

**SHRI CHHATRAPATI SHIVAJI COLLEGE, OMERGA**

# **Taxonomy of Angiosperms**

Notes for B. Sc. II (Botany) Paper VII)

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**B. Sc. II, Semester III, Paper -VII**

**Taxonomy of Angiosperms**

Unit :1

1. Salient features, origin and evolution of Angiosperms
2. Bentham and Hooker's system of classification upto series level, its merits and demerits
3. Taxonomy in relation to anatomy, embryology, palynology, ecology and cytology
4. Concept of Binomial Nomenclature and its advantages
5. Concept of genus, species and epithet.
6. Herbaria and Botanical Gardens.

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## Taxonomy of Angiosperms

### Salient Features of Angiosperms

Angiosperms form the most dominant group of plants with at least 2,34,000 species (Thorne, 1992), a number much greater than all other groups of plants combined together. Not only in numbers, Angiosperms also found in a far greater range of habitats than any other group of land plants.

The pollen grains and ovules are produced in flowers and they produce seeds that are encased by an outer layer called a fruit are two main features of the angiosperms.

Through their color, smell and edible nectar, flowers attract insects and animals that unwittingly carry pollen between flowers to achieve pollination; this is much more efficient than merely releasing pollen into the wind. Likewise, fruits may also help recruit animal, this time to help disperse the seeds. Reproduction in flowering plants will be examined in more detail in a separate lab exercise.

### Wood Structure

Woody trees are found in the gymnosperms and in the angiosperms. Most commonly, the bulk of a tree trunk is made up of a central region of xylem tissue; the phloem tissue consists only of a small ring just below the bark. Each ring of the wood represents the xylem growth that occurred during one growing season (thus the name “annual ring”). During each growing season, the cells initially produced are large-bored and thin-walled (“early wood”), but later in the season the cells become small-bored and thick-walled (“late wood”).

Some trees are said to have hard wood and others soft wood. Hard wood trees are prized for their strength, beauty of the ring structure, and also as firewood since they burn more slowly and give off more heat. The difference lies in the formation by some trees of special cells called “vessels”. Vessel cells are much bigger in diameter than the normal “tracheid” cells of the xylem, and have highly reinforced cell walls – which are what makes the wood much harder.

Following are the salient features of the Angiosperms-

- The sporophyte, which is the dominant plant in the life cycle, is differentiated into roots stem and leaves.
- The highest degree of perfection of the vascular system with true vessels in the xylem and companion cells in the phloem.
- The organisation of the microsporophylls (Stamen) and megasporophylls (carpels) into a structure called flower, which is typical only of the angiosperms.
- The presence of four microsporangia [pollen sacs] per microsporophyll [stamen].
- The ovule sacs are always enclosed in an ovary, which is the basal region of Megasporophylls.
- Production of two kinds of spores, microspores [pollen grains] and megaspores. Angiosperms thus are heterosporous.

- Presence of a single functional megaspore which is permanently retained within the nucellus or megasporangium.
- Adaptation of flowers to insect pollination.
- Pollination consists of the transference of pollen grains from anther to stigma. Spore dimorphism having resulted in the production of gametophytes, male and female.
- Extreme reduction in size, duration of existence and complexity of the Gametophytes, which are extremely parasitic.
- The male gametophyte has reached the limits of reduction. It consists only of the pollen grain and the pollen tube contains the tube nucleus and two male gametes or nuclei. The male cells (gametes) are non-ciliated.
- The female gametophyte lacks any extensive development of vegetative tissues. It consists of three egg apparatus cells, three antipodal cells and two polar nuclei in the center of the embryo sac.
- The non-motile male cells or nuclei are carried bodily to the neighborhood of egg apparatus by the pollen tube.

The identity of the ancestors of the flowering plants is a most difficult problem which is as yet far from being solved. Several groups of plants have been considered as ancestral stock for angiosperms.

### ***Bennettlean ancestry***

Since Saporta (Saporta and Marion, 1885) Bennettiales have often been proposed as possible ancestors of angiosperms, and in this connection the resemblance in structure between the strobili of the Mesozoic genus *Cycadeodea* and the flower of *Magnolia* has often been pointed out. But this resemblance is wholly superficial, they are alike only in that both are bisexual and both consist of an elongated axis on which are arranged successively and in the same order, protective bracts (perianth members in *Magnolia*), microsporophylls and megasporophylls. But along with these few similarities there are profound differences. The microsporophylls (stamens) of *Magnolia* (as in other primitive angiosperms) are free and arranged spirally on the axis, but in Bennettiales they are whorled and mostly connate. The megasporophylls of the Bennettiales are very reduced, simplified stalk-like structures, sometimes very abbreviated, each bearing at its apex a solitary erect ovule. Between these stalk-like megasporophylls and alternating with them, are sterile organs (interseminal scales) which appear to be modified sterilized megasporophylls. These sterile scales, with their tightly packed expanded apices, form a kind of protective armour round the ovules. Protection of the ovules is achieved, therefore, in a very different way from that found in the angiosperms. Another special feature of the Bennettiales is the presence in the ovule of a distinct micropylar tube, formed by the integument and serving for the reception of the microspores. In angiosperms there is no such micropylar tube; the microspores are caught by the stigma, not by the ovule. The bennettilean seed differs from that of the primitive angiosperms in being exalbuminous, the embryo itself filling almost all the seed cavity, and nutritive tissue being entirely absent or very scanty. All these show that the Bennettiales cannot have been the ancestors of the angiosperms.

Though the Bennettiales cannot be the ancestors of the angiosperms, it is quite possible that they are connected through common ancestry like seed-ferns (see Arber and Parkin, 1907).

### *Gnetalean ancestry*

This theory was proposed by Wettstein (1901) and supported by Markgraf (1930) and Fagerlind (1947). The Gnetales resemble angiosperms in many respects. Both of them have two cotyledons; unlike all other Gymnosperms have vessels in their secondary wood, two integuments and net veined leaves.

Gnetales, in many respects, have attained an evolutionary level higher than that of some of the primitive angiosperms. For instance, the living genera *Ephedra*, *Welwitschia* and *Gnetum* have vessels in the secondary wood, yet some angiosperm families such as Winteraceae (woody) and Nymphaeaceae (herbaceous) have xylem completely devoid of them. Furthermore, special investigations (Thompson, 1918) have shown that the vessels of *Welwitschia*, *Ephedra* and *Gnetum* originated in an entirely different way from those of Angiosperms.

### *Isoetalean Ancestry of Monocotyledons*

Proposed by Campbell (1928), this theory is essentially based on marked similarity between *Isoetes* and Monocots especially *Najas flexilis*. *Isoetes* is predominantly herbaceous and geophilous. It is also either aquatic or amphibious. Like most of the Filicineae, it is found in humid tropics, a habitat, which is also characteristic of a large number of monocotyledons. Campbell also pointed out the marked similarity in habit and resemblances in the embryo and anatomy of the older sporophyte between Isoetales and some other lower aquatic monocotyledons.

Engler and his associates have also postulated the probable origin of Monocotyledons from various groups of Pteridophytes, through intermediate and hypothetical group, protangiosperms. According to Engler this group is not represented in the fossils because many of them were herbaceous. On the basis of similarities in their vascular bundles Engler also postulate direct derivation of Monocotyledons from Ophioglossaceae.

This theory of Pteridophytes ancestry is highly unacceptable because the monocotyledons are now considered as most advanced group of angiosperms and derived from Dicotyledons.

### *Coniferalean Ancestry of Amentiferae*

This theory has been proposed by Eichler (1875), Engler (1882, 1892), Engler and Prantl (1924), Rendle (1904, 1930), Hagerup (1934, 1936) and Doyle (1945). These authors have pointed out the resemblances of angiosperms to conifers and considered that coniferales might have given rise to primitive (hypothetical) group of angiosperms known as Amentiferae. The inflorescences of the Amentifers like Casuarinaceae, Salicaceae and Fagaceae with their simple and naked flowers were compared with those of conifers.

This theory is not acceptable because the amentiferae group is now considered as an advanced group of angiosperms. The advanced features in Amentiferae include anemophilous flowers, unisexual flowers, naked flowers etc. The wood anatomical data suggest that Amentiferae are highly advanced. Hence coniferales as the ancestors of Angiosperms and Amentiferae as primitive group of Angiosperms is ruled out.

### *Pteridospermean Ancestry*

Pteridosperms (Seed ferns) were considered as ancestors of Angiosperms by Long (1966). Features like reticulate venation, monopodial branching, presence of cambium, presence of microsporophylls and megasporophylls on the same plant. Origin of sepals from leaves and petals from sepals and stamens, development of triploid endosperm as extreme reduction of female gametophyte, similarities of seed structure and existence of one or several ovules subtended by a cupule together with information provided by *Glossopteris* reproductive structures are enough to bring seed ferns (Pteridosperms) closest to Angiosperms.

But Pteridosperm ancestry of angiosperms appears to be untenable because of two serious objections. The scalariform xylem elements never occur in Pteridosperms while they are common in angiosperms. No satisfactory explanation is given for cupule as an equivalent of carpellary wall in case of multiovulate cupules.

### *Pentoxylalean theory*

Pentoxylales have many similarities with *Pandanus*. These include: erect habit, dioecious nature, tuft of leaves, axillary inflorescence, peduncle with tracheids and spiral thickening and bordered pitting, two layered seed coat of which the inner one is usually tanniferous, seeds enclosed in a fleshy layer sarcotesta, endospermic seeds and minute embryo.

Based on these similarities, Meeuse (1961) considered Pentoxylales as ancestors of Angiosperms. In spite of resemblances, authors like Pant and Kidwai (1971) hold that they could equally be the result of parallel evolution.

### *Caytonialean Ancestry*

Caytonialean ancestry of Angiosperms was proposed by Thomas (1925, 1936) and supported by Stebbins (1974). Caytoniales are fossil plants of middle Jurassic period. Caytoniales had angiosperm-like anthers produced in groups or single on branching pinnate structures, which may be described as sporophylls. Such structures are comparable with the branched stamens found in such plants as *Ricinus*, *Hypericum* and *Calothamnus*. Caytoniales are characterized by a curved cup-like structure called cupule, in which the ovules are enclosed. Proponents of Caytoniales as the ancestors of angiosperms point to the almost sealed cupule as suggestive of the way a carpel might have evolved. The caytoniales also exhibited leaves with a net-like pattern of venation and tubes leading to the micropyle of the ovule. Thomas suggested that the carpel wall of angiosperm may represent, a pair of concrescent cupules and that the possible origin of stigma should be considered in the light of these ancient forms.

Caytoniales, however, are now shown to have relationships with Pteridosperms and they are now classified as Mesozoic remnants of that group. The ancestors of Angiosperms must have had open megasporophylls with exposed ovules, as is evident from the morphological studies on the nature of their carpel. Thus the ovary-like pouches of Caytoniales cannot be taken to be the fore-runners of angiosperm carpel.

Further the presence of pollination drop, direct pollination, fleshy canals in the inner side of the curved cupules, highly cuticularised winged pollen and absence of connective like structure in tetralocular synangia of Caytoniales negate the theory of Caytoniale ancestry of Angiosperms.

### ***Durian Theory of Origin of Angiosperms***

*Durio zibethinus*, a member of Bombacaceae from Burmese and Malayan forests was considered by Corner (1949), as a surviving model of primitive angiosperms. It is a cauliflorous tree and bears large, coloured, loculicidal spiny capsules with fleshy arillate seeds. There are about 45 angiospermous families, which show arillate genera mostly distributed in the tropics. According to this theory the primitive angiosperms are mesophytic, tropical in distribution, with cycad like tree habit, compound leaves, probably monocarpic and producing a large terminal cluster of arillate follicles.

The theory has been criticized by a number of morphologists including Pijl (1952), Parkin (1953), Metcalfe (1954) and Eames (1961).

Although some groups have been eliminated as likely ancestors of Angiosperms, Darwin's abominable mystery is not completely solved. However, it appears likely that plants having some angiosperm features could have evolved from the seed fern line late in the Jurassic or very early Cretaceous period. Certainly a vast gene pool was available at the time to give rise to the first angiosperms, which might be called *Proangiosperms*.

### ***Some examples of Primitive angiosperms***

Post Darwinian systems can be broadly categorized into two groups: the Englerian school and the Ranalian school. The Englerian school considered simplicity as primitive and complexity as advanced and is based on the concept of progressive evolution. The Ranalean School considered the Ranales group as the primitive and evolution proceeded in both progressive and retrogressive manner. Most taxonomists now agree that the Magnoliales/Ranales are the primitive. Some examples of primitive angiosperms are given below.

#### **Winteraceae**

Many contemporary taxonomists, including Gundersen (1950), Cronquist (1988) and Thorne (1983, 1992) regard the Winteraceae as the most primitive family of angiosperms. All the seven genera of the family – *Drimys*, *Pseudowintera*, *Bubbia*, *Belliolum*, *Exospermum*, *Zygogynum* and *Tetrathalamus* – have vesselless wood. In members of *Drimys* sect. *Tasmannia* we find very primitive carpels reminiscent of folded (conduplicate) young leaves. Moreover, in certain species of this section, e.g., *Drimys piperita*, the carpel margins at pollination time are only approximated, not fused, and are united not by the epidermis but solely by the papillose hairs of the stigmatic surfaces. The latter form broad zones running along the inner surfaces of the carpel and extend laterally from the extreme margins to the ovuliferous zones. Except its papillose hairs, this primitive stigmatic surface bears little resemblance to the normal strictly localised stigma, which forms a distinct part of the carpel.

Pollen grains fall and germinate on the papillose hairs covering the free margins of the carpels, and the pollen tubes penetrate between the interlocking papillose hairs of the closely-adhering inner stigmatic surfaces of the carpel. Strictly speaking, therefore, only the papillate surfaces of the extreme margins of the carpels function as a stigmatic surface, the inner papillate zones performing the function of the so-called 'transmitting tissue' in facilitating the passage of pollen tubes. A similar type of carpel is found in some species of *Bubbia* and *Exopsermum*.

### **Magnoliaceae**

Magnoliaceae is considered by many taxonomists, including Hutchinson (1959, 1969) as the primitive most angiospermous family. Hallier (1905) compared the elongated floral axis bearing numerous spirally disposed carpels with sporophyll bearing axis of Bennittitales. Arber and Parkin (1907) and Lotsy (1911) also support the primitive nature of the family. Anatomically they are mostly of rather primitive type, their vessels usually having scalariform perforation and scalariform intervacular pitting. They are also trees, a primitive character, seen in most of the Magnoliales. The flowers of Magnoliaceae are even more primitive than their wood. The floral axis is elongated and numerous stamens and carpels are spirally arranged (a primitive feature). The stamens are more or less laminar. The pollen in Magnoliales is of the very primitive monosulcate type. Another primitive feature of the family is the very small embryo in the seeds and the presence of abundant endosperm, a characteristic of the Magnoliales in general.

### **Degeneriaceae**

For many years Takhtajan considered Winteraceae along with Degeneriaceae to represent the most primitive angiosperms. Finally, however, he (Takhtajan, 1997) chose Degeneriaceae as the most primitive family. The stamens and carpels show primitive characters. The stamens have a distinct median vein, which dichotomies at the apex, and two lateral veins. Two pairs of long narrow microsporangia are situated one on each side between the 5 median and lateral veins on the abaxial surface of the stamen; as in most of the Magnoliaceae they are immersed in sterile sporophyll tissue. The carpel shows an extremely primitive conduplicately folded structure.

The carpel margins are not only completely free, but before anthesis are noticeably distant from each other. There are numerous ovules in two rows situated quite remote from the margins. At the flowering time the broad areas between the carpel margins and the ovules stand close together but are not actually coherent except in the lower part of the carpel; the stigmatic surfaces extend along the margins of the carpel on the inner sides, each forming a zone between the margin and the ovuliferous region, and are thus of a very primitive type. Only when the fruit develops do the contiguous adaxial surfaces become concrescent. Pollen grains are caught by the outcurving glandular-hairy carpel margins, where they germinate, the pollen tubes growing down between the loosely interlocking papillose, glandular hairs of the marginal areas to reach the ovules.

### **Angiosperms Diversity**

Flowering plants (Angiosperms) represent the most dominant group of plants on this planet with approximately 255, 265 species (Thorne, 2006) depicting a wide variety of habit and growing in



diverse habitats. The group represents tall evergreen trees often reaching more than 100 m in height (*Eucalyptus regnans*), tall deciduous trees (*Populus nigra*, *Platanus orientalis*), evergreen shrubs (species of *Rhododendron*, *Euonymus*, *Skimmia*), herbaceous plants more than a metre tall (*Zea mays*, *Saccharum officinarum*, *Silybum marianum*) or almost microscopic not more than 1-2 mm (*Wolffia arrhiza*). Several angiosperms with weaker stems may twine around the support (*Ipomoea*, *Convolvulus*), climb with the help of tendrils (*Cucurbita*, *Cucumis*), hooks (*Galium*) or thorns (*Bougainvillea*). The leaves may be as small just 1-2 mm (*Pilea microphylla*) or over 20 m long (*Raphia fainifera*). Broad rounded floating leaves of *Victoria amazonica* often reach 2 m in diameter and can support the weight of a child. Although flowering plants are largely green and photosynthetic, few grow as partial (*Viscum*) or total parasites on roots (*Balanophora*) or even leaves (*Arceuthobium*- growing on pinus leaves and being amongst the smallest angiosperms). A few, mainly the species of orchids (*Dendrobium* spp.) and *Tillandsia* grow as epiphytes.

Angiosperms form the most successful group of present day plants presenting a unique combination of characters, not found in any other group of plants. Like ferns and some gymnosperms they have macrophyllous leaves with complex parallel (monocots) or reticulate (Dicots) venation patterns. Angiosperms are similar to gymnosperms in producing seeds, the seeds are enclosed in ripened ovary (fruit) and not naked like gymnosperms. Both groups also produce pollen tube (siphonogamous mode of reproduction), but the pollen grains of angiosperms germinate on stigma, whereas they land and germinate directly on ovule. The sieve tubes of angiosperms are associated with companion cells.

Double fertilization resulting in triploid endosperm and highly reduced male and female gametophytes are unique to angiosperms. The angiosperms also have vessels, which though also found in gymnosperms like *Gnetum* and *Ephedra*, are of different nature, mainly scalariform pitting in angiosperms, but circular in these gymnosperms. The pollen grains of angiosperms are also unique in having non-laminate endexine and ectexine differentiated into a foot-layer, columellar layer and tectum (tectum absent in Amborellaceae). The angiosperm flower typically is a hermaphrodite structure with carpels surrounded by stamens and the latter by petals and sepals, since insect pollination prevails. Arbuscular mycorrhizae are also unique to angiosperms (except Amborellaceae, Nymphaeales and Austrobaileyales). The vessel elements of angiosperms typically possess scalariform perforations.

There may be individual exceptions to most of these characters. Vessels are absent in some angiosperms (Winteraceae) while some gymnosperms have vessels (Gnetales). The flowers are unisexual without perianth in several Amentiferae, which also exhibit anemophily. In spite of these and other exceptions, this combination of characters is unique to angiosperms and not found in any other group of seed plants.

### Classification of Angiosperms

Keeping the things arranged is a basic human instinct. Laboratories, libraries workshops, shops etc are easier to work in if there is a system to keep track of things. Biology is no exception. It is lot easier to study living things if we have a system that keep something apart from other things. Biologists called this system as classification or taxonomy. Typically, classification can be defined as the systematic arrangement of similar organisms into categories on the basis of their structural or evolutionary relationships.

The naming and classification of plants undoubtedly began in the earliest stages of civilization. Our own observations show that plants are of many kinds, and we immediately seek for a name to apply to a plant of interest. The primitive people and tribal communities of today, as well in the past, apply common names to those plants that are peculiar or that affect their life in any way. Early classification systems were utilitarian; plants were grouped as to whether they were beneficial or harmful.

With increasing civilization, especially as knowledge grew concerning the uses of plants in food and medicine, the necessity of plant names became even greater. And ultimately, as the number of known plants increased and as botanists collected plants from far corners of the earth, it became necessary to group plants into large categories following rational principles. The collection, naming and classification of plants nowadays are carried out mainly with the objective of showing their origins and relationship, and also to provide positive identification for the hundreds of thousands of different kinds of plants.

### *Kinds of Classification*

According to the principle employed, mainly three kinds of classifications are recognized. They are: Artificial, Natural and Phylogenetic. In practice, these may overlap.

**Artificial Classification** is based on convenient or conspicuous diagnostic characters without attention to characters indicating relationship; often a classification based on a single arbitrarily chosen character such as flower colour, habit, habitat, time of flowering or arrangement of leaves, rather than an evaluation of the totality of characters. The earlier pre-Darwinian systems of classification were largely artificial. Linnaeus' sexual system, which is based on the number of stamen and pistils, falls in this category since unrelated plants can have same number of stamen and pistils in their flowers.

**Natural Classification** is one which is based on over-all resemblances in external morphology, and unlike artificial systems, involved as many characters as possible. It is presumed that the larger the number of characters shared by different plants, more closely are they related to each other. Overall gathering data from diverse disciplines like palynology, embryology, anatomy, phytochemistry, cytology etc, and not the morphology alone nowadays ascertain similarity. Later pre-Darwinian systems, which were based on over-all resemblances in gross morphology, were mostly natural.

**Phylogenetic Classification** is based on hypothesized evolutionary relationship. In the years, following Darwin's Origin of Species (1859) the theory of evolution gradually replaced the concept of special creation of species. It was found that species are not fixed or unchanging, but have evolved from pre-existing species during geological time. It is now considered that, in general, similarities in structure are evidences of evolutionary relationship.

Thus have arisen modern phylogenetic systems of classification based on relationship by descent. Such systems utilize previously determined natural groups, and categories – genera, family, and orders – of the natural systems are arranged in scheme that presumably reflects evolutionary relationships. Since 1980's phylogenetic classification has been made much more facile by using molecular data. Data from many sources are used to determine relationship. Thus any phylogenetic scheme of plant classification is subject to change as our knowledge of the various groups increased.

## Natural Systems of Classification (Systems based on form relationship)

The wealth of plant material collected by the botanist world over during eighteenth century could not be satisfactorily identified with the help of Linnaeus' sexual system and a need was realized for a more objective classification. This resulted in the development of still better systems (based on overall resemblance in external morphology), which, unlike artificial systems, involved as many characters as possible.

**Michel Adanson** (1727-1806), a French botanist, published a two volume work *Familles des Plantes* (1763). He recognized 58 natural orders according to their natural affinities. He based his classification on using as many characters as possible and giving equal weightage to all the observable characters. This is precursor of modern computer aided Numerical Taxonomy, which is often called Adansonian Taxonomy.

**Antonie Laurent de Jussieu** (1748-1836), a French botanist published his system in *Genera Plantarum* (1789) incorporating his uncle's (Bernard de Jussieu, 1669-1776) work along with his own. He laid emphasis on number of cotyledons, presence or absence of petals and position of the stamens with respect to the ovary.

**Augustin Pyrame de Candolle** (1778-1841), a Swiss botanist, published his views on classification in his work *Theorie Elementaire de la Botanique* (1813) and introduced the term **Taxonomy** to designate the theory of plant classification. He was first to use the characteristics of vascular tissues in the classification of plants and recognized two major groups - Vasculares (Vascular bundle present) and Cellulares (no vascular bundle).

### **George Bentham (1800-1884) and Joseph Dalton Hooker (1817-1911)**

George Bentham, an Englishman, was an amateur botanist until almost middle age, after which time he gave the subject of systematic botany all his attention. In addition to being most critical, discrimination and analytical systematist he also was an accomplished linguist and Latinist. Prior to his joint publication with Hooker of the *Genera Plantarum*, Bentham published world monographs of the families Labiatae, Ericaceae, Polemoniaceae, Scrophulariaceae and Polygonaceae. Bentham was the author of the 7-volume *Flora of Australia*.

Sir Joseph Dalton Hooker, son of the botanist Sir William Jackson Hooker (1785-1865), was more the plant explorer and plant geographer than was Bentham. He collected plants from Himalayas, Lebanon, Antarctic and Atlas mountains. He succeeded his father as Director of Royal Botanical Gardens, Kew. Joseph Dalton Hooker also wrote *Flora of British India* (1872-1897), *Student's Flora of British Isles* (1870) and also revised later editions of *Handbook of British Flora*. He also supervised the publication of *Index Kewensis*.

Bentham and Hooker published their 3 volume work *Genera Plantarum* in Latin, at intervals between 1862 and 1883. This work comprised the names and descriptions of all genera of seed plants then known, classified according to their own system. This system was patterned directly on that of de

Candolle. But every genus was studied anew from the material of British and continental herbaria. Full and complete descriptions were prepared from studies and dissections of the plants themselves and did not represent a compilation made from literature.

Bentham and Hooker divided all seed plants into 3 classes, 3 subclasses, 21 series, 25 cohorts and 202 orders. Originally it was designed to include 200 orders and each order was given a definite number. Orders Vochysiaceae and the Cyrilleae were incorporated later. These were not given separate numbers but were included as 20a and 46a respectively.

## Identification of families based on Classification of Bentham and Hooker

Class Dicotyledons (Embryo with two cotyledons, stem with open bundles, venation reticulate, flowers tetramerous or pentamerous).

Subclass 1. Polypetalae (flowers with two whorls of perianth, inner (petals) free).

Series 1. Thalamiflorae (sepals usually free, free from ovary, flowers hypogynous, stamens borne on thalamus, disc usually absent).

*Order Ranales* (stamens usually many, carpels free, endosperm conspicuous, embryo small)

Family Ranunculaceae: Herbs, leaf base sheathing, flowers spirocyclic, stamens and carpels many, spirally arranged, carpel one or many and free, fruit achene or follicle.

*Order Parietales* (stamens few or many, carpels united, placentation parietal)

Family Brassicaceae (Cruciferae): Herbs, inflorescence racemose, flowers tetramerous, petals cruciform, stamens 6, tetradynamous, ovary with false septum and replum, fruit siliqua or silicula. *Order Malvales* (stamens many, carpels united, placentation axile)

Family Malvaceae: Plants mucilaginous, stipules present, epicalyx present, sepals united, stamens epipetalous, stamens monadelphous, anthers monotheous, fruit a capsule or schizocarpic.

Series 2. Disciflorae (sepals free or united, free or adnate to ovary, flowers hypogynous, disc conspicuous, stamens borne on outer or inner base of disc).

*Order Geraniales* (carpels united, placentation axile, ovules 1-2, disc annular)

Family Rutaceae: Leaves gland-dotted, sepals united, stamens free or polyadelphous, fruit a berry.

Series 3. Calyciflorae (sepals united, adnate to ovary, flowers perigynous or epigynous).

*Order Rosales* (flowers usually perigynous, carpel 1 or free in bud; styles distinct)

Family Fabaceae (Leguminosae): Leaves usually compound, leaf base pulvinate, stipules present, bracts usually caducous, odd sepal anterior, carpel 1, placentation marginal, fruit a legume. Three subfamilies:

Faboideae (Papilionoideae): Flowers zygomorphic, sepals united, corolla papilionaceous, aestivation vexillary, posterior petal outermost in bud, stamens diadelphous).

Caesalpinioideae: Flowers zygomorphic, sepals free, corolla not papilionaceous, posterior petal innermost in bud, stamens free, usually in two whorls.

Mimosoideae: Flowers actinomorphic, sepals united, petals valvate, stamens usually many, free or united.

*Order Umbellales* (flowers epigynous, stamens 5, carpels united, placentation axile, ovule 1 in each locule)

Family Apiaceae (Umbelliferae): Leaves compound with sheathing base, inflorescence an umbel, petals often notched, stamens 5, inflexed in bud, carpels 2, fruit cremocarp, tipped by stylopodium.

Subclass 2. Gamopetalae (flowers with two whorls of perianth, inner (petals) united).

**Series 1. Inferae** (ovary inferior, stamens usually as many as corolla lobes).

**Series 2. Heteromerae** (ovary superior, carpels more than 2).

**Series 3. Bicarpellatae** (ovary superior, stamens usually as many or lesser than corolla lobes, carpels two).

**Order Gentianales** (Leaves generally opposite, flowers actinomorphic, stamens as many as and alternating with corolla lobes)

**Family Apocynaceae:** Plants with milky latex, throat of corolla tube with scales, pollinia absent, carpels with free ovaries and united styles, fruit a follicle, seed with a tuft of hairs.

**Family Asclepiadaceae:** Plants with milky latex, throat of corolla tube with scales, pollinia present, anthers united with stigma to form gynostegium, carpels with free ovaries and united styles, fruit a follicle, seed with a tuft of hairs. (Thorne, Takhtajan, APG II merge Asclepiadaceae with Apocynaceae, recognizing it as subfamily Asclepiadoideae).

**Order Polemoniales** (Leaves generally alternate, flowers actinomorphic, stamens as many as and alternating with corolla lobes)

**Family Solanaceae:** Stem with internal phloem, ovary with axile placentation, swollen placenta, septum oblique, ovules numerous, fruit a berry or capsule.

**Order Personales** (Leaves generally opposite, flowers zygomorphic, stamens fewer than corolla lobes, ovules usually many in each locule)

**Family Acanthaceae:** Inflorescence a spike, bracts and bracteoles conspicuous, anther lobes unequal in size, ovary 2-chambered, ovules 4 or more, fruit a capsule, seeds with jaculators.

**Order Lamiales** (Leaves generally opposite, flowers zygomorphic, stamens fewer than corolla lobes, ovule usually one in each locule)

**Family Lamiaceae:** Plants aromatic, stem 4-angled, inflorescence mixed with cymose lateral branches, often verticillaster, stamens 2-4, ovary finally 4 chambered due to false septa, ovules 4, attached to the sides of false septa, ovary deeply 4-lobed, style usually gynobasic, fruit drupe or schizocarpic breaking into 4 nutlets.

(Nearly two-thirds of genera formerly placed in Verbenaceae are now (Thorne, APG II) transferred to Lamiaceae now characterized by inflorescence with cymose lateral clusters, minute stigmas and ovules attached to the sides of false septa).

**Subclass 3. Monochlamydeae** (flowers without perianth or with one whorl of perianth, commonly sepaloid).

**Series Curvembryeae** (plants terrestrial, flowers usually bisexual, stamens as many as perianth lobes, ovule usually solitary, embryo curved, ovary superior).

**Family Chenopodiaceae:** Herbs covered with white bloom, flowers small often greenish, perianth herbaceous, stamens opposite perianth lobes, all fertile and similar, carpels 2, ovary superior, fruit a nut enclosed in persistent perianth.

**Series Unisexuales** (flowers unisexual, perianth sepaloid or much reduced, ovule one or two in locule).

**Family Euphorbiaceae:** Plants usually with milky latex, leaves alternate, flowers unisexual, carpels 3, ovary superior, 3-chambered, ovule with a caruncle.

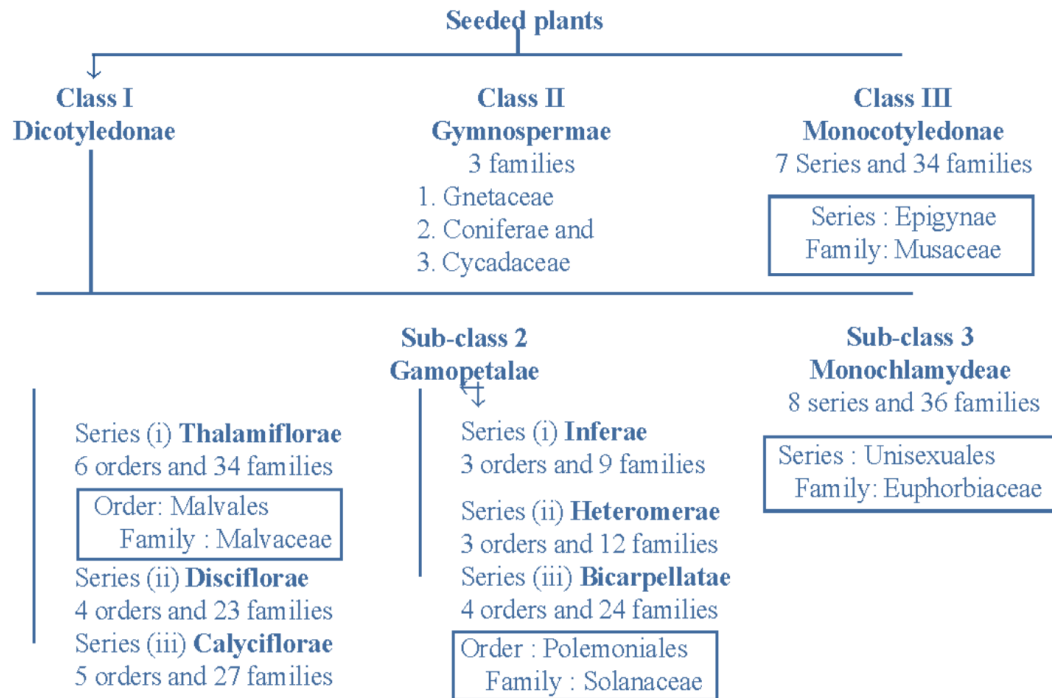
**Class Monocotyledons** (Embryo with single cotyledon, stem with closed bundles, venation parallel, flowers trimerous).

**Series 3. Coronarieae** (inner perianth petaloid, ovary superior with axile placentas, endosperm copious).

**Family Liliaceae:** This large family with more than 250 genera and nearly 3700 species has been split into several families and restricted to just 11 genera and 545 species, rest being segregated to Alliaceae, Asphodelaceae, Agavaceae, Asparagaceae, etc (Thorne, APG II).

**Series 7. Glumaceae** (flowers enclosed in glumes, perianth of scales or none, ovary superior, unilocular, ovule 1).

**Family Poaceae (Gramineae):** Herbs or shrubs with hollow internodes and jointed stems, leaves distichous with distinct sheath enclosing the stem and linear blade with often a ligule at their junction, spikelet with two glumes, flowers reduced, enclosed in lemma and palea, perianth represented by lodicules, ovary superior, stigmas feathery, fruit caryopsis.



*Outline of Bentham and Hooker's classification of plants*

*Distribution of taxa in Bentham and Hooker's classification of plants*

| S.No. | Classes and sub-classes   | No. of families |
|-------|---|-----------------|
| 1.    | Dicotyledonae<br>i. Polypetalae<br>ii. Gamopetalae<br>iii. Monochlamydeae | 84<br>45<br>36  |
| 2.    | Gymnospermae  | 3               |
| 3.    | Monocotyledonae   | 34              |
|       | Total   | 202             |

In this work the family of contemporary systems was termed as order while that of an order was termed as cohort. The name cohort was first used by Endlicher for a taxon of higher level.

Bentham and Hooker's system in Post-Darwinian in chronology but Pre-Darwinian in concept. It is interesting to know that the publication of Darwin's theories of evolution and Origin of Species coincided with the time of production of the first volume of Bentham and Hooker's Genera Plantarum. Hooker then favoured

a complete reorganization of their classification but was deterred from effecting it by Bentham, who did not accept the essentials of Darwin's work, although he did so about a decade later.

### Merits of Bentham and Hooker's classification System

1. Bentham and Hooker's classification is the most natural system, based on actual examination of specimens.
2. The description of plants is quite accurate and reliable.
3. As it is easy to follow, it is used as a key for the identification of plants in Kew herbarium and several other herbaria of the world.
4. Although this system is natural, most of the aspects of this system show affinity to modern concepts of evolution. For example, the order Ranales, which is the first order in the arrangement of plants, has been given a primitive position in this system. Recent taxonomic findings also indicate that the members of Ranales are the most primitive living angiosperms.
5. The placement of monocotyledonae after the dicotyledonae also appears to be in accordance with the evolutionary trends.

### Demerits of Bentham and Hooker's classification System

1. The placement of Gymnospermae in between dicotyledonae and monocotyledonae is an error.
2. Several important floral characters have been neglected in this system.
3. Advanced family Orchidaceae has been considered as primitive among monocotyledons and it is placed in the beginning of the system.
4. In this system, some closely related families have been separated and placed under different groups. For example, all the families of series Curvembryae of Monochlamydeae are related to Caryophyllaceae of series Thalamiflorae of Polypetalae, but they are separated.
5. Unrelated families have been grouped nearer. For example, Podostemaceae of series Multiovulatae aquaticae of Monochlamydeae deserves a place in Rosales of the series Calyciflorae of Polypetalae. Similarly Laurineae of series Daphnales of Monochlamydeae deserves a place in Ranales of the series Thalamiflorae of polypetalae. Thus, two unrelated families Podostemaceae and Laurineae are grouped nearer.

## Cytology in Relation to Taxonomy

Systematic application of chromosomal information is called cytotaxonomy. Usually the characters pertaining to chromosome number, morphology, size and the behaviour of chromosomes during meiosis are used for comparison or for interpreting evolutionary relationships.

### *Chromosome number*

All individuals within a species usually have the same chromosome number, although there are some exceptions. Chromosome numbers recorded for Spermatophytes vary from  $2n = 4$  in *Haplopappus gracilis* (Asteraceae) to  $2n = 500$  in *Kalanchoe* species (Crassulaceae). Some pteridophytes like the members of the family Ophioglossaceae and Polypodiaceae show unusually high chromosome number. The highest chromosome number has so far been recorded in *Ophioglossum reticulatum* ( $2n = 1260$ ).

The diversity of chromosome numbers and their relative constancy within species and populations provide an important taxonomic character. The chromosomal counts are usually reported as diploid number ( $2n$ ) from mitosis of sporophytic tissue, when it is based on mitosis in gametophytic material or on meiosis, counts are reported as haploid ( $n$ ). The gametophytic chromosome number of diploid species is known as base-number or basic chromosome number ( $x$ ). The chromosome number relationship within taxonomic groups can be divided into three classes. They are:

1. **Constant number.** In general, the number of chromosomes in each cell of all the individuals of a single species is constant. The more closely related species are likely to have the same chromosome number; and the more distantly related are likely to have different numbers. Sometimes the chromosome number is constant throughout the whole group, e.g., all the known species of *Pinus* and *Quercus* have the same basic number,  $n=12$ . In such cases chromosome number is of little help in distinguishing various taxa within the group.
2. **Polyploidy.** When various members of a taxon possess an exact multiple of the basic number of the chromosome, the series is called as polyploid. Polyploidy is wide-spread in plants; about 50% to 70 % of angiosperms so far investigated are reported to be polyploids. Several such examples are found in angiosperms and ferns. For example, in the genus *Salix* (Salicaceae) there are species with  $2n = 38$  (*Salix viminalis*),  $2n=76$  (*S. atrocineria*),  $2n=114$  (*S. phylicifolia*) and  $2n=152$  (*S. myrsinites*). These numbers are based upon 19, the gametophytic chromosome number of the diploid species. Similarly, in the genus *Festuca* there are species with  $2n = 14, 28, 42, 56,$  and  $70$ ; the base number being 7. Another interesting example of polyploid series is found in the genus *Taraxacum* with  $2n=16, 24, 32, 40$  and  $48$ . This type of polyploidy is known as **euploidy**.
3. **Aneuploidy.** When the chromosome numbers found within a group do not show simple numerical relationship to each other, then the series is termed as aneuploidy. Sometimes an increase or decrease in basic number of chromosomes may arise. Individual with  $2n + 1$  (a diploid with one extra chromosome) is known as trisomic, and one with one chromosome missing ( $2n - 1$ ) a monosomic. Normal diploids are called disomics. In nature a large number of plant groups are known to exhibit aneuploidy. Various aneuploid species of *Vicia* (Fabaceae) show a wide range of chromosome number from  $2n = 10, 12, 14, 24$  and  $28$

### *Chromosome structure*

In addition to variation in number, chromosomes vary in form, size, volume, and in the amount of distribution of heterochromatin. The appearance of the basic chromosome set (genome) under the light microscope is known as **karyotype**. The characteristics of karyotypes are taxonomically useful if the individual chromosomes are large enough to carry out detailed morphological studies. In most plants chromosome length varies from 0.5-30  $\mu$ . The monocotyledons usually have larger chromosomes than the dicotyledons. Generally woody plants have smaller chromosomes than the herbaceous ones. The location of the centromere determines the relative length of chromosome arms. Based on the position of centromere, the chromosomes may be V-shaped (metacentric), L-shaped (sub-metacentric), J-shaped (acrocentric) or i-shaped (telocentric). The V types of chromosomes have two equal arms and a median centromere and are termed as symmetrical; the other types are called asymmetrical.



In addition to the size and position of the centromere, the karyotypes can be differentiated on the basis of secondary constrictions and satellites (small bead-like appendages at the end of chromosomes). Now a day special staining techniques using Giesma and fluorochrome dyes are being used to study morphological features of the chromosomes.

### Behaviour of chromosomes at meiosis

A study of chromosomes behaviour during meiosis can help interpret aneuploid and polyploid changes and also identify other structural modifications that are commonly involved in chromosomal evolution (deletion, duplications, inversions, and translocations). The kind and degree of pairing (synapsis) show whether hybridization has occurred, indicate structural differences between parental chromosomes, and explain causes of sterility. The degree of chromosome homology in hybrids is an indication of the degree of relationship of parental species.

### Use of cytological variation at family level

Chromosome numbers and morphology have frequently proved useful within the family at tribal or generic levels. Engler and Prantl have recognized two major tribes –Helleboreae and Anemonieae - in the family Ranunculaceae that possess genera with base chromosome number of 7, 8, and 9 and the both have the genera with large and small chromosomes. The genera *Aquilegia* and *Thalictrum*, along with a few others, differ from most Ranunculaceae in having small chromosomes and basic chromosome number being 7 (rather than 8). These genera have thus been segregated into a separate tribe Thalictreae. Two other genera of the Ranunculaceae, *Coptis* and *Zanthorhiza*, with small chromosomes and the base number 9 have been removed to an additional tribe Coptideae.

The major subdivisions of the family Poaceae (subfamilies, tribes and genera) as recognized currently are characterized by the number and size of the chromosomes. For example, subfamily Pooideae has basic number 7 but certain tribes (e.g. Glycerieae,  $x = 10$ ) or genera (*Anthoxanthum*,  $x = 5$ ) within it deviate consistently and illustrate the relative nature of the concept of base number.

The base number of various subfamilies of Rosaceae is 7, 8 or 9. But the subfamily Pomoideae has 17 base number. This suggests that the members of subfamily Pomoideae are either polyploid hybrids between taxa with  $x = 8$  and  $x = 9$ , or are polyloids of taxa with  $x = 9$  with loss of one chromosomes.

### Cytological variation at and below generic level

The genus *Cistus* (Cistaceae) was earlier included in *Heliantherum*. The former has base number 8 and the latter 9. This supports the recognition of *Cistus* as a separate genus. In the genus *Tephrosia* (Fabaceae) all species possess  $2n = 22$  except *T. constricta* with  $2n = 16$ . This species has been treated as a separate genus, *Sphinctospermum* and the chromosomal studies supports this. Many workers have recognized the genera *Physaria* and *Lesquerella* of the family Brassicaceae as a single genus. Cytological evidence suggests that these two genera should remain separated.

The karyotype data have been extremely useful in distinguishing various species of *Clarkia*, *Viola*, *Nicotiana*, *Potentilla*, *Achillea*, *Gossypium* and many more genera. Three species of *Chlorophytum* (*C. bharuchae*, *C. glaucum* and *C. glaucoides*) are difficult to distinguish morphologically from one another. *C. bharuchae* has  $2n = 16$  while the other two have  $2n = 42$ . The species having  $2n = 42$  differ in their karyomorphology. *Monotropa hypopitys* (Monotropaceae) was originally treated a single species with two varieties,

var. *hirsuta* and var. *glabra*. Cytological studies revealed that var. *hirsuta* was hexaploid ( $2n = 48$ ) and the var. *glabra* was diploid ( $2n = 16$ ). The hexaploid was retained as the species *M. hypopitys* and the var. *glabra* was raised to the specific rank as *M. hypophegea*.

## Chemistry in Relation to and Taxonomy (Phytochemistry /Chemotaxonomy)

Plants produce a number of chemical substances in various amounts, and quite often the biosynthetic pathways responsible for these compounds also differ from one taxonomic group to another. The distribution of these compounds and their biosynthetic pathways correspond well with existing classification of plants based on traditional morphological characters. At present there are many groups of plants in which phytochemical data have contributed to substantial taxonomic improvements.

Although in theory all the chemical constituents of a plant are potentially valuable to a taxonomist, in practice some molecules are more valuable than others. Apart from inorganic compounds, which are of little use, three broad categories of chemical compounds are recognized: primary metabolites, secondary metabolites, and sementides.

Primary metabolites are compounds involved in vital metabolic pathways, and most of them are of universal occurrence in plants. Aconitic acid and citric acid, which participate in Krebs cycle, are found in all aerobic organisms; the presence or absence of such compounds is therefore not of much taxonomic value. The same is true of 22 amino-acids that are known to be constituents of plant proteins, or any of the sugars that figure in the Calvin cycle of photosynthesis. However, variation in the quantity of these metabolites may sometimes be taxonomically useful.

Secondary metabolites are generally the byproducts of metabolism and perform non-vital functions. They are less widespread in plants compared to primary metabolites and this restricted distribution among plants renders them valuable as taxonomic information. Secondary plant products are largely waste substances, foodstores, pigments, poisons, scents etc. Although secondary metabolites are not indispensable for normal growth and development of plants, they are important in chemical defense against predators and pathogens, as allelopathic agents and as attractants in pollination and dispersal of fruits.

Sementides are the information-carrying molecules such as proteins, DNA, and RNA. Based on sequential transfer of genetic information DNA is a primary sementide, RNA a secondary sementide, and proteins are tertiary sementides. Sometimes the sementides together with larger polysaccharides, having molecular weight over 1,000, are known as macromolecules such as proteins, DNA, RNA, cytochrome C, and the primary and secondary metabolites as micromolecules (molecular weight less than 1000).

In addition to these there are some compounds that are directly visible, e.g. starch grains, raphids, silica, crystals etc. and have been used in systematics by many earlier workers. Chemotaxonomic characters, like any others, are useful at all taxa levels. Some of the important taxonomic evidences, especially from secondary metabolites, are briefly discussed here.

**Non-proteinic amino acids:** Amino acids that are not associated with the proteins are known as non-proteinic amino acids. There are more than 300 such amino acids. Discontinuous distribution and less susceptibility to rapid change increase their taxonomic significance. Presence of Cyclopropyl amino

acid in Sapindaceae and Aceraceae show their close relationship. Canavanine, a close analogue of arginine is found only in the Fabaceae. In *Vicia*, 7 infrageneric groups are recognized on the basis of non-proteinic amino acids.

**Alkaloids:** Alkaloids are heterogeneous group of organic nitrogen containing bases, often with a heterocyclic ring. There are more than 5000 alkaloids separated from angiosperms. They are physiologically active in animals, often used medicinally (morphine, cocaine, atropine, colchicines, quinine, berberidine, strychnine). Certain types are limited in distribution in various taxonomic groups and therefore are of systematic value.

The alkaloid protopine is present in all the species of Papaveraceae and Fumariaceae, suggesting their close relationship. Family Solanaceae and Convolvulaceae are characterized by the presence of similar types of tropane alkaloids. Benzyloisoquinoline alkaloids occur in members of Magnoliales, Laurales, Ranunculales, as well as Nelumbonaceae. Secologanin type indole alkaloids are present in the family Apocynaceae, Loganiaceae, and Rubiaceae. Morphine is restricted to *Papaver somniferum*, coniine to a few members of Apiaceae, quinine to *Cinchona* spp., ephedrine to *Ephedra* spp., and strychnine to a few species of *Strychnos*.

**Flavonoids:** Flavonoids are the largest group of naturally occurring phenols. Phenols contain the hydroxyl group(s) attached directly to the aromatic nucleus (e.g. C<sub>6</sub>H<sub>5</sub>OH). Flavonoids are variously classified as flavones, flavonones, isoflavones and isoflavonoids, flavonols, anthocyanidins etc. Flavonoids have been proved to be most useful of all chemical compounds in taxonomy.

Flavonoid chemistry has been used to support a hypothesized relationship between Fabaceae and Sapindales. Presence of phenylated flavonoids in Fabaceae and Rutaceae suggests that both the families are closely related. Sterculiaceae is closely related to Malvaceae due to the presence of cyanidin and gossypetin in both the families. Presence of tricetin and lutealin in Arecaceae and Poaceae suggests their close relationship. Cronquist and Takhtajan have placed family Juglandaceae in the Hamamelidae, while Thorne assigned Juglandaceae to the Rurales. But the presence of 5-methoxylated flavonols favours its relationship with Hamamelidae.

**Betalains:** Betalains are nitrogenous red (betacyanins) and yellow (betaxanthin) pigments functionally equivalent to phenolics. Due to the presence of nitrogen they are excluded from the general definition of phenolics. Betalains are present in the ten families of angiosperms, which are traditionally included in a single order Centrospermae (Caryophyllales). Family Caryophyllaceae and Molluginaceae lack betalains but have been retained in this order on other grounds. Presence of betalains in Cactaceae, which were earlier not regarded as a member of Centrospermae, suggests its placement in Centrospermae.

**Glucosinolates:** These are mustard oil glucosides – source of hot mustard oils. Glucosinolates are confined to the order Brassicales (family Brassicaceae, Capparaceae, Resedaceae, Tovariaceae and Moringaceae).

**Cyanogenic Glycosides:** Cyanogenic glycosides are defensive compounds, which on hydrolysis release hydrogen cyanide. This process is called cyanogenesis. More than 80 families of angiosperms have been recorded to possess cyanogenic compounds. The important ones are- Passifloraceae, Turneraceae, Linaceae, Fabaceae, Asteraceae, and Poaceae.

**Polyacetylenes:** A group of non-nitrogenous compounds produced by linkage of acetate units via fatty acids. Present in several closely related asterid families, including Asteraceae and Apiaceae.

**Terpenoids:** Terpenoids are large and diverse group of compounds formed in the mevalonic acid pathway. The terpenoids have been classified on the basis of number of C<sub>5</sub> (or isoprene) units present in them into monoterpenoids, sesquiterpenoids, diterpenoids, triterpenoids or polyterpenoids.

Volatile monoterpenoids and sesquiterpenoids are the major components of essential oils, which are characteristic of Magnoliales, Laurales, Illiciales, and Piperales and also in the distantly related families such as Myrtaceae, Rutaceae, Apiaceae, Lamiaceae, Verbenaceae and Asteraceae.

**Sesquiterpene lactones** are characteristic of many tribes of Asteraceae. Triterpenoid betulin is peculiar to *Betula* spp. Presence of triterpene saponins in both Apiaceae and Pittosporaceae support the hypothesized phylogenetic relationship of these two families.

**Iridoids** (9- or 10-carbon monoterpenoid derivatives) have been used to support relationships in the many families of asterid clade. Asperuloside iridoid is common in Rubiaceae. Acubin is found in Cornaceae, Scrophulariaceae, Orobanchaceae etc. *Buddleia*, an acubin-containing genus is transferred from Loganiaceae to Buddleiaceae.

## **Taximetrics in Relation to Taxonomy (Numerical Taxonomy)**

Application of numerical methods (data) in the classification of taxonomic units is called numerical taxonomy. It involves exhaustive quantitative estimation of characters from all parts of the plants as well as from all the stages in the life cycle. The numerical data thus collected for various plant groups is tabulated systematically. Because of the large number of characters, numerical taxonomy relies heavily on computers and statistical methods. To minimize sampling error, at least 100-200 characters should be observed. The main objective of numerical taxonomy is to clarify and illustrate the degrees of similarity or relationship in an objective manner. Numerical taxonomy is based on equal weighting, an idea developed by Michel Adanson in 1750s, of characters to avoid the pitfalls of purposely choosing characters that are thought to be important by the systematist. It attempts to use only uncorrelated characters selected after studying the plants. Only unit characters (characters that cannot be subdivided) are used.

The pioneers in the field of numerical taxonomy are R.R. Sokal and P.H.A. Sneath. They published two important books- **Principles of Numerical Taxonomy (1963)** and **Numerical taxonomy: The Principles and Practice of Numerical Classification (1973)**. This became a standard work and the taxonomist throughout the world started employing these methods in classification. Classifications based on numerical taxonomy make no assumption about phylogeny; no statement regarding evolution of the group.

### *Operational steps in numerical taxonomy*

- a) **Selection of units to be studied:** The basic unit of study in numerical taxonomy is called the “Operational Taxonomic Unit (OTU). Depending on the purpose of study, the OTUs can be the different populations of a species when range of variation in a species is to be examined, or different species if a genus is to be evaluated, and so on. Thus the OTUs may differ in rank from study to study.
- b) **Selection of characters (attributes) that will be scored for each OUT:** A character may be defined as any feature whose expression can be measured, counted or otherwise assessed. For the purpose of numerical taxonomy characters should be unit characters; if they are multiple they are to be broken down into unit characters. Characters may be qualitative (non-numeric) or quantitative (numeric).
- c) **Coding of characters and characters matrix:** Once the characters are selected, they are coded or given some symbol or mark. The characters most suited for numerical taxonomy are two-state or binary characters (leaves present or absent, habit woody or herbaceous). The positive characters are recorded as + or as 1 and negative characters as – or as 0. If a given character is missing in an organism, the character is scored as NC (no comparison). However, all characters may not be two-state. There may be qualitative multistate (flower colour white, red, yellow, blue, purple) or quantitative multistate (leaves two, three, four, five at a node) characters. Such multistate characters can be recorded into two-state (flowers white or not white; leaves four or more vs leaves less than four).
- d) **Estimation of similarity:** Once the data have been codified and entered in the form of a matrix, the next step is to calculate the degree of similarity between every pair of OTUs. A match is scored if the same symbol occurs in two OTUs otherwise a mismatch is scored. There are various mathematical formulae to describe the degree of similarity or distance between each pair-wise comparison of OTUs.  
  
*For example OTU A and B agree in three characters (first, eighth and ninth) and disagree in seven characters. Thus their similarity is  $3/10 \times 100 = 30$  percent and dissimilarity is  $7/10 \times 100 = 70$  percent.*
- e) **Construction of similarity matrix.** Once the similarity or distance between every pair of OTUs is calculated the data are presented in a second matrix, where both rows and column represents OTUs, that gives all pair-wise S- values.
- f) **Cluster analysis and construction of dendrogram.** Cluster analysis is a procedure for arranging OTUs into homogenous clusters on the basis of their mutual similarities. In computer analysis, the computer sorts out (cluster) the OTUs according to their overall similarity. These clusters are called phenones and can be arranged in a tree-diagram or dendrogram. A tree diagram based on phenetic evidence is also called a phenogram. It shows at what similarity levels various clusters occur.

Similarity value for other clusters is also calculated and a dendrogram depicting similarity of each cluster, as shown below, is constructed.

## **Anatomy in Relation to Plant Taxonomy**

### **Importance of Anatomical Characters in Taxonomy**

Anatomical characters are conserved and stable and thus can be used as a “Taxonomic Character” for Plant Systematics of Plant Taxonomy. Anatomical characters of all the plant parts can be used such as the characters of stem, root, leaves, bark, stomata, trichomes, internal parts etc. Anatomical features can be used in Taxonomy for:

### **The identification of plants**

- Establishing genetic relationships
- Solving taxonomic disputes

### **Peculiarities of Anatomical Characters**

- The anatomy of the fragmentary materials (such as a piece of wood) can be performed, thus we don't require the complete portion of the specimen.
- Anatomical studies of herbarium specimens can be studied.
- High range of anatomical character variability is available among plants.
- Most of the anatomical characters are conserved (do not change).
- Anatomical characterization can be done without any sophisticated instrumentation.

### **Anatomical Characters used in Plant Systematics:**

1. Trichomes
2. Stomata and Epidermal Features
3. Leaf anatomy
4. Nodal anatomy
5. Stem anatomy
6. Sclereids and Fibres
7. Cambium
8. Wood Anatomy

#### **(1). Trichomes**

- The characters of trichomes are used to compare closely related taxa.
- Features of trichomes used: glandular, non-glandular, unicellular, multicellular, shape and size of trichomes etc.  
Examples:
- Non-glandular trichomes: Lauraceae, Moraceae

- Stellate hairs – Malvaceae
- Mucilage hairs – Rumex
- Stinging hairs – Urticaceae
- Silica hairs – Grasses

## (2). Stomata and Epidermal Features

- Features like types of stomata and distribution of stomata are commonly used.
- The SEM features of stomata and epidermis are used for comparison.
- Some families are specific for their stomata such as:
  - Anomocytic Stomata Ranunculaceae
  - Anisocytic Stomata in Brassicaceae
  - Diacytic Stomata in Caryophyllaceae
  - Paracytic Stomata in Rubiaceae
  - Gramineous Stomata in Poaceae (dumbbell-shaped guard cells)
- About 35 different types of stomata have been described from vascular plants and most of them can be used as taxonomic evidence.
- The Sunken stomata in plants indicate its xerophytic habitat.
- Stomatal Index: The percentage of stomata form to the total number of epidermal cells is called the stomatal index.
- $\text{Stomatal Index} = (S / (S + E)) \times 100$
- Stomatal index can also be used as a criterion for classification and identification of plant groups.
- Stomatal distribution on leaves are specific and based on the leaves are classified into Epistomatic leaf (stomata on the upper surface), Hypostomatic leaf (stomata on the lower surface) and Amphistomatic (Stomata on both the surface of the leaf).

Ø Based on development, there are two types of stomata:

(a). Syndetochealic Stomata

(b). Haplochealic Stomata

(a). Syndetochealic Stomata:

- A type of stoma in which the two guard cells and the subsidiary cells are all derived from a single mother cell.
- Syndetochealic stomata are considered as primitive type.
- Usually occur in Gymnosperms.

(b). Haplochealic Stomata

- A type of stoma in which the two guard cells are derived from a single mother cell and the subsidiary cells are derived from a different initial.
- Haplochealic stomata are considered as advanced.
- Commonly occurs in Angiosperms.

The developmental pattern of stomata indicates the phylogeny of the plant.

### (3). Leaf Anatomy

- Leaf anatomy is extensively used in the systematics of the Cyperaceae family.
- Characters leaf anatomy used in plant taxonomy are:
- The gross anatomical architecture of the leaf (dicot and monocot).
- Structural variability: Features of mesophyll, bundle sheath, hydathodes, Kranz anatomy, foliar nectaries and glands, oil glands, stomatal crypts and features of leaf abscission etc.
- Nodal Anatomy

Three different types of nodes based on anatomical characteristics.

- Unilacunar node: A node with one lacuna or leaf gap.
- Three types are found
- **Single leaf trace:** Nerium, Calotropis, Lantana
- **Two traces:** Clerodendron splendens
- **Three traces:** Withania somnifera

**Trilacunar node:**

- A node with three lacunae or leaf gaps
- Example Azadirachta

**Multilacunar node:**

- A leaf with many lacunae or leaf gaps.
- Example: Rumex, Polygonum, Aralium
- Example: Entire order Centrospermales possess unilacunar node.

### (5). Stem Anatomy

- Gross anatomy of dicot and monocot stem can be used in systematics.
- The commonly used anatomical criteria of the stem in plant taxonomy are:
- Features of epidermis, hypodermis, distribution of collenchyma, sclerenchyma, variations in the endodermis, characteristics of piths, storage region, number – shape and distribution of vascular bundles.
- Examples:
- Bicollateral vascular bundles in Cucurbitaceae.
- Accessory cortical and medullary bundles in Nyctaginaceae.
- Anomalous secondary thickening in Bignoniaceae.
- Included phloem in Amaranthaceae.
- Anomalous secondary thickening in monocots.

### (6). Sclereids



- Nature, type and distribution of sclereids and fibres have taxonomic significance.  
Example:
- Monocot fibres are hard fibres (Coir, Musa).
- Dicot fibres are soft fibres (Jute).
- Asterosclereids (star-shaped) in Nymphaeaceae.
- Trichosclereids: branched hair like (Leaves of Olea).
- Macrosclereids: Columnar cells (Seed coats of Legumes).
- Osteosclereids: bone line (Seed coats of Pisum).
- Reaction wood and distribution of Gelatinous Fibres.

### (7). Cambium

- Important features of cambium considered for plant systematics are:
- Features of cambium.
- Formation of secondary cambium (normal or accessory, stelar or extrastelar).
- Storied vs Nonstoried cambium.
- Homogenous vs Heterogenous cambium.
- Developmental features of ray and fusiform initials.

### (8). Wood Anatomy

- Wood anatomy is extensively used in solving taxonomic disputes.
- Wood anatomy is also used to detect adulteration in medicinal plants.
- Powder microscopy of wood can be used for identification of adulteration.
- Colour and odour of wood are characteristic and it can be used for the identification of wood in the timber industry.

### Features of Wood used in Systematics

- ✓ (A). Vessels
- ✓ (B). Wood Parenchyma
- ✓ (C). Ray System
- ✓ (D). Storied structures

#### (A). Vessels

- ✓ Features of vessels – distribution pattern, diameter, perforation features, thickening pattern etc.
- ✓ Solitary vessels are considered primitive than vessels arranged in groups.
- ✓ Non-porous wood is more primitive than porous wood.
- ✓ Non-porous wood:- wood of Gymnosperms.
- ✓ Porous wood:- wood of Angiosperms.
- ✓ Diffuse-porous wood is primitive than ring porous wood.

#### (B). Wood Parenchyma

- Based on the distribution pattern, two types of wood parenchyma.
- (i). Apotracheal type:
  - Here the parenchyma is distributed without any specific relation to the vessels.
  - Parenchyma is not in direct contact with vessels.
  - Three different types:
    - Diffuse apotracheal type
    - Banded apotracheal type
    - Terminal apotracheal type
- (a). Diffuse apotracheal type:
  - Parenchyma cells occur singly among fibres and tracheids.
  - Example: *Adina cordifolia*
- (b). Banded apotracheal type:
  - A parenchyma cell occurs in bands.
  - Example: *Pterygota*, *Lophopetalum*
- (c). Terminal apotracheal type
  - Bands of parenchyma cells confined to the ends of growth rings.
  - Example: *Michelia*, *Acer*
- (ii). Paratracheal type
  - Here the parenchyma cells are distributed in close association with vessels.
  - Two types:
    - (a). Abaxial type: parenchyma cells found in association with the abaxial surface of vessels (surface away from the centre of the vessels).
    - (b). Vasicentric type: Parenchyma cells completely surrounded the vessel.

#### (C). Rays

- Features of rays used in systematics and phylogenetics.
- Abundance, ray diameter, width and cellular composition.
- Degree of wall thickening.
- Pitting pattern in ray cells.
- Homogenous and heterogeneous ray system.
- Heterogeneous rays are considered primitive than homogenous rays.

#### (4). Storied structures

- Storied: The arrangement of cells in horizontal series seen in tangential section.
- Storied structures are considered advanced than non-storied cells.

Modern taxonomists consider that the gross morphological characters are not always sufficient to provide means of differentiation in determining the genetically and evolutionary relationship between taxa. To achieve this the taxonomical evidences from anatomy, embryology, palynology, cytology, palaeobotany, ecology, biochemistry etc. are discussed.

Dr. V. Puri has said “One of the most significant modern trends in plant taxonomy is towards a synthesis between the older methods, outlook and more recent developments in our knowledge of plants”.

Bailey (1949) has said, if a truly natural classification is to be attained, it must be based upon “the analysis and the harmonization of evidence from all organs, tissues and parts”.

## **Embryology in Relation to Taxonomy**

A recognition of the value of Embryology in taxonomy was delayed because of the time and trouble involved in collecting embryological data. According to Maheshwari (1964) and Bhojwani and Bhatnagar (1978), the characters of taxonomic value in delimiting plant groups include the:

- ❖ Anther;
- ❖ Quadripartition of the microspore mother cell;
- ❖ Development and organisation of the pollen-grain,
- ❖ Development and structure of the ovule;
- ❖ Origin and extent of the sporogenous tissue in the ovule;
- ❖ Megasporogenesis and development of the embryosac;
- ❖ Form and organisation of the mature embryosac;
- ❖ Fertilisation;
- ❖ Endosperm;
- ❖ Embryo and
- ❖ Seed-coat.

### **Cyperaceae:**

In the family Cyperaceae, while all four microspore nuclei are produced after meiosis, three of them are cut off on one side of the pollen grain and only the fourth develops to form the generative cell and then the male gametes.

All genera and species of Cyperaceae studied in Europe and Japan (and at Delhi by Mr. C.K. Shah) show this character and it is possible to identify a member of this family just as definitely by a microscopic study of its anthers as by other floral characters.

Further, the simultaneous type of microspore formation and the functioning of all the four microspores in the Juncaceae indicate that it is this family from which the Cyperaceae have probably been derived.

### **Centrospermales:**

The Cactaceae agrees with the rest of the Centrospermales in having the following embryological characters:

- (a) Glandular anther tapetum whose cells become two-to four-nucleate;

- (b) Microspore-mother cells is which two meiotic divisions are succeeded by a simultaneous quadripartition into the microspores;
- (c) Trinucleate pollen-grains;
- (d) Campylotropous ovules with strongly curved funiculi and massive nucellar;
- (e) A hypodermal archesporial cell which cuts off a wall cell;
- (f) A micropyle formed by the swollen tips of the inner integument which protrude out and approach the functions;
- (g) Formation of a nucellar cap originating from, periclinal division of cells of the nucellar epidermis;
- (h) Functioning of the chalazal megaspore of the tetrad:
- (i) Formation of a monosporic eight-nucleate embryo-sac;
- (j) Functioning of the perisperm as the main storage region;
- (k) Disappearance of most of the endosperm in the mature seed generally leaving merely a single-layered cap over the radicle.

#### **Loranthaceae:**

The studies of Johri and associates (1957) on the Loranthaceae show that the Loranthoideae is embryologically different from the Viscoideae as regards mode of development of embryo-sac, endosperm, embryo and in the location of the viscid zone of the fruit and that the subfamilies should be raised to the status of families.

#### **Onagraceae and Trapaceae:**

A monosporic tetranucleate embryo-sac is characteristic of all members of the Onagraceae and is not found in any other family of angiosperms. The genus *Trapa* having an eight-nucleate embryo-sac, which was once placed in the Onagraceae, has since been removed and assigned to a new family Trapaceae.

Manasi Ram's (1956) work on *Trapa bispinosa* fully confirms this view. Earlier, Eames (1953) expressed the view that on anatomical evidence also *Trapa* does not belong to the Onagraceae and is not even closely related to it. Table I presents the embryological differences between the families Onagraceae and Trapaceae.

#### **Santalaceae:**

Gagnepain & Boureau (1946, 1947), raised doubts about the position of *Exocarpus* and stated that instead of being regarded as an angiosperm it should be assigned to the gymnosperms and given a place somewhere near the Taxaceae. Lam (1948) commented as follows: "At any rate, *Exocarpus* seems an

interesting case and probably represents a transition between the protangiospermous gymnosperms and the Monochlamydeae”.

The embryological studies of Manasi Ram (1958) have clearly shown, however, that *Exocarpus* is a perfectly valid angiosperm with an archesporial cell functioning as a megaspore mother cell, an embryo-sac of the Polygonum type, a cellular endosperm with a chalazal haustorium, and a pericarp derived from the wall of the ovary. Its correct position, therefore, lies in the Santalaceae to which it was assigned by previous systematists.

#### **Other taxonomal cases settled by embryological data:**

*Paeonia* was previously kept in Ranunculaceae but later on it was found that by anatomy and pollen characters, this genus differs from other members of Ranunculaceae. Embryological studies found that embryogeny of *Paeonia* is very different from other members of Ranunculaceae and this genus was then shifted from Ranunculaceae.

In Butomaceae *Butomus* is unique in having a monosporic 8-nucleate embryo sac; *Butomopsis*, *Limnocharis* and *Hydrocleis* has bisporic, 5-nucleate embryo sacs. *Butomus* is retained in Butomaceae while all the others are transferred to Alismataceae.

Embryological evidences supported Hutchinson's (1959) treatment of Alismataceae and Butomaceae as separate families and the placement of the latter along with Hydrocharitaceae in the same order.

The separation of *Hippocratea* from Celastraceae into a separate family Hippocrateaceae.

The genus *Sphenoclea* is placed under Campanulaceae based on embryological studies.

The splitting of Gentianaceae into Menyanthaceae and Gentianaceae; Malvaceae into Bombacaceae and Malvaceae.

Embryogeny of *Lemna*, *Wolffia* and *Arisaema* confirms older views of an intimate relationship of the duck weeds with the aroids.

It may be emphasized that while the embryologist lays no claim to erect a phylogenetic system of its own, embryological data need to be considered along with information from other sources in order to approach a natural system of classification.

### **Palynology in Relation to Taxonomy:**

#### **Pollen characters:**

Palynology is the science of pollen and spores and its applications. It is derived from the Greek word *palynēin* meaning to scatter. The significance of pollen attributes in taxonomy has been realised during the last three decades.

The outer wall of pollen-grains is endowed with unique structural traits which are broadly categorised in order of their importance in phylogeny into the apertures, exine ornamentation, exine strata, shape and size.

According to Bailey and Nast (1943), "there are families of dicotyledons in which the pollen is of very considerable taxonomic significance not only in the differentiation of subfamilies and tribes but also of genera and species". A few examples will illustrate the statement.

The Caryophyllales is recognised by centrospermous type of pollen with a spinulose and punctate-perforate tectum. The Malvaceae and the Compositae contain typically spinulose exine, the Plumbaginaceae verrucate pollen and the Gramineae smooth, sulcate ones.

#### **NPC system:**

The pollen classification is based on number-position character analysis, called NPC system. As a rule, the number of apertures is only one in the cryptogams and gymnosperms whenever the grains are aperturate but the position is distal in the latter and proximal in the former and the apertures are non-trichotomous (e.g. monolete) or trichotomous (e.g. trilete) in character.

The apertural conditions of pollen-grains have been looked upon as strong characters in solving taxonomic problems. It has been recommended that taxa with the same general NPC formula be grouped together and those showing aberrant NPC separately. For example, the Parietales of Engler-Diels has been probed by means of 'palynological compass needle'.

The NPC formula for the order is 345, i.e. pollen-grains are 3-termate (N3), zonotreme (P4) and colpate (C5). A significant variant is the Canellaceae where the pollen has one distal colpus; here NPC is 133, hence Hutchinson (1959) proposed shifting of Canellaceae from Parietales.

#### **Apertural conditions:**

A general analysis of the apertural conditions in the plant kingdom reveals that apertures are ill-developed (primorphous) in thallophytes. In the archegoniates (comprising bryophytes, pteridophytes and gymnosperms), pollen-grains are trimorphous and in the angiosperms polymorphous.

The above morphological situation provided a logical base for classifying the plant kingdom into the Primorphosporatae (Syn. Thallophyta), Trimorphosporatae (Syn. Archegoniatae) and Polymorphosporatae (Syn. Angiospermae) by Nair (1974). This analysis has thrown light on the phylogeny and evolution of the primitive angiosperms.

#### **Stenopalynous and Eurypalynous taxa:**

In angiospermic taxa, termed as "Stenopalynous", the pollen type is constant; while in others, called "Eurypalynous", there are different pollen types varying in size, shape, aperture, exine stratification, etc.

The stenopalynous taxa are, as a rule, very natural. The occurrence of a pollen type, representative of a stenopalynous taxon in a plant of doubtful affinity, may provide an important indication of its taxonomic position.

Amongst the eurypalynous taxa some may be natural and others quite heterogeneous. Different pollen types in eurypalynous taxa furnish important indications in classifying them into subgroups and then arranging these subgroups according to varying degrees of similarity between each other.

In certain cases this may even result in the splitting up of a taxon or submerging of others. Numerous examples of such rearrangements in families and genera have been given by Erdtman.

As pointed out by Bailey and Nast "There are families of dicotyledons in which the pollen is of very considerable taxonomic significance, not only in the differentiation of subfamilies and tribes, but also of genera and species". For example, after the studies of Lindau and Bremekamp pollen structure has become an indispensable character in the taxonomy of Acanthaceae.

#### **Number of nuclei in pollen:**

The number of nuclei in the pollen at the time of dispersal has been used by taxonomists. The angiosperm pollen is either binucleate or trinucleate according to the precocity of division of the generative nucleus. The binucleate condition is considered as more primitive than the trinucleate.

In the Centrospermae, the pollen is uniformly trinucleate. The monocot (Liliaceae) is binucleate, the apetalous and polypetalous dicots are binucleate and gamopetalous members trinucleate.

### **Ecology in Relation to Taxonomy**

The ecological criteria are of comparatively little direct importance in taxonomy, though ecological criteria at the interspecific level can not be neglected.

In flowering plants, tolerance and plasticity are widespread. The tolerance of a plant population is determined by its ability to survive and reproduce upon exposure to a range of environmental factors. The tolerance is greater when the range is wider. On the other hand, plasticity is ascertained by the degree to which the appearance of plants vary in moving from one set of factors to the other.

#### **Ecotypes:**

Ecological studies can help in determining the taxonomic status of a species. On the basis of developmental morphology, culture experiments and other analytical data, the two species of *Lindenbergia*, *L. polyantha* and *L. urticaefolia*, have been demonstrated to be ecotypes of the same species, the former being a calcicolous or a miniature form of the latter.

*Euphorbia thymifolia* exhibits ecotypic differentiation in response to the calcium content of the soil the red ecotype is a facultative calcicole and the green one an obligate calcifuge.

Pursuing the matter further, the red plant shows three physiologically distinct ecotypes. Depending on the soil exchangeable calcium, *Boerhaavia diffusa*, *Gomphrena celosioides* and *Mecardonia dianthera* give rise to appropriate calcicolous and calcifugous ecotypes.

*Euphorbia hirta* bears three forms: one upright form, growing in protected habitats, is a distinct ecotype from the other prostrate one; the latter also appears as a compact form of the footpath and a diffuse one of the grazed lands which are interconvertible in reciprocal transplants.

## Botanical Nomenclature

Botanical nomenclature is branch of botanical science that deals with determination or application of a correct name to a plant or taxon. It arose out of the need for a universal system of naming the plants. Since the beginning of spoken language people have attached names to plants or things important to them. Plants have been given common names or vernacular names that vary from language to language and country to country and therefore cannot be used universally. To overcome these difficulties raised by common names, botanists have given scientific names to all the known plants. Scientific names are methodical and universal and thus provide means for international communication. In botanical nomenclature the names given to the plants are either Latin names or names are taken from some other language and Latinized.

Before Linnaeus, the names of plants were descriptive or polynomials i.e. composed of several words in a series. (e.g., *Eupetorium cannabinum, foliss in caule ad genicula ternis, floribus parvis, umbellatum in summis caulibus dispositus, marilandicum*)

**Carolus Linnaeus** established binomial system of nomenclature in his *Species Plantarum* (1753). In binomial system of naming, genus and species – just two names - replace the long string of words used in polynomials. Thus after Linnaeus the name of above plant species became *Eupatorium purpureum*. A plant may have more than one common name, but will have only one scientific name (binomial).

First proper set of rules of nomenclature of plants was drafted by Alphonse de Candolle and passed by the International Botanical Congress at Paris in 1867. The code is known as Paris code. Subsequent Congresses and codes like Rochester code (1882), Vienna code (1905), American code (1907) and Brussels's code (1910) discussed various aspects of nomenclature and suggested many modifications and amendments in the rules. Two codes, American vs. European, existed till late 1800s and early 1900s. Efforts were made to harmonize the basic difference between the Vienna and the American codes at the Fifth International Botanical Congress held in Cambridge in 1930 and for the first time in botanical history, a code of nomenclature came into being that was international in function as well in name. International Botanical Congress is held at an interval of 5-6 years and the code is named after the name of the place where the congress is held. Several changes have been made in the code during the last 100 years and now the rules of nomenclature are almost stabilized.



## International Code of Botanical Nomenclature (ICBN)

The International Code of Botanical Nomenclature is the set of rules according to which plants are given their botanical names (scientific names). The code specifies the standards and forms of names to be applied to each taxon of plants. According to the code May 1, 1753, the date of publication of Linnaeus' *Species Plantarum*, is considered the starting point of present day nomenclature. Over the period of time several versions of code have been published, the most recent one is St. Louis code which the XVI International Botanical Congress adopted in 1999. This supersedes the earlier versions. The recent International Botanical Congress was held in Vienna in 2005 and the Vienna code will supersede the present St. Louis code.

It is beyond the scope of this chapter to enter into detailed discussion of the International Code of Botanical Nomenclature. Only salient features will be discussed here. The code is divided into three divisions:

- **Division I.** Principles
- **Division II.** Rules and Recommendations; further divided into seven chapters and sections (Articles 1-62).
- **Division III.** Provisions for the governance of the code

In addition, there are five appendices in the code:

- **Appendix I.** Names of hybrids
- **Appendix IIA.** Nomina familiarum, fungorum, pteridophytorum et fossilium conervenda et rejicienda (conserved and rejected family name of fungi, pteridophytes and fossils)
- **Appendix IIB.** Nomina familiarum bryopytorum et spermatophytorum conervenda (conserved bryophyte and spermatophyte family names)
- **Appendix IIIA.** Nomina generica conervenda et rejicienda (conserved and rejected generic names)
- **Appendix IIIB.** Nomina specifica conervenda et rejicienda (conserved and rejected specific names)
- **Appendix IV.** Nomina utique rejicienda (rejected names and all combinations based on these names)
- **Appendix V.** Opera utique oppressa (list of publications and the category of taxa that are not validly published)

The principle forms the basis of botanical nomenclature. The detailed provisions of the code are divided into rules, set out in the articles and recommendations. The main objective of the rules is to put nomenclature of the past into order and also provide for that for future. The rules are mandatory to follow. Names contrary to rules are considered illegitimate and cannot be maintained. The recommendations deals with subsidiary points, and are laid down to bring uniformity and clarity, particularly in future nomenclature. Names contrary to recommendations cannot be rejected, but are not examples to be followed.

## Principles of ICBN

There are six principles on which International code of botanical nomenclature is based.

- I. Botanical nomenclature is independent of zoological and bacteriological nomenclature.
- II. The application of the taxonomic groups is determined by means of nomenclatural types.
- III. The nomenclature of a taxonomic group is based on priority of publication.
- IV. Each taxonomic group with particular circumscription, position and rank can bear only one correct name, the earliest that is in accordance with the rules, except in specified cases.
- V. Scientific names of taxonomic groups are treated as Latin regardless of their derivation.
- VI. Rules of nomenclature are retroactive unless expressly limited.

The subject of nomenclature can be divided into following aspects:

### I. The Taxonomic Hierarchy (Concept of Genus, Species & Epithet)

It was Linnaeus who for the first time introduced hierarchical classification by placing each organism into a layered hierarchy of taxonomic categories or groups. Different groups of plants classified for taxonomic purposes are called taxa. Every individual plant is treated as belonging to an indefinite number of taxa of subordinate ranks, among which the rank of species is basic. The principle ranks of taxa in descending order are: Kingdom, Division, Class, Order, Family, Genus and Species. Thus, each species is assignable to a genus, each genus to a family and so on.

Feature of taxonomic hierarchy:

- a. Names of taxon above the rank of family is treated as plural noun and is written with an initial capital letter. Such names are generally based upon the name of an included genus, called the type genus. Each rank has a distinctive ending that is attached to the stem of the type genus. Suffixes used to form these names are:

- aceae for families (e.g. Magnoliaceae, ending on the genus Magnolia)
- ales for order (Magnoliales)
- opsida for class (Magnoliopsida)
- phyta for division (Magnoliophyta)

| Old names           | Alternative names |
|---------------------|-------------------|
| <i>Cruciferae</i>   | Brassicaceae      |
| <i>Guttiferae</i>   | Clusiaceae        |
| <i>Leguminosae</i>  | Fabaceae          |
| <i>Umbelliferae</i> | Apiaceae          |
| <i>Compositae</i>   | Asteraceae        |
| <i>Labiatae</i>     | Lamiaceae         |
| <i>Palmae</i>       | Arecaceae         |
| <i>Gramineae</i>    | Poaceae           |

- b. Names of genera are treated as nouns in the nominative singular, underlined (or italicized), and the first letter is capitalized. They may be taken from any source whatsoever, and may even be composed arbitrarily.
- c. The scientific name of a species is a binary combination consisting of the name of the genus followed by specific epithet.
- d. The specific epithet is usually considered to be an adjective; it is also italicized or underlined and written in all lower case. However, species named after people may be capitalized. The specific epithet may be derived from any source, or may even be composed arbitrarily.
- e. To be complete, the scientific names include authority (name of the person who described the species). The author's name is never italicized or underlined. To save the space, author's names are generally abbreviated (e.g. L. or Linn. For Linnaeus).
- f. Alternative family names. There are some family names, which were not based on any included genus, and their ending was also not according to rules. The code has suggested alternative names for such families. Use of both is allowed by the code.

## 2. Rule of Priority

Priority of publication is an important part of the rules of nomenclature and even forms one of the six principles of the code. Each family or taxon of lower rank can have only one correct name special exception being the families mentioned above. The earliest legitimately published name is the correct name. The correct name of a species is the combination of the earliest validly published generic name with the earliest validly published specific epithet, except in cases of limitation of priority by conservation.

Conserved names are legitimate even though initially they may have been illegitimate. The conserved names may be at level of family, genus or species. The same taxon may have been given different names by different workers; the later names are called 'Synonyms' and are illegitimate. For example, *Malus pumila* Miller, 1768; *Pyrus malus* Linn, 1753; *Malus domestica*, Bork.,1863; *Malus communis* Poiret,1884. Here the name *Pyrus malus* Linn. has priority over other names and all other names are synonyms.

Priority begins with the date of publication of Linnaeus' *Species Plantarum* (May 1, 1753) for Spermatophytes and Pteridophytes, and applies to the rank of family and below. Publication of the names of Spermatophytes and Pteridophytes earlier than 1753 has no status of priority. Principle of priority has also been limited for other groups of plants by ICBN.

## 3. The Type method or Typification

The principle and Articles of ICBN provide that the names of taxonomic groups will be based on nomenclatural types. This means that all names are permanently attached with some taxon or specimen designated as type. For species and infraspecific taxa the type is a specimen; this is that specimen on

which the species was based and originally described. Names of the taxa above the species, viz. genus, family etc. are based on the name of that immediate lower taxon on which that group was originally based. For example, the family Lamiaceae was based on the genus *Lamium*, and thus, *Lamium* is the type genus of the family Lamiaceae. *Manisuris myuros* L. was the species on which the genus *Manisuris* was based and thus *Manisuris myuros* is the type species of the genus *Manisuris*. The various kind of types designated by the Code are:

- **Holotype:** It is that single specimen (which may be whole plant or part of a plant) designated by the author of the species to represent the type of the species. According to the nomenclatural rules, it is obligatory to designate the Holotype.
- **Isotype:** These are the duplicate specimens of the same plant from which the Holotype was made; collected from the same place, same time and by the same author.
- **Syntype:** Any specimen cited in the protologue when no holotype was designated, or any one of two or more specimens simultaneously designated as types.
- **Lectotype:** A specimen or illustration designated from the original material as the nomenclatural type, if no holotype was selected at the time of publication, or if holotype is missing.
- **Paratype:** The specimens other than the Holotype and The Isotypes studied by the founding author at the time of describing new taxon are called paratype.
- **Neotype:** If Holotype, Isotype, Syntype or Paratypes are lost, or are not available, a specimen or illustration is selected to serve as nomenclatural type. This is called Neotype.
- **Epitype:** A specimen or illustration selected to serve as an interpretative type when the holotype, lectotype or previously designated neotype, or all original material associated with a validly published name, is demonstrably ambiguous and cannot be critically identified for purpose of the precise application of the name of the taxon.

The principle of typification does not apply to names of taxa above the rank of family.

#### 4. Valid and Effective Publication

Requirements of the code for the publication of new names are:

- a. The name must have proper ending for its rank, for example, -ceae for family, -ales for order.
- b. The name of the author and the rank must be given.
- c. The name must be accompanied with a full description and a diagnostic description in Latin.
- d. The nomenclatural type must be designated.
- e. In case of new combination, the full reference of the basionym must be given.

The publication is made effective by making printed matter available to the scientific community through its publication in a journal and its distribution to the libraries.

#### 5. Author citation

A botanical or scientific name should be accompanied by the name of author or authors who first published the name validly. The names of the authors are generally abbreviated. Linnaeus gave the name *Argemone mexicana*, and hence it should be written as *Argemone mexicana* Linn. Author's name provide historical information about the plant i.e. when and where was the name published.

- If two or more authors are associated with the publication of a new species, their name are joined by *etor* &, e.g. *Millettia auriculata* Wight *et* Arn.
- When a name proposed by one author is published validly by another author, the name of two authors are linked by *ex*, e.g. *Berberis asiatica* Roxb. *ex* DC.
- If an author publish a new species in the work or publication of another author, the names of authors are linked by *in*, e.g. *Nepeta ciliaris* Benth. *in*Wall.
- Parenthetical authors denote a change in the name of a taxon by transfer or by upgrading or downgrading the level of the taxon. When a species is changed from one genus to another, the name of the author whose specific epithet is being used in the changed name is placed within parenthesis, and the author who made the change outside the parenthesis, e.g. *Leucas nutans* (Roth) Spreng, based on the basionym *Phlomis nutans* Roth.

## 6. Legitimacy of names

To be legitimate, a name should not only be effectively and validly published, but should fulfill certain other criteria too. It should be the first validly published name for the taxon, because if there is already a validly published name for the taxon, the second name becomes a superfluous name.

## 7. Rejection of names

If two or more names have been applied to a taxon, the correct name must be the earliest legitimate name. Superfluous names (new names given to taxa already having legitimate names) are rejected. later homonyms (a name spelled exactly like a name previously and validly published for a taxon of same rank) are rejected. *Astragalus rhizanthus* Boiss(1843) is a later homonym of *Astragalus rhizanthus* Royle(1835) and must be rejected. A tautonym (a name where specific epithet repeats the generic name unaltered) is illegitimate and rejected., e.g. *Malus Malus*; *Nasturtium nusturtium*. Names not published validly, lacking typification or Latin diagnosis are rejected.

### 7. Change of names

Changes in names are necessitated due to:

- i) Detection of illegitimate names, such as tautonyms, later homonyms, etc
- ii) Discovery of an earlier valid name.
- iii) Change in the concept of the taxon, such as merger with the another taxon(reducing to synonymy), or splitting of one taxon in to two (creation of new taxon), raising the rank of a taxon, or transfer of a taxon from one higher taxon to another (new combination).

## Herbaria and Botanical Gardens

## Herbarium

Herbarium is a collection of pressed, dried plant specimens mounted on specified sheets, identified and arranged in the order of an approved and well known system of classification. It also refers to the institution where dried plant specimens are maintained and studied. eg. Herbarium of Botanical Survey of India, Coimbatore.

A twig with leaves, inflorescence or flowers is collected from shrubs and trees. In the case of herbs, the collected plant specimens should contain both vegetative and reproductive parts. They are dried by keeping them between the folds of old newspapers. It is necessary to change these papers at regular intervals, until the plants are well dried. The plant specimens along with their parts are dried in a plant press (fig.1.2). It consists of two boards with straps, which help in tightening the newspapers with specimens between the boards. The dried specimens are pasted on the herbarium sheets of standard size 41 cm X 29 cm. The process of attaching dried and pressed plant specimens on herbarium sheets is known as mounting of specimens. All the mounted specimens are sprayed with fungicide like 0.1% solution of Mercuric chloride. To protect these dried specimens from the attack of insects, pesticides such as naphthalene and carbon disulphide can be used. The heavy parts of plants such as seeds and fruits are kept in packets and attached to the sheets.

When a new name for a species is suggested, it is the rule that plant specimens of the same should necessarily be deposited in a recognized herbarium. These specimens are called type specimens. The name of the family is always based on type genus. These specimens are most valuable part of herbarium and they are handled with special care. They are stored in fire-proof cabinets.

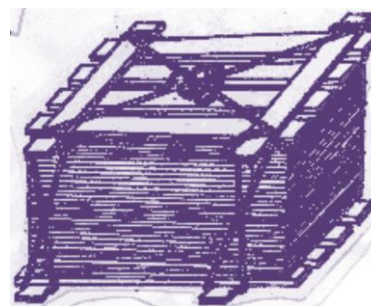
If the herbarium specimens are handled with special care, they will be in good condition for a long time. Precautions should be taken against attacks of fungi and insects. It is always better to use chemicals, which can repel the insects from herbarium specimens. The herbarium is always accompanied with a label. It carries the information about the botanical name of the plant, name of the family, habit, place and date of collection and name of the person who collected the specimens.

### Importance of herbarium

- Herbarium is a source of knowledge about the flora of a region or locality or a country.
- It is a data store in which the information on plants are

*Some Important National and International Herbaria*

| S.No. | Name of herbarium   | Total No. of specimens |
|-------|---|------------------------|
| 1.    | Herbarium of Royal Botanical Gardens, Kew, London, England. | More than 60,00,000    |
| 2.    | Herbarium of Indian Botanical Garden, Kolkata, India.       | More than 10,00,000    |
| 3.    | Botanical Survey of India, Coimbatore, Tamil Nadu.          | More than 1,90,000     |
| 4.    | Presidency College Herbarium, Chennai, Tamil Nadu.          | More than 10,000       |
| 5.    | Rapinat Herbarium, Trichy, Tamil Nadu.                      | More than 12,000       |



available.

- The type specimens help in the correct identification of plants.
- It provides materials for taxonomic and anatomical studies.
- Typical pollen characters have been well emphasized in taxonomy.
- Morphological characters of the pollen remain unaltered even after storage upto nearly 200 years.
- It is very much useful in the study of cytology, structure of DNA, numerical taxonomy, chemotaxonomy, etc. It acts as a reservoir of gene pool studies.

Because of its importance, several herbaria have been established at the national and international centers.

## **Botanical Gardens**

A **botanical garden** (or **botanic garden**) is a well-tended area displaying a wide range of plants labeled with their botanical names. It may contain specialist plant collections such as cacti and succulent plants, herb gardens, plants from particular parts of the world, and so on; there may be greenhouses, shadehouses, again with special collections such as tropical plants, alpine plants or other exotic plants. Visitor services at a botanical garden might include tours, educational displays, art exhibitions, book rooms, open-air theatrical and musical performances and other entertainment.

Botanical gardens are often run by universities or other scientific research organizations and often have associated herbaria and research programmes in plant taxonomy or some other aspect of botanical science. In principle their role is to maintain documented collections of living plants for the purposes of scientific research, conservation, display and education, although this will depend on the resources available and the special interests pursued at each particular garden.

The origin of modern botanical gardens can be traced to European medieval medicinal gardens known as physic gardens, the first of these being founded during the Italian Renaissance in the 16th century. This early concern with medicinal plants changed in the 17th century to an interest in the new plant imports from explorations outside Europe as botany gradually established its independence from medicine. In the 18th century systems of nomenclature and classification were devised by botanists working in the herbaria and universities associated with the gardens, these systems often being displayed in the gardens as educational "order beds". With the rapid rise of European imperialism in the late 18th century botanic gardens were established in the tropics and economic botany became a focus with the hub at the Royal Botanic Gardens, Kew, near London.

A **contemporary botanic garden** is a strictly protected natural urban green area where a managing organization creates landscaped gardens and holds documented collections of living plants and/or preserved plant accessions containing functional units of heredity of actual or potential value for purposes such as scientific research, education, public display, conservation, sustainable use, tourism and recreational activities, production of marketable plant-based products and services for improvement of human well-being.

The "New Royal Horticultural Society Dictionary of Gardening" (1999) points out that among the various kinds of organisations now known as botanical gardens there are many public gardens with little scientific activity, and it cites a more abbreviated definition that was published by the World Wildlife Fund and IUCN when launching the "Botanic Gardens Conservation Strategy" in 1989: "A botanic garden is a garden containing scientifically ordered and maintained collections of plants, usually documented and labeled, and open to the public for the purposes of recreation, education and research." This has been further reduced by Botanic Gardens Conservation International to the following definition which –

"Encompasses the spirit of a true botanic garden" and "A botanic garden is an institution holding documented collections of living plants for the purposes of scientific research, conservation, display and education."

Worldwide there are now about 1800 botanical gardens and arboreta in about 150 countries (mostly in temperate regions) of which about 400 are in Europe, 200 in North America, 150 in Russia, and an increasing number in East Asia. These gardens attract about 150 million visitors a year so it is hardly surprising that many people gained their first exciting introduction to the wonders of the plant world in a botanical garden.

Historically, botanical gardens exchanged plants through the publication of seed lists (these were called Latin: *Index Semina* in the 18th century). This was a means of transferring both plants and information between botanical gardens. This system continues today although the possibility of genetic piracy and the transmission of invasive species has received greater attention in recent times.

The International Association of Botanic Gardens was formed in 1954 as a worldwide organization affiliated to the International Union of Biological Sciences. More recently coordination has also been provided by Botanic Gardens Conservation International (BGCI) which has the mission "To mobilize botanic gardens and engage partners in securing plant diversity for the well-being of people and the planet". BGCI has over 700 members – mostly botanic gardens – in 118 countries and strongly supports the Global Strategy for Plant Conservation by producing a range resources and publications, and by organizing international conferences and conservation programs.





Communication also happens regionally. In the United States there is the American Public Gardens Association (formerly the American Association of Botanic Gardens and Arboreta), and in Australasia there is the Botanic Gardens of Australia and New Zealand (BGANZ).

### *Grand gardens of ancient history*

The Hanging Gardens of Babylon with the Tower of Babel in the background, a 16th-century hand-coloured engraving by Martin Heemskerck. Near-eastern royal gardens set aside for economic use or display and containing at least some plants gained by special collecting trips or military campaigns abroad, are known from the second millennium BCE in ancient Egypt, Mesopotamia, Crete, Mexico and China. In about 2800 BCE the Chinese Emperor ShenNung sent collectors to distant regions searching for plants with economic or medicinal value. It has also been suggested that the Spanish conquest of Mesoamerica influenced the history of the botanical garden as gardens in Tenochtitlan established by king Nezahualcoyotl, also gardens in Chalco and elsewhere greatly impressed the Spanish invaders, not only with their appearance but also because the indigenous Aztecs employed many more medicinal plants than did the classical world of Europe.

Early medieval gardens in Islamic Spain resembled botanic gardens of the future an example being the 11th century Huerta del Ray garden of physician and author Ibn Wafid (999–1075 CE) in Toledo. This was later taken over by garden chronicler Ibn Bassal (fl. 1085 CE) until the Christian conquest in 1085 CE. Ibn Bassal then founded a garden in Seville, most of its plants being collected on a botanical expedition that included Morocco, Persia, Sicily and Egypt. The medical school of Montpellier was also founded by Spanish Arab physicians and by 1250 CE it included a physic garden but the site was not given botanic garden status until 1593.



### *Beginnings of botanical science*

The Chelsea Physic Garden was established in 1673. Here's the garden in summer 2006. During the 16th and 17th centuries the first plants were being imported to these major Western European gardens from Eastern Europe and nearby Asia (which provided many bulbs) and these found a place in the new gardens where they could be conveniently studied by the plant experts of the day. For example, Asian introductions were

described by Carolus Clusius (1526–1609) who was director, in turn, of the Botanical Garden of the University of Vienna and Hortus Botanicus Leiden. Many plants were being collected from the Near East, especially bulbous plants from Turkey.

Clusius laid the foundations of Dutch tulip breeding and the bulb industry, and he helped create one of the earliest formal botanical gardens of Europe at Leyden where his detailed planting lists have made it possible to recreate this garden near its original site. "The *hortus medicus* of Leyden in 1601 was a

perfect square divided into quarters for the four continents, but by 1720 however it was a rambling system of beds, struggling to contain the novelties rushing in" and it became better known as the *hortus academicus*. His *Exoticorum libri decem* (1605) is an important survey of exotic plants and animals that is still consulted today. The inclusion of new plant introductions in botanic gardens meant that their scientific role was now widening as botany gradually asserted its independence from medicine.

In the mid to late 17th century the Paris Jardin des Plantes was a centre of interest with the greatest number of new introductions to attract the public. In England the Chelsea Physic Garden was founded in 1673 as the "Garden of the Society of Apothecaries". The Chelsea garden had heated greenhouses and in 1723 appointed Philip Miller (1691–1771) as Head Gardener. He had a wide influence on both botany and horticulture as plants poured into it from around the world. The garden's golden age came in the 18th century, when it became the world's most richly stocked botanical garden. Its seed-exchange programme was established in 1682 and still continues today.

### *Royal Botanic Gardens, Kew*

Royal Botanic Gardens, Kew, London, established 1759. The Palm House built 1844–1848 by Richard Turner to Decimus Burton's designs. The Royal Gardens at Kew were founded in 1760, initially as part of the Royal Garden set aside as a physic garden. William Aiton (1741–1793), the first Curator, was taught by garden chronicler Philip Miller of the Chelsea Physic Garden whose son Charles became first Curator of the original Cambridge Botanic Garden (1762). In 1759 the "Physick Garden" was planted and by 1767 it was claimed that "the Exotick Garden is by far the richest in Europe". Gardens such as the Royal Botanic Gardens, Kew (1759) and Orotava Acclimatization Garden (Spanish), Tenerife (1788) and the Real Jardín Botánico de Madrid (1755) were set up to cultivate new species returned from expeditions to the tropics; they also helped found new tropical botanical gardens. From the 1770s, following the example of the French and Spanish, amateur collectors were supplemented by official horticultural and botanical plant hunters. This was the great era of European, and especially British, imperialism which was "the means by which ideas, knowledge, styles of economy, politics and goods were given international reach" and justified as the spreading of "civilization" through "development" and "improvement".



At this time England was importing many woody plants from North America, and the popularity of horticulture had increased enormously encouraged by the horticultural and botanical collecting expeditions overseas fostered by the directorship of Sir William Hooker and his keen interest in economic botany. At the end of the 18th century, Kew, under the directorship of Sir Joseph Banks,

enjoyed a golden age of plant hunting, sending out collectors to the Southern African Cape, Australia, Chile, China, Ceylon (now Sri Lanka), Brazil and elsewhere, and acting as "the great botanical exchange house of the British Empire". From its earliest days to the present Kew has in many ways exemplified botanic garden ideals and is respected worldwide for the published work of its scientists, the education of horticultural students, its public programmes, and the scientific underpinning of its horticulture.

### *Plant classification*

The large numbers of plants needing description were often listed in garden catalogues and it was at this time that Carl Linnaeus established the system of binomial nomenclature which greatly facilitated the listing process. Names of plants were authenticated by dried plant specimens mounted on card (a *hortus siccus* or garden of dried plants) that were stored in buildings called herbaria, these taxonomic research institutions being frequently associated with the botanical gardens, many of which by then had "order beds" to display the classification systems being developed by botanists in the gardens' museums and herbaria. Botanical gardens had now become scientific collections as botanists published their descriptions of the new exotic plants, and these were also recorded for posterity in detail by superb botanical illustrations. In this century botanical gardens effectively dropped their medicinal function in favour of scientific and aesthetic priorities and the term "botanic garden" came to be more closely associated with the herbarium, library (and later laboratories) housed there than with the living collections – on which little research was undertaken.

### **Role and functions**

Many of the functions of botanical gardens have already been discussed in the sections above, which emphasize the scientific underpinning of botanical gardens with their focus on research, education and conservation. However, as multifaceted organizations all sites have their own special interests. In a remarkable paper on the role of botanical gardens Ferdinand Mueller (1825–1896), the director of the Royal Botanic Gardens, Melbourne (1852–1873), stated that "in all cases the objects [of a botanical garden] must be mainly scientific and predominantly instructive". He then detailed many of the objectives that were being pursued by the world's botanical gardens in the middle of the 19th century, when European gardens were at their height. Many of these are listed below to give a sense of the scope of botanical gardens' activities at that time, and the ways in which they differed from parks or what he called 'public pleasure gardens':

- Availability of plants for scientific research
- Display of plant diversity in form and use
- Display of plants of particular regions (including local)
- Plants sometimes grown within their particular families
- Plants grown for their seed or rarity
- Major timber (American English: *lumber*) trees
- Plants of economic significance
- Glasshouse plants of different climates
- All plants accurately labelled
- Records kept of plants and their performance

- Catalogues of holdings published periodically

Botanical gardens must find a compromise between the need for peace and seclusion, while at the same time satisfying the public need for information and visitor services that include restaurants, information centers and sales areas that bring with them rubbish, noise and hyperactivity. Attractive landscaping and planting design sometimes compete with scientific interests — with science now often taking second place. Some gardens are now heritage landscapes that are subject to constant demand for new exhibits and exemplary environmental management.

Many gardens now have plant shops selling flowers, herbs and vegetable seedlings suitable for transplanting; many, like the UBC Botanical Garden and Centre for Plant Research and the Chicago Botanic Garden, have plant breeding programs and introduce new plants to the horticultural trade.

work, etc.