

ANGIOSPERMS

Angiosperms: Origin And Evolution

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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 are also found in a far greater range of habitats than any other group of land plants.

Ancestors of Angiosperms

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.

Bennettilean ancestry

Since Saporta (Saporta and Marion, 1885) Bennettitales 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 Bennettitales they are whorled and mostly connate. The megasporophylls of the Bennettitales 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 Bennettitales 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 bennettitalean 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 Bennettitales cannot have been the ancestors of the angiosperms.

Though the Bennettitales 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. Further more, 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 inflorescence 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 Caytonialean 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 Ralian school. The Englerian school considered simplicity as primitive and complexity as advanced and is based on the concept of progressive evolution. The Ralian 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 Gunderson (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*, *Bellium*, *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 *Exospermum*.

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 Bennittiales. 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

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.

ANGIOSPERM TAXONOMY

Taxonomy, the science of classifying plants into groups and identifying them from each other, may be considered as the oldest sciences in the world. When the primitive man distinguished the plants that he can eat safely, from those he cannot, he laid the foundation of taxonomy. When he found that the fruits and seeds that he identified as useful to him are not available everywhere he was wandering, he thought of settling in one place and cultivating them, thus heralding the advent of civilization.

The first classification of plants was thus according to whether they are useful or not. When man came to realize that most of the plants are of some use or other, he attempted classification according to their size and habit – into herbs, shrubs and trees. This was followed by various “Natural” systems of classification. The discovery of the presence of male and female parts in the flowers and that the seeds are the products from the union of these two, generated various theories about the origin and evolution of the flower as well as many “Evolutionary” and “Phylogenetic” systems of classification.

What is Taxonomy?

The literal meaning of the term taxonomy means “lawful arrangement” or arrangement by rules (from Greek, *taxis* = arrangement; *nomos* = law, rule). This term can be used in any branch of science e.g. Taxonomy of plants, Taxonomy of animals, Taxonomy of rocks etc. This means in this chaotic world of objects, taxonomy brings an orderly classification of all the things.

The term taxonomy was first introduced to plant science by A.P. de Candolle in 1813. According to him plant Taxonomy means theory of plant classification.

The term taxonomy is based on the term taxon. The word ‘taxon’ was first used by a German Biologist Adolf Meyer in 1926 for animal groups. In botany it was proposed by Herman J. Lam in 1948.

Phases of Development in Plant Taxonomy

According to Davis (1963) there are four phases in Plant Taxonomy. They are

1) Exploratory or Pioneer Phase

The discovery, description, naming, identification and classification of plants.

2) Consolidation or Systematic Phase

The synthesis, mostly based on gross morphology, of field and herbarium knowledge in the preparation of floras, manuals, monographs, and form-based classification systems.

3) Experimental or Biosystematic Phase

The analysis of breeding systems, variation patterns, evolutionary potential and pertinent work in the chemical, numerical, cytological, anatomical, embryological and palynological aspects of systematics.

4) Encyclopaedic or Holotaxonomic Phase

The analysis and synthesis of all information and types of data in the development of one or more classification systems based on evolutionary or phylogenetic relationships.

Valentine and Love (1958) recognised the first three phases while Davis and Heywood (1963) added the fourth one.

The first two phases which are mainly descriptive and based on gross morphological features correspond to the “Alpha” taxonomy by Turrill (1938). The last two phases correspond to the “Omega” classification by Turrill (1938).

According to Radford *et al.* (1974) taxonomy includes identification, characterisation and classification.

Aims and Objectives

The three main aims of plant taxonomy are classification, identification and nomenclature.

Classification

Man has to distinguish objects around him. For this purpose he has to classify them. Early man classified objects around him as animate and inanimate, useful and unwanted, plants and animals etc. In plants he classified them as those that are useful to him and not useful to him. Then he classified them based on habit; herbs, shrubs and trees. When he found the sexual parts, the stamens and the ovary he tried to classify them based on these sexual parts. Later when the number of plants increased he tried to classify them based on Natural relationships. After the Theory of Evolution by Darwin Botanists are classifying the plants according to the phylogenetic relationships.

Identification

There are millions of species around man and these include several thousands of plant species. Man devised various methods to identify them. Modern botanists identify the plants with the help of keys.

Nomenclature

For communicating about the plants around him man has given names to plants. Since there are different languages botanists have devised a method of naming plants known as Binomial nomenclature. These names are in Latin.

Identification, nomenclature and classification are the three important aspects of plant taxonomy. These are the main aspects of modern taxonomy also. Evidences obtained from different branches and their utilization is the important part of modern plant taxonomy.

History of Plant Classification

Current plant classification systems are labors and insights of many workers throughout the centuries. According to Radford *et al.* (1976), although there are no sharp lines dividing the various periods, the history of plant classification can be broken down as follows:

- 1) Period of Ancients: to ca. 1500
- 2) Period of Herbalists: 1500-ca. 1580
- 3) Period of Mechanical Systems: 1580-ca. 1760
- 4) Period of Natural Systems: 1760 to ca. 1880
- 5) Period of Phylogenetic Systems: 1880 to date.

Period of Ancients

Theophrastus (370-285 BC)

Theophrastus, a student of Aristotle is considered as the Father of Botany. His two works about plants are *Enquiry into plants* and the *Causes of Plants*.

Theophrastus differentiated between centripetal (indeterminate) and centrifugal (determinate) inflorescences, recognized differences in ovary position and in polypetalous and gamopetalous corollas.

The plants were further recognized into annuals, biennials and perennials. Theophrastus wrote about nearly 500 different kinds of plants and he called them by the names then in common usage.

Parasara (250 – 120 B.C.)

Parasara was an Indian scholar who compiled *Vrikshayurveda* (Science of Plant Life), one of the earliest works dealing with plant life from a scientific stand point. Plants were classified into numerous families (ganas) on the basis of morphological features not known to the European classification until 18th century. Samiganyan (Leguminosae) were distinguished by hypogynous flowers, five petals of different sizes, gamosepalous calyx and a fruit, actually a legume. Swastikaganyan (Cruciferae) similarly has a calyx resembling a swastika, ovary superior, 4 free sepals, 4 free petals, six stamens of 2 are shorter and 2 carpels forming bilocular fruit.

Caius Plinius Secundus (23-79 AD)

“Pliny the Elder”, a Roman admiral wrote *Historia Naturalis* (AD 77) a 37 volume work where he described about the universe, plants and animals. 9 volumes of this work were devoted to medicinal plants.

Pedanius Dioscorides (First century AD)

Dioscorides was a contemporary of Pliny but we do not know exactly when he lived. He was a physician of Roman Emperor Nero. He traveled extensively to study plants. In his *Materia Medica* (AD. 1), Dioscorides described about 600 plant species and their uses. In this book Dioscorides grouped plants together with atleast a superficial degree of “natural” relationships, e.g., the mints (Lamiaceae) are grouped together and the umbels (Apiaceae) are grouped together. This work was illustrated and served to be one of the most authentic books for Europeans for next 1500 years. *De Historia stirpium* included both good descriptions and illustrations

Albertus Magnus (1193-1280)

He wrote on many subjects. The botanical work *De Vegetabilis* dealt with medicinal plants and provided descriptions of plants based on first hand information. Magnus was the first to recognize, on the basis of stem structure, the difference between Monocotyledonous and Dicotyledonous plants. In other major respects he accepted the classification of Theophrastus. The criteria used by Magnus for major categories are: leafy vs. non-leafy; leafy plants divided into Monocots and Dicots, Dicots divided into herbaceous and woody kinds.

Period of Herbalists

Herbal is an illustrated account of medicinal plants. In the late 1400's shortly after the advent of printing, a series of herbals was published under the name of *Gart der Gesundheit* or *Hortus Sanitatis*. These books were often more compilation of the local medical folklore, with crude illustrations, and they were usually published without attribution to any author.

Fifteenth and sixteenth century botany experienced a great general awakening in the field of medicine and classification. This was the period of plant description and illustration. Many of the world famous herbals appeared during these 200 years.

Otto Brunfels (1464 – 1534)

He was practicing physician, *Herbarium Vivae Eicones* (1530-1536), a 3 volume work, written by Otto Brunfels is not much valuable from the classification point of view but is well known for illustration of living plants. He was the first person to recognize the Perfect (flowers visible when held at arm's length) and Imperfecti (flowers not visible).

Jerome Bock (1498-1554)

Bock, a German, wrote under Latinisation his name as *Hieronymus Tragus*. He divided plants into trees, shrubs and herbs but endeavored to bring together related plants within these categories. He gave concise descriptions. In addition he provided notes on the natural distribution of many plants. He described all this in his book *Neue Kreuterbuch* (1539). He described 567 species.

Leonhart Fuchs (1501-1566)

Fuchs, a Professor of medicine, grew many of his medicinal plants and observed their characteristics. He gave fine engravings. He described New world plants. He was a Bavarian physician. His herbal, *De Historia stirpium* (1542) included both good descriptions and illustrations of 487 species of medicinal plants.

Valerius Cordus (1515-1544)

He traveled in the forests of Germany and Italy. His work *Historia Plantarum* published in 1561, many years after his death, contained accurate descriptions of 502 species, 66 apparently new. He gave excellent descriptions.

The quality of description and illustration improved greatly during the period of Herbalists. There was a large increase in the number of plants known; the discovery of new world had an important impact during this period. There was some attempt to group closely related plants together. Some large natural families were recognized, such as composites, umbels, grasses, rushes etc. Many genera commemorate herbalists names, as for example, *Brunfelsia* for Brunfels, *Fuchsia* for Leonard Fuchs, *Lobelia* for Mathias de l'Obel, *Gerardia* for John Gerard, *Clusia* for Charles L'Ecluse.

Period of Mechanical Systems

It is from the sixteenth and seventeenth centuries onwards that the science of botany developed as an independent discipline. As a result, there were attempts to study more and more plants and a large number of characters in order to arrive at a satisfactory classification.

Andraea Caesalpino (1519-1603)

Caesalpino was the first botanist to try to base a taxonomic scheme upon reason and logic rather than purely on utilitarian concepts. He was philosophically an Aristotelian in his approach and he based his classification on the assumption that certain features of plant structures were intrinsically more useful than others. Such an approach is termed *a priori* reasoning and while it may lead to erroneous conclusions it does provide a way of testing an hypothesis.

Caesalpino's (1583) famous book, *De plantis Libri* contains descriptions of about 1520 plant species. The most fundamental drawback of his system is total denial of sex inspite of observation of presence of ovary, seed and fruit.

Jean Bauhin (1541-1631)

Jean Bauhin, a French and Swiss physician, is important for his excellent illustrated *Historia Plantarum universalis* published posthumously (1650) in three volumes. This was a comprehensive work and dealt with synonymy of about 5000 plants. In addition, it included description, which for the first time in botanical history were good diagnoses of the species he treated. He recognized crucifers and labiates.

Gaspard Bauhin (1560-1624)

Gaspard Bauhin, a Swiss botanist and brother of Jean Bauhin, put out a monumental opus in his *Pinax theatri botanici* (1623). This is a register of 6000 different kinds of plants known to exist up to that time and it contains an account of what name the various different botanists and herbalists had used for each

plant. In other words, Gaspard Bauhin accounted for the rapidly developing synonymy. His other books include *Phytopinax* (1596), *Prodromus theatri botanici* (1620) and *Pinax theatri botanici*.

Gaspard Bauhin classified plants on the basis of texture and form. He is to be remembered also as one of the first to distinguish nomenclaturally between species and genera. To many of the plants classified and described by him, he gave a generic name and specific (trivial) epithet. This binary nomenclature, with which Linnaeus is usually credited, was founded, therefore, by Bauhin more than a century before its use by Linnaeus.

John Ray (1628-1705)

Another man who made a note worthy contribution to the growth of systematic botany throughout the 17th century was the Englishman, John Ray. He published numerous works, but most significant for us are his *Methodus plantarum nova* (1628) and the *Historia plantarum* (3 volumes, 1686-1704). Ray proposed a classification accounting for nearly 18000 species, and under the main divisions of woody and herbaceous plants, he recognized the taxa of monocots and dicots, the classes based on fruit type (cone bearing, nut bearing, bacciferous, pomiferous, pruniferous and siliquous), and subdivided these on the basis of leaf and flower characters.

Pierre Magnol (1638-1715)

French botanist Magnol was the first to use the term family in the classification of plants. In 1689 he listed 76 families. He used conspicuous characters of roots, stems, flowers and seeds.

Joseph Pitton de Tournefort (1656-1708)

Tournefort worked as a Professor of Botany at the Jardin des Plantes in Paris. He collected plants from Greece, Asia minor, France and Spain. His publications include *Elements de Botanique* (1694) and *Institutiones Rei Herbariae* (1700). He is the author of modern genus concept and is considered to have had a good concept of genera. He gave generic descriptions and recognized 698 genera and 10,146 species. Tournefort is also the first botanist to use the term Herbarium. Tournefort divided flowering plants into 2 large categories, trees and herbs. Each of these was subdivided into groups based on characters such as apetalous or petalous and then on polypetalous or gamopetalous and flowers regular or irregular

Carolus Linnaeus (1707-1778)

Carolus Linnaeus is regarded as father of modern taxonomic botany and zoology.

Rudolf Camerarius in 1694 discovered sexuality in plants. Linnaeus was impressed by the ideas of Camerarius and considered the male and female sex organs (stamens and gynoecium) as important for classification of plants. He classified all plants based on sexual characters and hence his classification is known as sexual system.

While working under the guidance of Dr. Rudbeck, Linnaeus published his first paper in 1729 on sexuality of plants. In 1730 he published, under the latinized title of *Hortus Uplandicus*, an enumeration of plants in Uppsala Botanic Garden. In this book he listed the plants according to Tournefort system. But in the revised edition of *Hortus Uplandicus* published in 1732 he arranged the plants according to his own system, his so-called sexual system. This served as the basis for his later publication *Systema Naturae* (1735), where he classified plants, animals and minerals. In 1737 four of his valuable publications—*Flora Lapponica*, *Hortus Cliffortianus*, *Critica Botanica* and *Genera Plantarum* have been published.

He proposed his sexual system of classification in *Genera plantarum* (1737) where he gave descriptions to 935 genera. This was published in five editions and two supplements and in all a total of 1336 genera were diagnosed.

Linnaeus' systematic contributions did not arrive on the scene in one piece. They were proposed in several publications over the years, but the place where he got it all together in his '*Species Plantarum*', a two volume catalogue of the plant kingdom, published in May, 1753. This book marks the first consistent use of binomial nomenclature, and it has subsequently been adopted by the botanical community as the starting point for modern botanical nomenclature. In *Species Plantarum* (1753) Linnaeus diagnosed 6000 species and 1000 genera.

Linnaeus recognized 24 classes, which are based on number, union and length of stamens. These classes were subdivided into orders on the basis of number of styles and unisexuality. All the non-flowering plants and lumped together in a single class, the Cryptogamia. Although this system is highly artificial it was accepted at that time because it provided a very easy means of identification.

In *Philosophia Botanica* (1751), Linnaeus enumerated 67 "natural orders". Some of these represent natural groups like Palmae, Orchidaceae, Graminae, Coniferae, Compositae, Boraginaceae etc, but some orders are quite mixed, the monocots and dicots appearing together.

Linnaeus had a large number of students who explored several parts of the world. He died in 1778 and his collections were sold by his widow to an English botanist, J.E. Smith. Later, these became the property of the Linnaean society of London, founded in 1788.

Period of Natural Systems

During this period plants were classified based on their relationships and plants that looked alike were kept together.

Michel Adanson (1727-1806)

Adanson, a French botanist, while exploring the plants wealth in Africa, realized the inadequacy of the Linnaean system and developed his own system in *Families des Plantes* (1763). He rejected artificial classifications. He emphasized equal weighing of characters and believed that all organs should be taken into account. He rejected *a priori* reasoning. Adanson is considered as "Grand Father of Numerical Taxonomy".

De Jussieu

The de Jussieu family of France had four members who made noteworthy contributions to botany. Antoine (1686-1758), Bernard (1699-1796), Joseph (1704-1779) and Antoine Laurent (1748-1836). The first three of them are brothers while Antoine Laurent is nephew of Bernard. All four of them were connected with the Jardin des Plantes in Paris. Antoine and Bernard studied under Pierre Magnol.

Bernard never published his system during his lifetime due to personal dissatisfaction over perfection of his system. He rearranged the plants in a garden at La Trianon, Versailles according to his own system, which was not based on habit and was not purely artificial.

Antoine Laurent de Jussieu published his uncle's system, with some improvements in '*Genera Plantarum*' (1789). This is the first major work to be natural in its approach, which in practice meant that plants that looked alike were grouped together.

Antoine Laurent de Jussieu divided the flowering plants into 15 classes and these classes were subdivided into 100 natural orders corresponding to most major families. Each of these was clearly differentiated, named and provided with a description. Some related families such as Palmae, Liliaceae, Amaryllidaceae and Iridaceae were grouped together.

de Candolle

Three generations of de Condolles have contributed much to the science of systematic Botany. The first of this Swiss-French family is Augustin Pyramus de Candolle (1778-1841).

A.P. de Candolle published in 1813 a book entitled *Theorie Elementaire de la Botanique* in which the basic principles of plant classification were given. He introduced the term Taxonomy to designate the theory of plant classification.

A.P. de Candolle's monumental work *Prodromus Systematis Naturalis Regni Vegetabilis* was an attempt to write a Flora for the whole world. This work began in 1816 and before A.P. de Candolle died in 1841 seven volumes have been published. The next 10 volumes, written by specialists were published under the editorship of his son, Alphonse de Candolle (1806-1893). In this book A.P. de Candolle, proposed to classify and describe every species of seed plants then known to science. The Prodromus included descriptions of 58, 975 species of Dicotyledons and Gymnosperms known at that time.

After Prodromus a monograph series was published by Alphonse and later his son Anne Casimir (1836-1918). About 100 such monographs have been published which, even now, provide a lot of information.

Stephan Endlicher (1805-1849)

Endlicher, a Viennese Botanist divided the plants into the Thallophytes (algae, fungi and lichens) and Cormophytes (mosses, ferns and seed plants). He presented this system in his book *Genera Plantarum* (1840). Lower dicots were apetalous groups, a practice later followed in later (Englerian) systems as opposed to the beginning with Ranalian groups in de Candolle, Bessey and Hallier systems. Dicots were divided into Apetalae, Gamopetalae and Dialypetalae. Some parasitic Angiosperms were placed with Cryptogams.

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 Vochysiacae and the Cyrilleae were incorporated later. These were not given separate numbers but were included as 20 a and 46 a respectively.

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 Pantarum. 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.

Period of Phylogenetic Systems

The theory of Evolution proposed by Darwin in 1858 influenced taxonomy in many ways. Several systems conforming to this theory have been proposed since then and still continue to be proposed.

Post Darwinian systems can be broadly categorized into two groups: the Englerian school and the Ralian school. The Englerian school considered simplicity as primitive and complexity as advanced and is based on the concept of progressive evolution. The Ralian School considered the Ranales group as the primitive and evolution proceeded in both progressive and retrogressive manner.

Englerian school

August Wilhelm Eichler (1839-1887)

Eichler, a German, proposed his classification in his book *Bluthendiagramme* (1875-1878). This was not a Phylogenetic system in the modern sense, but Eichler did accept the concept of evolution. In 1883 he elaborated his earlier treatise into a unified system accounting for all major groups of the entire plant kingdom. Eichler began Dicots with Amentiferae and united apetalous and polypetalous dicots. He considered simplicity as primitive.

Adolf Engler (1844-1930)

Engler was a Professor of Botany at the University of Berlin and Director of Berlin Botanical Garden. In 1892 he published *Guide to Breslau Botanic Garden*. Engler in collaboration with Karl Prantl (1849-1893) presented a 20 volume work *Die Natürlichen Planzefamilien* (1897-1915). This was an illustrated work, with modern keys. It provided a means for identification of all the known genera of plants from Algae to the most advanced seed plants. A revised edition of this work was published by Engler in collaboration with Gilg in 1924 and with Diels in 1936 under the *Syllabus der pflanzenfamilien*. Engler considered Monocotyledons primitive than Dicotyledons.

According to Engler and his associates the most primitive flowering plants in both Monocotyledons and Dicotyledons have apetalous simple flowers in strobilus like inflorescences. Engler considered unisexual flowers as primitive and bisexual flowers as advanced. The Englerian school further maintains that these unisexual flowers were wind pollinated like the cone of Gymnosperms and that the different groups of Angiosperms have been derived from various groups of Gymnosperms as well as from Pteridophytes, thus proposing a polyphyletic origin.

The seed plants (termed Embryophyta Siphonogama by Engler) were divided into Gymnospermae and Angiospermae. The angiospermae was divided into two classes Monocotyledonae and Dicotyledonae, the latter into two subclasses Archichlamydeae (composed of Apetalae without petals and Choripetalae with separate petals) and Metachlamydeae (with united petals).

Englerian evolutionary principles were challenged by Bessey (1897), Hallier (1905), Arber and Parkin (1907) and others. Among the objectionable features was the acceptance by Engler of the Dichlamydeous flowers as derived from Monochlamydeous flowers, the derivation of all parietal placentation in syncarpous ovaries from axile placentation, of free central from parietal, and the interpretation of the majority of simple unisexual flowers as primitive.

Richard von Wettstein (1862-1931)

Wettstein, an Austrian Botanist, presented his system of classification in 1901 in *Handbuch der Systematischen Botanik*. This underwent revisions, the fourth and the last one being published posthumously in two volumes (1930-35). Wettstein believed that Angiosperms have evolved from Gymnosperms, which were very much similar to the present day Gnetales. His system is similar to that of Engler but Wettstein rearranged the relative positions of many Dicots families. Wettstein also differed with Engler in considering Dicotyledons as more primitive than Monocotyledons and the later to have

been derived from the Ranalean stocks. He considered the Casuarinales as the primitive most Angiospermous groups and believed that *Casuarina* was derived from *Ephedra*.

Alfred Barton Rendle (1865-1938)

An Englishman, Rendle presented his system in his 2-volume Classification of flowering plants (1904, 1925). A revision of this has been published in 1930 and 1938. This system is basically Englerian type and considered Amentiferae as primitive group. The Monocotyledons were treated primitive than Dicotyledons. Wind pollination and woodiness were considered by Rendle as primitive features. Rendle does not claim that his classification is phylogenetic in the complete sense. He divided the Dicotyledons into 3 groups. Monochlamydeae, Dialypetalae and Sympetalae.

The Ralian School

Arber and Parkin (1907) proposed that the extinct Gymnospermous group Bennettitales has given rise to *Magnolia* like Angiosperms. Bennettitales have bisexual strobilus and *Magnolia* also has bisexual flower. This view has been supported by several authors like Bessey (1915), Hutchinson (1959, 1969), Cronquist (1968, 1981), Takhtajan (1967, 1980) and others.

Charles Edwin Bessey (1845-1915)

C.E.Bessey was a Professor of Botany at the University of Nebraska, and student of Asa Gray. Bessey in 1893 read a paper presenting the nucleus of what was to become his well-known classification; this was amplified in 1897 and his final treatment published in 1915. This, in many respects, was a modification of Bentham and Hooker's system realigned according to evolutionary principles.

Bessey considered the seed plants to have had polyphyletic origin and to be composed to three separate phyla of which he dealt only with the Anthophyta (Angiosperms). He derived the Anthophyta from his Cycadophyta and the latter from implied Bennettitalian ancestry. He divided the Angiosperms into the Oppositifoliae (Dicotyledons) and Alternifoliae (Monocotyledons). His classification of these two taxa was based on evidence obtained from Paleobotanical, ontogenetical and morphological studies of homologies.

Bessey considered the Ranales or their ancestors as primitive Angiosperms. The evolutionary lines of development of various orders were summarized in a way of branched prickly pear plant, which is popularly known as Bessey's Cactus. There are three major series derived from a single stock. The branch on the left represent monocots, the other two branches indicate the two major groupings, Cotyloideae (the Rosalean line) and Strobiloideae (the Ralian line) within the Dicotyledons.

Bessey derived a set of "dicta" or propositions based upon his own experience and sources in the literature as to what structural features might be considered primitive, and what might be advanced, Primitive, in this case, refers to being present in the most ancient plants; advanced refers to a feature more recently evolved. Besseyan dicta have influenced the evolutionary thoughts of Angiosperm taxonomists to a very great extent. Subsequent studies have corroborated most of his conclusions. Bessey's contribution probably lies more in his set of "Phylogenetic dicta" than in his system per se. The phylogenetic dicta, which Bessey propounded, have, with modifications, provided the theoretical base and guiding principles for most of contemporary systems of Angiosperms classification.

John Hutchinson (1884-1972)

Hutchinson of England proposed a phylogenetic system in his 2-volume work. *The Families of Flowering Plants* (1926, 1934). He published his revised concepts in his book *British Flowering Plants* (1948). The revised edition of *The Families of Flowering Plants* was published in 1959 and third edition in 1973. In 1969 he published *Evolution and Phylogeny of Flowering Plants*. He based his system on 22 phylogenetic principles or dicta.

Hutchinson's system is basically in the Bentham- Bessey tradition. He considered the Angiosperm to be monophyletic possibly from an ancestral groups of Gymnosperms related to the Cycadeoids. He divided the Angiosperms into two subphyla Dicotyledons and Monocotyledons. The Dicotyledons were divided into those considered

“fundamentally and predominantly” woody (Lignosae) and those considered

“fundamentally and predominantly” herbaceous (Herbaceae). Parallel lines of development were considered to have occurred within two main groups. The Monocotyledons were derived from the stocks ancestral to Ranales.

The Division Lignosae started with Magnoliales and ended with Verbenales while Herbaceae started with Ranales and ended with Lamiales. The apocarpous Monocotyledons – Alismataceae and Butomaceae – were considered to be the most primitive members of the group because of their close resemblance to Ranales. There are three lines of monocot evolution-Calyciflorae, Corolliflorae and Glumiflorae. In the last revision in 1969 Hutchinson divided the Angiosperms into 411 families.

This includes 82 orders and 342 families in Dicotyledons and 29 orders and 69 families in Monocotyledons. The Lignosae was divided into 54 orders and Herbaceae into 28 orders.

The division of Dicotyledons into Lignosae and Herbaceae is considered unnatural by most workers. By this division he kept the related families widely separated e.g.; Magnoliaceae and Ranunculaceae, Umbelliferae and Araliaceae, Labiatae and Verbenaceae. Bignoniaceae and Scrophulariaceae. Hutchinson divided Monocots into 3 subphyla and considered criteria based on inflorescence to be phylogenetically more fundamental than those based on ovary position. In the phylogenetic tree, Hutchinson did not derive one order directly from the other but from its ancestral stock.

This is more safe and acceptable than to believe any present day order to be directly ancestral to any other.

Although Hutchinson's system has not been followed widely, it has provided a sound basis for the later phylogenetic systems by Oswald Tippo, Cronquist, Takhtajan and others. The arrangement of families within the Monocotyledons has been appreciated all over the world.

Hutchinson is generally considered as a “Splitter” as he accepted a large number of orders and families.

Karl Christian Mez (1866-1944)

Mez, Professor of Botany at the University of Koenigsberg, Germany, presented a paper in 1926, which was modified in 1936. This system is based on serodiagnostics data. According to this theory the relationships between larger groups of genetically related plants could be determined by study and analysis of their protein reactions. This physiological approach sometimes known as the serum diagnosis, consisted of mixing an extracted plant protein with serum, either, in animal or *in vitro* and following the formation of antibodies in the inoculated serum, of adding a protein extract prepared from the plant whose relationship is being studied. If a precipitation occurred when this second protein extract was added to the serum, a genetical relationship was believed to be indicated to exist between the plants involved. The proximity of relationship was considered to be indicated by the abundance and character of the precipitate and the degree of dilution of the serum and extract at which the precipitation would occur.

Armen L. Takhtajan (1910-1997)

Armen Takhtajan was Head of the Department of Higher plants at the Komarov Botanical Institute in Leningrad, Russia. He proposed an evolutionary system of classification of flowering plants in 1959 in his book *Die Evolution der Angiospermen* (in German). This was explained in 1966 in *System and Phylogeny of Flowering Plants* whose revised edition appeared in 1987 (both in Russian). An English version of his system appeared in 1969 in *Flowering Plants-Origin and Dispersal*. He revised his system in 1980 in Botanical review, in 1987 *Systema Magnoliophytorum* and lastly in 1997 in *Diversity and Classification of Flowering Plants*.

Takhtajan system is basically Bessey-Hallier tradition. Takhtajan took all available evidence-morphological, anatomical, embryological, cytological, chemical, ultrastructural, palynological and paleobotanical into consideration in classifying Angiosperms. His latest classification is according to International Code of Botanical Nomenclature. Accordingly Takhtajan divided the Magnoliophyta

(Angiosperms) into two classes-Magnoliopsida (Dicotyledones) and Liliopsida (Monocotyledones). Magnoliopsida is considered to be primitive. Takhtajan system is Ranalean in tradition and considered that Angiosperms have evolved from Bennettitalean ancestors and the Magnoliales were considered primitive among Angiosperms.

Takhtajan (1997) in his last classification divided the Magnoliopsida into 11 subclasses-Magnoliidae, Nymphaeidae, Nelumboideae, Ranunculidae, Caryophyllidae, Hamamelididae, Dilleniidae, Rosidae, Cornidae, Asteridae and Lamiidae while class Liliopsida was divided into six subclasses – Liliidae, Commelinidae, Arecidae, Alismatidae, Triuridae and Aridae. His subclasses were divided into super orders and orders. The Magnoliopsida includes 11 subclasses 56 super orders, 175 orders and 488 families while Liliopsida is categorized into 6 subclasses, 16 super orders, 38 orders and 104 families. So a total of 592 families are seen in the classification of Angiosperms by Takhtajan. Takhtajan considered the Liliopsida (Monocotyledones) to have been derived from Magnoliales. Takhtajan's system is based on his 67 phyletic principles.

He considered Angiosperms to be monophyletic and Monocotyledons to have been derived from primitive Dicotyledons. Among the subclass Takhtajan considered Magnoliidae to be the primitive most group from which all other subclasses have been derived. He considered the Asteridae the most Advanced among Magnoliopsida. He considered the vesselless Dicotyledonous family Winteraceae as the primitive most family among Angiosperms and Poaceae the most advanced family among Angiosperms.

For many years Takhtajan considered Winteraceae along with Degeneriaceae to represent the most primitive angiosperms. Finally, however, he chose Degeneriaceae as the most primitive family, placed under the order Magnoliales. He shifted Winteraceae to a separate order Winterales higher up in the phyletic line after order Eupomatiales after Magnoliales. This is interesting in light of the fact that many contemporary authors, including Cronquist (1988) and Thorne (1983, 1992) regard Winteraceae as the primitive most family of the living angiosperms.

Arthur Cronquist (1919-1992)

Arthur Cronquist of New York Botanical Garden presented a system in his book *Evolution and Classification of Flowering Plants* (1968). His revised system appeared in 1981 in his book *An Integrated System of Classification of Flowering Plants*. He further revised this in 1988 in his book *The Evolution and Classification of Flowering Plants* (ed. 2).

Cronquist's system is similar to that of Takhtajan except for minor details. Cronquist also took all the evidences-morphology, anatomy, embryology, palynology, chemistry, serology, cytology, ultrastructure-into consideration while classifying the flowering plants. Cronquist's system is also according to International Code of Botanical Nomenclature with regard to names of taxa.

Cronquist divided the Angiosperms into Magnoliopsida and Liliopsida. The Magnoliopsida is divided into six subclasses Magnoliidae, Hamamelidae, Caryophyllidae, Dilleniidae, Rosidae and Asteridae. The Liliopsida is divided into 5 subclasses-Alismatidae, Arecidae, Commelinidae, Zingiberidae and Liliidae. There are no super orders. The Magnoliidae is divided into 8 orders and 39 families, Hamamelidae into 11 orders and 25 families, Caryophyllidae into 3 orders and 14 families, Dilleniidae into 13 orders and 78 families, Rosidae into 18 orders and 116 families and Asteridae into 11 orders and 49 families. In the class Liliopsida Alismatidae is divided into 4 orders and 16 families, Arecidae into 4 orders and 6 families, Commelinidae into 7 orders and 16 families, Zingiberidae into 2 orders and 9 families and Liliidae into 2 orders and 19 families. A total of 386 families are there in Angiosperms in Cronquist's (1988) system of which 320 are under Magnoliopsida (Dicotyledones) and 66 under Liliopsida (Monocotyledones). Cronquist's system is also Ranalian and considered the Angiosperms to have been derived from Bennettitalean ancestors. Cronquist also considered the Magnoliidae the primitive group among Angiosperms and the Monocotyledons have been derived from primitive Ranales. Cronquist (1981) provided keys to orders and families.

Rolf Dahlgren (1932-1987)

Rolf Dahlgren of Copenhagen, Denmark presented the Angiosperm evolution in the form of a shrub in transection (Dahlgren, 1975, 1977, 1980). Dahlgren divided the Angiosperms into two classes

Magnoliopsida and Liliopsida. The Magnoliopsida have been divided into 24 super orders, 80 orders and 346 families while Liliopsida are divided into 7 super orders, 26 orders and 92 families.

Robert Thorne (1920-)

Robert Thorne (1976, 1977) presented a system of classification, which is Ranaian in tradition. He divided the Angiosperms into 21 super orders, 50 orders, 74 suborders and 321 families. The Angiospermae was named as Annonopsida and divided into two subclasses Dicotyledonae and Monocotyledonae. Thorne's system is also in the Bessey-Hallier tradition.

Identification

Recognising an unknown plant is an important constituent taxonomic activity. A plant specimen is identified by comparison with already known herbarium specimen in a herbarium, and by utilising available literature.

Taxonomic Keys

Keys are the devices useful in identifying an unknown. They represent one type of taxonomic literature. Flora usually incorporate diagnostic key by the use of which the reader may identify an unknown plant with one included in the work concerned. Keys do not offer descriptions of the plants concerned, but state only the essential diagnostic characters by means of which the taxa can be identified. Ideally they use the most conspicuous and clear cut characters without special regard to these considered taxonomically the most important. For this reason the sequence of taxa is often quite artificial and such keys are frequently termed artificial keys.

A synopsis is a device, usually in the format of a key presenting graphically the technical characters which in general or in the aggregate differentiate taxa. Such keys are known as synoptic keys. They were used in nineteenth century floras and monographs. These are usually very unsuitable for the purpose of identification.

Sequential keys

A sequential key is an artificial analytical device or arrangement whereby a choice is provided between two contradictory propositions resulting in the acceptance of one and the rejection of the other. A sequential key may be short and limited to a single pair of contradictory propositions (a couplet), or it may be composed of an extensive series of these.

The currently conventional and most acceptable type of key is the dichotomous key, a type usually of one of two formats. The Dichotomous key was first used by R. Morrison in his *Plantarum Umbelliferarum Distributio nova* (1672). In the Dichotomous key each statement of couplet are arranged in Yokes, and each lead is identified by a letter or figure. Each successive subordinate Yoke is indented under the one preceding it. An example of the dichotomous key with indented or Yoked leads is given below.

This example has been taken from "Flora of Anantapur District" by Pullaiah and Yesoda (1989).

Families of Gamopetalae

Indented Key

1. Stamens more than petals:
 2. Flowers usually unisexual; stamens inserted on the receptacle.....EBENACEAE
 2. Flowers bisexual, stamens inserted on the corollaSAPOTACEAE
1. Stamens as many as petals or fewer:
 3. Ovary inferior:

- 4. Anthers united around style (syngenesious):
 - 5. Flowers in involucrate heads, ovary unilocular.....ASTERACEAE
 - 5. Flowers not in heads, ovary 2-more locular.....LOBELIACEAE
 - 4. Anthers free.....RUBIACEAE
- 3. Ovary superior:
 - 6. Ovary unilocular:
 - 7. Ovule solitary.....PLUMBAGINACEAE
 - 7. Ovules 2-many.....GENTIANACEAE
 - 6. Ovary 2-many locular:
 - 8. Plants carnivorous, with small insectivorous bladders...
.....LENTIBULARIACEAE
 - 8. Plants not carnivorous:
 - 9. Leafless parasitic herbs, without chlorophyllOROBANCHACEAE
 - 9. Leafy plants with chlorophyll:
 - 10. Anthers forming a column with style and stigma (Gynostegium), pollen
agglutinated into wax like masses or pollinia.....ASCLEPIADACEAE
 - 10. Anthers free, pollen not agglutinated like masses ...APOCYNACEAE

The second arrangement of a dichotomous key has bracketed or parallel leads. The two leads of each couplet are always together. An example of bracketed key is given below.

Bracketed Key

- 1. Stamens more than corolla lobes.....2
- 1. Stamens as many as petals or fewer.....3
- 2. Flowers usually unisexual, stamens inserted on the receptacle.....EBENACEAE

- 2. Flowers bisexual, stamens inserted on the corollaSAPOTACEAE
- 3. Ovary inferior.....4
- 3. Ovary superior.....6
- 4. Anthers united around style (Syngenesious).....5
- 4. Anthers free RUBIACEAE
- 5. Flowers in involucrate heads, ovary unilocular.....ASTERACEAE
- 5. Flowers not in heads, ovary 2-more locular.....LOBELIACEAE
- 6. Ovary unilocular7
- 6. Ovary 2-many-locular.....8
- 7. Ovule solitaryPLUMBACINACEAE
- 7. Ovules 2-many.....GENTIANACEAE
- 8. Plants carnivorous, with small insectivorous bladdersLENTIBULARIACEAE
- 8. Plants not carnivorous.....9
- 9. Leafless parasitic herbs without chlorophyll.....OROBANCHACEAE
- 9. Leafy plants with chlorophyll10
- 10. Anthers forming a column with style and stigma (Gynostegium), pollen agglutinated into wax like masses or pollinia.....ASCLEPIADACEAE
- 10. Anthers free, pollen not agglutinated like masses.....APOCYNACEAE

Example No. 2

Genera in Caesalpiniaceae (from Flora of Andhra Pradesh by Pullaiah and Chennaiah 1997).

Indented Key

1a. Plants spiny:

2a. Leaflets reduced to scales or minute.....*Parkinsonia*

2b. Leaflets not reduced:

3a. Inflorescence corymb.....*Poinciana*

3b. Inflorescence not corymb:

4a. Pod winged at apex*Pterolobium*

4b. Pod not winged at apex.....*Caesalpinia*

1b. Plants not spiny:

5a. Leaves bilobed:

6a. Leaflets separated, fruits compressed.....*Hardwickia*6b. Leaflets jointed up to half of the length, fruits not compressed...*Bauhinia*

5b. Leaves compound:

7a. Leaves 2-pinnate:

8a. Inflorescence long raceme.....*Peltophorum*8b. Inflorescence corymbose clusters.....*Delonix*

7b. Leaves 1-pinnate:

9a. Petals 5.....*Cassia*9b. Petals 3 perfect, 2 sterile.....*Tamarindus***Bracketed Key**

1a. Plants spiny.....2

1b. Plants not spiny.....5

2a. Leaflets reduced to scales or minute.....*Parkinsonia*

2b. Leaflets not reduced.....3

3a. Inflorescence corymb.....*Poinciana*

3b. Inflorescence not a corymb.....4

4a. Pod winged at apex.....*Pterolobium*4b. Pod not winged at apex*Caesalpinia*

5a. Leaves bilobed.....6

5b. Leaves compound.....7

6a. Leaflets separated, fruits compressed*Hardwickia*6b. Leaflets jointed up to half of the length, fruits not compressed.....*Bauhinia*

7a. Leaves 2-pinnate.....8

7b. Leaves 1-pinnate.....9

8a. Inflorescence long receme.....*Peltophorum*8b. Inflorescence corymbose clusters.....*Delonix*9a. Petals 5.....*Cassia*9b. Petals 3 perfect, 2 sterile.....*Tamarindus*

Example. 3. Indented Key

Species of *Cleome*A. Gynandrophore present.....*C.gynandra*

AA. Gynandrophore absent:

B. Plants viscous with stalked gland including ovary and capsule.

C. Stamens 6.....*C.monophylla*

CC. Stamens 10 or more:

- D. Leaves simple.....*C. simplicifolia*
 DD. Leaves compound, palmately lobed.....*C. viscosa*
 BB. Plants not viscous, ovary and capsule glabrous:
 E. Leaves 3-foliolate, stamens 6:
 F. Fruits cylindric.....*C. aspera*
 FF. Fruits compressed, flat.....*C. felina*
 EE. Leaves 5-9-foliolate, stamens numerous.....*C. chelidonii*

When this key is changed into a bracketed key, then:

- A. Gynandrophore present.....*C. gynandra*

AA. Gynandrophore absent.....B

- B. Plants viscous with stalked gland including ovary and capsule.....C
 BB. Plants not viscous, ovary and capsule glabrous.....E
 C. Stamens 6.....*C. monophylla*
 CC. Stamens 10 or more.....D
 D. Leaves simple*C. simplicifolia*
 DD. Leaves compound, palmately lobed.....*C. viscosa*
 E. Leaves 3-foliolate, stamens 6.....F
 EE. Leaves 5-9-foliolate, stamens numerous.....*C. chelidonii*
 F. Fruits cylindric.....*C. aspera*
 FF. Fruits compressed, flat.....*C. felina*

There are advantages and disadvantages to each of this type of dichotomous keys. The yoked type has the advantage of grouping similar elements in such a manner that they can be grasped visually as groups. However in extended keys of this type there is a sloping and shortening of lines to the right with a result of loss of economy of page space. In the parallel or bracketed type, the advantages of the indented format are lost and conversely the disadvantages are offset, because there is no opportunity in the bracketed type to group blocks of leads visually with elements having one or more characters in common. In this type of format, however, all leads are of approximately the same line length and produce maximum efficiency of page space.

Suggestions for the Use of Keys

1. Select appropriate keys for the materials to be identified. The keys may be in a flora, manual, guide, handbook, monograph or revision. If the locality of unknown plant is known, select a flora, guide or manual treating the plants of that geographic area. If the family or a genus is recognized, one may choose to use a monograph or revision. If locality is unknown select one of the manuals treating such plants since most floras do not include cultivated plants unless naturalized.
2. Read both leads of a couplet before making a choice. Even though the first lead may seem to describe the unknown material, the second lead may be even more appropriate.
3. Use a glossary to check the meaning of terms do not understand.
4. Verify your results by reading a description, comparing the specimen with an illustration or an authentically named herbarium specimen.

Suggestions for Construction of Keys

1. Identify all groups to be included in a key.
2. Prepare a description of each taxon.
3. The key characters should be contrasting and not overlapping. Use macroscopic morphological characters and constant character states when possible. Avoid characters that can only be seen in the field.
4. Construct strictly dichotomous keys.
5. Use at least two characters per lead when possible.
6. Start both leads of a couplet with the same word if at all possible and successive leads with different words.
7. Mention the name of the plant part before descriptive phrases, e.g., leaves alternate, not alternate leaves or flower blue, not blue flowers.
8. Place those groups with numerous variable character states in a key several times when necessary.
9. Construct separate keys for dioecious, for flowering or fruiting materials and for vegetative materials when pertinent.

Multi-access Keys

Where as the sequential keys have a single commencing point i.e., a fixed sequence, multiaccess keys can be commenced at any position. Multiaccess keys are usually produced not on pages in a book, but on separate punched cards. They were apparently first used by A.T.J. Bianchi in 1931 and by S.H. Clarke in 1936. There are two types of punched card key. In the edge-punched key there is one card for each combination of attributes (i.e. one for each taxon) and each attribute is represented by one of the holes punched around the perimeter of the card. If a taxon possesses a particular attribute that position is clipped out to form an open notch instead of a circular hole. All the cards are stacked up with their corresponding holes aligned, and an attribute possessed by the specimen to be identified is chosen. A thin rod or knitting needle is then pushed through the appropriate position and the rod is lifted horizontally and gently shaken. All those cards (taxa) possessing that attribute will fall away from the stack leaving the cards without that attribute on the rod. The latter are put aside and the others are gathered up and the process repeated with them using further characters, until only one card falls out of the stack.

In the body-punched key (polyclave) the holes are punched in rows in the main body of the card. In this case each card represents an attribute and each taxon occupies a standard position on the card, if the taxon possesses that attribute its position is punched out. To identify a specimen some of its attributes are listed and the appropriate cards are selected. These are aligned and taxa which possess all the attributes being tested will show a hole right through the stack when held up to the light. Cards (attributes) are added to the stack until only one hole (taxon) remains.

Other punched card keys include *A polyclave to the monocotyledonous families of the world – a computer generated identification key* by C.K.Rao and J.Pankhurst (1986) and *British grasses: a punched-card key* by R.J.Pankhurst and J.M.Allison (1985). Both the above keys have been published by British Museum of Natural History.

Taxonomic Literature

Various forms of literature incorporating description, illustrations and identification keys are useful for proper identification of unknown plants. The library is therefore as important in taxonomic work as a herbarium and a knowledge of taxonomic literature is vital to the practising taxonomist. The literature of taxonomy is one of the oldest and most complicated literatures of science. Several bibliographic references, indexes and guides are available to help taxonomists to locate relevant literature concerning a taxonomic group or a geographical region. The major forms of literature helpful in identification are described below.

Floras

A Flora is the systematic enumeration of plants of a given region. It may be a small area, a district, a state, a country or a continent. Floras, especially modern Floras, give complete citation of the species according to ICBN, description, distribution, keys to the genera, keys to species and often illustrations.

e.g.,

Continent:	<i>Flora Europaea</i> by T.G.Tutin <i>et al.</i> (1964-80), <i>Flora Australiensis</i> by G. Benthams (1863-78).
Country:	<i>Flora of British India</i> by J.D.Hooker(1872-97), <i>Flora of India</i> by Botanical Survey of India (1994-), <i>Flora Malesiana</i> by C.G.Steenis (1948), <i>Flora USSR</i> by V.L.Komarov and B.K.Shishkin (1964-80).
State :	<i>Flora of Andhra Pradesh</i> by Pullaiah <i>et al</i> (1997), <i>Flora of Karnataka</i> by C.J.Saldanha (1986), <i>Flora of Orissa</i> by Saxena and Brahmam (1994).
District:	<i>Flora of Anantapur district</i> by Pullaiah and Yesoda (1989), <i>Flora of Medak District</i> by Pullaiah <i>et al</i> (1998), <i>Flora of Hassan Disctrict</i> by Saldanha and Nicolson (1978).

Manuals:

A manual is a more exhaustive treatment than a Flora, always having keys for identification, description and glossary. Manuals do not necessarily indicate place of deposition of plant specimens included. The main emphasis is placed on providing suitable keys and diagnostic descriptions.

e.g., *Manual of cultivated plants* by L.H. Bailey (1949),
Manual of Aquatic Plants by N.C.Fassett (1957),
Manual of Indian Forest Botany by Bor (1953)

Monographs:

A Monograph is a comprehensive taxonomic treatment of taxonomic group, generally a genus or a family. It gives significant information of a morphological and taxonomic nature concerning taxon. Strictly speaking it should cover the taxon as it exists throughout the world. Monograph gives information on anatomy, cytology, chemistry, genetics, geography, ecology etc.

e.g., The genus *Pinus* by N.T.Mirov (1967),
The genus *Crepis* by Babcock (1947),
The genus *Datura* by Blackslee *et al.* (1959).
Monograph on Indian Subtribe Cassiinae (Caesalpinaceae) by V.Singh 2001.

Revision:

Revision is a taxonomic treatment of a genus or family. It covers only morphological aspects.

Journals:

Several Botanical societies, Botanical gardens, Herbaria and Publishing companies are publishing Journals of Taxonomic research. Some of them are given below.

Rheedia Published by Indian Association for Angiosperm Taxonomy,

Bulletin Botanical Survey of India published by Botanical Survey of India,

Journal of Economic and taxonomic Botany published by Scientific Publishers, Jodhpur,

Taxon published by International Association of Plant Taxonomy, Berlin.

Kew Bulletin published by Royal Botanic Garden, Kew, England,

Systematic Botany from New York

Annals of Missouri Botanic Garden from U.S.A.

Plant Systematics and Evolution published by Springer – Verlag, New York.

General Taxonomic Indexes:

From time to time several indexes have been prepared for Angiosperms. Indexes serve as an aid to locating quickly the source of original publication of a name.

Index Kewensis Plantarum Phanerogamarum:

This is a comprehensive index of scientific names of seed plants. It was published in 1893-1895 in two volumes under the direction of J.D.Hooker and B.D.Jackson. It consists of an alphabetical list of genera published from the time of Linnaeus to the year 1885. Under each generic name was given, in alphabetical sequence, every species epithet known to have been published followed by the name of the author, the place of publication and an indication of the native country of that plant. Later on supplements were published regularly at the interval of 5 years. So far 19 supplements have been published by Kew Botanical Gardens. The Index Kewensis and supplements are now available on CD-ROM and it includes 968,000 records.

Gray Herbarium Card Index, Cambridge, Mass.

A card index is a data base of 287,225 records of New World Vascular plant taxa at the level of species and below.

Index Holmiensis

Published from Swedish Museum of Natural History it gives Plant distribution maps of vascular plants. 8 Volumes have been published up to 1995.

Index Londonensis, Oxford 1900-1935.

This is an alphabetical index of illustrations of flowering plants, ferns and fern allies appearing from 1753 to 1935.

Flowering Plant Index of Illustrations and Information:

It was compiled by R. T. Saacson (1979). It is a 2-volume index of all illustrations of flowering plants.

Index Nominum Genericorum:

It is a 3-volume work published in 1979 and gives a list of all generic names. The first supplement appeared in 1986. It is also available on the internet.

Dictionaries:

Numerous valuable Dictionaries have been published but by far the most useful is Dictionary of Flowering Plants and Ferns published by J.C. Willis. The 8th edition revised by Airy Shaw appeared in 1973. The book contains valuable information concerning genera and families, providing name of the author, distribution, family and number of species in the genus.

Suggested Further Reading

- 1) Davis, P.H. and V.H. Heywood. 1963. *Principles of Angiosperm Taxonomy*. Oliver and Boyd. London.
- 2) Jones, S.B. Jr. and A.E. Luchsinger. 1986. *Plant Systematics*. Prentice hall, New Jersey.
- 3) Lawrence, G.H.M. 1951. *Taxonomy of Vascular Plants*. MacMillan, New York.
- 4) Naik, V.N. 1984. *Taxonomy of Angiosperms*. Tata McGraw Hill, New Delhi.
- 5) Pullaiah, T. 2004. *Taxonomy of Angiosperms*. Regency Publications, New Delhi (2nd ed.).
- 6) Radford, A.E., W.C. Dickison, J.R. Massey and C.R. Bell. 1976. *Vascular Plant systematics*. Harper and Row, New York.
- 7) Singh, G. 1999. *Plant Systematics: Theory and Practice*. Oxford & IBH. New Delhi.
- 8) Sivarajan, V.V. 1991. *Introduction to the Principles of Plant Taxonomy*. Oxford & IBH, New Delhi.
- 9) Singh, Gurcharan. 1999. *Plant Systematics Theory and Practice*. Oxford & IBH, New Delhi.
- 10) Stace, C.A. 1980. *Plant Taxonomy and Biosystematics*. Edward Arnold, London.