Deapartment of Botany
Durgapur Government College
Module: e-resource
B.Sc. (Botany Honours)
3rd Semester
Plant Systematics

Taxonomic hierarchy Concept of taxa (family, genus, species); categories and taxonomic hierarchy; species concept (taxonomic, biological, evolutionary)

Taxonomic groups, categories and ranks are inseparable once a hierarchical classification has been achieved. *Rosa alba* is thus nothing else but a **species** and *Rosa* is nothing other than a **genus**. However, the differences do exist in concept and application.

The **categories** are like shelves of an almirah, having no significance when empty, and importance and meaning only after something has been placed in them. Thereafter, the shelves will be known by their contents: books, toys, clothes, shoes etc. Categories in that sense are artificial and subjective and have no basis in reality.

They correspond to nothing in nature. However, they have a fixed position in the hierarchy in relation to other categories. But once a group has been assigned to a particular category the two are inseparable and the category gets a definite meaning because it now includes something actually occurring in nature. The word genus does not carry a specific meaning but the genus *Rosa* says a lot. We are now talking about roses. There is practically no difference between **category** and **rank**, except in the grammatical sense. *Rosa* thus belongs to the **category genus**, and has **generic rank**. If categories are like shelves, ranks are like partitions, each separating the given category from the category above. **Taxonomic groups**, on the other hand, are objective and non-arbitrary to the extent that they represent discrete sets of organisms in nature. Groups are biological entities or a collection of such entities. By assigning them to a category and providing an appropriate ending to the name (Rosaceae with ending –**aceae** signifies a family which among others also includes roses, belonging to the genus *Rosa*) we establish the position of taxonomic groups in the hierarchical system of classification. Some important characteristics, which enable a better understanding of the hierarchical system of classification, are enumerated below.

1. Different categories of the hierarchy are higher or lower according to whether they are occupied by more inclusive or less inclusive groups. Higher categories are occupied by more inclusive groups than those occupying lower categories.

2. Plants are not classified into categories but into groups. It is important to note that a plant may be a member of several taxonomic groups, each of which is assigned to a taxonomic category, but is not itself a member of any taxonomic category. A plant collected from the field may be identified as *Poa annua* (assigned to species category). It is a member of *Poa*

(assigned to genus category), Poaceae (assigned to family category) and so on, but the plant can't be said to be belonging to the species category.

3. A taxon may belong to other taxa, but it can be a member of only one category. *Urtica dioica*, thus, is a member of *Urtica*, Urticaceae, Urticales, and so on, but it belongs only to species category.

4. Categories are not made up of lower categories. The category family is not made up of the genus category, since there is only one genus category.

5. The characters shared by all members of a taxon placed in a lower category provide the characters for the taxon immediately above. Thus, the characters shared by all the species of *Brassica* make up the characters of the genus *Brassica*. The characters shared by *Brassica* and several other genera form distinguishing characters of the family Brassicaceae. It is important to note that the higher a group is placed in the hierarchy, the fewer will be the characters shared by the subordinate units. Many higher taxa, as such (e.g. Dicots: Magnoliopsida) can only be separated by a combination of characters; no single diagnostic character may distinguish the taxa. Dicots are thus conveniently separated from monocots by possession of two cotyledons, pentamerous flowers, reticulate venation and vascular bundles in a ring as against one cotyledon, trimerous flowers, parallel venation and scattered vascular bundles in monocots. But when taken individually, *Smilax* is a monocot with reticulate venation and *Plantago* is a dicot with parallel venation. Similarly *Nymphaea*, is a dicot with scattered bundles, and the flowers are trimerous in *Phyllanthus*, which is a dicot.

UTILIZATION OF CATEGORIES

Taxonomic categories possess only relative value and an empty category has no foundation in reality and obviously can't be defined. An important step in the process of classification is to assign taxa to an appropriate category. It thus becomes imperative to decide what should be the properties of taxa to be included in a particular category? Only with a proper utilization of the concept of categories can their application in hierarchical systems be meaningful. The problem is far from resolved. An attempt will be made here to discuss the relevant aspects of the inclusion of type of entities or groups of entities under different categories.

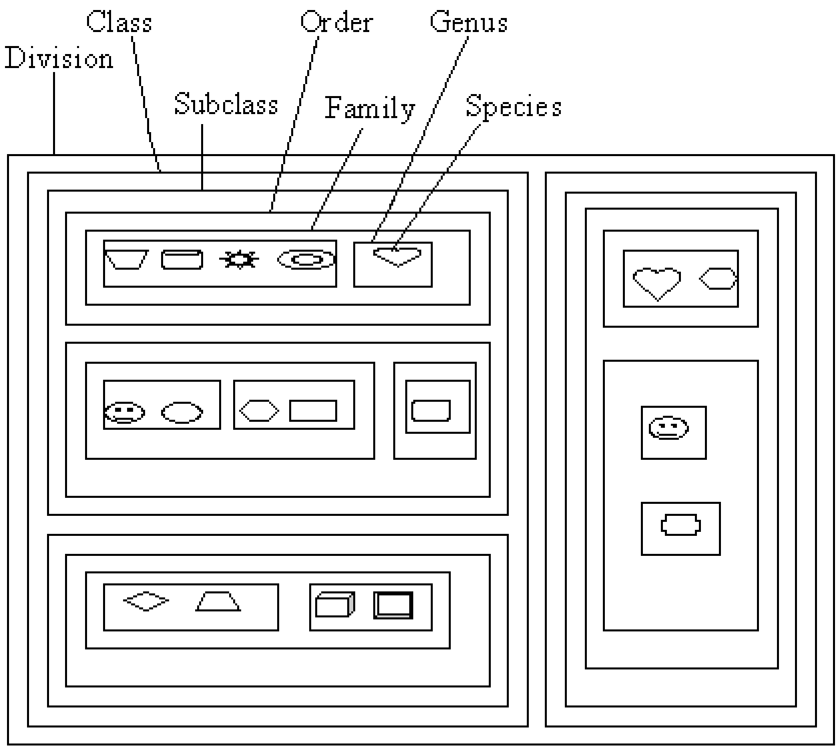


Figure: Processes of assembling taxonomic groups according to the hierarchical system, depicted by box-in-box method. In the above example, there are 18 species grouped into 10 genera, 6 families, 4 orders, 3 subclasses, 2 classes and 1 division.

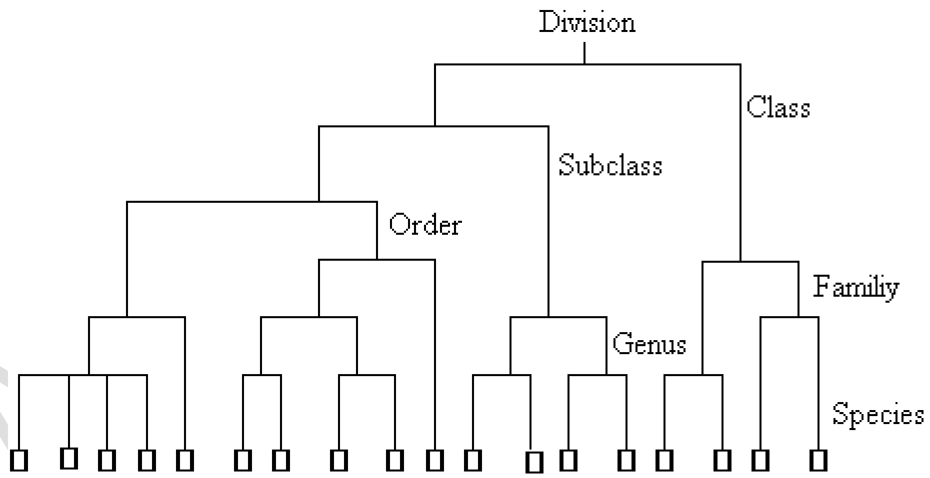


Figure: Dendrogram method for depicting the hierarchical system based on same hypothetical example as in previous Figure.

SPECIES CONCEPT

Darwin aptly said: 'Every biologist knows approximately what is meant when we talk about species, yet no other taxon has been subjected to such violent controversies as to its definition'. A century and a half has passed, so much advancement in the taxonomic knowledge has been achieved, yet the statement of Darwin is as true today as it was then.

Numerous definitions of species have been proposed, making it futile to recount all of them. Some significant aspects of the problem will be discussed here. Probably the best explanation of diversity of opinions can be explained as under.

'***The species is a concept. Concepts are constructed by the human mind, and as humans think differently we have so many definitions of a species.'*** Obviously a concept can't have a single acceptable definition. The word species has different meaning for different botanists. According to ICBN, which has attempted to clarify the meaning of the word species, '***species are convenient classificatory units defined by trained biologists using all information available***'. The word species has a dual connotation in biological science. First, the species is a naturally-occurring group of individual organisms that comprises a basic unit of evolution. Second, the species is a category within a taxonomic hierarchy governed by various rules of nomenclature.

Species as Basic Unit of Taxonomy

The following information serves to substantiate the view that species constitutes the basic unit of classification or, for that matter, taxonomy (systematics):

1. Species is considered the basic unit of taxonomy, since in the greater majority of cases, we do not have infraspecific names. This is especially common in families such as Apiaceae (Umbelliferae) and Liliaceae.
2. Species, unlike other taxa, can be described and recognized without relating to the taxa at other ranks. Thus we can sort herbarium sheets into different species without difficulty, without knowing or bothering to know how many genera are covered by these sheets. We cannot recognize genera or describe them without reference to the included species. Species is thus the only category dealing directly with the plants.
3. Whether defined in terms of morphological discontinuity or restriction of gene exchange, species is unique in being ***non-arbitrary to both inclusion and exclusion***. A group is non-arbitrary to inclusion if all its members are continuous by an appropriate criterion. It would be arbitrary to inclusion if it shows internal discontinuity. A group is non-arbitrary to exclusion if it is discontinuous from any other group by the same criterion. A group not showing discontinuity with other groups is arbitrary. All higher taxa although non-arbitrary to exclusion are arbitrary to inclusion, i.e. they exhibit internal discontinuity as now species with external discontinuity form part of these taxa.

Ideal Species

A perfect situation! Species that can be easily distinguished and have no problem of identity. Such species, however, are very few; common examples include Apiaceae, Asteraceae and the genera *Allium* and *Sedum*. The following characteristics are expected in an ideal species:

1. The species poses no taxonomic problems and is easily recognized as a distinct entity on the basis of morphological characters.
2. It exhibits no discontinuity of variation within, i.e. it contains no subspecies, varieties or formas.
3. It is genetically isolated from other species.
4. It is sexually reproducing.
5. It is at least partially outbreeding.

Unfortunately, ideal species are rare among the plant kingdom and the greater majority of species pose situations contrary to one or more of the above criteria.

TAXONOMIC SPECIES CONCEPT

The doctrine of fixity was challenged by Lamarck (1809) and finally Darwin (1859), who recognized continuous and discontinuous variation and developed his taxonomic species concept based on morphology, more appropriately known as the **Morphological species concept**. According to this concept, the species is regarded as ***an assemblage of individuals with morphological features in common, and separable from other such assemblages by correlated morphological discontinuity in a number of features***. The supporters of this view believe in the concept of continuous and discontinuous variations. The individuals of a species show continuous variation, share certain characters and show a distinct discontinuity with individuals belonging to another species, with respect to all or some of these characters.

Du Rietz (1930) modified the taxonomic species concept by also incorporating the role of geographic distribution of populations and developed the **morpho-geographical species concept.** The species was defined as ***the smallest population that is permanently separated from other populations by distinct discontinuity in a series of biotypes***.

The populations recognized as distinct species and occurring in separate geographical areas are generally quite stable and remain so even when grown together. There are, however, examples of a few species pairs which are morphologically quite distinct, well adapted to respective climates, but when grown together, they readily interbreed and form intermediate fertile hybrids, bridging the discontinuity gap between the species. Examples are *Platanus orientalis* of the Mediterranean region and *P. occidentalis* of United States. Another well-known pair is *Catalpa ovata* of Japan and China and *C. bignonioides* of America. Such pairs of species are known as **vicarious species** or **vicariants** and the **phenomenon** as **vicariance** or **vicariism**. **Morphological** and **morpho-geographical** types of taxonomic species have been widely accepted by taxonomists who even take into account the data from genetics, cytology, ecology, etc., but firmly believe that **species recognized must be delimited by morphological characters**.

The taxonomic species concept has several advantages:

1. It is useful for general taxonomic purposes especially the field and herbarium identification of plants.
2. The concept is very widely applied and most species have been recognized using this concept.
3. The morphological and geographical features used in the application of this concept can be easily observed in populations.
4. Even experimental taxonomists who do not recognize this concept, apply this concept in cryptic form.
5. The greater majority of species recognized through this concept correspond to those established after experimental confirmation.

The concept, however, also has some inherent drawbacks:

1. It is highly subjective and different sets of characters are used in different groups of plants.

2. It requires much experience to practice this concept because only after considerable observation and experience can a taxonomist decide the characters which are reliable in a particular taxonomic group.
3. The concept does not take into account the genetic relationships between plants.

BIOLOGICAL SPECIES CONCEPT

The biological species concept was first developed by Mayr (1942) who defined species as ***groups of actually or potentially interbreeding natural populations, which are reproductively isolated from other such groups***. The words 'actually or potentially', being meaningless, were subsequently dropped by Mayr (1969). Based on the same criteria, Grant (1957) defined species as ***a community of cross-fertilizing individuals linked together by bonds of mating and reproductively isolated from other species by barriers to mating***. The recognition of biological species thus involve: (a) interbreeding among populations of the same species; and (b) reproductive isolation between populations of different species. Valentine and Love (1958) pointed out that species could be defined in terms of gene exchange. ***If two populations are capable of exchanging genes freely either under natural or artificial conditions, the two are said to be conspecific (belonging to the same species). On the other hand, if the two populations are not capable of exchanging genes freely and are reproductively isolated, they should be considered specifically distinct***. The concept has several advantages:
1. It is objective and the same criterion is used for all the groups of plants.
2. It has a scientific basis as the populations showing reproductive isolation do not intermix and the morphological differences are maintained even if the species grow in the same area.
3. The concept is based on the analysis of features and does not need experience to put it into practice.
The concept, first developed for animals, holds true because animals as a rule are sexually differentiated and polyploidy is very rare. When applying this concept to plants, however, a number of problems are encountered:
1. A good majority of plants show only vegetative reproduction, and hence the concept of reproductive isolation as such cannot be applied.
2. Reproductive isolation is commonly verified under experimental conditions, usually under cultivation. It may have no relevance for wild populations.
3. Genetic changes causing morphological differentiation and those causing reproductive barriers do not always go hand in hand. *Salvia mellifera* and *S. apiana* are morphologically distinct (two separate species according to the taxonomic species concept) but not reproductively isolated (single species according to the biological species concept). Such species are known as **compilospecies**. Contrary to this, *Gilia inconspicua* and *G. transmontana* are reproductively isolated (two separate species according to the biological species concept) but morphologically similar (single species according to the taxonomic species concept). Such species are known as **sibling species**.
4. Fertility-sterility is only of theoretical value in allopatric populations.
5. It is difficult and time consuming to carry out fertility-sterility tests.
6. Occurrence of reproductive barriers has no meaning in apomicts.
7. Necessary genetic and experimental data are available for only very few species.

Stebbins (1950), it would appear, combined two concepts when he stated that ***species must consist of systems of populations that are separated from each other by complete or at least sharp discontinuities in the variation pattern, and that these discontinuities must have a genetic basis***.

These populations with isolating mechanisms (different species) may occur either in the same region (**sympatric species**) or in different regions (**allopatric species**). Fortunately, although the taxonomic and biological concepts are based upon different principles, the species recognized by one concept, in the majority of cases, stand the test of the other. Morphology provides the evidence for putting the genetic definition into practice.

EVOLUTIONARY SPECIES CONCEPT

This concept was developed by Meglitsch (1954), Simpson (1961) and Wiley (1978). Although maintaining that interbreeding among sexually reproducing individuals is an important component in species cohesion, this concept is compatible with a broad range of reproductive modes. Wiley (1978) defines: ***an evolutionary species is a single lineage of ancestor-descendant populations which maintains its identity from other such lineages, and which has its own evolutionary tendencies and historical fate***. This concept avoids many of the problems of the biological concept. Lineage is a single series of demes (populations) that share a common history of descent, not shared by other demes. The identity of species is based on **recognition systems** that operate at various levels. In sexually reproducing species, such systems include recognition because of phenotypic, behavioural and biochemical differences. In asexual species phenotypic, genotypic differences maintain the identity of species. Identity in both sexual and asexual species may also be due to distinct ecological roles. Viewed from the standpoint of evolutionary species concept, however, the important question is not whether two species hybridize, but whether two species do or do not lose their distinct ecological and evolutionary roles. If, despite some hybridization, they do not merge, then they remain separate species in the evolutionary perspective.

Several other terms have been proposed to distinguish species based on specific criteria. Grant (1981) recognizes **microspecies** as 'populations of predominantly uniparental plant groups which are themselves uniform and are slightly differentiated morphologically from one another'; they are often restricted to a limited geographical area. Microspecies develop in inbreeding species, but are usually not stable over longer periods. They may undergo cross-fertilization sooner or later forming recombinant types which themselves become new microspecies. Several microspecies have been found in *Erophila verna* mostly representing single biotypes or groups of similar biotypes some of which are marked by only one or two characters. These may be distinguished as **clonal microspecies** (reproducing by vegetative propagation, e.g. *Phragmites*), **agamospermous microspecies** (reproducing by agamospermy, e.g. *Rubus*), **heterogamic microspecies** (reproducing by genetic systems, e.g. *Oenothera biennis* or *Rosa canina*), and **autogamous microspecies** (predominantly autogamous and chromosomally homozygous, e.g. *Erophila*). The term microspecies was first suggested by Jordan (1873) and as such they are often termed as **Jardanons** to distinguish them from **Linnaeons**, the normal species, first established by Linnaeus. Microspecies are distinct from **cryptic species**, which are morphologically similar but cytologically or physiologically different. Stace (1989) uses the term **semi-cryptic species** for the latter.

GENUS

The concept of genus is as old as folk science itself as represented by names rose, oak, daffodils, pine and so on. A genus ***represents a group of closely-related species***. According to Rollins (1953), the function of the genus concept is to bring together species in a phylogenetic manner by placing the closest related species within the general classification. When attempting to place a species within a genus, the primary question would be, is it related to the undoubted species of that genus? Mayr (1957) defined genus as a ***taxonomic category which contains either one species or a monophyletic group of species, and is separable from other genera by a decided discontinuity gap***. It was earlier believed that a genus should always be readily definable on the basis of a few technical floral characters. A more rational recognition should take the following criteria into consideration:

1. The group, as far as possible, should be a natural one. The monophyletic nature of the group should be deduced by cytogenetic and geographic information in relation to morphology.
2. The genera should not be distinguished on a single character but a sum total of several characters. In a number of cases, genera are easily recognized on the basis of adaptive characters (adaptations in response to ecological niches), as in the case of establishing aquatic species of *Ranunculus* under a separate genus *Batrachium*.
3. There is no size requirement for a genus. It may include a single species (**monotypic genus**) as *Leitneria, Ginkgo, Milula* or many (**Polytypic genus**): *Euphorbia* (2100 species), *Astragalus* (2000) *Carex* (1800), *Senecio* (1500) and *Acacia* (1300) being the examples of large genera. The genus *Senecio* was earlier included more than 2500 species, but it has now been split into several genera. The only important criterion is that there should be a decided gap between the species of two genera. If the two genera are not readily separable, then they can be merged into one and distinguished as subgenera or sections. Such an exercise should take into consideration the concept in other genera of the family, size of the genus (it is more convenient to have subgenera and sections in a larger genus) and traditional usage.
4. When generic limits are being drawn, it is absolutely necessary that the group of species should be studied throughout the range distribution of the group, because characters stable in one region may break down elsewhere.

FAMILY

A **family,** similarly, represents a group of closely-related genera. Like genus, it is also a very ancient concept because the natural groups now known as families, such as legumes, crucifers, umbels, grasses have been recognized by laymen and taxonomists alike for centuries. Ideally, families should be monophyletic groups. Like the genus, the family may represent a single genus (Podophyllaceae, Hypecoaceae, etc.) or several genera (Asteraceae: nearly 1100). Most taxonomists favour broadly-conceived family concepts that lend stability to classification. Although there is no marked discontinuity between Lamiaceae (Labiatae) and Verbenaceae, the two are maintained as distinct families. The same tradition prevents taxonomists from splitting Rosaceae, which exhibits considerable internal differences.

System of Plant Classification: 3 Types

The following points highlight the top three types of system of plant classification. The types are: 1. Artificial Classification 2. Natural Classification 3. Phylogenetic Classification.

Artificial Classification:

The earliest systems of classification which remained dominant from 300 B.C. up to about 1830 were artificial systems, which were based on one or a few easily observable characters of plants, such as habit (trees, shrubs, herbs, etc.) or floral characters (particularly the number of stamens and carpels). Such types of classification using some arbitrary or at least easily observable characters, often irrespective of their affinity, is called artificial. The sexual system of Linnaeus is a good example of artificial classification, which uses only one attribute i.e. the number of stamens for grouping plants into 24 Classes as a result of which, various unrelated taxa, which are not at all related but, similar in one respect only, have been placed under the same Class.

Natural Classification:

These systems of classifications are based upon overall resemblances, mostly in gross morphology, thus, utilizing as many taxonomic characters as possible, to group taxa. Charles Darwin’s proposed theory of evolution (1859) postulates that, the present day plants have descended from those existing in the ancient past, through a series of modifications in response to changing environmental conditions, which means that all present day plants are related to each other in one way or another. Thus, the closely related plants should naturally be grouped together. This is called natural classification. Thus, larger the number of characters shared by different taxa, the more closely related they are to each other. This is the basis of modern classification.

Phylogenetic Classification:

The classification systems proposed after Darwin’s theory are mostly phylogenetic i.e. they use as many taxonomic characters as possible in addition to the phylogenetic (evolutionary) interpretations. These are expressed in the form of phylogenetic trees or shrubs showing presumed evolution of the groups. The natural systems are two-dimensional i.e. based on the data available at any time and is known as Horizontal Classification, whereas the addition of the third dimension i.e. past history or ancestral history results in phylogenetic classification also known as Vertical Classification or Evolutionary Classification.

Bentham and Hooker’s Classification:

The most important and the last of the natural systems of classification of seed plants was proposed by two British taxonomists George Bentham (1800-1884), a self trained botanist, and Joseph Dalton Hooker (1817-1911), the first director of the Royal Botanical Garden, Kew (England). They recorded precise description of most of the plants known at that time. Their monumental work which took about quarter of a century for completion was described in three volumes of Genera Plantarum, published in Latin during July 1862 and April 1883. Bentham and Hooker’s system of classification is still used and followed in several herbaria of the world. It is supposed to be the best system for the students to identify plants in the laboratory.

Salient Features of Bentham and Hooker's system:

1. It is a classification of only the "seed plants" or phanerogams.

2. They described 97,205 species of seed plants belonging to 7,569 genera of202 families starting from Ranunculaceae up to Gramineae.

3. They classified all the seed plants into 3 groups or classes i.e. Dicotyledons (165 families), gymnosperms (3 families) and monocotyledons (34 families).

4. They included disputed orders among Ordines Anomali which they could not place satisfactorily.

5. Monocotyledons were described after the dicotyledones.

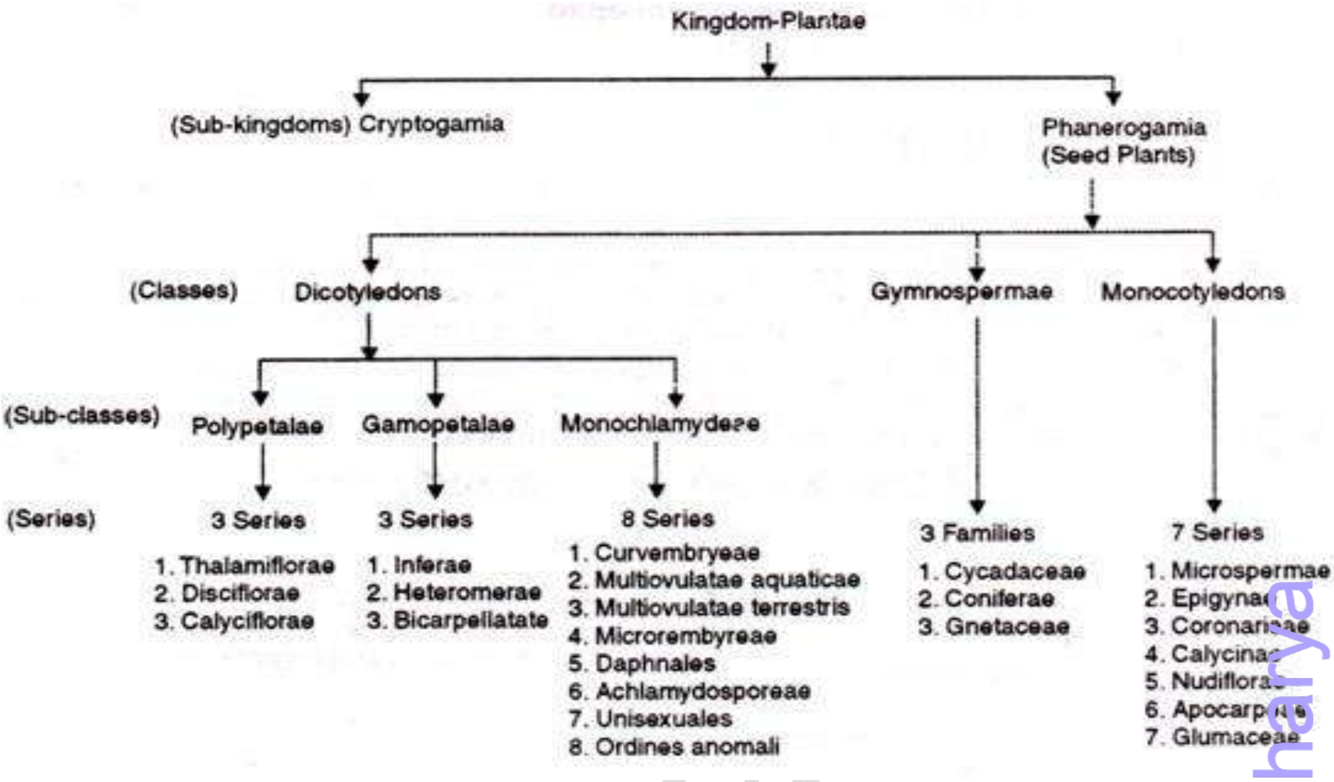
6. The dicotyledons were divided into 3 Divisions (Polypetalae, Gamopetalae and Monochlamydeae) and 14 series. Each series again divided into cohorts (modern orders) and cohorts into orders (modern families).

7. The authors did not mention anything about the origin of the angiosperms.

8. Creation of the Disciflorae, a taxon not described by the earlier taxonomists.

9. Among the Monochlamydeae, major taxa, like the series, were divided on the basis of terrestrial and aquatic habits.

10. Polypetalae carries 82 families, 2610 genera & 31,874 species. Gamopetalae carries 45 families 2619 genera & 34,556 species. Monochlamydae includes 36 families, 801 genera & 11,784 species. Similarly Monocotyledons consist 34 families, 1495 genera and 18,576 species.



Merits of Bentham and Hooker's System:

1. Each plant has been described either from the actual specimen or preserved herbarium sheets so that the descriptions are detailed as well as quite accurate.

2. The system is highly practical and is useful to students of systematic botany for easy identification of species.

3. The flora describes geographical distribution of species and genera.

4. The generic descriptions are complete, accurate and based on direct observations.

5. Larger genera have been divided into sub genera, each with specific number of species.

6. Dicots begin with the order Ranales which are now universally considered as to be the most primitive angiosperms.

7. Placing of monocots after the dicot is again a natural one and according to evolutionary trends.

8. The placing of series disciflorae in between thalami florae and calyciflorae is quite natural.

9. The placing of gamopetalae after polypetalae is justified since union of petalsis considered to be an advanced feature over the free condition.

Demerits of Bentham and Hooker's System:

1. Keeping gymnosperms in between dicots and monocots is anomalous.

2. Subclass monochlamydeae is quite artificial.

3. Placing of monochlamydeae after gamopetalae does not seem to be natural.

4. Some of the closely related species are placed distantly while distant species are placed close to each other.

5. Certain families of monochlamydeae are closely related to families in polypetalae, e.g. Chenopodiaceae and Caryophyllaceae.

6. Advanced families, such as Orchiadaceae have been considered primitive in this system by placing them in the beginning. Placing of Orchidaceae in the beginning of monocotyledons is unnatural as it is one of the most advanced families of monocots. Similarly, Compositae (Asteraceae) has been placed near the beginning of gamopetalae which is quite unnatural.

7. Liliaceae and Amaryllidaceae were kept apart merely on the basis of characters of ovary though they are very closely related.

8. There were no phylogenetic considerations.

Cronquist's System of Classification (1981):

Arthur Cronquist was the Senior Curator of New York Botanic Garden and Adjunct Professor of Columbia University. He presented an elaborate interpretation of his concept of classification in "The Evolution and Classification of Flowering Plants"(1968). The further edition of his classification was published in "An Integrated System of Classification of Flowering Plants" (1981). The latest revision was published in the 2nd edition in 1988 in "The Evolution and Classification of Flowering Plants". He discussed a wide range of characteristics important to phylogenetic system. He also provided synoptic keys designed to bring the taxa in an appropriate alignment. He also represented his classification in charts to show the relationships of the orders within the various subclasses. His system is more or less parallel to Takhtajan's system, but differs in details. He considered that the Pteridosperms i.e., the seed ferns as probable ancestors of angiosperm.

The following principles were adopted by Cronquist (1981) to classify the flowering plants:

1. The earliest angiosperms were shrubs rather than trees.

2. The simple leaf is primitive than compound leaf.

3. Reticulate venation is primitive than parallel venation.

4. Paracytic stomata is primitive than the other types.

5. Slender, elongated, long tracheids with numerous scalariform pits are primitive. Further specialisation leads to shorter broad vessels with somewhat thinner walls and transverse end walls with few larger perforations. Later on, the perforation becomes single and large.

6. Long and slender sieve elements with very oblique end walls where the sieve areas scattered along the longitudinal wall with groups of minute pores are primitive. Whereas, the phloem with short sieve tube elements where end walls having a single transverse sieve plate with large openings is a derived condition.

7. The area and activity of cambium and also the length of fusiform initial is more in primitive form which gradually becomes reduced in advanced one.

8. Plants with vascular bundles arranged in a ring are primitive rather than scattered vascular bundle as found in monocots.

9. Plants with large and terminal flowers are primitive, those may arrange in monochasia or dichasia and the other type of inflorescences have been derived from these types.

10. Flowers with many large, free and spirally arranged petals; many linear and spirally arranged stamens and free carpels as found in Magnoliaceae are primitive, and other types got evolved through gradual reduction, aggregation, elaboration and differentiation of floral members.

11. Plants with unisexual flowers are evolved from bisexual floral ancestors.

12. The large and indefinite number of floral members are primitive than the small and definite numbers.

13. Androecium with many stamens is primitive than the reduced numbers.

14. Linear stamens with embedded pollen sacs as found in some Magnolian genera are considered more primitive than the others.

15. Uniaperturate pollen grains are considered as primitive and the triaperturate type are derived from it.

16. Insect pollinated plants are considered as primitive from which wind pollinated plants got evolved.

17. The gynoecium comprising of many carpels arranged spirally on a more or less elongated receptacle is considered as primitive. Further evolution leads to the reduction of the number of carpels which are arranged in a single whorl and then undergo further fusion.

18. Axial placentation is primitive from which other types have been evolved.

19. Anatropous ovule is primitive from which other types have been evolved.

20. Ovule with two integuments (bitegmic) is primitive and, either by fusion or abortion, unitegmic condition has been evolved.

21. Embryo-sac with 8-nuclei (Polygonum-type) is primitive from which embryo-sac with 4-nuclei (Oenothera-type) has been derived through reduction.

22. Monocotyledons have been developed from dicotyledons through abortion of one cotyledon.

23. The follicle (fruit) is considered as primitive. Further, dry and dehiscent fruit is more primitive than fleshy and indehiscent fruit.

According to him **"many of the evolutionary trends bear little apparent relation to survival value and that there are some reversals"**.

In 1981, he divided the Division Magnoliophyta (Angiosperms) into two classes Magnoliatae (Dicotyledons) and Liliatae (Monocotyledons). He divided Magnoliatae into 6 subclasses and 55 orders, of which magnoliales is the primitive and Asterales is the advanced taxa.

On the other hand, the class Liliatae has been divided into 4 subclasses and 18 orders, of which Alismatales is the primitive and Orchidales is the advanced taxa. The class Magnoliatae consists of 291 families and Liliatae with 61 families.

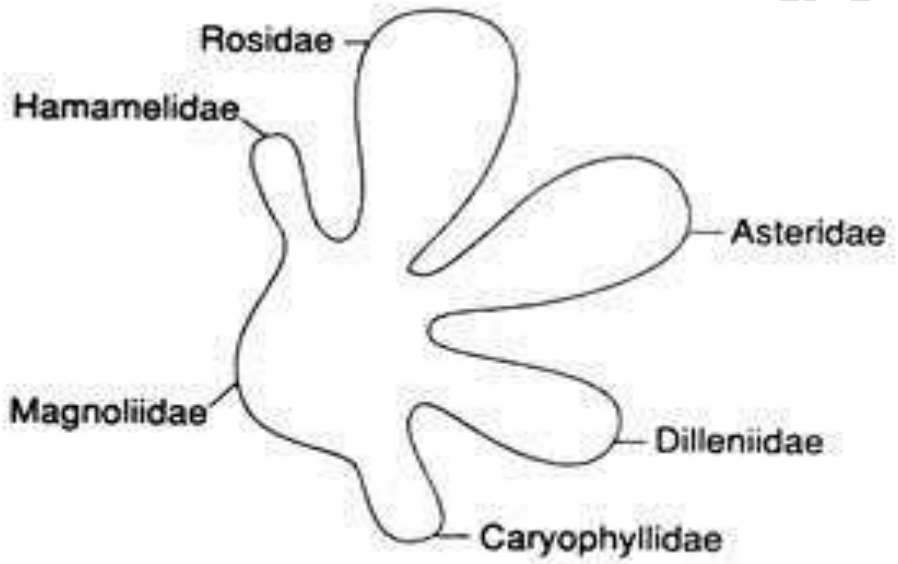


Fig. 4.24 : Probable relationship among subclasses of Magnoliopsida (Dicots). Sizes of balloons are proportional to the number of species under each subclass (Cronquist, 1988)

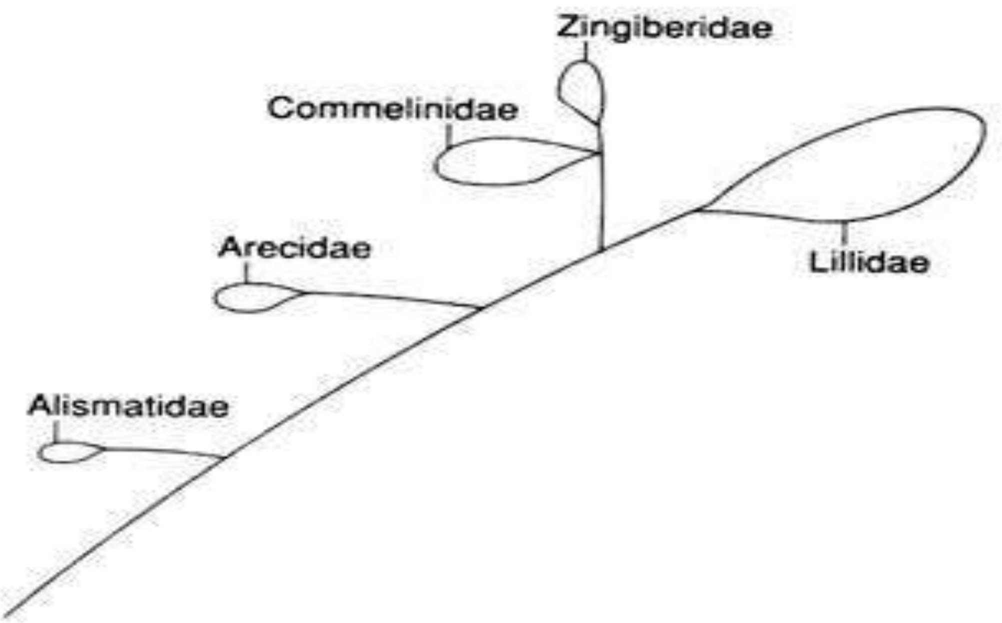


Fig. 4.25 : Probable relationship among subclasses of Liliopsida (Monocots). Sizes of balloons are proportional to the number of species under each subclass (Cronquist, 1988)

Merits:

1. There is general agreement of Cronquist's system with that of other contemporary systems like Takhtajan, Dahlgren and Thorne.

2. Detailed information on anatomy, ultra- structure phytochemistry and chromosome — besides morphology — was presented in the revision of the classification in 1981 and 1988.

3. The system is highly phylogenetic.

4. Nomenclature is in accordance with the ICBN.

5. The family Asteraceae in Dicotyledons and Orchidaceae in Monocotyledons are generally regarded as advanced and are rightly placed towards the end of respective groups.

6. The relationships of different groups have been described with diagrams which provide valuable information on relative advancement and size of the various subclasses.

7. The family Winteraceae (vessel-less wood present similar to Pteridosperms) placed at the beginning of dicotyledons is favoured by many authors.

8. The subclass Magnoliidae is considered as the most primitive group of Dicotyledons. The placement of Dicotyledons before Monocotyledons finds general agreements with modern authors.

Demerits:

1. Though highly phylogenetic and popular in U.S.A., this system is not very useful for identification and adoption in Herbaria since Indented keys for genera are not provided.

2. Dahlgren (1983, 89) and Thorne (1980, 83) treated angiosperms in the rank of a class and not that of a division.

3. Superorder as a rank above order has not been recognised here, though it is present in other contemporary classifications like Takhtajan, Thorne and Dahlgren.

4. The subclass Asteridae represents a loose assemblage of several diverse sympetalous families.

5. Ehrendorfer (1983) pointed out that the subclass Hamamelidae does not represent an ancient side branch of the subclass Magnoliidae, but is remnant of a transition from Magnoliidae to Dilleniidae, Rosidae, and Asteridae.

6. There is a difference in opinion with other authors regarding the systematic position of some orders like Typhales, Arales, Urticales etc.

TAXONOMIC EVIDENCES FROM PALYNOLOGY, CYTOLOGY, PHYTOCHEMISTRY AND MOLECULAR DATA

Palynology in Relation to Taxonomy:

Palynology is the science, which deals with Pollen grains. The term is derived from Greek verb Palynein means to scatter. Pollen grains are often easily disseminated by wind etc., Pollen grains are found in every nook and corner, e.g., in glacier ice, in the air over the poles and over the oceans. Fossil spores are found in peat and other sediments, in lignite, coal and shales. They are evident since Pre-Cambrian times hundreds of millions of years ago. Pollen grains morphology plays an important role in classification. Pollen grains may be vesiculate (with air sacs); saccate or non saccate, fenestrate or non-fenestrate, colpate (furrows or colpi present) or porate (apertures present at the poles). According to position of apertures six subdivisions are made e.g., ceta (down, inwards in a tetrad), ann (up; outwards in a tetrad), zone is the zonal position i.e., at the equator, and panto is uniform distribution all over the spore surface.

Basic evidentiary characters:

(i) Pollen unit type,

(ii) Pollen grain polarity,

(iii) Pollen grain shape,

(iv) Pollen grain symmetry,

(v) Pollen grains nuclear state,

(vi) Pollen wall architecture,

(vii) Exine stratification,

(viii) Exine structure,

(ix) Exine sculpture,

(x) Aperture type,

(xi) Aperture number,

(xii) Aperture position,

(xiii) Aperture shape, and

(xiv) Aperture structure.

In Magnoliidae the pollen is binucleate.

In Caryophyllidae the pollen is trinucleate.

In Ericaceae the pollen is in tetrads.

In Asclepiadaceae pollen remain in Pollinia.

In Taraxaccurn the pollen wall is echinate.

In Quercus the pollen wall is scabrate.

Pollen grains of Linaceae and Plumbaginaceae (Plumbagineae-Aegtality) are approximately of same type. The similarity in pollen morphology between Linaceae at Plumbagineae is greater than that of Plumbaigineae and Staliceae. In Plumbagineae the pollen grains are zonotreme (3—colpate) or pantotreme (e.g., Linum heterosepalum); Pantotrenre is found in Plumbagella micrantha. The evolution is traced from arboreces Linaceae to the Plumbagineae and to herbaceous Staliceae. Napenthaceae and Droseraceae (except Drosophyllum) have spinuliferous pollen tetrads. Such type of pollen tetrads are not found in any other plant. Relationship between Polygalaceae and Ephedraceae are based on similarity between their pollen grains. In Phytolaccaceae the pollen of Phytolacca is 3-zonocolpate, whereas that of Rivinia is Pantocolpate. Seven genera of Polygpnaceae i.e., Koenigia, Persicaria, Polygonum, Pleuropteropyrum, Bistoria, Tiniaria and Fagopyrum are different in their Pollen morphology. In family Salicaceae Salix has long narrowed 3-furrowed pollen, Populus has spherical pollen without apertures. At specific level in Anemori A. obtusifolia the pollen grains are 3-zonocolpate, A. rivularis is pantocolpate, A. alchemillaefoliath, is pantoporate, and A. fulgen is spiraperturate. Podophyllum is separated from Berberidaceae as it has united pollen grains. Some families are recognized on the basis of pollen sculpture e.g., Malvacae and Asteraceae has spinuous exine; Plumbaginacae has verrucate exine and Poaceae has smooth sulcate exine of pollen grain. On the basis of Palynological characters Fumariaceae is separated from Papaveraceae and Nelumbonaceae from Nymphaeaceae. Hutchinson kept Araceae and Lemnaceae under Arales. However, Arecaceae has sculptured exine and Lemnaceae has spinous exine in Pollen grains. Malvacae and Bombacaceae are separated on the basis of palynological studies where Malvaceae shows spinose exine and Bombacacee shows reticulate exine in Pollen grains. Depending upon palynological studies two distinct phylogenetic stocks in the dicots have been suggested. One represented by Magnoliaceae with monocolpate type and the other represented by Ranunculaceae with tricolpate type of pollen grains. Monocots are considered to be closely related to magnolian stock on the basis of Monocolpate element. The Magnolian dicots are considered to be ancient palynologically as compared to Ranalian dicots where new apertural forms are present (monocolpate totally absent). Kuprianova (1948) suggested that most of the monocots are evolved from Arecaceae or Liliaceae. Helobiae are not related to other monocots but are specialized polycarpous with ranalian affinities.

Cytology in Relation to Taxonomy:

Cytology is the study of the morphology and physiology of cells. Normally anatomists deal with shapes, size, wall structure, pattern, etc. but cytologists deal with the internal organelles of the cell and detailed structure of cell wall.

Some evidential characters are:

(i) Chromosome number, structure, type,

(ii) Chromosome meiotic behaviour,

(iii) Ploidy level and type, and

(iv) Chromosome aberration etc.

Cytological evidences is used for distinguishing taxa; to determine the origin of groups and to understand the evolutionary history of related taxa particularly those at the infraspecific and specific levels cytotaxonomy is a part of experimental taxonomy. Such studies are helpful in determining the categories of genus, species etc. generally in cases of controversy. The study of homologies of the chromosome in the hybrids as determined in meiosis, is significant indicator in knowing the degree of genetic relationship. Hutchinson separated Pandanus, Typha and Sporgonium on the basis of chromosome morphology and kept them under two different orders Pandanales and Typhales. Darlington and Janki Animal (1945), Darlington and Wylie (1955), Love (1977) etc., worked a lot on the chromosome number of various plants. International Association of Plant Taxonomy (IAPT) published on Index to Plant chromosome number in series of Ragnum vegetabile (1967- 77) in 9 volumes. Diploid numbers are indicated as 2n and haploid as n. The gametophytic chromosome number of diploid species is designated as base number (x). In diploids n = x, in polyploids n is multiple of x. e.g., in hexaploid sp 2n = 6x and n = 3x as 2n = 24 and n = 21. Angiosperm, the chromosome number varies greatly e.g., n = 2 in Haplopappus gracilis (Asteraceae) and highest is n = 132 in Poa litloroa (Poaceae). According to Raven (1975) the original base number for angiosperm is x = 7. In Ranunculaceae, it is generally x = 8. Thallictrum and Aquilegia have x = 7. They have been placed in separate tribes. Hutchinson placed them in two families Ranunculaceae and Helleboraceae based bearing and follicle bearing fruits. Paeonia with x = 5 is placed in Paeoniaceae. According to Radford (1988) n = 8 in Delphinium ajacis and n = 16 in D. carolinianum. In Poaceae the subfamily Poideae has x = 7 and Bambusoideae has x = 12. Ploidy level also plays a significant role in taxonomy e.g., Triticum contains diploid (2n = 14), Triploid (2n = 21) and Hexaploid (2n = 42) etc., Senecio (Asteraceae) includes S. squalidus (2n = 20) a diploid, S. vulgaris (2n = 40) a tetraploid and S. combrensis (2n = 60) a hexaploid. According to Stace (1989) S. Combrensis is an allohexaploid between other two species. Due to different karyo type of Butomus from that of Limnocharis, Hydrocharis, Tenagocharis, it is kept in Butomaceae while others are retained in Alismataceae. Chromosomes show variation in size, position of centromere and secondary construction etc. The structure of genome (chromosome set) in a species is called Karyotype and its diagrammatic representation as Idiogram. Cyperaceae and Juncaceae are separated due to distinct floral structure. They have holocentric chromosomes and now considered closely related. The karyotype study of members of Agavaceae confirms the shifting of Agave from Amaryllidaceae (inferior ovary) and Yucca from Liliaceae (superior ovary) into Agavaceae. The members of Agavaceae have two type of Karyotypes consisting of 5 large and 25 small chromosomes. Meiotic behaviour of chromosomes is helpful in comparing the genomes to detect degree of homology e.g., Triticum aestivum is haxaploid (A A B B D D)where 'A' is derived from T. monococcum (diploid) and 'B' from Aegilops speltoides and D is derived from Aegilops squarrosa (diploid). 2N = 26 is the characteristic of Amborellaceae; 2N = 16 of Trimeniaceae, Babcock (1947) separated the closely related genera on the basis of chromosomal number and morphology. Youngia is separated from Crepsis while Pterotheca was merged with Crepis. Tragopogon mirus is tetraploid species as on amphiploid two diploid species T. doubius and T. porrifolius. The populations or infraspecific taxa showing different chromosomes number or morphology are taken as Cytotypes. Rudall (1997) suggested transfer of Hosta (Hostaceae) Camassia and Chlorogatum (Liliaceae), to family Agavaceae on the basis of bimodal karyotype. Judd 2002 and Thorne (2003) also supported the statement.

Phytochemistry in Relation to Taxonomy:

The science of chemical taxonomy is based on classification of Plants on the basis of their chemical constituents related with the molecular characteristics.

Chemotaxonomy includes:

(i) Investigation of pattern of the compounds existing in plants,

(ii) Investigation pattern of the compounds in plant parts likes bark, wood, leaves, roots etc.

Basic characters as evidence come from:

(i) Flavonoids,

(ii) Terpenoids,

(iii) Carotenoids,

(iv) Polysaccharides,

(v) Alkaloids,

(vi) Aminoacids,

(vii) Fattyacids,

(viii) Aromatic compounds, and

(ix) C_3-C_4 photosynthesis etc.

Development of plant natural product chemistry revealed possibility of characterizing classifying, and establishing phyletic relationships of genera, in (1999) it was first indicated correlating between chemical properties and morphologically character i.e., morphologically similar plants possess similar chemicals.

Popularity of Phytochemistry is due to:

(a) Development of rapid analytical techniques.

(b) Belief that data from many sources should be employed for classification.

Classification on the basis of Mol. wt.
- → Micromolecules (mol. wt. less than 1000) (AA, Alk, Phenol, Terpenes)
- → Macromolecules (mol. wt. more than 1000) Protein, Nucleic acids etc.

Mentzar (1966) provided biogenetic classification on the basis of natural relationships between various constituents.

Micromolecules:

(a) Primary metabolites (Organic acid, Amino acid, Sugar, Chlorophyll) present in each plant

(b) Secondary metabolites (Alkaloids, Terpenoids, phenols, Specific Glucosids etc.,) present in plants.

Macromolecules:

Chemicals for various functions Semantides (DNA, RNA, Protein etc.) Non- semantides (Starch, cellulose etc.)

Primary metabolites:

(i) These are compounds present in vital metabolic pathways.

(ii) They are universal in distribution.

(iii) They are of little taxonomic value.

Among the Amino acids the distribution of single amino acids restricted e.g., Lathyrus martinus has protein which is absent in other species of Lathyrus.

Lipids:

Members of Asteraceae lack unsaturated lipids. Lipids are heterogenous group present in storage organs. It depletes in dark.

(1) Linolenic rich seeds e.g., Rhamnaceae.

(2) Linoleic rich seeds e.g., Juglans, Liliac etc. Oleic and Palmitic rich e.g., Acanthaceae, Annonaceae, Malvaceae etc.

Pigments:

Chlorophyll and carotenoids are fat soluble Biloproteins and Anthocyanins are soluble in water. Anthocyanins and Betalins never coexist. Betalins are low molecular weight substances. Betacyanin gives purple colour and Betaxanthin gives yellow colour. Phytochemistry can supply data of use to the taxonomists. It is mainly based on the supposition that related plants will have a similar chemistry e.g., in Pinus every species has different type of terpentine. In Lichen chemical methods are largely used for the identification of genera and species.

The DNA based molecular markers are applied in various aspects of taxonomy to analyse:

(i) Genetic identity.

(ii) Genetic relatedness among populations, geographic populations and species.

(iii) Pedigree.

(iv) Differentiation among isolated species.

(v) Phylogenetic structure at various micro and macro levels.

A number of molecular parameters are useful in carrying out phylogenetic and systematic studies. Of the various molecular approaches the PCR based technology offers maximum potential for genetic analysis, phylogenetics and systematics. Taxonomists have realized power of MAAP markers is recording taxonomic ambiguities.

Plant herbaria world over started incorporating the DNA profile of the specimens with increasing use of computers and micro-processors analysis of PCR products, documentation and archival of data sophistication in instrumentation is started for future analysis of genetic system.

Use of automated tissue processors for isolation of DNA, robotic sample handling and transfer systems for further treatment of the DNA and for automation of PCR, use of different fluorochromes labeled primers in conjunction with advanced gel electrophoresis systems for carrying out multiplex PCRs in a single tube, advanced imaging technology which permits efficient data analysis etc., are the integral part of laboratory engaged in molecular taxonomy.

Mitochondrial DNA is studied in many plants. Each mitochondrian contains several copies of mt DNA and each cell contains many mitochondria. Generally mt DNA is circular but is linear in Chlamydomonas reinhardtii mt DNA is larger circular with many non-coding sequences in vascular plants.

Chloroplast DNA: cp DNA can be easily isolated and analysed. The DNA of chloroplast is highly conserved type. The cp DNA circular molecule with 2 regions in opposite direction encoding same genes are called inverted repeats. Between inverted repeats single copy regions are present. The important gene in mitochondria is MatK gene.

In all cp DNA same set of genome are found but arranged differently in different species. The genes present in cp DNA include genes for r-RNA, t-RNA, ribosomal proteins and about 100 different polypeptides and subunits of enzyme coupling CO_2. The important gene on cp DNA is rbcL encoding large subunit of photosynthetic enzyme i.e., RUBISCO. This gene is not found in parasites. It is a long gene consisting of 142 bp.

NUMERICAL TAXONOMY AND CLADISTICS

Numerical taxonomy or taximetrics, nowadays frequently and perhaps more appropriately referred to as phenetics, refers to the application of various mathematical procedures to numerically encoded character state data for organisms under study. Thus, it is the analysis of various types of taxonomic data by mathematical or computerized methods and numerical evaluation of the similarities or affinities between taxonomic units, which are then arranged into taxa on the basis of their affinities. According to Heywood the numerical taxonomy may be defined as the numerical evaluation of the similarity between groups of organisms and the ordering of these groups into higher ranking taxa on the basis of these similarities. The period from 1957 to 1961 saw the development of first methods and of theory of numerical taxonomy. Plants as we all know are classified based on their characters. It was Michel Adanson, a French botanist, who for the first time put forward a plan for assigning numerical values to the similarity between organisms and proposed that equal weightage should be given to all the characters while classifying plants. He used as many characters as possible for the classification, and such classifications came to be known as Adansonian classifications. Numerical taxonomy was however largely developed and popularized by Sneath and Sokal. The application of Adansonian principles and use of modern methods and electronic data-processing techniques, have helped in the evolution of several new classifications of plants during the past few decades.

Principles of Numerical Taxonomy:

Numerical taxonomy involves two aspects:

(a) Construction of Taxonomic Groups:

i. In numerical taxonomy, first, individuals are selected and their characters spotted out. There is no limitation to the number of characters to be considered. However, the larger the number of characters, better is the approach for generalization of the taxa.

ii. The resemblances among the individuals are then established on the basis of character analysis, which can often be worked out with the help of computers, the accuracy of which depends on the appropriateness in character. The best way to delimitate taxa is, to utilize maximum number of characters, with similar weightage given to all of them.

(b) Discrimination of the Taxonomic Groups:

When the taxonomic groups chosen for the study show overlapping of characters, discrimination should be used to select them. Discrimination analysis can be done by various techniques, specially devised for such purposes. Numerical taxonomy is thus, based on certain principles, also called neo Adansonian principles.

Following seven principles of numerical taxonomy have been enumerated by Sneath and Sokal:

(i) The greater the content of information in the taxa, and more the characters taken into consideration, the better a given classification system will be.

(ii) Every character should be given equal weightage in creating new taxa.

(iii) The overall similarity between any two entities is a function of the individual similarities in each of the many characters, which are considered for comparison.

(iv) Correlation of characters differ in the groups of organisms under study. Thus distinct taxa can be recognized.

(v) Phylogenetic conclusions can be drawn from the taxonomic structure of a group and from character correlations, assuming some evolutionary mechanisms and pathways.

(vi) The science of taxonomy is viewed and practiced as an empirical science.

(vii) Phenetic similarity is the base of classifications.

Merits of Numerical Taxonomy:

According to Sokal and Sneath, numerical taxonomy has the following advantages over conventional taxonomy:

a. The data of conventional taxonomy is improved by numerical taxonomy as it utilizes better and more number of described characters. The data are collected from a variety of sources, such as morphology, chemistry, physiology, palynology, cytology, molecular biology, etc.

b. As numerical methods are more sensitive in delimiting taxa, the data obtained can be efficiently used in the construction of better keys and classification systems, creation of maps, descriptions, catalogues, etc. with the help of electronic data processing systems. Numerical taxonomy has in fact suggested several fundamental changes in the conventional classification systems.

c. The number of existing biological concepts have been reinterpreted in the light of numerical taxonomy.

d. Numerical taxonomy allows more taxonomic work to be done by less highly skilled workers.

Demerits of Numerical Taxonomy:

Numerical taxonomy can however prove to be disadvantageous from the following points of view:

a. The numerical methods are useful in phenetic classifications and not phylogenetic classifications.

b. The proponents of "**biological**" species concept, may not accept the specific limits bound by these methods.

c. Character selection is the greatest disadvantage in this approach. If characters chosen for comparison are inadequate, the statistical methods may give less satisfactory solution.

d. According to Steam, different taxonometric procedures may yield different results. A major difficulty is to choose a procedure for the purpose and the number of characters needed in order to obtain satisfactory results by these mechanical aids. It is necessary to ascertain whether a large number of characters would really give satisfactory results than those using a smaller number.

Application of Numerical Taxonomy:

Numerical taxonomy has been successfully applied in the following studies:

a. Study of similarities and differences in bacteria, other micro-organisms and several plants and animal groups.

b. Delimitation of several angiospermic genera like Oryza, Sarcostemma Solarium, and other groups including Farinosae of Engler and a few others.

c. In the study of several other angiospermic genera including Apocynum, Chenopodium, Crotalaria, Cucurbita, Oenothera, Salix, Zinnia, wheat cultivars, Maize cultivars, etc.

d. Phytochemical data from seed protein and mitochondrial DNA RFLP studies has been numerically analyzed by Mondal et al. to study the interspecitic variations among eight species of cassia L .Based on the results of electrophoretic patterns, the degree of pairing affinity (PA) or similarity index was calculated by the following formula, according to the method of Sokal & Sneath and Romero Lopes et al.:

$$PA = \frac{\text{Bands common to species A and B}}{\text{Total bands in A and B}} \times 100$$

Separate dendograms expressing the average linkage were computed using the cluster method UPGMA, which showed that the eight species could be placed into two categories or clusters (Fig. 9.6) with C. alata, C siamea, C. fistula and C. reginera, all being trees or large shrubs and characterized by the absence of foliar glands on petiole or rachis and presence of dense axillary terminal racemes greater than 30 cm long, being clustered into one group, whereas the other four species, i.e., C. occidentalis, C. sophera, C. mimosoides and C. tora, forming the other cluster, all being herbs or undershrubs and characterized by the presence of short corymbose racemes less than 10 cm long and with foliar glands, either on petiole or rachis.

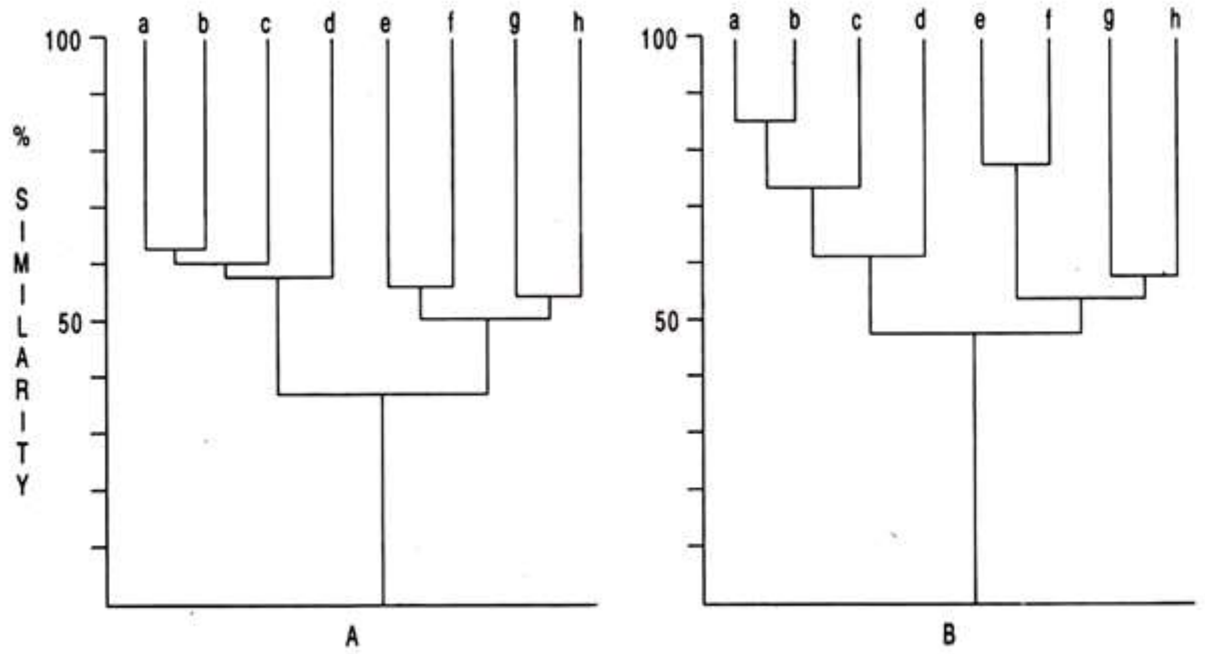


Fig. 9.6 : Dendogram representing the 'average linkage' relationship among the eight species of *Cassia* shown by (A) seed protein electrophoresis and (B) mtDNA restriction fragments (a) *C. occidentalis,* (b) *C. sophera,* (c) *C. mimosoides,* (d) *C. tora,* (e) *C. alata,* (f) *C. siamea,* (g) *C. fistula,* (h) *C. renigera.*