1.General Introduction

The order **Sapindales** Sensu Cronquist containing 17 families, the Aceraceae, Akaniaceae, Anacardiaceae, Burseraceae, Cneoraceae, Connaraceae, Greyiaceae, Hippocastanaceae, Simaroubaceae, Staphyleaceae, Julianaceae, Meliaceae, Melianthaceae, Rutaceae, Sapindaceae, Stylobasiaceae and Zygophyllaceae, is distinguished by a combination of characters such as compound or cleft leaves, haplo - or diplostemonous androecium, well-developed nectariferous disk and syncarpous ovary with a few ovules in each locule. According to Cronquist (1981) the Sapindales are a well-defined natural order with Staphyleaceae and Zygophyllaceae occupying peripheral positions. These two families differ from the rest in having stipulate leaves and more than two ovules in each locule.

The order Sapindales was first defined by Lindley (1853) with the type family Sapindaceae. The families grouped in this order were included earlier in the Terebinthales with the type family Terebinthaceae (Anacardiaceae). Lindley's Sapindales included the Sapindaceae, Tremandraceae, Polygalaceae, Vochyaceae, Staphyleaceae, Petiveriaceae, Aceraceae, Malpighiaceae and Erythroxylaceae. This circumscription of the order was followed by later taxonomists though some differed in the content of the order. Bentham and Hooker (1862) constituted their Sapindales with 3 families i.e. the Sapindaceae (incl. Aceraceae, Melianthaceae, Staphyleaceae and Hippocastanaceae), Sabiaceae and Anacardiaceae and excluded other families and placed them in the Geraniales. The Sapindales visualized by Engler and Prantl (1895) encompassed 11 suborders and 23 families which also included the families grouped in the Celastrales and Balsaminales. But they kept the families Rutaceae, Simaroubaceae, Burseraceae and Meliaceae in a separate order the Geraniales. Their Sapindales are characterised either by pendulous ovules with dorsal raphe and micropyle upwards or erect with ventral raphe and micropyle downwards. The opposite situation of the raphe prevails in the Geraniales.

Rendle (1950) defined the Sapindales (Anacardiaceae, Sapindaceae, Aceraceae and Hippocastanaceae) as having diplostemonous condition and 2 to 3 carpels and the Rutales and Geraniales having obdiplostemonous androecium. Among the latter two orders, the Rutales (Rutaceae, Simaroubaceae, Burseraceae and Meliaceae) are distinguished by well-developed disk and oil glands in their leaves. The Staphyleaceae were included in the Celastrales having one whorl of stamens. Hutchinson (1973) distributed the families of Sapindales s.l. in 4 orders (1) Rutales (2) Meliales (3) Sapindales and (4) Malpighiales. The monadelphous condition existing in the Meliaceae, according to him, is one of the striking features and therefore lead to the formulation of a unifamilial order, the Meliales. The Zygophyllaceae and Balanitaceae are accomodated in the Malpighiales. After comparing the herbarium specimens of the Geraniaceae and Rutaceae, Hutchinson vehemently opposed the existance of any resemblence between them. The Rutaceae, according to him, is a climax group and cannot be related to any other family.

Bessey (1915) placed the Geraniales and Sapindales in two different subclasses in the class Oppositifolia, the former order in subclass Strobiloideae and the latter in subclass Cotyloideae. He suggested that these two subclasses had originated from different ancestors. The Geraniales are derived from the Ranales and the sapindales from the Rosales. Takhtajan (1980) in his latest scheme of classification reconstructed the Sapindales (13 families) away from the Rutales (14 families), both evolved from a common Saxifragalean ancestor. Dahlgren (1980) erects a large superorder Rutiflorae to include six orders, the Rutales, Sapindales, Polygalales, Geraniales, Balsaminales and Tropaeolales. According to him, these orders are very closely related to each other. Thorne (1981), in his treatment, is similar to Cronquist (1981) in having Rutales and Sapindales in a single order Rutales but in addition he incorporates Juglandinae, Myricinae and Fabinae.

From the various above-mentioned classificatory schemes it is clearly evident that the 'core group' families are interrelated to each other to form a network and this is the reason behind the difficulty in delimiting various orders. Dahlgren (1980) affirms that this complex is the most variable in the Angiosperms. The families are closer to each other to such an extent that it is not easy to isolate them from the remainder. The same opinion was expressed by Gibbs (1974), who commented that it is difficult to separate the families into manageable orders. However all these reshufflings resulted in the emergence of two distinct groups; the first group with the Rutaceae, Meliaceae, Simaroubaceae and Burseraceae sticking together and the second group with Sapindaceae and their allies the Aceraceae, Hippocastanaceae and Melianthaceae and to a lesser extent the Staphyleaceae and Zygophyllaceae. These two groups are either merged in one order or kept in twin orders. When the Rutales and Sapindales are considered distinct, the placement of the Burseraceae and Anacardiaceae remains debatable. The Anacardiaceae are kept next to the Burseraceae by Cronquist, Takhtajan and Gunderson. These two families greatly resemble each other in morphological and chemical characters. The habit, flower and fruit are same in both the families. They also possess resin canals or ducts. Chemical similarities these families share are the presence of biflavones which are not located in any other family of the Sapindales or the Rutales. But Dahlgren, Hutchinson and Rendle keep the Burseraceae and Anacardiaceae in different orders. Similarly the Zygophyllaceae also are variously grouped in Geraniales, Rutales, Sapindales, Linales or Malpighiales. Morphologically their affinities lie with the Geraniales (herbaceous habit, number of stamens, numerous ovules in each carpel) but chemically they are closer to the Rutales (alkaloids and terpenoids). Seed characters (Corner, 1976) indicate that the Zygophyllaceae are out of place in Sapindales but close to the Malpighiales. Thorne (1981) prefers to place it in Linales. The placement of Staphyleaceae also is a subject of dispute. Though it is placed next to the Sapindaceae or in Celastrales, Dickson (1986) finds this family more comfortable in the Cunoniales. The familial status of Aceraceae, Hippocastanaceae and Melianthaceae also remained debatable in taxonomic circles. Though most of the taxonomists do not agree, data from palynology, embryology and chemistry support the merger of these families within the Sapindaceae.

The Sapindales s.l. exhibit a great diversity in their chemistry of the secondary metabolites they elaborate, the distribution of which is greatly useful in assessing the relationships existing among various families. The chemistry of the Rutales (incl. Rutaceae, Meliaceae, Simaroubaceae, Ptaeroxylaceae, Cneoraceae and Burseraceae) is reviewed and discussed at length in an exhaustive chemotaxonomic treatment 'Chemistry and Chemical Taxonomy of the Rutales' (Waterman and Grundon, 1983) which appeared recently. The order Sapindales (including the Rutales) is distinguished by producing a wide variety of terpenoids, alkaloids and phenolics.

Triterpenoids appear to be a common constituent of the Sapindales, occuring free or as glycosides (saponins). Free pentacyclic triterpenes which normally occur in waxes and oils are widely distributed in the Burseraceae, Meliaceae, Simaroubaceae, and Rutaceae. Saponins based on hederagenin moiety are common in the Sapindaceae, Aceraceae and Hippocastanaceae while saponins with a steroidal skeleton are reported from the Sapindaceae, Meliaceae and Zygophyllaceae. The terpenoid bitter principles which form the characteristic compounds of this order are derived from C_{30} precursor compounds. These compounds, designated as limonoids and quassinoids, are seen in the Rutaceae, Meliaceae, Cneoraceae and Simaroubaceae. A loss of 4 carbon atoms from a C_{30} triterpene leads to tetranortriterpenoids (C_{26}). Further degradations give rise to C_{20} and C_{19} quassionoids. C_{30} derivatives of tirucallane or euphane which form the precursors of the limonoids are seen in some members of the Meliaceae (**Melia**). But this family is specialised in elaborating C_{26} tetranortriterpenoids in wide variety. These variations resulted by the ring cleavages and oxidations include (1) intact carbon skeleton (**Trichilia**), (2) ring D cleaved, (3) ring C cleaved (**Melia, Azadirachta,** (4) ring B cleaved (**Toona**), (5) ring A cleaved or (6) both A & B rings cleaved (**Trichilia**). Tetranortriterpenoids with a spirolactone ring (**Carapa**) also is seen in this family. C_{25} Pentanortriterpenoids are characteristic of the Cneoraceae. The Rutaceae produce a homogeneous group of closely related highly functionalised largely A and D-ring secolimoniods (C_{26}) and the distribution of limonoids tend to be dominated by limonin itself. The Simaroubaceae produce quassinoids (Simaroubolides) which are C_{20}/C_{19} triterpenoids which have lost C-17 and attached side-chain carbons and represent a further step down on an oxidative pathway. The report of limonoids in the Burseraceae is to be varified.

Diterpenes are widespread in the Burseraceae, Rutaceae, Zygophyllaceae and Anacardiaceae. **Volatile oils** rich in monoterpenes form a characteristic feature of the Rutaceae, though they occur as components of oleo-resins in the Burseraceae. Monoterpenes as minor components of resins occur in Cneoraceae, Simaroubaceae and Meliaceae.

Alkaloids of wide variety occur in the Rutaceae and very few plants outside this family produce them. The alkaloids of the Rutaceae have been reviewed recently (Mester, 1983). These alkaloids are derived from 1) anthranilic acid (**simple** quinolines, furo - and pyrano-quinolines, acridones and quinazolines), 2) tryptophan (indoles, carbazoles, β--carbolines, canthin-6-ones), 3) phenylalanine or tyrosine (isoquinolines, benzophenanthridines, aporphines), 4) histidine (histamine, pilocarpine) and 5) ornithine and lysine

(Stachydrine). Anthranilic acid derived alkaloids are confined to the Rutaceae, while quinazolines and β -carbolines are reported from a few members of the Zygophyllaceae and Simaroubaceae. The Meliaceae elaborate a few pyridine derivatives.

Phenolics form another group of secondary metabolites existing in great variety in many of the families included here. The various phenolics include lignans (and neolignans), coumarins, chromones, flavonoids and tannins. Lignans are detected only in the Rutaceae and Burseraceae. Coumarins form another characteristic feature of the Rutaceae. More than 300 coumarins, reported from this family, include simple, alkoxy, acyl and dimeric forms. This elaboration is absent in rest of the Sapindales though a few coumarins are reported from some families. The Hippocastanaceae contain a few of the rutalean coumarins such as fraxin, aesculetin etc. The Simaroubaceae produce scopoletin while the Meliaceae produce a few cinnamate-derived simple coumarins. Scopoletin is seen in some members of the Sapindaceae, Anacardiaceae, Aceraceae and Burseraceae, though in the last family coumaranolignans are found. Chromones are not uncommon in the Rutales. Both coumarins and chromones are fairly frequent in the Ranunculaceae and Apiaceae. There appears to be a high degree of similarity betwten these compounds of the Rutaceae and the Apiaceae and this is cited as an evidence of a probable relationship existing between them. The variations include simple chromones (Meliaceae, Cneoraceae), pyranochromones (Rutaceae, Simaroubaceae), hydroxy methyl chromones (Ptaeroxylaceae), oxepinochromones (Cneoraceae and Pteroxylaceae) and 2-phenethyl chromones (**Flindersia**).

The **flavonoid** pattern of the Rutales is not sufficiently known except for the Rutaceae. The dominent flavonoid pigments of this family are the flavonols quercetin and kaempferol, though myricetin occurs in a few members. Fully or partially methylated flavonols and flavones form a distinguishing feature of the genus **Citrus**. Deoxy-flavonoids (both 5- and 7-) are seen in **Casimiroa** and **Sargentia** (Rutaceae). 2'-Oxygenation and isoprenylation are two other biosynthetic features of the flavonoids of this family. Myricetin is also reported from the Anacardiaceae and Simaroubaceae whereas isoprenoid flavones are located in Sapindaceae also. Biflavones are seen in the Anacardiaceae and Burseraceae.

The Sapindales, being woody, are tanniferous and most the families yield commercial tannins. The Rutaceae, Sapindaceae and Meliaceae synthesise condensed tannins; the Simaroubaceae and Burseraceae produce hydrolysable tannins and the Aceraceae and Anacardiaceae contain both the types.

Other interesting compounds of the Sapindales include 1) non-protein amino acids such as hypoglycin which have a restricted distribution, located in the Sapindaceae and Hippocastanaceae, 2) mono-amines from **Acer** and **Staphylea**, 3) seed cyanolipids from the Sapindaceae, 4) irritant polyphenols, alkyl catechols, from the Anacardiaceae and 5) copper-containing glycoproteins from **Rhus**.

The fluid boundaries (Table 1.1) existing in defining the Sapindales are seen in the related/supposedly related orders such as the Geraniales, Celastrales and Rhamnales also and as a result, certain families included whithin the former order get reshuffled frequently and transferred to the latter orders in various schemes of classification. The confusion existing in the classification of these taxa is represented in Fig.1.1. All these orders were grouped by Bentham and Hooker (1862) in their 'Disciflorae', a group generally known as "dust-bin taxa" in taxonomic circles. To delimit the boundaries of the Sapindales, it becomes, to some extent, mandatory to examine the chemical interrelationships of the families grouped in all these orders. Therefore, in the present work, represen-

	Bentham and Hooker (1862)	Engler and Prantl (1935)	Wettstein (1935)	Gunderson (1950)	Rendle (1950)	Hutchinson (1973)	Thorne (1976)	Takhtajan (1980)	Dahlgren (1980)	Cronquist (1981)
Balsaminaceae	Geraniales	Geraniales	Gruinales	Geraniales	Geraniales	Geraniales	Geraniales	Geraniales	Balsaminales	Geraniales
Geraniaceae									Geraniales	
Oxalidaceae										
Zygophyllaceae						Malpighiales		Rutales		Sapindales
Meliaceae			Terebinthales	Rutales	Rutales	Meliales	Rutales		Rutales	
Simaroubaceae						Rutales				
Rutaceae										
Burseraceae										
Anacardiaceae	Sapindales	Sapindales			Sapindales	Sapindales			Sapindales	
Sapindaceae				Sapindales				Sapindales		
Aceraceae										
Hippocastanaceae										
Melianthaceae										
Staphyleaceae			Celastrales		Celastrales		Rosales			
Celastraceae	Celastrales			Rhamnales		Celastrales	Santalales	Celastrales	Celastrales	Celastrales
Rhamnaceae		Rhamnales	Rhamnales		Rhamnales	Rhamnales	Rhamnales	Rhamnales	Rhamnales	Rhamnales
Vitaceae							Cornales		Vitidales	

Table 1.1 The Fluid Boundaries Existing Among the Families Included in the Sapindales and Related Taxa.

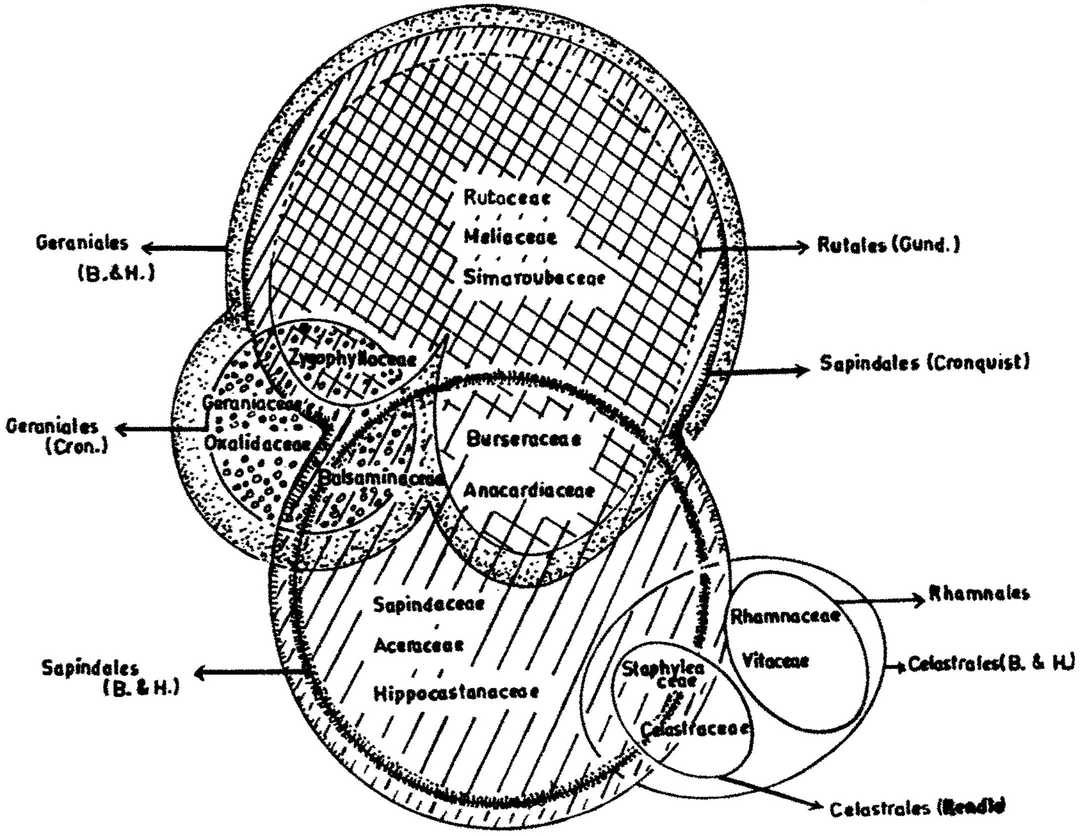

Fig. 1.1 The fluid boundaries of the Sapindales, Rutales, Geraniales and Celastrales

tative taxa from the orders Geraniales, Celastrales and Rhamnales also are examined for their chemical constitution and affinities.

The order **Geraniales** are distinguished from the Sapindales by their herbaceous habit, bisexual flowers, compound leaves, elastically dehiscent schizocarpic fruit and in developing a strong tendency towards zygomorphy in flowers. Lindley was the first to create the Geraniales which then consisted of families Balsaminaceae, Geraniaceae, Hydroceraceae, Tropaeolaceae and Oxalidaceae. Later on one or all the families of closely related orders Polygalales, Linales, Malpighiales, Sapindales, and Euphorbiales were included within this order by various taxonomists. Therefore, the content of the order vary greatly with different systematic treatments. The number of families included in Geraniales are : 11 by Bentham and Hooker (1862), 21 families grouped in 6 suborders by Engler and Prantl (1931), 20 by Bessey (1915), 13 by Thorne (1976), 19 by Takhtajan (1980) and 5 each by Hutchinson (1973) and Cronquist (1981). The Geraniaceae, Oxalidaceae, Tropaeolaceae, Limnanthaceae and Balsaminaceae are consistantly grouped in the Geraniales. These five families constitute the Geraniales of Cronquist who keeps this order as a herbaceous offshoot of the Sapindales. As already seen, the Rutaceae, Meliaceae, Burseraceae and Simaroubaceae are either retained in Geraniales (Bentham and Hooker, loc. cit., Engler and Prantl, loc. cit) or shuffled to various orders. According to Cronquist the Zygophyllaceae are intermediate between his Sapindales and Geraniales. Takhtajan (1980) comments that the Geraniales are related to the Rutales especially to the Rutaceae. Similarly Dahlgren (1980) places the Geraniales next to the Sapindales within the Superorder Rutiflorae. Among the four families, the Geraniaceae, Oxalidaceae, Tropaeolaceae and Balsaminaceae, the similarities existing among the first three families are agreed upon by most of the taxonomists. However Behnke (1981) separated the Oxalidaceae with Plc' plastids from the Geraniaceae having S-type plastids and places the former next to the Connaraceae (Connarales). Though the Balsaminaceae and Tropaeolaceae have zygomorphic flowers, their relationship is debated. Engler and Prantl (1931) as also Lawrence (1951) group the Balsaminaceae in the Sapindales under a separate suborder Balsamineae, on the basis of the apotropous ovule. The latter author rules out the resemblances between the Balsaminaceae and Tropaeolaceae considering that the spur of the former family as derived from calyx while that of Tropaeolaceae is receptacular in origin. Dahlgren (1980) is of the opinion that the superficial similarities between these two families may or may not indicate relationship and the affinity of the Balsaminaceae with the Geraniaceae is also dubious and therefore, erects a unifamilial order Balsaminales to accommodate the Balsaminaceae.

The Celastrales contain a single large family the Celastraceae and a number of small satellite families which were once treated as tribes in this family. They are characterised by simple leaves, haplostemonous condition, hypo- to perigynous flowers, extrastaminal disk and usually numerous ovules in a locule. The Staphyleaceae also sometimes are included in this order. Cronquist relates the Celastrales to Rosales, Sapindales, Euphorbiales and Santalales. Though the presence of numerous ovules in the Celastraceae rules out the possibility of any ancestry from the Sapindales, they might have been considered evolved from the primitive Sapindales or from the Rosales. According to Thorne (1981) the Celastrales are the most ridiculous unnatural assemblage of plants. He proposes the order to have relationships with the Santalales. Dahlgren (1980) keeps the Celastrales very close to the Sapindales and Vitidales.

The Rhamnales, another order closely related to the Sapindales, consist of three families the Rhamnaceae, Vitaceae and Leeaceae. This order differs from the Celastrales in having haplostemonous stamens opposite to petals and instrastaminal disk. Cronquist and Takhtajan propose that both the Celastrales and Rhamnales have evolved parallel from a diplostemonous Rosalean ancestor with the former retaining the outer whorl of stamens alternate to petals and the latter preserving the inner whorl of stamens opposite to the petals. Thorne feels that the Vitaceae are wrongly grouped with the Rhamnaceae and he keeps his order Rhamnales containing the Rhamnaceae and Eleagnaceae in Malviflorae. Dahlgren also favours this idea. The characters shared by these two orders are exotestal seed coat, mucilaginous receptacle, similar phloem fibres and vessel elements, lepidote vesture and the unusual peptide alkaloids. The Vitaceae differ from the Rhamnaceae in all the above-mentioned characters. The seed structure in the Vitaceae are very primitive and are cornelean. The sieve element plastids of the Vitaceae are P1c" which are similar to those found in the Gunneraceae of the Cornales (Behnke, 1981) whereas the Rhamnaceae possess S-type plastids as found in the Euphorbiaceae.

Chemically also these orders i.e. the Geraniales, Celastrales and Rhamnales exhibit some similarities with the Sapindales. Quinazolines and β-carbolines (similar to those identified from the Zygophyllaceae) are reported from the Celastraceae and Rhamnaceae. These two families elaborate their own 'special' alkaloids also. Thus the alkaloids of the Celastraceae, the maytansinoids, exhibit a unique chemical structure - the 19-membered amide ring. Besides these alkaloids the family contains xanthines, phenylalkylamines and spermidines. The Rhamnaceae synthesise cyclopeptide alkaloids. All the three orders are particularly flavonol-rich. Simple flavonols such as myricetin, quercetin and kaempferol are isolated from the Celastraceae, Rhamnaceae and Geraniaceae. 5-Deoxy flavonols and also hydrolysable tannins are common in the last family.

Mention has already been made on the attempt on a chemotaxonomic treatment of the Rutales (Waterman and Grundon, 1983). But this study is far from complete and leaves much to be desired. Though a number of taxonomic conclusions on the phylogeny and grouping of the order, families and some subfamilies, are drawn in this work, the data, on the strength of which the judgements are made, are based on very poor sampling. Only the already available data are consulted and as such data based on a systematic screening, which is a prime requisite for any taxonomic interpretation, are missing. Some of the inferences drawn, based on a single occurrence of a compound in a remotely connected taxon, are quite strange and alarming to a classical taxonomist. Definitely great weightage is given to the chemical characters in this treatment. The taxonomic status of the taxa at lower levels of hierarchy is never discussed (except for the Rutaceae) though enough data enabling such assessments are available.

Taking into account of all these lacunae existing in the treatments concerning of the family, a systematic study on the chemical constituents of the families included in the Sapindales s.l. and related taxa is undertaken. This work is not an exhaustive one, but care is taken to give proper representation of the available taxonomic units at all levels and the controversial taxa. The data procured thus and the data already available are analysed critically and the trends seen in the relationships and phylogeny of the various taxa are evaluated. This work is intended to be a beginning of a comprehensive study on the chemotaxonomic studies on the constituent taxa so that other conscientious workers in this field can add more data and arrive at a viable sound taxonomic treatment. Though this Ph. D. programme was concieved to be dealing with the chemotaxonomical aspect of the Sapindales, during the course of work it was felt that the data from other disciplines also are to be incorporated to get a true picture of the relationships. To avoid undue weightage on certain characters and to remove subjectivity, cladistic methodology is resorted to. This led to an impartial assessment of the affinities and distances among the component taxa and the evolutionary levels achieved by them.

Cladistics

Cladism and numerical taxonomy are the two major methods to formalise taxonomic methods and make the results repeatable more accurately. Both produce dendrograms. The dendrograms of numerical taxonomy represent the similarities and dissimilarities prevailing among various taxa and lay very little stress on phylogeny as well as relationships. Therefore, cladistics is a statistical method often adopted to construct a phylogenetic tree connecting various taxa, using evidences from various disciplines. A cladogram is the pictorial representation of this analysis which depicts the evolution in a branching pattern and the interelationships existing among various taxa. Once the cladogram is prepared, the taxa are grouped to arrive at a final classification which is more logical and has a predictive value.

Cladistics provides a quantitative comparison of a large number of characters simultaneously and gives an efficient summary of character distribution. The phylogenetic interpretations which are vaguely defined and inconsistantly used, are quantified and formalised. As a result cladistics elevates systematics from intuitive taxonomy to a legitimate branch of science. The results thus obtained are accountable and consistant. One of the fundamental and laudable aims of cladistics is to increase the amount of objectivity and repeatability in the discovery and representation of evolutionary history and correspondingly decrease the amount of subjectivity and intuition.

In cladistics organisms are ranked entirely on the basis of recency of common descent, i.e., on the basis of sequence of dichotomies in the inferred phylogeny. It was Henning (1966) who proposed to emphasize the branching pattern and this became the basis of the present day cladism. In cladistic methodology phylogenetically significant characters are assigned numerical states and are coded in a binary form, 0 for the ancestral state (plesiomorphic state) and 1 for the derived state (advanced, apomorphic state). The total advanced characters would then be added up to achieve some sort of a relative position, one to the other, in an imaginary tree diagram.

The essential distinctive feature of cladism is that a group is considered to be monophyletic, and thus taxonomically acceptable, only if it includes all the descendants from the most recent common ancestor. This opposes the traditional taxonomic view that a group can still be considered monophyletic after some of its more divergent branches have been trimmed off. Another important concept is that no existing taxon can be ancestral to any other existing taxon and the descendant must be included in the same taxon as its ancestor. The polarity of the character states (primitive/advanced) is determined by comparing with a related group, an outgroup, and if only one of a pair of character states under consideration is found in the outgroup then that state is considered to be plesiomorphic (primitive) in the ingroup. However the processes like hybridisation, parallelism, convergence and divergence as well as polyphyletic origin cannot be represented in a cladistic analysis.

With the increasing number of characters and taxa, the calculations in cladistic methodology become tedious necessitating the deployment of a computer. A number of computer programmes such as PHYSYS, PHYLIP, WAGS, PIM etc. are available. Some of these programmes involve as many as 225 steps (Dahlgren and Bremer, 1985). The computer produces a number of phylogenetic trees (sometimes more than a hundred) from which the most parsimonious tree is selected by the taxonomist. At this stage the judgement of the taxonomist plays some role because he would select the tree which comes closer to his concepts.

Unfortunately, the cladistic methodology is always frowned upon by the classical taxonomists and as a result a lot of heat is being generated. Cronquist (1987), in one of his most vehement criticisms, loathes over the cult of cladism which, at present, is much modified (distorted ?) version of the original concept and therefore has a much narrower outlook. He calls for a restraint on the indiscriminate use of cladistics in classification which, at times, resulted in the disruption of some of the present classificatory schemes without giving any alternatives. However, Cronquist agrees and also supports the basic idea of formalizing taxonomy. He recommends 'Wagner's ground plan divergence method' for the construction of cladograms, over the complex computer methods.

Wagner was one of the few who formalised the cladistical approach to taxonomy. He proposed a diagram, refered to as ground plan divergence method which is popularly known as Wagner's 'Bull's Eye' chart. Such diagrams are projected as targets with radiating lines from a zero (central or primitive) point to an ever-expanding circular periphery where the more advanced taxa are positioned by numerical scores. The bull's eye chart consists of a number of concentric semicircles about a common base-point that represents the ground plan. The first circle (nearest the base-point) represents divergence from the groundplan in one character and the second represents divergence in two characters. Species that have diverged in the fewest characters from the groundplan appear on the semicircle(s) nearest the base-point and species that have diverged in more characters appear on progressively remote semicircles. All the taxa are connected by lines to the base point.

Calculation on the distances (quantified affinity) between the taxa is a significant feature in cladistics. Based on the relative distances/affinities the organisms are arranged in subsequent branches. Wagner networks and Wagner trees are two convenient methods to quantify relationships among the taxa. Between these two, the latter one is preferred over the former because the tree is directional and can be superimposed on a Wagner's bull eye chart. Such a diagram provides the nature and number of clades as also the evolutionary levels achieved by the different taxa in a group.

In the **present work** 186 plants belonging to the Sapindaceae (27), Anacardiaceae (20), Burseraceae (9), Rutaceae (26), Meliaceae (20), Simaroubaceae (9), Zygophyllaceae (6), Geraniaceae (including Oxalidaceae and Balsaminaceae - (28), Celastraceae (14), Rhamnaceae (9) and Vitaceae (18), have been analysed for their leaf phenolics and other natural products such as alkaloids, saponins and tannins. The results obtained are analysed in concurrence with other taxonomic evidences to evaluate the existing classificatory schemes of the various taxa. In addition, cladistic analyses of the genera and also of the families have been attempted to arrive at acceptable groupings of plants.

Objectives

The principal objectives of the present project are as follows :

1. To delimit the orders Sapindales (Rutales), Geraniales, Celastrales and Rhamnales.

2. To assess the taxonomic validity of the orders Balsaminales, Meliales, Rhamnales (<u>sensu</u> Thorne) and Vitidales.

3. To find out the interrelationships existing among these orders and among the families grouped in them.

4. To asses the validity of the following families :-

   a) Aceraceae
   b) Hippocastanaceae
   c) Melianthaceae
   d) Staphyleaceae
   e) Flindersiaceae
   f) Balanitaceae
   g) Peganaceae
   h) Geraniaceae
   i) Oxalidaceae
   j) Balsaminaceae
   k) Averrhoaceae
   l) Leeaceae
   m) Hippocrateaceae

5. To asses the taxonomic identity of the subfamilies included within the Sapindaceae (Sapindoideae and Dodonioideae), Rutaceae (Aurantioideae, Toddalioideae, Rutoideae) Meliaceae (Swietenoideae, Cedreloideae) and also the tribes in all the families.

6. To examine the status and position of the following plants :-

a) **Filicium decipiens** Thw. (grouped in Burseraceae/Anacardiaceae/Sapindaceae)

b) **Chloroxylon swietenia** DC. (included in Meliaceae/Rutaceae/Flindersiaceae)

c) **Peganum harmala** L. (grouped in Zygophyllaceae/Rutaceae/Peganaceae).

d) **Balanites aegyptiaca** Delile (placed in Zygophyllaceae/Simaroubaceae/Balanitaceae)

e) **Litchi chinensis** Sonn. (in genus **Nephelium** or **Litchi**)

f) **Acer negundo** (in **Acer** or **Negundo**)

g) **Spondias axillaris** Roxb (in **Spondias** or **Chaerospondias**)

h) **Protium caudatum** W. & A. (in **Protium** or **Commiphora**)

i) **Bursera serrata** Colebra (in **Bursera** or **Protium**)

j) **Melia azadirachta** L. (in **Azadirachta** or **Melia**)

k) Merger of all the genera in the subfamily Simarouboideae into **Quassia**.

l) Splitting of the genus **Vitis** into separate genera **Cissus**, **Tetrastigma**, **Ampelocissus** and **Vitis**.

m) **Sapindus trifoliatus** (which is merged with S. **emarginatus**).

n) **Glycosmis pentaphylla** var. **linearifoliola** (grouped with **G. pentaphylla**).

o) **Tribulus rajasthaniensis** (grouped in **T. terrestris**).

7. To subject the genera of each major family (Sapindaceae, Anacardiaceae, Burseraceae, Rutaceae, Meliaceae and Simaroubaceae) to a cladistic analysis for obtaining an impartial grouping of the genera and to compare these results with the results obtained from the chemotaxonomical analysis.

8. To undertake a cladistic analysis of all the 19 families including the controversial taxa to arrive at a plausible grouping enabling a better classificatory scheme.

9. To trace out the phylogeny of the Sapindales and related orders.

10. To find out new sources of bioflavonoids, alkaloids, saponins and tannins.

The **thesis** is arranged in the following manner. The second chapter embodies the methodology adopted for the chemical and cladistic analyses. The major families studied **i.e.**, the Sapindaceae, Anacardiaceae, Burseraceae, Rutaceae, Meliaceae, Simaroubaceae, Zygophyllaceae, Geraniaceae, Celastraceae, Rhamnaceae and Vitaceae form individual chapters. In each chapter the morphological, anatomical, palynological and embryogical characters of the families are explained, followed by the chemical data availed by the present work and the chemotaxonomic conclusions drawn. In all the major families cladistic analyses of the genera (when the number of species is more than 20) or the species (when the number of plants is less) are done by constructing a wagner tree and superimposing it on a Wagner bull's eye chart. Dendrogram based on the cladograms are prepared to visualise the various grouping of plants. The interrelationships of the families screened and the groupings resulted are discussed in the next chapter and these results are compared with the results of the cladistic analysis on these families. The results and conclusions are summarised in the last chapter. The appendix include : (1) some more chemical data on 24 plants belonging to the Malpighiaceae (9), Linaceae (4) and Guttiferae (11), generated alongwith the present project and their relevence on the taxonomy of the Sapindales, (2) separate tables listing new sources of bioflavonoids and herbarium numbers (alongwith the place and date of collection) of the specimens and, (3) list and reprints of the research articles published during the course of present work.