15. Summary and Conclusions

The Sapindales of Cronquist, containing fifteen families, are considered as an assemblage of a number of taxa which possess diverse features but have, in common, the compound or cleft leaves, haplo- or diplostemonous androecium, well developed nectary disk and syncarpous ovary with a limited number of ovules. The families included here were distributed in various orders such as the Rutales, Geraniales Celastrales or Meliales by different authors. The assortment of various families within these orders varied with the authors This reflects the difficulty experienced in circumscribing the taxa which remain interlinked to each other.

Eventhough the families Sapindaceae, Anacardiaceae, Burseraceae, Rutaceae, Simaroubaceae, Meliaceae and Zygophyllaceae are considered as 'core' families, the placement of certain uni- or bigeneric satellite families is debated. The status and position of some of them remained controversial. They are treated either as peripheral groups or placed in separate orders.

From the economic point of view this order gains prominance due to the timber (**Chloroxylon, Carapa, Khaya, Flindersia, Swietenia Dysoxylum, Harpullia, Schleichera, Mangifera**), gums (most of the Anacardiaceae and Meliaceae members), resins (Burseraceae), sugars (Aceraceae), tannins (**Rhus, Schleichera, Filicium, Geranium** etc) and a number of pharmacologically active principles. The family Simaroubaceae is well-known for their bitter quassinoids which display antileukemic activity and also antiviral, antifeedant and insecticidal properties. The limonoids of Meliaceae and Rutaceae are antifeedants and cytotoxic. Other principles of this group include alkaloids (acronychine, berberine, fagarnonine, indoles, maytansinoids, pilocarpine, wilfordine etc.), sterols (guggulsterols), phenolics (flavonoids, coumarins and quinones) and saponins (diosgenin, hederagenin).

In the present work leaves of 117 plants belonging to the Sapindales s.l. and 69 plants which are grouped in related orders such as Geraniales, Celastrales and Rhamnales have been subjected to a chemical analysis for various markers such as flavonoids, phenolic acids, tannins, saponins, iridoids, proanthocyanidins, coumarins and quinones. These data alongwith the data collected from previous works and other disciplines have been utilised for assessing the interrelationships prevailing within the taxa at various levels of hierarchy. The major families (the Sapindaceae, Anacardiaceae, Burseraceae, Rutaceae, Meliaceae and Simaroubaceae) have been subjected to a cladistic analysis taking characters from morphology, anatomy and chemistry and Wagner trees are prepared and superimposed on Wagner "Bull's eye" charts. Dendrograms also are prepared from the cladograms. In addition, all these families, taken up in the present work were analysed cladistically using data from morphology, anatomy, embryology, palynology and chemistry and the groups resulted are assessed.

Flavonols and proanthocyanidins form the major phenolic pigments of the group. Flavonols are particularly abundant in the Anacardiaceae, Burseraceae, Meliaceae, Zygophyllaceae, Balsaminaceae, Geraniaceae, Celastraceae and Rhamnaceae. Flavones and/or glycoflavones dominate the Oxalidaceae, though they occur in appreciable proportions in the Sapindaceae, Anacardiaceae and Simaroubaceae. Biflavones are seen in Anacardiaceae and Burseraceae only. The families free of proanthocyanidins are the Zygophyllaceae, Geraniaceae, Oxalidaceae and Balsaminaceae. Saponins are more common in the Sapindaceae, Zygophyllaceae and Rhamnaceae. Alkaloids are abundant in the Rutaceae, Simaroubaceae, Zygophyllaceae, Celastraceae and Rhamnaceae and to a lesser extent in the Meliaceae. Iridoids are absent from all these taxa.

Based on the distribution of the chemical characters

the groups recognised are : (1) Rutales (Burseraceae, Rutaceae, Peganaceae, Meliaceae, Simaroubaceae and Zygophyllaceae) (2) Sapindales (Sapindaceae, Melianthaceae and Staphyleaceae (?) (Anacardiaceae positioned in between the two orders included as a suborder in any of the two) (3) Geraniales (Geraniaceae, Oxalidaceae) (4) Balsaminales (Balsaminaceae) (5) Celastrales (Celastraceae) (6) Rhamnales (Rhamnaceae) and (7) Vitidales (Vitaceae and Leeaceae). The first four orders arise from a common stock while the origin of other orders is unconfirmed.

The cladogram of the families agrees more or less with the above grouping. The Anacardiaceae finds a place within the Rutales close to the Rutaceae. But the staphyleaceae and Melianthaceae separate out from the Sapindaceae to form a group closer to the Celastrales. Another major difference is the placement of the Zygophyllaceae which gets grouped with the Geraniaceae. The closeness of the Vitaceae and Rhamnaceae also is clearly evident.

The Sapindaceae (including the Aceraceae, Hippocastanaceae, Melianthaceae and Staphyleaceae) appeared to be homogeneous in possessing similar flavonoid profile. **Acer** and **Aesculus** are very similar to the rest of the genera and therefore the identities of the Aceraceae and Hippocastanaceae are chemically invalid and these groups are considered tribes within the Sapindaceae. **Melianthus** and **Staphylea** showing differences in chemical constituents from the rest of the Sapindaceae are treated as closely related families. The specialisation seen in the chemistry of **Dodonea** warrants a subfamily status to the tribe Dodonieae. **Litchi** is found to differ from **Nephelium** and therefore, its separate generic status is upheld. **Filicium decipiens** is found to be at home in the Sapindaceae. The separate identity of **Sapindus laurifolius** from **S. emarginatus** is established. **Acer negundo**, the

exceptional species in the genus **Acer**, is accepted as **Negundo aceroides**. The cladogram groups the genera into 4 groups which may be treated as tribes. The family Sapindaceae is found to be a chemically advanced taxon.

The Anacardiaceae is found to be rich in flavonols and proanthocyanidins, flavones, glycoflavones and biflavones are the other flavonoids located in the family. The tribes proposed by different authors do not get much support from chemistry. The tribes which are distinct are Rhoideae and Semecarpeae. The shifting of **Dracantomelum** to the Rhoideae and **Anacardium** to the Semecarpeae is recommended. The separate identity of **Chaerospondias** (from **Spondias**) is established. The cladogram groups the plants of the Rhoideae and Mangiferae in separate branches. The heterogeneity seen in the morphological features of the family is reflected in their chemistry also. On the whole the Anacardiaceae form a cluster of primitive taxa.

The Burseraceae contain flavonols, biflavones and proanthocyanidins as the dominant phenolics. These features bring the family very close to the Anacardiaceae. The tribe Canarieae is chemically distinct though the Protieae and Boswellieae share a number of features. **Filicium decipiens** Thw. is found to be different from the Burseraceae members and therefore its placement in the Sapindaceae is upheld. **Protium caudatum** exhibits enough chemical differences to keep it away from **Commiphora**, a genus in which it is grouped at times. Since the genera **Protium** and **Bursera** are not very distinct chemically, **Protium serratum** may be grouped either in **Protium** or in **Bursera** (**B.serrata**). The Burseraceae occupy a very low level of specialisation. The cladogram emphasizes all these characters as also the homogeneity of the family.

The Meliaceae are a homogeneous taxon predominated by flavonols, proanthocyanidins, saponins and alkaloids. The differences in the chemical characters of **Chloroxylon** recommend its shifting from this family. The two subfamilies Swietenoideae and Melioideae are chemically distinct, though the tribal classification is not supported. **Azadirachta** shows a separate identity from the **Melia**. The cladogram divides the family into two groups A and B of which the former is subdivided into three subgroups. The group B corresponds to the subfamily Swietenioideae. The family as a whole is a highly evolved taxon.

Though all the three types of flavonoids - the flavones, glycoflavones and flavonols are seen in the Rutaceae, flavonols predominate. The subfamily Toddalioideae is distinct while the Aurantioideae and Rutoideae are intimately connected chemically. **Chloroxylon swietenia** gets accomodated among the plants of this family. **Glycosmis pentaphylla** var. **linearifoliola** Tanaka is chemically distinct from G. **pentaphylla** and therefore, a new name **Glycosmis linearifoliola** is recommended for the former plant. With its diversification and complexity in the flavonoid and terpenoid chemistry the Rutaceae form a specialised climax group. The cladogram distinguishes the subfamilies Rutoideae and Aurantioideae.

The Simaroubaceae contain flavones, glycoflavones and proanthocyanidins equally distributed. Since each genus exhibits a distinct flavonoid profile the merger of all the genera of the subfamily Simarouboideae into a single genus **Quassia** is not supported. **Balanites** is found to be dissimilar in not synthesising the quassinoids characteristic of the Simaroubaceae and therefore, its exclusion from the family is recommended. The family is an advanced taxon.

The study on the Zygophyllaceae showed the flavonols

to be the major phenolics of the family. Flavones are located in **Balanites** and **Peganum**, two controversial genera. The separation of **Peganum** as a family Peganaceae is supported. **Balanites** appears to occupy an isolated position within the family. The chemical identity of **Tribulus rajastaniensis** away from **T. terrestris** is established. The affinities of the family with the Meliaceae, Simaroubaceae as well as the differences with the Sapindales are discussed.

The family Geraniaceae (including the Oxalidaceae, Averrhoaceae and Balsaminaceae), is chemically heterogeneous. The Oxalidaceae elaborated the advanced flavones and glycoflavones while the Geraniaceae s.l. retained the flavonols and tannins. The Balsaminaceae produced quinones and reduced the flavonol content. **Averrhoa** is similar to the rest of the Oxalidaceae in its chemistry and thus is at home in this family. Among the three families, the Geraniaceae form the basic stock from which two lines of evolution are traced, the first one to the Oxalidaceae and the second to the Balsaminaceae. The specialisation achieved by the Balsaminaceae is worthy of its elevation to an order, the Balsaminales.

Flavonols and proanthocyanidins predominate the family Celastraceae. Flavones and glycoflavones are rare, located in one plant each. The diversification achieved by this family in its alkaloid, terpenoid and phenolic chemistry is commendable and proves it to be a separate line of specialisation. **Salacia** is very similar to the other plants, invalidating the separate family status of the Hippocrateaceae. The tribal classification also do not get any support from the chemical characters.

The Rhamnaceae contained flavonols, quinones and proanthocyanidins highly prevalent. Flavones and glycoflavones are rare and these characters make the family a natural taxon.

The Rhamnaceae are distinct in producing quinones and peptide alkaloids. **Colletia** exhibits a number of exceptional characters.

The Vitaceae and Leeaceae are found to be dissimilar in that the former family contains flavones, glycoflavones and flavonols while the latter produces highly hydroxylated compounds such as myricetin and gallic acid. Both these families do not synthesise the quinones and peptide alkaloids characteristic to the Rhamnaceae and therefore, cannot be grouped in the Rhamnales. The specialised morphological features warrant the formation of a separate order the Vitidales to circumscribe the Vitaceae and Leeaceae. The classification of **Vitis** to 4 genera also gets support from chemistry.

The **highlights** of the present investigation are summarised below:

(1) The Sapindales **Sensu** Cronquist consist of two groups of plants which are placed in two separate orders, the Sapindales and Rutales. The Sapindales consist of the Sapindaceae (including the Aceraceae and Hippocastanaceae) and the Rutales contain the Burseraceae, Simaroubaceae, Rutaceae, Meliaceae and Anacardiaceae. The Anacardiaceae appear to be the connecting link between these two orders.

(2) One line of evolution from the Burseraceae seems to be of the Rutalean families while the other line leads to the Sapindales. The Sapindaceae are the most advanced taxon among all the families.

(3) The Zygophyllaceae, though share a number of chemical characters with the Rutales, find a proper place in the Geraniales. The order Geraniales consists of the Geraniaceae, Oxalidaceae and Zygophyllaceae.

(4) The Rhamnales consist of three families (the Rhamnaceae, Vitaceae and Leeaceae) and Celastrales, of the Celastraceae. (based on cladistics).

(5) The Melianthaceae and Staphyleaceae are erroneously placed in the Sapindales and that they have their affinities with the Celastrales and Geraniales.

(6) The concept of the unifamilial order Balsaminales evolving from the Geraniales appears to be logical.

(7) The families which remained controversial and are found valid taxa are:-

(a) Melianthaceae
(b) Staphyleaceae
(c) Peganaceae
(d) Oxalidaceae
(e) Balsaminaceae and
(f)Leeaceae.

(8) The families which are proposed earlier but did not get any support from the chemical evidences are :-

(a) Aceraceae
(b) Hippocastanaceae
(c) Flindersiaceae
(d) Balanitaceae
(e) Averrhoaceae
(f) Hippocrateaceae

(9) The subfamilies which appear to be taxonomically valid are:-

(a) Dodonioideae and Sapindoideae (Sapindaceae)
(b) Aurantioideae and Rutoideae (Rutaceae)
(c) Swietenoideae and Cedreloideae (Meliaceae)

(10) The families in which the tribal classification do not get any support from the present investigation are :-

(a) Anacardiaceae,
(b) Meliaceae, and
(c) Celastraceae.

(11) The Controversial plants which are now placed in confirmed positions are :-

(a) **Filicium decipiens** Thw. in the Sapindaceae
(b) **Chloroxylon swietenina** DC in the Rutaceae
(c) **Peganum harmala** L. in the Peganaceae
(d) **Balanites aegyptiaca** Delile in the Zygophyllaceae
(e) **Litchi chinesis** Sonn. in the genus **Litchi.**
(f) **Acer negundo** L. in the genus **Negundo** as **N. aceroides** Moench.
(g) **Spondias axillaris** Roxb. in the genus **Chaerospondias** as **C. axillaris** Burtt. & Hill.
(h) **Protium candatum** W.& A. in the genus **Protium.**
(i) **Bursera serrata** Colebra in the genus **Bursera**
(j) **Melia azadirachta** L. in **Azadirachta** as **Azadirachta indica** A.Juss.

(12) Comments on the merger/splitting of the taxa

(a) All the genera in the subfamily Simarouboideae are found to have their own chemical identity and therefore, the merger of all of them into **Quassia** is not favoured.

(b) Since the genus **Vitis** is found to be heterogeneous, the splitting of this taxon into four genera **Cissus, Tetrastigma, Ampelocissus** and **Vitis** is favoured.

(13) The status of the following taxa are established

(a) **Sapindus laurifolius** Vahl. from **S. emarginatus** Vahl.

(b) **Tribulus rajastaniensis** Bhandari et Sarma from **T. terrestris L.**

(c) **Glycosmis pentaphylla** var. **linearifoliola** Tanaka as a new species **G. linearifoliola** (Sp.nov.) away from G. **pentaphylla** Corr.

(14) Cladistic analyses of six major families i.e. the Sapindaceae, Anacardiaceae, Burseraceae, Rutaceae, Meliaceae and Simaroubaceae have been carried out and unbiased grouping of the taxa are arrived at.

(15) All the plant families (including the controversial ones) are subjected to a cladistic analysis using characters taken from morphology, anatomy, embryology, palynology and chemistry and the phylogenetic groups and evolutionary patterns are recognised.

(16) The present study revealed a number of new sources of bioflavonoids alkaloids, saponins and tannins (Appendix 2)

(17) Chemical data on some more related (?) families such as the Malpighiaceae, Clusiaceae and Linaceae, which are generated alongwith the present project, are given at the end and the affinities of these taxa are assessed.

(18) The study proves beyond doubt that the chemical characters are as reliable as any other taxonomic character because the grouping based solely on chemical characters are greatly similar to the grouping arrived at using cladistic methods.