

Diversity of Seed Plants and Their Systematics

Angiosperms II (Nomenclature, Classification with emphasis on Bentham and Hooker and Engler and Prantl, Taxonomic evidence – Role of Cytology, Phytochemistry and Taxometrics)

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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, 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.

History and Development of Plant Classification

In order to understand the field of taxonomy or classification at the present day, it is necessary to have some knowledge of the history of the subject and the development of the ideas associated with it. The observations made by the earlier workers were never wasted; subsequent workers with some modifications incorporated them into classifications. Scientists have struggled to find correct classification systems to use. They have eventually agreed on the systems we use today.

The discipline of plant classification has extremely deep cultural roots in all parts of the world. Ancient men who made their living by gathering food from the wild were probably much more familiar with the local plants, in terms of species recognition, than most people today. Though several cultural groups like African, Asian and Native American carried a wealth of botanical information into modern times, present systems of angiosperm classification have been derived from a European base. Historical development of classification is briefly reviewed here.

The Ancients

Theophrastus (370 – 285 B.C.). He was a Greek philosopher and is regarded as the “Father of Botany”. He was born in the city of Eresus. A pupil of Plato, and later a pupil and assistant to Aristotle, he embodied to the full extent the culture and learning of ancient Greece. For most of his life he lived in the midst of Lyceum botanical garden, established by Aristotle at Athens, and there he taught and wrote books representing many fields of knowledge. Theophrastus covered most aspects of botany: description of plants, distribution, classification, propagation, germination and cultivation. He is accredited with more than 200 publications; only few of his writings survive today. His two important botanical works “**Inquiry into Plants**” and “**The causes of Plants**” provided a systematic treatment of over 500 species according to habit (herbs, under-shrubs, shrubs and trees) and separated according to flowering and non-flowering. He recognized and described families among flowering plants, such as carrot family, known today as Umbelliferae (Apiaceae). He recognized genera, in the sense of a group of species, and applied to them Greek names then in use. A few generic names currently in use, such as *Daucus*, *Asperagus*, *Anemone*, and *Narcissus*, originated during his time.

Dioscorides (1st century A.D.) was a Greek physician in Roman army. His most famous work was *De Materia Medica*, which discussed the medicinal qualities of 600 plants. This included natural grouping of species that represent well-defined modern families (Apiaceae, Fabaceae, Lamiaceae). The plant descriptions in his *De Materia Medica* were adequate for identification, including methods of preparation, medicinal uses, and doses. His work was used in various translations and editions for next 1000 years.

The Middle Or Dark Ages

The period from the fall of the Rome to the Renaissance is often called dark ages because of intellectual stagnation. Very little original botanical work was done during this period. Most workers copied and translated the ancient work of Greeks and Roman.

Albertus Magnus (1193-1280 A.D.) was only botanist of note during this period. His contemporaries popularly called him “Doctor Universalis”. In his work *De Vegetabilis* he is believed to have first differentiated monocots from dicots.

RENAISSANCE, THE HERBALISTS AND TRANSITION PERIOD

The renaissance in Europe that started in the 14th century marked the beginning of an active period in which artistic, social, scientific, and political thoughts turned into new directions. Two major technological innovations – printing press and science of navigation – contributed to renaissance and especially to plant taxonomy. With the invention of printing press in 1440, many large volumes about plants and their medicinal uses, known as herbals, were produced throughout Europe. The authors of these books (herbals) are known as ‘herbalists’. It helped making knowledge available about the practical uses of plants, primarily from medicinal standpoint, to all. Herbalists did not propose any original systems of classification but marked the period of original work rather than copying the ancient work. Navigation made explorations easy and the collection of new species from ongoing explorations forced the herbalist to extend the initial efforts of the ancients to structure and order flowering plant diversity. Many natural and well-defined genera and families were established during this period. Prominent herbalists and their works are:

Otto Brunfels (1464-1534). German Herbalist. *Herbarium Vivae Eicones*.

Gerome Bock (1469-1554). German. *Neu Kreuterbuch*.

Leonhard Fuchs (1501-1556). German. *De Historia Stirpiu*, *New Kreuterbuch*.

John Gerard (1542-1612). English. *The Herball*, or, *Generall Historie of Plantes*.

Rombert Dodoens (1517-1585). Flemish. *Cruydeboek*.

Herbalists advanced science of botany but systems adopted by herbalists although commendable in their own way, had very little systematic basis. It was from the sixteenth and seventeenth century onwards that attempts were made to study more and plants and a large number of characters in order to arrive at a satisfactory classification. Some of the 16th and 17th century botanists are:

Andrea Caesalpino (1519-1603), an Italian, tried to base his classification on logic rather than utilitarian concept. He published *De Plantis* in 1583, which contain description of about 1500 plants. This was the first methodical classification of plants based on definite morphological criteria. Caesalpino recognized the usefulness of fruits and seeds in classification. His views influenced the later botanists like Tournefort, John Ray and Linnaeus.

Casper Bauhin (1560-1624). A Swiss botanist; published *Pinax theatri botnici* in which he listed 6000 plants. He also provided synonymy i.e. the other names used for a species by earlier workers and binomials for many plants that he named. Bauhin is credited with modern concept of genera and species.

John Ray (1628-1705), a British botanist and philosopher formulated the principle that all parts of the plant should be used for classification- a principle now recognized as the corner stone of a natural system. His system of classification is presented in his *Methodus Plantarum* (1703), which contain description of 18000 species of plants. He grouped plants by their resemblance to one another and divided the plant kingdom into herbs and trees and further divided herbs into imperfectae (flowerless) and perfectae (flowering plants). Flowering plants and trees were further divided into dicotyledons and monocotyledons.

J.P. de Tournefort (1656-1708). French botanist produced a classification that was purely artificial (based on few features). He is regarded as the “father of genus concept”. In his publication *Institutiones Rei Herbarie* (1700) he provided descriptions for 698 genera. He differentiated genera on the basis of floral and vegetative characters. Linnaeus later adopted most of the Tournefort’s genera that were distinguished by floral characters. The systems based on habit and the pre-Linnaean era ends with the system of Tournefort.

The Sexual Or Artificial System

The botanical research on the European flora and subsequent explorations resulted in the collection of more and more plants by the eighteenth century that required a simple and efficient system of naming and classification. This demand produced several purely artificial systems of which Linnaeus’ sexual system is most important

Carolus Linnaeus (1707-1778). It is to Swedish botanist, Carolous Linnaeus, that we owe the modern methods of naming plants. He is considered as “Father of Taxonomy”. Before the time of Linnaeus it was the general custom to name plants with a single name followed by a set of descriptive nouns and adjectives (polynomials). Linnaeus established what has come to known as ‘binomial system’ of nomenclature, which involves naming of plants by two names – one for the genus and one for the species. In addition to establishing the practice of binomial nomenclature, Linnaeus also set up a system of classification that was more comprehensive than any previously devised. This system is usually called as ‘sexual system’ or ‘artificial system’, because Linnaeus based his classification on number of stamens and their relation to one another and to other floral parts. Linnaeus divided plants into 24 classes, of which 23 were of flowering plants and the 24th class includes non-flowering plants i.e. ferns, mosses, fungi and algae. While the artificial approach allowed quick sorting and identification, its application produced unnatural grouping. The important publications of Linnaeus are: *Syatema Naturae*(1735), *Genera Plantarum*(1737) and *Species Plantarum*(1753). Because of the consistent use of binomial nomenclature, the date of publication of his *Species Plantarum* (1st May, 1753) is considered as a starting point of the modern botanical nomenclature.

The system of Linnaeus was very simple and convenient and remained in force until the beginning of the 19th century.

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 **Sir J.D. Hooker** (1817-1911). These two English botanists associated with Royal Botanic Gardens, Kew, presented the most elaborate natural system of classification in their three-volume work *Genera Plantarum* (1862-83). This was a major landmark in botany, for its system as well as for its quality. All genera of seed plants then known were very carefully and accurately described in Latin observing living specimens or dissected herbarium material. The geographical distribution of each genus was given. They followed de Candolle's system with some modifications. The *Genera Plantarum* provided the classification of seed plants, including gymnosperms, describing 200 orders (equivalent to present day families) and 7569 genera. The larger genera were further divided into subgenera and sections. They estimated the seed plant to include 97,205 species. This was the last great work produced on the assumption that angiosperm taxa are fixed entities, unchanging through time and placed on earth by God. British and Indian herbaria are still arranged following the system of Bentham and Hooker.

Bentham and Hooker divided seed plants into three classes (Dicotyledones, Gymnosperms and Monocotyledones), three sub-classes, 21 series, 25 cohorts and 202 orders (initially 200 orders). Orders Vochysiaceae and Cyrillae were incorporated later.

OUTLINE OF SYSTEM OF BENTHAM AND HOOKER, 1862-1883

I. CLASS: DICOTYLEDONES (two cotyledones, exogenous growth)

Sub class 1. POLYPETALAE (petals separate)

Series I. Thalamiflorae (Petals and stamens hypogynous and usually many)

Cohort 1. Ranales (Gynoecium apocarpus)

Orders: 1, Ranunculaceae; 2, Dilleniaceae; 3, Calycanthaceae; 4, Magnoliaceae;
5, Annonaceae; 6, Menispermaceae; 7, Berberidaceae; 8, Nymphaeaceae

Cohort 2. Parietales (Parietal placentation)

Orders: 9, Sarraceniaceae; 10, Papavaraceae; 11, Cruciferae; 12, Capparideae; 13,
Resedaceae; 14, Cistineae; 15, Violarieae; 16, Canellaceae; 17, Bixineae

Cohort 3. Polygalineae (Calyx and corolla 5, ovary 2 locular)

Orders: 18, Pittosporaceae; 19, Tremendreae; 20, Polygaleae; 20a, Vochysiaceae

Cohort 4. Caryophyllinae (Free central placentation, ovary 1-locular)

Orders: 21, Frankeniaceae; 22, Caryophyllae; 23, Portulacaceae; 24, Tamarascineae

Cohort 5. Guttiferales (Stamens numerous, calyx imbricate)

Orders: 25, Elatineae; 26, Hypericineae; 27, Guttiferar; 28, Ternstroemiaceae; 29, Dipterocarpeae; 30, Chlaenaceae

Cohort 6. Malveles (Stamens numerous, calyx valvate)

Orders: 31, Malvaceae; 32, Sterculiaceae; 33 Tiliaceae

Series II. DISCIFLORAE (Ovary superior, immersed in the disc of flower)

Cohort 7. Geraniales (Ovules pendulous, raphe ventral)

Orders: 34, Lineae; 35, Humiriaceae; 36, Malpighiaceae; 37, Zygophylleae; 38, Geraniaceae; 39, Rutaceae; 40, Simarubeae; 41, Ochnaceae; 42, Burseraceae; 43, Meliaceae; 44, Chaillatiaceae

Cohort 8. Olacales (Ovules pendulous, raphe dorsal)

Orders: 45, Olacineae; 46, ilicineae; 46a, Cyrilleae

Cohort 9. Celastrales (Ovules erect, raphe ventral)

Orders: 47, Celastrineae; 48, Stackhousieae; 49, Rhamneae; 50, Ampelideae

Cohort 10. Sapidales (Ovules scending, raphe ventral or inverted)

Orders: 51, Sapidaceae; 52, Sabiaceae; 53, Anacardiaceae

Ordines anomaly: 54, Coriareae; 55, Moringeae

Series III. CALYCIFLORAE (Sepals united, often adnate to ovary; stamens peri- or, epigynous, ovary often inferior)

Cohort 11. Rosales (Flowers usually bisexual, regular or irregular; stamens indefinite, often twice or more the number of petals, styles distinct)

Orders: 56, Connaraceae; 57, Leguminosae; 58, Rosaceae; 59, Saxifragaceae; 60, Crassulaceae; 61, Droseraceae; 62, Hamamelideae; 63, Bruniaceae; 64, Halorageae

Cohort 12. Myrtales (Flowers regular or irregular, stamens definite, rarely indefinite, flowers peri- or epigynous)

Orders: 65, Rhizophoreae; 66, Cobretaceae; 67, Myrtaceae; 68, Melastomaceae; 69, Lythraeae; 70, Onagraceae

Cohort 13. Passiflorales (Ovary syncarpous, parietal placentation)

Orders: 71, Samydaceae; 72, Loaseae; 72, Turneraceae; 74, Passifloreae; 75, Cucurbitaceae; 76, Begoniaceae; 77, Datisceae

Cohort 14. Ficoidales (Flowers regular or irregular, ovary syncarpous, inferior to Superior, parietal, basal or axile placentation)

Orders: 78, Cactaceae; 79, Ficoideae

Cohort 15. Umbellales (Flowers regular, usually bisexual, ovary inferior, umbel inflorescence)

Orders: 80, Umbelliferae; 81, Araliaceae; 82, Cornaceae

Sub Class 2. GAMOPETALAE (Petals fused)

Series IV. Inferae (Ovary inferior, stamens no. = petal no. and alternating with them)

Cohort 16. Rubiales (Stamens epipetalous, anthers distinct, ovary 2- many locular, ovules 1- many)

Orders: 83, Caprifoliaceae; 84, Rubiaceae

Cohort 17. Asterales (Stamens epipetalous, ovary 1- locular, 1-ovuled)

Orders: 85, Valerianeae; 86, Dipsaceae; 87, Calycereae; 88, Compositae;

Cohort 18. Campanales (Stamens free, ovary 2-6 locular, ovules many)

Orders: 89, Stylideae; 90, Goodenovieae; 91, Campanulaceae

Series V. Heteromerae (Ovary superior, stamen as many or double the number of petals, carpels more than 2)

Cohort 19. Ericales (stamens double or as many as corolla lobes and alternating with them, ovary 2-many locular)

Orders: 92, Vacciniaceae; 93, Ericaceae; 94, Monotropeae; 95, Epacrideae; 96, Diapensiaceae; 97, Lennoaceae

Cohort 20. Primulales (Stamens as many as petals and opposite them, ovary 1locular)

Orders: 98, Plumbagineae; 99, Primulaceae; 100, Myrsineae

Cohort 21. Ebenales (Stamens as many as petals and opposite them, ovary 2-many locular)

Orders: 101, Sapotaceae; 102, Ebenaceae; 103, Styraceae

Series VI. Bicarpellatae (Stamens as many as petals and alternating with them, ovary bicarpellay and superior)

Cohort 22. Gentianales (Corolla regular, leaves opposite)

Orders: 104, Oleaceae; 105, Salvadoraceae; 106, Apocynaceae; 107, Asclepiadaceae; 108, Loganiaceae; 109, Gentianaceae

Cohort 23. Polemoniales (Corolla actinomorphic, leaves alternate)

Orders: 110, Polemoniaceae; 111, Hydrophyllaceae; 112, Boraginaceae; 113, Convolvulaceae; 114, Solanaceae

Cohort 24. Personales (Corolla zygomorphic, ovules many)

Orders: 115, Scrophulariaceae; 116, Orobanchaceae; 117, Lentibulariaceae; 118, Columelliaceae; 119, Gesneriaceae; 120, Bignoniaceae; 121, Pedaliaceae; 122, Acanthaceae

Cohort 25. Lamiales (Corolla zygomorphic, ovules 4)

Orders: 123, Myoporineae; 124, Selaginaceae; 125, Verbenaceae; 126, Labiatae

Ordo anomalus: 127, Plantagineae

Sub Class 3. MONOCHLAMYDEAE (Perianth 1 two seriate, mostly sepaloid)

Series VII. Curvembryeae (Endosperm mealy, embryo curved, ovary one ovuled)

Orders: 128, Nyctagineae; 129, Illecebraceae; 130, Amaranthaceae; 131, Chenopodiaceae; 132, Phytolaccaceae; 133, Batideae; 134, Polygonaceae

Series VIII. Multiovulatae aquaticae (Many ovuled aquatic herbs)

Order: 135, Podostemaceae

Series IX. Multiovulatae terrestris (Many ovuled terrestrial herbs)

Orders: 136, Nepanthaceae; 137, Cytineae; 138, Aristolochiaceae

Series X. Micrembryeae (Carpel 1-2 ovuled, seed endospermic, embryo minute)

Orders: 139, Piperaceae; 140, Chloranthaceae; 141, Myristiceae; 142, Monimiaceae

Series XI. Daphnales (Ovary usually monocarpellary, ovules 1-few, stamens perigynous, perianth usually sepaloid)

Orders: 143, Laurineae; 144, Proteaceae; 145, Thymeliaceae; 146, Penaeaceae; 147, Elaeagnaceae

Series XII. Achlamydosporeae (Ovary 1 locular, 1-3 ovuled, seeds without testa)

Orders: 148, Loranthaceae; 149, Santalaceae; 150, Balanophoreae

Series XIII. Unisexuales (Flowers unisexual)

Orders: 151, Euphorbiaceae; 152, Balanopseae; 153, Urticaceae; 154, Platanaceae; 155, Leitneriaceae; 156, Juglandaceae; 157, Myricaceae; 158, Casuarinaceae; 159, Cupuliferae

Series XIV. Anomalous families (Ordines anomaly)

Orders: 160, Salicineae; 161, Lacisternaceae; 162, Empetraceae; 165, Ceratophylleae

CLASS 2 – GYMNOSPERMAE

Orders: 164, Gnetales; 165, Coniferae; 166, Cycadaceae

CLASS 3- MONOCOTYLEDONES (One cotyledon, endogenous growth)

Series XV. Microspermae (Inner perianth petaloid, ovary inferior, seeds minute)

Orders: 167, Hydrocharideae; 168, Murmanniaceae; 169, Orchidaceae;

Series XVI. Epigynae (Inner perianth petaloid, ovary inferior, endosperm plenty)

Orders: 170, Scitamineae; 171, Bromeliaceae; 172, Haemodoraceae; 173, Irideae;
174, Amaryllideae; 175, Taccaceae; 176, Dioscoreaceae

Series XVII. Coronarieae (Inner perianth petaloid, ovary free and superior)

Orders: 177, Roxburghiaceae; 178, Liliaceae; 179, Pontederiaceae; 180,
Philydraceae; 181, Xyridaceae; 182, Mayaceae; 183, Commelinaceae;
184, Rapateaceae

Series XVIII. Calycinae (Inner perianth sepaloid, ovary free)

Orders: 185, Flagellariaceae; 186, Juncaceae; 187, Palmae

Series XIX. Nudiflorae (Perianth absent or represented by hairs or scales)

Orders: 188, Pandaneae; 189, Cyclanthaceae; 190, Typhaceae; 191, Aroideae;
194, Lemnaceae

Series XX. Apocarpae (Perianth in 1 or 2 whorls, or absent; ovary superior,
apocarpous, no endosperm)

Orders: 193, Triurideae; 194, Alismaceae; 195, Niadaceae

Series XXI. Glumaceae (Flowers solitary, sessile in the axils of bracts and arranged
in heads or spikelets with bracts; perianth of scales or none, ovary
1- locular, 1- ovuled)

Orders: 196, Eriocaulaceae; 197, Centrolepideae; 198, Restiaceae; 199, Cyperaceae;
200, Gramineae

Phylogenetic Classifications

Evolutionary theory proposed by Darwin (1859) influenced taxonomy in various ways. This theory states that all species today are the result of an extensive process of evolution that began several billion years ago with single celled organisms. As the theory of evolution became widely accepted, it displaced other explanation for the origin and diversity of life, such as spontaneous or abiogenesis (hypothetical generation of life from non-living matter) of complex organisms and creationism (belief that the origin of universe and every thing on it is due to an event of creation brought about by the deliberate act of God). Plants and animals were now recognized as being dynamic entities that change through time, and one species-giving rise to successive species.

Once the existence of the evolutionary process was acknowledged, the natural systems of de Candolle and also of Bentham and Hooker were found to be inadequate and classifications based on phylogeny (presumed ancestral history) were proposed. Phylogenetic systems, have of course, their base in natural systems, and like these are built upon understanding of plant morphology with an addition of evolutionary concept. Since Darwin's time most botanists have tried to incorporate evolutionary relationships into classifications.

A.W. Eichler (1839-1887), a German botanist divided plants into Phanerogamae and Cryptogamae. Phanerogamae (seed plants) were divided into Gymnospermae and Angiospermae, and the latter were further divided into Monocotyleae and Dicotyleae. He arranged families from primitive to advance series.

Adolf Engler (1844-1930) and **Karl Prantle** (1849-1893). These two German botanists published jointly a multivolume work *Die Natürlichen Pflanzen Familien* (1887-1915) wherein they proposed their system of classification. In this system the flowering plants were supposed to have originated along two independent lines from unknown, wind pollinated gymnosperms. One line led to the most primitive modern dicots, the "Amentiferae", a group of wind-pollinated plants with small, apetalous flower in unisexual inflorescence. The

other line led to the most primitive modern monocots, the Pandanales. Thus, they proposed a polyphyletic origin of angiosperms. The evolutionary trends as suggested by Engler and Prantl are as under:

Apetalous → free petals → connate

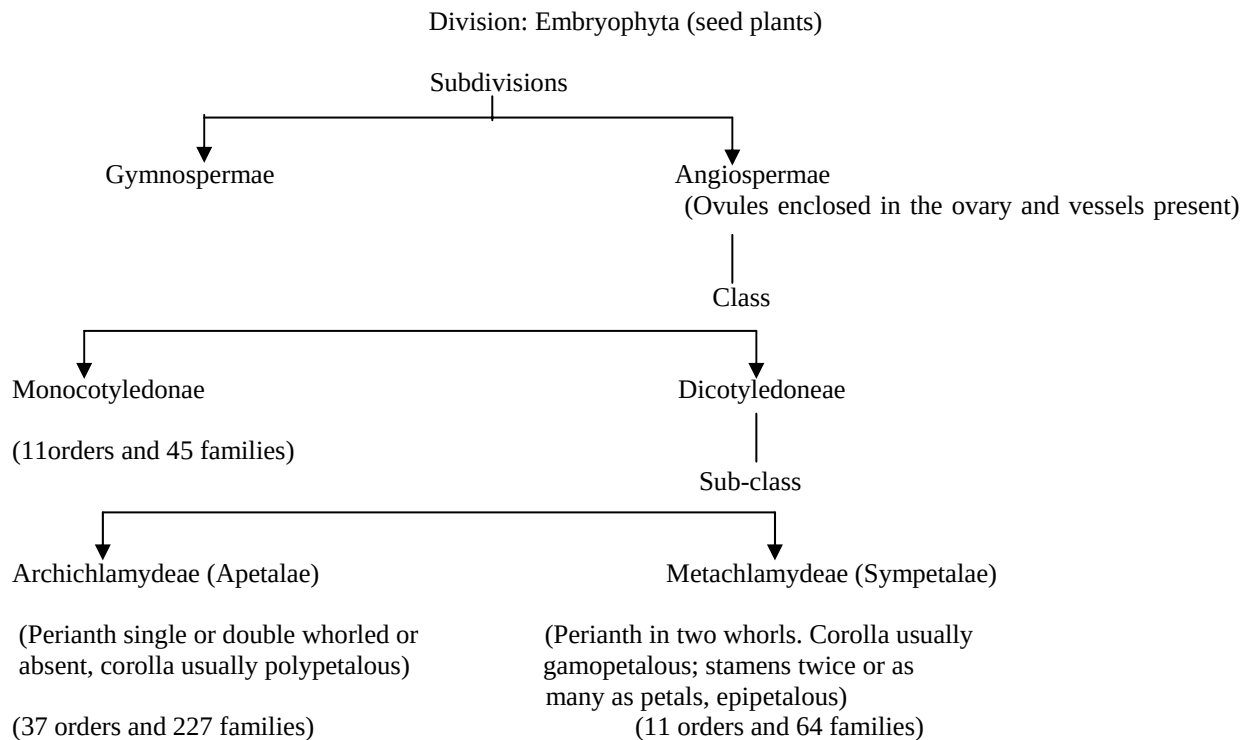
Actinomorphic → zygomorphic

Unisexual → bisexual

Hypogynous → epigynous

Their work included the keys and description of all known genera of plants, from algae to angiosperms. They divided the plant kingdom into 14 divisions. Divisions 1-13 deal with algae, fungi, bryophytes and pteridophytes; division 14 pertains to the classification of embryophyta or seed plants. Embryophyta is divided into two subdivisions – the Gymnospermae and Angiospermae. Classification of Engler and Prantl is followed in many American and Continental European herbaria for the arrangement of plant specimens.

Outline of Engler and Prantl's system



Charles E Bessey (1845-1919), was the first American to make significant contribution to plant classification. He devised a set of about 30 'dicta' or guiding principles stating which features was primitive and which were advanced in angiosperms. Bessey considered Ranales as the basal group from which both monocotyledons and dicotyledons have evolved, but also believed that all angiosperms originated from strobiliferous, cycad ancestors.

John Hutchinson (1884-1972), a British botanist associated with Royal Botanic Gardens, Kew proposed a system which first appeared in Kew Bulletins and later in a two volume work *The families of Flowering Plants* (1926, 1934). This work went under several revisions and final edition appeared in 1973. His classification was based on 24 principles that are similar to Bessey's dicta. He recognized 418 families of flowering plants belonging to 112 orders.

Angiosperms were considered monophylatic in origin from some hypothetical proangiosperms. Dicots are considered more primitive than monocots, and were regarded as evolved along two separate lines, Herbaceae – including predominantly herbaceous families - and Lignosae – including fundamentally woody families. The Magnoliales are considered most primitive of Lignosae and Ranales the most primitive of Herbaceae. The main drawback of the system is the primary division into woody and herbaceous lines and neglecting other equally important floral characters. This has resulted into wide separation of some families that resemble one another rather closely on the basis of floral characters.

Subsequently many improved systems of classifications based on information from various sources have been proposed. Some of the contemporary botanists who have proposed phylogenetic classifications are:

Armen Takhtajan (1910-1997). Russian. The latest classification of Takhtajan was published in 1980 with the heading "Outline of the classification of flowering plants".

Arthur Cronquist (1919-1992). American. Published his system in his book, *Evolution and Classification of Flowering Plants* (1968).

Robert Thorne (1920). American. Published "A synopsis of a putatively phylogenetic system of classification of flowering plants" in 1968.

Rolf Dahlgren (1932-1987). Danish. He initially published his system in a textbook of angiosperm taxonomy in 1974, which was revised subsequently in 1975 and 1980.

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, foliis in caule ad genicula ternis, floribus parvis, umbellatum in summis caulibus dispositis, 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 bryophytorum et spermatophytorum conservanda (conserve bryophyte and spermatophyte family names)

Appendix IIIA. Nomina generica conservanda et rejicienda (conserved and rejected generic names)

Appendix IIIB. Nomina specifica conservanda 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 deal 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:

1. The Taxonomic Hierarchy (Taxa and Their Ranks)

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:

- a. **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.
- b. **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.
- c. **Syntype:** Any specimen cited in the protologue when no holotype was designated, or any one of two or more specimens simultaneously designated as types.
- d. **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.
- e. **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.
- f. **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.
- g. **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 *et* or *&*, 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.

8.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).

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 μ . 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 polyploids 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*.

Phytochemistry and Taxonomy (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 ifrageneric groups are recognized on the basis of non-proteinic amino acids.

Alkaloids: Alkaloids are heterogenous 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. Benzyloquinoline 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_6H_5OH). 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 tricin 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 C₅ (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 or 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). The coded data may be entered in the form of a character matrix as shown below.

Character Matrix

<i>Characters</i>										
OTU	1	2	3	4	5	6	7	8	9	10
A	0	1	1	0	0	0	1	1	1	0
B	0	0	0	1	1	1	0	1	1	1
C	0	0	1	0	0	1	0	0	0	1
D	1	1	0	0	0	1	1	1	1	0

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.

The simple matching coefficient can be determined as follows:

Matches between two OTUs

Simple matching coefficient (S) = ----- x 100

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.

Similarity (S-value) Matrix

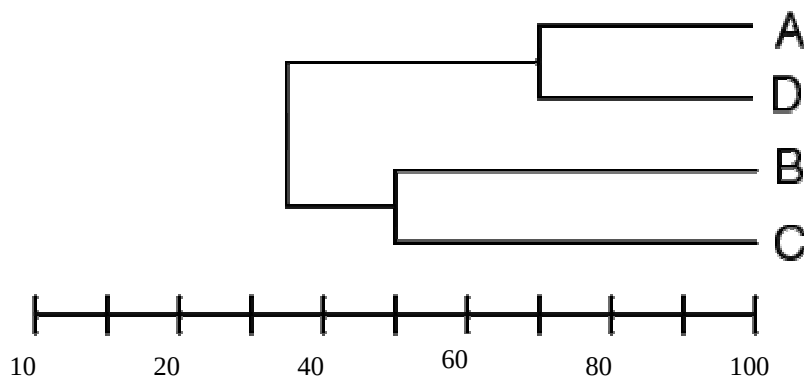
	A	B	C	D
A	--	30.0	40.0	70.0
B		--	50.0	40.0
C			--	30.0
D				--

- 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. If A is paired with D and B is paired with C, the similarity value at which these two clusters are joined will be:

$$\frac{(A \text{ to } B) + (A \text{ to } C) + (D \text{ to } B) + (D \text{ to } C)}{4} = \frac{30 + 40 + 40 + 30}{4} = \frac{140}{4} = 35$$

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

Dendrogram



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