangostana* and *G. thwaitesii* (Fig. 3f).

Howard (1962, 1974, 1979), is of the opinion that petiole vasculature is significant in the identification of vascular plant species. Based on his findings, he put forward a key to separate the vascular patterns encountered within Dicotyledons. Dickison (1969, 1973, 1989) investigating the nodal anatomy of Dilleniaceae, Conneraceae and Alseusmiaceae respectively emphasized the systematic value of anatomical structure of petiole in establishing relationships between taxa. The importance of petiolar vasculature in the identification of species within Clusiaceae has been emphasized by Metcalfe & Chalk (1950) and Schofield (1968).

The present study revealed that a vascular bundle sheath of 3-7 layers in thickness was present in the petioles of all the Sri Lankan taxa of the genus concerned. However in the two taxa *G. morella* and *G. echinocarpa* which are restricted to altitudes between 500 mm. – 1000 mm and above 1000 mm respectively, there seems to be a tendency of the bundle sheath to break in to groups. In addition, there are isolated cells with highly thickened walls within such vascular bundle sheath groups. Whether this has any relationship with environmental conditions needs further investigation.

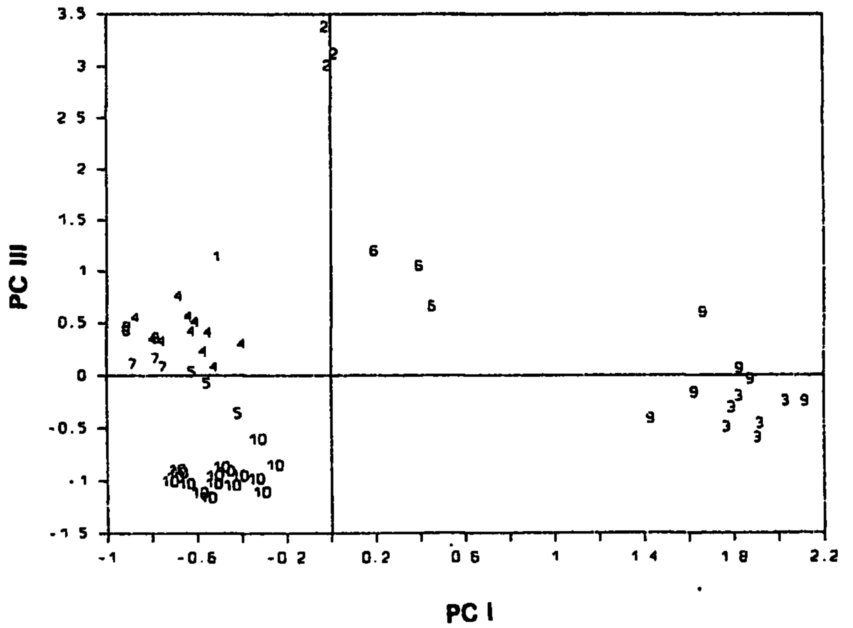

Figure 7 PCA scatter diagram produced by plotting the first PC against the second for lamina, petiole, young stem and wood anatomical characters of the Sri Lankan *Garcinia* sp. Percentage of trace along PC 1 = 33.4 %, and along PC 2 = 19.4 % . For species codes follow Table 2.

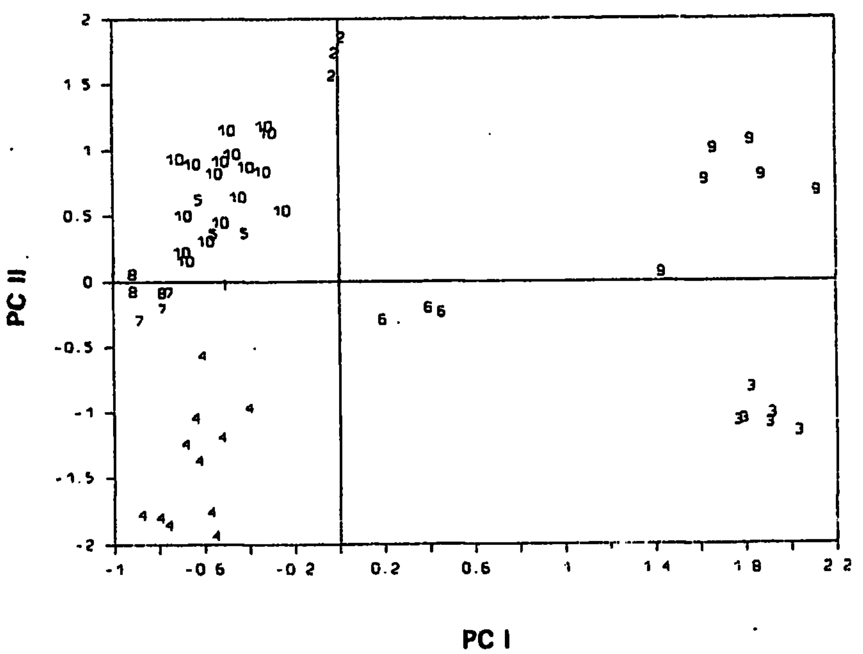

Figure 8 PCA scatter diagram produced by plotting the first PC against the third for lamina, petiole, young stem and wood anatomical characters of the Sri Lankan *Garcinia* sp. Percentage of trace along PC 1 = 33.4 %, and along PC 2 = 11.4 % . For species codes follow Table 2.

In the non-endemic *Garcinia magostana*, single to groups comprising of 4-6 sclerenchymatous cells were observed to be distributed in the bundle sheath. The endemic taxa *G. quaesita, G. terpnophylla* and *G. zeylanica* show such similar characters to *G. mangostana* in having scattered sclerenchyma cells or small groups of 2-3 such cells with in the bundle sheath. Further, the endemics *G. hermonni* and *G. thwaitesii* show similar characters to the non endemics *G. spicata* and *G. xanthochymus* in having slightly lignified bundle sheath cells.

Metcalfe & Chalk (1950) identified six distinct types of vascular structures in petioles of Guttiferae. According to them, in *Garcinia mangostana*, the main vascular strand forms a completely closed tube surrounding few collateral bundles. Based on petiolar vascular structures, Schofield (1968) divided the genera in Guttiferae in to two groups. viz:-

- those with an open or incurved vascular arc.
- those including *G. mangostana* with a siphonostele in which a large medullary plate (medullary bundles) was enclosed.

However, according to the present study, all the Sri Lankan taxa including *G. mangostana* (Plate 2C) showed a common vascular structure with a single arc- shaped collateral strand open on the adaxial side with incurved distal ends nearly meeting to form a closed tube (Plate 2D).

Further more, Schofield (1968) pointed out that in order to understand the complete sequence of changes in vascularization it is desirable to view sections from all parts of the petiole and midrib. Based on such observations, the present study revealed four main changing patterns as depicted in Fig. 4.

1. the two distal ends of the vascular bundle rolled up just beginning to get separated from the main vascular stand in *G. spicata* and *G. morella* (Fig. 4a & b).

   Even though these two species show a relationship on this basis, taking into account the fact that these two taxa are non-endemic and the *G. spicata* is widely distributed within the dry zone and that *G. morella* is found in both dry and wet zones, their direct relationship is of doubt. However, on these lines, these two species could be considered to have evolved on two different lines as shown in Fig. 4.

2. the two distal ends of the vascular bundle curled up to touch each others in the two endemic species *G. zeylanica* and *G. quaesita* (Fig. 4 c, d & e).

   Even though this nature is close to the non- endemics *G. spicata* and *G. morella*, whether there is a direct association between them is yet to be known and needs further study which is beyond the scope of this study. However, such a study taking in to account the ecological factors would be of interest since the two endemics *G. zeylanica* and *G. quaesita* are restricted to the wet zone lowlands.

   As shown in Fig. 4c, d, e & f, it is possible that *G. echinocarpa* and *G. terpnophylla* have a very close relationship to the two endemics *G. zeylanica* and *G. quaesita*. Further, this idea is supported on the basis that *G. echinocarpa* and *G. terpnophilla* are confined to higher elevation than *G. zeylanica* and *G. quaesita*.

3. the two distal ends of the vascular strand curled up and curved back coming towards each other (Fig. 4g & h) and the curled up distal parts separated and grown inwards to rise to the condition depicted in Fig. 4 i & j, in the endemic *G. hermonii* and the non-endemic *G. xanthochymus*. On this basis, these two species show close affinities.

4. the two distal ends of the vascular strands curled up broadly, touching each other and finally separated and

fused into an additional vascular strand (Fig. 4 k, l, & m) in the endemic *G. thwaitesii* and the exotic *G. mangostana*. This suggests that these two species are closely related on this basis.

In all the species concerned, the phloem and the xylem of the petiole are interrupted by parenchymatous rays of 1-2 cells in thickness. Within the rays, tanniniferous cells were observed in the three endemic species *G. quaesita, G. terpnophyla, G. zeylanica* and in the doubtful endemic *G. echinocarpa*. It is interesting to note that these 4 species also showed similar lamina vascular bundle structure.

Schofield (1968) noted that unilacunar-unitrace nodal structure is a characteristic feature of the genus *Garcinia*. The present study also found that Schofield's observations to be correct with respect to the Sri Lankan taxa.

Stevens (1974, 1976, 1980) used various terms to describe the outline shapes of young stems in cross sectional view. Based on his classification system it is observed that the Sri Lankan taxa of the genus is characteristic of being oval - shaped.

According to Wilkinson (1979), Lavier–George in 1936 has emphasized the importance of utilyzing cuticular features in characterizing and diagnosing vascular plant species. Further, Metcalfe and Chalk (1950) pointed out that the characters of the cuticle within the members of Guttiferrae are of value in the delimitation of taxa concerned. On such basis *G. echinocarpa* and the non – endemic *G. spicata* could be separated from the rest as they possess cuticular protrusions in the young stems. These were quite common in the young stem and petiole while rare on the abaxial surface of the mid rib indicating a gradual diminution from the stem towards the apex of the lamina. However, in *G. echinocarpa*, cuticular protrusions were observed to be present but rare in the young stem and absent in the petiole and lamina .

Metcalfe & Chalk (1950) and Metcalfe (1979) pointed out the importance of anatomical characters such as the type of vascular bundle, presence and the nature of pericycle, degree of sclerosis of pith parenchyma cells in the young stem in systematic studies. The vascular bundles of the young stem within the Sri Lankan taxa concerned showed a uniform structure where the phloem and the xylem were in a continuous ring interrupted with parenchymatous rays of 1-4 cells in thickness. Within these rays tanniniferous cells were observed only in the three endemic species *G. quaesita, G. zeylanica* and *G. terpnophyla* and in the doubtful endemic *G. echinocarpa*.

It is observed that the Sri Lankan *Garcinia* species could be characterized by the presence of a highly interrupted pericyclic ring of 1-6 cells in thickness. However, it is further observed that there is a considerable amount of variation with respect to the diameter of the pericyclic fibres and their lumen within the taxa concerned. Based on the results of correlation matrix it is clearly seen that their variations are related to ecological and habitat factors and the differences in altitude. This correlation could be attributed to the mechanical stresses and strains the plant has to undergo within their ecological habitats and as such has little or no taxonomic value in the delimitation of the species concerned.

Vesque (1893) and Solereder (1908) were of the opinion that the nature and distribution of crystals in different tissues is impoprtant in the separation of taxa within the genus *Garcinia*. The present study revealed that crystals of the druse type i.e. spheroidal aggregates of prismatic crystal type according to Esau (1976) and Fahn (1990) were present within the parenchymatous cells of the lamina mesophyll, ground tissues of the petiole and cortical and pith tissues of the young stem of all the Sri Lankan taxa . Even though of little taxonomic value, such druses were observed to be more abundant in *G. echinocarpa* than in any other species considered. Solereder (1908) has observed prismatic crystals in the lamina epidermal cells of *G. echinocarpa*. However, the present study did not encounter such finding. On the other hand, *G. morella* stands out from other Sri Lankan species in having druse crystals in the epidermis of the lamina. On this basis, this character would be of value in the delimitation of the non-endemic species *G. morella* from the rest of the taxa concerned.

The importance of the nature, size and distribution of secretory structures within the plant body in the identification of member of

Garcinia has been discussed by Solereder (1908), Metcalfe & Chalk (1950) and Schofield (1968). In the present study, schizogenous secretory spaces indicated by Esau (1965) were observed in all the species concerned (Plate 2A). These spaces were mainly observed in the spongy tissue of lamina, ground tissue of the midrib and petiole and in the cortex and pith of young stem in all the taxa. However it is interesting to note that two species *G. morella* and *G. spicata* stand out from the rest of the Sri Lankan taxa on the basis that such secretroy spaces were observed in the palisade tissue - a character which could be utilized to distinguish the two species from the rest. Further, in addition to schizogenous secretory spaces (Plate 4 a), lysigenous spaces as mentioned by Esau (1965) were commonly present in the mid rib and lamina of *G. xanthochymus* and *G. morella* (Plate 2B). This feature could be used to distinguish these two taxa from the rest.

As a characteristic feature of the sri lankan species of *Garcinia*, tanniniferous cells were observed to be present in the mesophyll and the ground tissue of the midrib, and the cortical region of the young stem. However, such cells even though of little taxonomic value, were highly abundant in *G. echinocarpa*, scattered in *G. hermonii, G. mangostana, G. morella, G. thwaitesii* and *G. xanthochymus* and less frequent in *G. quaesita, G. terpnophylla* and *G. zeylanica*.

WOOD

The potential use of wood anatomy for taxonomic purposes was suggested by many workers such as Kieser in 1815, De Candole in 1818 and Hartig in 1859 (Baas, 1982). From the 19th century, considerable development in the study of wood anatomy for the interpretation of systematic, phylogenetic and ecological studies has been achieved by the workers such as Rendle & Clark (1934), Record (1936), Baily (1953, 1957), Radford et al. (1974) and Dickison (1975). Heart & Theobald (1977) dealing with the Sri Lankan fraction of Theaceae have shown the significance of wood anatomy in recognizing the genera and species within the family. Further, Heart & Theobald (1979) have emphasized the significance of comparative vegetative anatomy and their application in the study of Sri Lankan Gesneriaceae.

Gamble (1881) and Pearson & Brown (1932) described the wood anatomical characters such as ray histology and vessel distribution of the genera within the family Clusiaceae in relation to hard wood identification. Solereder (1908) and Metcalfe & Chalk (1950) have given general descriptions of wood anatomy of the genus *Garcinia*. Vestal (1937) made general descriptions of wood anatomy of individual species within the genus concerned. Further, Janssonius (1952) based on wood anatomical characters, constructed a valuable key to identify species within the genus.

The present study shows that most of the qualitative wood anatomical characters of the species considered are homogenous. All the Sri Lankan taxa are characterised by non-storied diffused porous wood in which the growth rings are absent. Pores are solitary or paired to multiples of 3-5 in groups and are radially distributed. Solitary pores are circular to oval and rarely angular in outline (Plate 2E). However, the angularity of vessel elements in transverse section has been considered as an indication of evolutionary primitiveness of Angiosperms (Bonsen & Kucera, 1990). On this basis the genus *Garcinia* of Sri Lanka could be considered as almost been evolved as *Calophyllum* of Sri Lanka where Somaratne & Herat (2001) has showen that only circular or oval- shaped pores were present.

The individual quantitative wood anatomical characters such as length, diameter, distribution and frequency of vessel elements; length and diameter of fibres seem to be important only in the process of grouping the Sri Lankan taxa concerned but seems to have limited value in the delimitation of the species. It is observed that the Sri Lankan taxa of the genus concerned are characterized by having libriform fibres which are non septate and thick walled. Baretta- Kuipers (1976) working on Bonnetiaceae, Theaceae and Guttiferae, has pointed out that the ratio between fibre length / vessel element length could be used as an indicator of the degree of specialization. In the present study, the scatter plot (Fig. 5) between length and vessel element length of the specimens, showed that there is a clear separation of some species such as *G. quaesita* and *G. hermonii* while there is an overlap between the species *G. spicata, G. thwaitesii, G. xanthochymus* and *G. zeylanica*. Further, there is a grouping tendency between the two non-endemics *G. morella* and *G. mangostana*, while the endemic *G. terpnophyla* tends to group together with the doubtful endemic taxon *G. echinocarpa* (Fig. 5).

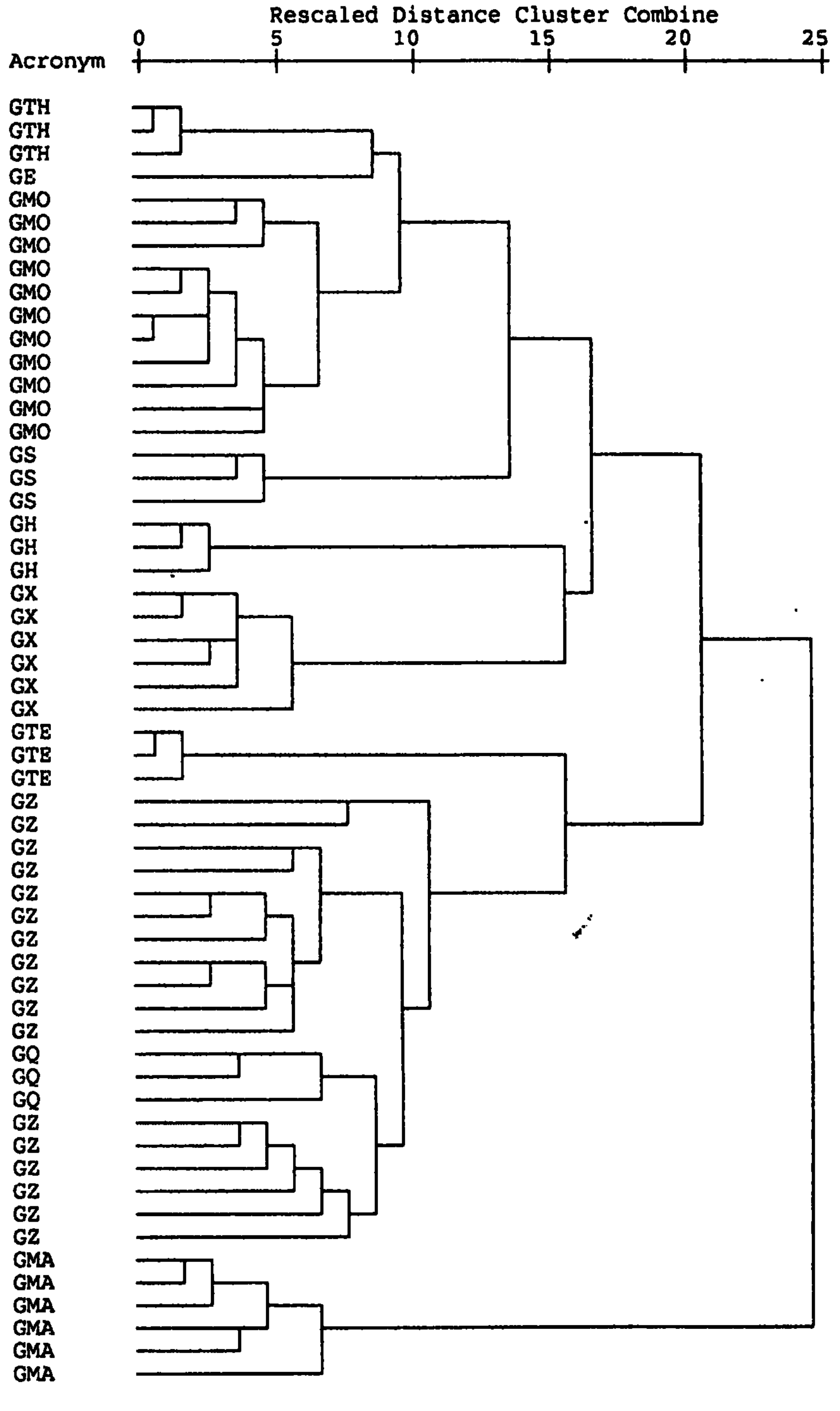

Figure 9 Phenogram based on Euclidian distance matrix, including 29 quantitative lamina, petiole, young stem and wood anatomical characters of 56 specimens of the Sri Lankan *Garcinia* Sp. For acronyms of species follow Table 2.

Further more, according to Baretta - Kuipers (1976), when the fibre length/ vessel length ratio approaches one, such woods could be considered as less specialized. The present study revealed that the fibre length/ vessel element length ratio varies from 1.8 to 3.3 within the genus as shown in Figure 6. In this respect, the least specialized wood is found in *G. morella* and the most specialized in the doubtful endemic *G. echinocarpa.*

According to the present study, all the species considered possess axial parenchyma in regular apotracheal bands out of which some bands are associated with vessels; a character which could be used only to characterize the Sri Lankan genus. Tyloses were not observed in wood of any species considered.

Chattaway (1955, 1956) pointed out that the type of crystals and the characters of the crystal bearing cells are important in the identification of hardwoods. According to Metcalfe & Chalk (1950) and Metcalfe (1983), the occurance of chambered crystalliferous cells in axial parenchyma in some genera of Guttiferae is of taxonomic significance. The present study observed that prismatic crystals were present in chambered cells where the cells divided into chambers by septa (chambered crystalliferous cells) as well as in normal cells of the axial parenchyma of all the species considered (Plate 2F). Such crystals were observed to be very abundant in *G. echinocarpa, G. mangostana, G. hermonii* and *G. spicata* while less frequent in *G. terpnophyla, G. xanthochymus, G. thwaitesii* and *G. morella*. However, the druse crystals observed by Metcalfe & Chalk (1950) in the axial parenchyma of *Garcinia* were not observed in any of the Sri Lankan taxa of the genus. Crystals were also absent in the ray cells.

Based on Kribs (1935), the rays of all the taxa considered were dominantly heterogenous (Krib's type II B) and rarely homogenous (Krib's type I). Square, procumbant and upright cells were observed in heterogenous rays of all the species. On this basis, *G. xanthochymus* could be easily separated where the upright cells were dominant in heterogenous rays while in the others, they were confined to 1-4 marginal rows.

Based on the ray classification of Chattaway (1932), three groups of taxa with low, very low and rather low rays could be identified within the Sri Lankan fraction of the genus. The only species with rather low rays; *G. quaesita*, could be separated on this basis. In the rays of all the taxa, radial intercellular secretory canals of the schizogenous type were rarely observed.

Based on the frequency of rays, three groups of taxa could be identified, but individual species could not be delimited. In each of the taxa concerned a mixture of uniseriate, biseriate and multiseriate rays was observed. Such rays were observed in different proportions and on such basis two groups could be recognized.

1. Group of taxa in which uniseriate rays predominating while few biseriate and multiseriate rays scattered within the wood. This would include *G. spicata* and *G. xanthochymus*.

2. Group of taxa in which biseriate and multiseriate rays predominating while few uniseriate rays scattered within the wood. This included *G. echinocarpa, G. hermonii, G. mangostana, G. morella, G. quaesita, G. terpnophyla, G. zeylanica* and *G. thwaitesii.*

The variation of wood anatomical characters with ecological variation has been specially emphasized in recent years by workers such as Baas (1973, 1976, 1982), Carlquist (1975, 1977) and Chalk (1983). Graff & Bass (1974). Somaratne & Heart (2001) working on *Calophyllum* showed that there is no correlation between altitude and wood anatomical characters except for the variation in fibre diametre. The results of the present study partly agrees with them on the basis that the wood anatomy of the Sri Lankan *Garcinia* is not significantly correlated to altitude except for vessel length and vessel frequency. Further, the findings of the present study are in agreement with Dickison (1975) on the basis that the vessel element length shows a relationship to rainfall.

Statistical analysis

Based on the data collected for the present study, it is observed that characters such as the shape and the degree of undulation in the anticlinal walls of the epidermal cells, stomatal types, the presence of druse crystals in the epidermis, presence of lysigenous secretory cavities in addition to schizogenous canals in lamina; the shape and the structure of the mid rib vascular bundle and the nature of bundle sheath in lamina petiole; the presence of cuticular protrusions and the nature of pericycle in the young stem; the proportion of uniseriate and multiseriate rays and the dominant cell type in heterogenous rays of wood could be used to delimit the sri Lankan taxa of the genus into smaller groups or units. However, it is further observed that these smaller groups overlap with each other. Based on the vascular changes from petiole along the midvein, up to the midway of lamina it has been noticed that there are grouping and evolutionary tendencies within the Sri Lankan genus. A similar pattern of species distribution was observed in the scatter diagram between fibre length and vessel element length (Fig. 5). The other anatomical characters considered under the headings of lamina, petiole, young stem and wood, are of limited value in the delimitation of taxa within the genus, but could be of value in the characterization of the Sri Lankan fraction of the genus. In this study, the basic idea of employing statistical procedures using all the possible anatomical features and ecological parameters considered was to find out the possible relationships between taxa and the degree of specialization within them.

Multivariate analyses have been extensively used in the field of biology. Sneath & Sokal (1973) have shown the importance of multivariate statistical techniques in numerical taxonomy. Based on multivariate techniques, Jansen et al. (1979), Jacobseni (1979), Khidir & Wright (1982), Robertse et al. (1980), Khordhopani & Ingrouille (1991) and Hedren (1990 a) successfully solved the problems in allozymic variations in *Capsicum*, variations between *Allium cernum* and *Allium stellatum*, systematics of Graminae, wood anatomy of South African *Acacia*, morphological patterns in *Acacia* in Sudan and the African complex of *Justicia striata* respectively. On this basis, mean values of quantitative anatomical data of lamina, petiole young stem and wood of the species considered were subjected to PCA in order to obtain several scatter diagrams. These scatter diagrams were used to interpret taxonomic patterns reflected by the above data. Further Cluster analysis was attempted to generate a grouping system.

Principle Component Analysis (PCA) and Cluster Analysis (CA) of combined anatomical characters of lamina, petiole, young stem and wood.

Component loading of each anatomical character along the component axes are given in Table 4. The characters such as diameter of petiole and young stem, thickness of cuticle and epidermis of young stem, diameter of vessels and thickness of lamina indicated a considerable contribution to the first principle component axis. On the other hand length and breadth of lamina epidermal cells, height of palisade and length of vessel elements showed heavy loading along the second component axis while the variables such as thickness of lamina cuticle and epidermis are heavily loaded along the third component axis. Since the loading of variables along the fourth and fifth component axes is less and it could be considered negligible. The resulting scatter plots (Fig. 7 & 8) revealed that there is a more or less clear grouping pattern of specimens and thus those characters considered in the study are important in the delimitation of the species within the Sri Lankan fraction of the genus. The results obtained in the cluster analysis based on the Eucledian distance calculated from the mean values for each specimen (Fig. 9) also supported the above conclusion.

The results of PCA and CA combined together show that almost all the species considered within the genus could be better separated based on quantitative anatomical characters of lamina, petiole, young stem and wood when combined together rather than when used alone. Some of the specimens of species such as *G. zeylanica*, *G. quaesita* and *G. morella* are indiscriminately clustered and grouped with the other specimens in all the phenograms and PCA scatter plots respectively. Such deviation could be attributed to the dependency of anatomical characters on environmental factors. As such due allowance should be made to the environmental influence on anatomical characters in the interpretation of clustering and grouping of specimens. However, further studies are needed before the conclusive decisions on the ecological variation of anatomical characters are made, which is beyond the scope of the present study.

The separation of specimens into distinct groups in PCA (Fig. 7 & 8) and CA (Fig. 9), indicates that the anatomical variability among species is less and they are confined to distinct habitats rather than to diverse habitats. The distinct groups of specimens belong to the species *G. spicata* mainly distributed in the dry and arid zones, *G. mangostana* and *G. xanthochymus* restricted to the wet zone lowlands, and *G. echinocarpa* restricted to the wet zone at altitudes above 1000 mm. Specimens of *G. morella* were clustered into two groups reflecting its ecological origin or the habitat differences i.e. dry and wet zones. As such the two endemics *G. quaesita* and *G. zeylanica* clustered together and are found to be sharing the same habitat.

Statistical correlation

Metcalfe & Chalk (1950) pointed out that the systematic anatomists must rely on the characters which are more fixed and less plastic; that is less liable to become modified in response to environmental factors. Among the quantitative characters which were found to be important in PCA and CA in the present study, the thickness of lamina; diameter of petiole and young stem; cuticle thicknesses of lamina, petiole and young stem; frequency of vessels; length and diameter of fibres; height, width and frequency of rays of wood are found to show little or no significant correlation with the external factors such as temperature, rainfall and altitude. As such, based on Metcalfe & Chalk (1950), these characters could be considered as more or less fixed and therefore of high taxonomic value.

Oever et al. (1981) and Carlquist & Hoekman (1985) working with Symplocaceae and Staphyleaceae respectively, showed that there is a significant inter-correlation among wood anatomical characters such as vessel wall thickness to vessel diameter and vessel diameter to vessel distribution frequency; vessel element length to fibre length and ray height. The present study supports the above workers on the basis that there was a highly significant correlation coefficient ($p < 0.05$) between vessel diameter, vessel frequency, vessel length and fibre diameter. As far as the Sri Lankan species are concerned, no work has been done on such correlation. However, such correlation is of great value in selecting diagnostic characters. Further work is needed on these lines of study to generalize the relationships among the anatomical features.

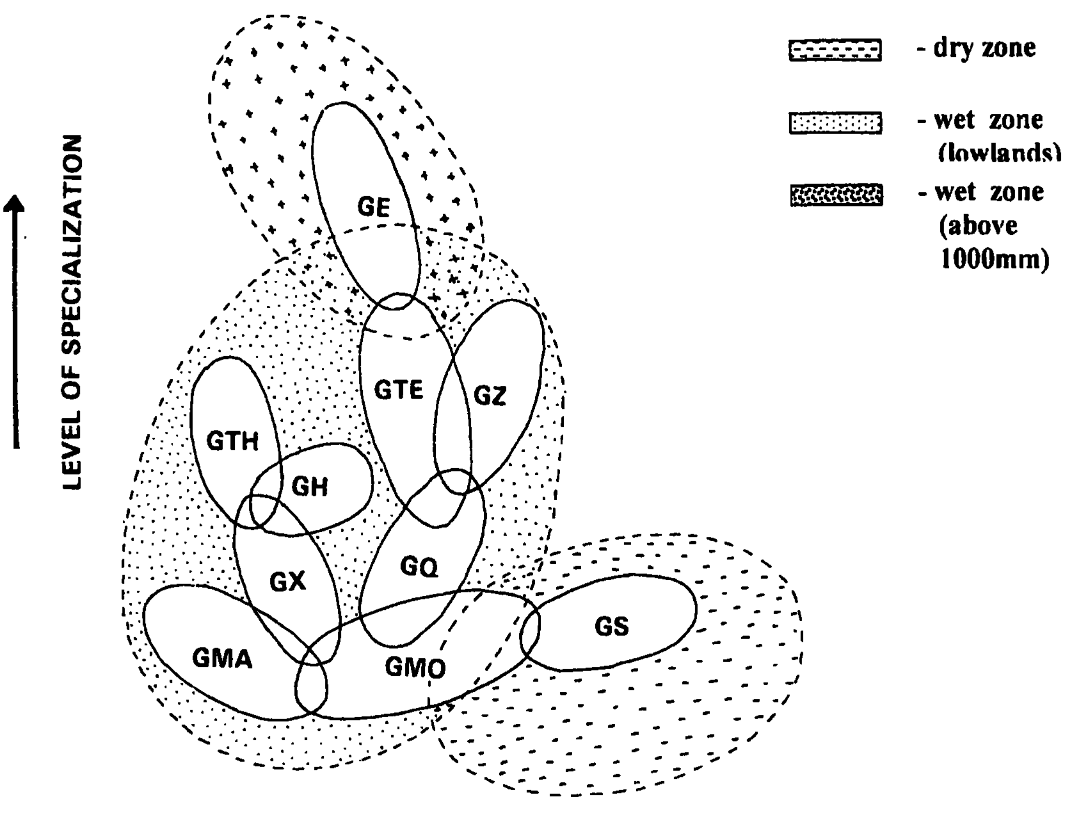

Figure 10 Diagrammatic representation of the possible evolutionary relationships and degree of specialization in relation to ecological distribution of the Sri Lankan species of *Garcinia*. For species acronyms, follow Table 2.

CONCLUSION

The present study revealed quantitative and qualitative characters which are of taxonomic value in characterizing the Sri Lankan genus as a whole and in establishing species boundaries. Among such quantifiable characters, the thickness of lamina, diameter of petiole and young stem, cuticle thickness of lamina, petiole and young stem; frequency of vessels and the height and frequency of rays in wood; all of which are found to show little or no correlation with the external factors such as temperature, rainfall, altitude are of higher value in delimiting the taxa concerned. The quantitative characters found to be important in species delimitation were the shape and the degree of undulations in the anticlinal walls of the epidermal cells, stomatal types, the presence of druse crystals in the epidermis, presence of lysigenous secretory cavities in addition to schizogeneous canals in lamina; the shape and the structure of the midrib vascular bundle and the nature of bundle sheath in lamina and petiole; the presence of cuticular protrusions and the nature of pericycle in the young stem; the proportion of uni-seriate and multi-seriate rays and the dominant cell type in heterogeneous rays of wood.

Kostermans (1980) based on morphological characters recognized ten species of *Garcinia* to be represented in Sri Lanka. Further, out of the ten, Kostermans (1980) pointed out that *Garcinia mangostana*, *G. morella*, *G. spicata*, *G.xanthochymus* and *G. echinocarpa* are non-endemic and are found distributed in other tropical regions of the world. Even though, Kostermans (1980) mentioned that *G. echinocarpa* is non –endemic to Sri Lanka, he was in doubt of its occurance in the closest land mass India and whether the taxon is the same as to the taxon he believed which was present in India. However, Trimen (1893) had earlier stated that *G. echinocarpa* is endemic to Sri Lanka.

From field collections, observations and from other literature, it is clear that *Garcinia spicata* is mainly distributed within the dry and arid zones of Sri Lanka, *G. morella* is found within the dry zone and wet zone lowlands while *G. mangostana* and *G. xanthochymus* are restricted to the lowlands of the wet zone. As far as the doubtful endemic *G. echinocarpa* is concerned, it is restricted to the wet zone at altitudes above 1000 mm.

On the other hand out of the ten species of *Garcinia* represented in Sri Lanka according to Kostermans(1980), *G. quaesita*, *G. zeylanica*, *G. terpnophyla*, *G. thwaitesii* and *G. hermonii* are endemic to Sri Lanka. From field collections. Observations and from other literature, it is seen that these species are mainly confined to the wet zone lowlands of Sri Lanka.

In a situation of this nature where non-endemic species of a taxon are found restricted to the lowlands of wet and dry zones, specially in an island isolated from a big land mass, the endemic species found in the wet lowlands extending to high altitudes must have evolved from the stock of non-endemic species. This idea was very much supported by the present study based on vegetative anatomical characters and by the results obtained from anatomical data and analyzing them by statistical methods. Based on such studies, it is possible to suggest relationships between the non-endemic and the endemic species of *Garcinia*.represented in Sri Lanka and also to suggest a possible evolutionary sequence within them as depicted in Fig. 10.

From Figure 10, it is clear that the basic stock responsible for the evolution of endemic Sri Lankan taxa are mainly the non-endemics *Garcinia mangostana*, *G. morella*, *G. spicata* and *G. xanthochymus*. Based mainly on anatomical characters of lamina, fiber length/vessel element length ratios and ecological considerations, it is possible to suggest that *G. thwaitesii* and *G. hermonii* have evolved on two evolutionary lines from the basic stock through *G. xanthochymus*. Similarly, *G. quaesita* evolved from the stock through *G. morella*, has given rise to *G. terpnophyla* which in turn has given rise to *G. echinocarpa*. From these observations, the present study agrees with Trimen (1893) that *G. echinocarpa* is endemic to Sri Lanka. On the other hand it could be suggested that *G. zeylanica* has evolved from *G. quaesita* at almost the same time as *G. terpnophylla* for the reason that the former shows close affinities to *G. terpnophyla* and *G. quaesita*.

ACKNOWLEDGEMENTS

We are grateful to the National Science Foundation of Sri Lanka (earlier NARESA) for providing financial assistance and Prof. (Mrs.) U.

Coomaraswamy, the Vice Chancellor of the Open University of Sri Lanka (former Head of the department of Botany) for providing research facilities in the department of Botany. Our thanks are also due to Mr. S. Somaratne, department of Botany, The Open University of Sri Lanka for the assistance given in statistical analysis. We also thank our colleagues who made helpful criticisms during preparatory stages of the manuscript and for providing constant encouragement throughout the study. Further, the support given by the laboratory staff of the Botany Department, The Open University of Sri Lanka during field and laboratory work is gratefully acknowledged.

REFERENCES

Abu-Asab, M.S. & P.D. Cantino, (1987). Phylogenetic Implications of Leaf Anatomy in Sub-tribe Melittidinae (Labiatae) and Related Taxa. *Journal of Arnold Arboratum* **68** : 1-29.

Alston, A.G.H. (1931). Suppliment to the Trimen's Handbook to the Flora of Ceylon, Part VI. Dalau & Co. Ltd., London. Pp. 101.

Bass, P. (1973). The Wood Anatomical Range in *Ilex* (Aquifoliaceae) and its Ecological and Phylogenetic Significance. *Blumea* **21** : 193- 258.

Bass, P. (1976). Some Functional Aspects of Vessel Member Morphology. In *Wood Structure in Biological and Technological Research,* P. Bass, A. J. Bolton & D. M. Catling (eds.). Leiden University (Leiden Botanical Series **3**: 157-181).

Baas, P. (1982). Systematic, Phylogenetic and Ecological Wood Anatomy. In *History and New Perspectives in Wood Anatomy,* P. Bass, (ed.), Martinus Nijhoff/Dr. W .Junk publishers, The Hague. Pp. 23-58.

Baas, P.P.M. Esser, M.E.T. van der Vesten and M. Zandee (1988). Wood Anatomy of Oleaceae. *International Association of Wood Anatomists Bulletin n.s.* **9** : 103 – 182.

Baily, I. W. (1953). The Anatomical Approach to the Study of Genera. *Chronica Botanica* **14**(2): 121 - 125.

Baily, I. W. (1957). The Potentialities and limitations of Wood Anatomy in the Study of Phylogeny and Classification of Angiosperms. *Journal of Arnold Arboratum* **38**: 243-251.

Baranova, M.A. (1987). Historical Development of the Present Classification of Morphological Types of Stomates. *Botanical Review* **53**(1): 53-79.

Baretta-Kuipers, T. (1976). Comparative Wood Anatomy of Bonnetiaceae, Theaceae and Guttiferae. In *Wood Structure in Biological and Technological Research,* P. Bass, A.J. Bolton & D.M. Catling (eds.), Leiden University (Leiden Botanical Series **3**: 76-101).

Bonsen, K.J.M. & L.J. Kucera. (1990). Vessel Occlusion in Plants: Morphological and Evolutionary Aspects. *International Association of Wood Anatomists Bulletin n.s.* **11** (4): 393-399.

Burmann, J. (1737). *Thesaurus Zeylanicus Exhibiens Plantas in Insule Zeylana Nascentes.* Janssonio - Wassbergions & Salonem Schuuten, Amsterdam. Pp. 130-131.

Carlquist, S. (1975). *Ecological Strategies of Xylem Evolution.* University of California Press. Burkley, California. Pp. 185- 206.

Carlquist, S. (1977). Ecological Factors in Wood Evolution: A Floristic Approach. *American Journal of Botany* **64** : 887-896.

Carlquist, S. & D.A. Hoekman (1985). Ecological Wood Anatomy of Staphyleaceae: Ecology, Statistical Correlations and Systematics. *Flora* **177** : 195-216.

Chalk, L. & M.M. Chattaway (1934). Measuring the Length of Vessel Members. *Tropical Woods* **40** : 19 - 26.

Chalk, L. (1983). Vessels. In *Anatomy of the Dicotyledons,* Vol. II, 2nd ed., C. R. Metcalfe & L. Chalk (eds.), The clarendon press, Oxford. Pp. 21-25.

Chalk, L. (1983). Wood Anatomy, Phylogeny and Taxonomy. In *Anatomy of the Dicotyledons*, Vol. II, 2nd ed., C. R. Metcalfe & L. Chalk (eds.), The clarendon press, Oxford. Pp. 44- 47.

Chalk, L. (1983). The Effects of Ecological Conditions on Wood Anatomy. In *Anatomy of the Dicotyledons,* Vol. II, 2nd ed., C. R. Metcalfe & L. Chalk (eds.), The clarendon press, Oxford. Pp. 48 – 52.

Chattaway, M.M. (1932). Proposed Standards for Numerical Values used in Describing Wood. *Tropical Woods* **29** : 20 - 28.

Chattaway, M.M. (1955). Crystals in Woody Tissue. Part 1. *Tropical woods* **102** : 55-74.

Chattaway, M.M. (1956). Crystals in Woody tissue. Part II. *Tropical Woods* **104** : 100-124.

Committee on Nomenclature of Wood Anatomists (1957). International Glossary of terms used in wood anatomy. *Tropical Woods* **107**: 1- 36.

D'Arcy, W. G. & R.C. Kaeting (1979). Anatomical Support for the Taxonomy of *Calophyllum* (Guttiferae) in Panama. *Annals Missouri Botanical Garden* **66** : 557 - 571.

Desrousseaux M. (1792). In *Encyclopedie Methodique Botanique, Par M. le Chevalier De Lamark.* Panckoucke, Paris.

Dickison, W.C. (1969). Comparative Morphological Studies in Dilleniaceae. IV. Anatomy of the Node and Vascularization of the Leaf. *Journal of Arnold Arboratum* **50** : 384-400.

Dickison, W.C. (1973). Anatomical Studies in the Connaraceae, III. Leaf Anatomy. *Journal of Elisha Mitchell Scientific Society* **89** (1 & 2): 121-138.

Dickison, W.C. (1975). The Base of Angiosperm Phylogeny: Vegetative Anatomy. *Annals Missouri Botanical Garden* **62** : 590-620.

Dickison, W.C. (1989). Stem and Leaf Anatomy of the Alseuosmiaceae. *Aliso* 12(3) : 567 - 578.

Dilcher, D. L. (1974). Approaches to the Identification of Angiosperm Leaf Remains. *Botanical Review* **40** : 15 - 107.

Esau, K. (1965). *Plant Anatomy.* 2nd ed. Wiley Eastern Limited, New Delhi.

Esau, K. (1976). *Anatomy of Seed Plants.* 2nd ed. John Wiley & Sons, New York. Pp. 36- 39.

Fahn, A. (1990). *Plant Anatomy,* 4th ed. Butterworth-Heinemann Ltd., Linacre House, Jordan Hill, Oxford. Pp. 31- 54.

Gamble, J.S. (1881). *A manual of Indian Timbers.* Sampson Law Maston & Co. Ltd., London. Pp 298.

Graff, N.A. van der & P. Baas (1974). Wood Anatomical Variation in Relation to Latitude and Altitude. *Blumea* **22** : 101-121.

Hedren, M. (1990 a). The *Justicia striata* Complex in Tropical Africa *(Justicia.* Sect. Hannieria, Acanthaceae). *Nordic Journal of Botany (Section of Tropical Botany)* **10** : 357 - 398.

Hedren, M. (1990 b). The *Justicia elegantula* Complex (Acanthaceae) in Tropical Africa. *Botanical Journal of Linnaean Society* **103** : 263 - 280.

Herat, T .R. & W .L. Theobold (1977). Comparative Studies of Vegetative

Anatomy in the Theaceae of Sri Lanka. *Botanical Journal of Linnaen Society* **75** : 375 - 386.

Herat, R.M. & W.L. Theobald (1979). Comparative Studies of Vegetative i Anatomy and Morphology of the Gesneriaceae of Sri Lanka. *Bot. l J. Linn. Soc.* **78** : 286 - 298.

Hermann, P. (1717). *Musaeum Zeylanicum, Sive Catalog us Plantarum in Zeylona Sponte nascentium.* Lugduni Batavorum, Isaac Severinus. Pp. 15, 28, 46, 66.

Howard, R.A. (1962). *The vascular structure of the petiole as a taxonomic character.* Reprint from" Advances in Horticultural Science and their Applications", Vol. III. Pergamon Press, Oxford. Pp. 87- 92.

Howard, R.A. (1974). Stem-node-leaf Continuum of the Dicotyledonae. *Journal of Arnold Arboratum* **55** : 125 - 173.

Howard, R.A. (1979). The Petiole. In *Anatomy of the Dicotyledons,* Vol. I, 2nd ed. C.R. Metcalfe & L. Chalk (eds.), The clarendon press, Oxford.

International Association of Wood Anatomists Committee (1964). *Multilingual Glossary of Terms used in Wood Anatomy*. Konkordia, Winterthur.

International Association of Wood Anatomists Committee (1989). IAWA List of Microscopic Features for Hard Wood Identification. E.A. Wheeler, P.Bass & P.E. Gasson (eds.), *International Association of Wood Anatomists Bulletin n.s.* **10**(3) : 219 – 332.

Jacobseni, T .D. (1979). Numerical Analysis of Variation between *Allium cernuum* and *Allium Stellatum* (Liliaceae). *Taxon* **28** (5/6) : 517- 523.

Jansen, J.J., M.J. Mcleod, W.H. Eshbaugh & S.J. Guttman. (1979). Numerical Taxonomic Studies of Allozymic Variation in *Capsicum* (Solanaceae). *Taxon* **28** (4):315-327.

Janssonius, H.H. (1952). *Key to the Javenese Woods (On the basis of anatomical features)* E.J. Brill, Leiden. Pp. 119- 124.

Johansen, D.A., (1940). *Plant Microtechnique.* McGraw Hill Book Co. Inc., New York.

Khidir, W.H. & K. Wright. (1982). Systematics of Graminae : A Cluster Analysis Study. *Taxon* **31** (1) : 9-36.

Kordopani, M. & M.Ingrouille. (1991). Patterns of Morphological Variation in the *Acasia* species (Mimosaceae) of Northern Sudan. *Botanical Journal of Linnaen Society* **105** : 239-256.

Kostermans, A.J.G.H., (1976). Notes on the Clusiaceae of Sri Lanka and Reduction of *Pentaphalangium* Warb. *Ceylon Journal of Science (Biological Sciences)* **12**: 55- 71.

Kostermans, A.J.G.H. (1980). Clusiaceae (Guttiferae). In *A Revised Handbook to the Flora of Ceylon, Vol. I.* M. D. Dassanayake & F.R. Fosberg (eds.). Amerind, New Delhi. Pp. 72-79.

Kribs. D.A. (1935). Salient Lines of Structural Specialization in the Wood Rays of Dicotyledons. *Botanical Gazette* **96** : 547-557.

Linnaeus, C. (1747). *Flora Zeylanica.* Samlu & Literis, Laurentii, Siavii, Holmiae. Pp. 90- 91, 201 - 202.

Metcalf, C.R. & L. Chalk. (1950). *Anatomy of the Dicotyledons,* Vol. I. Clarendon Press, Oxford.

Metcalf, C.R. (1979). The leaf: General Topography and Ontogeny of the Tissues. In *Anatomy of the Dicotyledons,* Vol. I, 2nd ed. C. R. Metcalfe & L. Chalk (eds). The clarendon press, Oxford. Pp. 150- 165.

Metcalfe, C.R. (1979). The stem. In *Anatomy of the Dicotyledons,* Vol. I, 2nd ed. C. R. Metcalfe & L. Chalk (eds). The clarendon press, Oxford. Pp. 166- 180.

Metcalfe, C.R. (1983), Wood structure. In *Anatomy of Dicotyledons,* Vol. II, 2nd ed. C. R. Metcalfe & L. Chalk (eds). The clarendon press, Oxford.

Moon, A. (1824). *Catalogue of Indigenous and Exotic Plants Grown in Ceylon.* The Government Press, Ceylon. Pp. 37, 73.

Muller - Oombois, O. (1968). Ecogeographic Analysis of Climate Map of Ceylon with Special Reference to Vegetation. *Ceylon Forester* **VIII (3 & 4)** : 38 - 58.

Oever, L. van der, P. Baas and M. Zandee (1981). Comparative wood anatomy of Symplocos and latitude and altitude of provenance. *International Wood Anatomists Bulletin n.s.* **2** (1):2-24.

Payne, D.O. (1970). On the Ontogeny of Stomata and Other Homologous Structures. *Plant Science Series. Allahabad.* **1** : 1-24.

Pearson, R. S. & H. P. Brown. (1932). *Commercial Timbers of India,* Vol. I & II. Govt. India, Calcutta. Pp. 43- 61.

Pierre, L. (1885). Flore de la Cochinchine. Vol. 1. Octave Doin, Paris.

Planchon, J.E. & J. Triana. 1860. Memoire sur la Famille des Guttiferes. *Annuls of Science Natural Botanical Series* **V** (Tome XIII): 306 - 376.

Radford, A.E., W.C. Dickison, J.R. Massey & C.R. Bell. (1974). *Vascular Plant Systematics.* Harper & Row publishers, New York, Evanston, San Francisco, London.

Record, S. J. (1936). Classification of Various Anatomical Features used in Classifying Dicotyledonous Woods. *Tropical Woods* **47** : 12 - 27.

Record, S.J. & M.M. Chattaway. (1937). List of Anatomical Features used in Classifying Dicotyledonous Wood. *Tropical Woods* **57** : 11. - 17.

Rendie, B.J. & S.H. Clark. (1934). The Diagnostic Value of Measurement in Wood Anatomy. *Tropical Woods* **40** :27- 40.

Robertse, P.J. G.Venter & H.Janse van Rensoberg. (1980). The Wood Anatomy of the South African *Acacia. International Association of Wood Anatomists Bulletin* n.s. **1** (3) : 93-103.

Roxburgh, W. (1832). *Flora Indica*, Vol. II. W. Thacker & Co., Calcutta and Parbury Allen & Co. London.

Sass, E.J. (1958). *Plant Microtechnique*, 3rd ed. Iowa State University Press. Ames, Iowa, U.S.A.

Schofield, E.K. (1968). Petiole Anatomy of the Guttiferae and Related Families. *Mem. New York Botanical Garden* **18** : 1-55.

Siegel, A.F. (1988). *Statistical and Data Analysis*. John Wiley & sons, United States.

Sneath, P.H.A. & R.R. Sokal. (1973). *Numerical Taxonomy*. W.H. Freeman & Co., San Francisco. Pp. 880

Solereder, H. (1908). *Systematic Anatomy of the Dicotyledons* (transl. L. A. Boodle & F. E. Fritch, Revised by D. H. Scott). Vol. 1.Clarendon Press, Oxford. Pp. 120 – 126.

Somaratne, S. & T. R. Heart. (2001). A Comparative Vegetative Anatomical Study of the Genus *Calophyllum* in Sri Lanka. *Ceylon Journal of Science (Biological Science)* **28** : 51-80.

SPSS Inc. (1990). SPSS Statistical Data Analysis *[SPSS/PC + Statistics (TM) 4.0 for the IBM PC/XT/A T and PS/2]*. SPSS Inc., Michigan Avenue, Chicago, Illinois, USA. Pp. B1-E6.

Stevens, P.F. (1974). A Review of *Calophylum* in Papuasia. *Australian Journal of Botany* **22** : 349-411.

Stevens, P.F. (1976). The Old World Species of *Calophyllum* (Guttiferae), 1, The Mascarene Species. *Journal of Arnold Arboratum* **57** (2): 167-184.

Stevens, P.f. (1980). A Revision of the Old World Species of *Calophyllum* (Guttiferae) *Journal of Arnold Arboratum* **61**: 117-424.

Survey Department. (1992). Topographic Sheets (one inch) of Sri Lanka. Revised in 1973, Reprint 1992. Survey Department, Colombo.

Thwaites, G.H.K. (1864). *Enumeratio Plantarum Zeylaniae*. Dalau & Co. Ltd., London. Pp. 51-52.

Tippo, O. (1938). Comparative Anatomy of the Moraceae and their Presumed Allies. *Botanical Gazette* **100** : 1-99.

Tippo, O. (1946). The Role of Wood Anatomy in Phylogeny. *American Midland Naturalist* **36** : 362-372.

Trimen, H. (1893). *Handbook to the Flora of Ceylon*, Part I, (Indian Reprint, 1984). Bishen Singh Mahendra Pal Sing, Dehradun. Pp. 98-104.

Trimen, H. (1931). *Handbook to the Flora of Ceylon*, Part VI, Supplemented by A.G.H. Alsonton. Dalau & Co. Ltd., London. Pp. 101.

Van Cotthem, W. (1970). A Classification of Stomatal Types. *Botanical Journal of Linnnaeun Society* **63** : 235-246.

Van Cotthem, W. (1973). Stomatal Types and Systematics In, *The Phylogeny and Classification of the Ferns*, A.C. Jermy, J.A. Crabbe & B.A. Thomas (eds.). Academic press, London. Pp. 134 - 152.

Vesque, J. (1893). Guttiferae. In *Monographieae Phanerogamarum*, Vol. 8, C. de Candolle (ed.), G. Mason, Paris. Pp. 229- 548.

Vestal, P.A. (1937). The Significance of Comparative Anatomy in Establishing the Relationship of the Hypericaceae to the Guttiferae and their Allies. *Philippine Journal of Science* **64**: 199-256.

Wheeler, E.A. (1986). Vessels per Square Millimeter or Vessel Groups per Square Millimeter? *International Association of Wood Anatomists Bulletin n.s.* 7(1):73-74.

Wilkinson, H.P. (1979). The plant surface (Mainly leaf). In *Anatomy of Dicotyledons*, Vol. I, 2nd ed.C. R. Metcalfe & L. Chalk (eds). The clarendon press, Oxford. Pp. 97-165.