Indira Gandhi
National Open University
School of Sciences

BBYCT-133
PLANT ECOLOGY AND TAXONOMY

Block

4

NOMENCLATURE AND SYSTEMS OF CLASSIFICATION

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BLOCK 4 : NOMENCLATURE AND SYSTEMS OF CLASSIFICATION

Block 4 consists of five units which primarily deal with classification and scientific naming of plants, codes, laws, provisions and rules for nomenclature of plant species. In this block you will study about various concepts and principles of binomial nomenclature. How to name a plant scientifically, various types of classification, numerical taxonomy and its application and cladistics.

In Unit 16 we will discuss the concepts and principles of binomial nomenclature. We will also learn the binomial systems put forth by Bauhin and Linnaeus and some important rules of nomenclature. Systematic botany is a challenging field of science. It involves identification, classification and nomenclature of plants. Carl Linnaeus, introduced the concept of - Binomial Nomenclature. According to him, each plant name will be of 2 words - binomial/binary consisting of a generic name followed by a specific epithet. No two different kinds of plants shall bear the same/similar binomial.

In unit 17 we have discussed how plants can be scientifically named . C. Linnaeus undertook a task of classifying and naming in a methodical manner the whole living world. This led to the dual-name system of naming species being permanently established. We have also discussed code that deals and determines the laws, provisions and rules for nomenclature of plants.

In Unit 18 you shall study about various types of plant classification, we have also described the historical background, outline, basis of classification, merits and demerits of the various systems of classification, especially the ones proposed by Linnaeus; Bentham and Hooker and Engler and Prantl.

In unit 19 you will study about numerical taxonomy and its applications which is one of the modern approaches to synthetic taxonomy.

Unit 20 deals with the concepts of phenetics and cladistics. Cladistics is based on shared derived characters (synapomorphies) between related groups.

Objectives:

After studying this block you will be able to:

- know the concept of taxonomical hierarchy; and explain the terms : taxon, category and rank; describe the salient characteristics of the taxonomic groups : species, genus, family and order; and discuss the “species-concept”;
- explain the concepts of binomial nomenclature and apply the principles of binomial nomenclature to the naming of plants and know the contributions of Bauhin and Linnnaeus;
- identify the basic principles that govern the International Code of Nomenclature for algae, fungi and plants;name and describe prominent laws and provisions that govern this code;
- describe the rules for Nomenclature that govern: Rank; Typification; Priority; Valid publication; Author citation and Retention and Rejection of scientific names;
- define numerical taxonomy and know various principles of numerical taxonomy; and
- define the phenetics, cladistics and the associated terms;construct and analyse phenograms.

UNIT 16

BINOMIAL NOMENCLATURE

Structure

16.1 INTRODUCTION

Systematic botany is a challenging field of science. It involves identification, classification and nomenclature of plants. It also provides a frame work for studying evolutionary trends among them. Nomenclature is primarily concerned with the procedure for naming plants and determination of the correct name of a known plant according to a nomenclatural system. Once a plant is identified it is imperative to designate it by a name. Nomenclature is done within the parameters established or regulated by a code.

A name provides identity to a plant. We should strive to identify and name each and every plant, both extant (living) and extinct (fossils). Naming is necessary because : (1) the plant has been identified/exists; (2) it could be important economically; (3) it could be potential to be of economic importance; (4) may be its wild relatives are potential for economic importance; (5) may be needed for reference for future identification etc. At the same time, a name also serves as a reference for retrieval of information.

In this Unit we will discuss the concepts and principles of Binomial Nomenclature. We will also learn the binomial systems put forth by Bauhin and Linnaeus and some important rules of nomenclature.

Objectives

After studying this unit you should be able to:

- ❖ explain the concepts of binomial nomenclature;
- ❖ apply the principles of binomial nomenclature to the naming of plants;
- ❖ justify the importance of scientific names; and
- ❖ know the contributions of Bauhin and Linnnaeus.

16.2 DEVELOPMENT OF CONCEPT

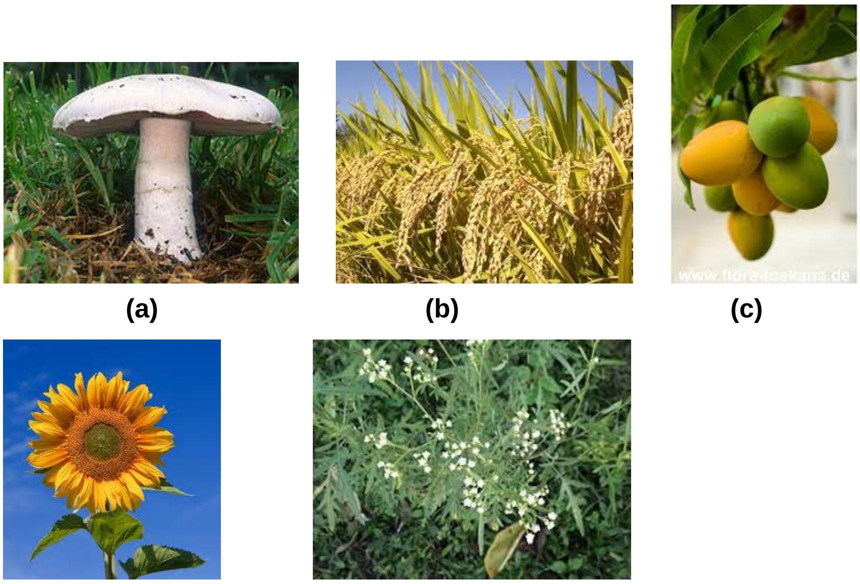
Name is a conventional tool to act as means of reference. For example, when we say mushroom, moss, paddy, sunflower, mango or congress grass (Fig. 16.1) we presume that the listener is able to visualize the plant we are referring to. Does he, actually? All the names mentioned above are common English names of the given plants. But, does each and every individual across the globe or for that matter in every state of our country identify and correlate these plants by the English name mentioned in Fig. 16.1. For example; congress grass is also known as santa marina, white top wee, famine weed, congress weed, fever few, brown weed, in English-speaking countries; but as carrot grass (gajar grass in Hindi) in India; or as ajenjo cimarron or amargosa in Spain; and as *Parthenium matricaire* in France. Similarly, mushroom is also called meadow mushroom, field mushroom, pink button in English; kumi/kumbi in Hindi; koon in Malayalam and bhuchatra/chatrakah in Sanskrit. All such names that are prevalent in society for the same plant are called common or vernacular names.

Another interesting example is of *Plantago major*, (broad-leaved plantain). It has 45 other English names, 11 French, 75 Dutch, 106 German names in addition to several others in different parts of the world. Similarly, true oak is *Quercus* (Fagaceae) while poison oak is *Toxicodendron* belonging to a totally different family Anacardiaceae.

Scientific names have evolved through a system over the last few centuries. Circumstances have dictated the necessity of distinguishing any one given plant from among any of the millions that exist or existed, anywhere regardless of the language spoken locally. Thus, any given plant can have one or more common or vernacular names but only one scientific binomial name. The plant(s) bearing these names have a very distinct identity unique to them. The science of nomenclature attempts to provide a distinct scientific name to each and every distinct biological species.

Let us now discuss the development of the concept of nomenclature, especially the binomial nomenclature of plants. This nomenclature is followed world-wide.

The advantage of scientific name is its definiteness as compared to the variability found in common names.



(a) (b) (c)

(d) (e)

Fig. 16.1: Some examples of common as well as scientific names: (a) mushroom (*Agaricus campestris*); (b) paddy (*Oryza sativa*); (c) mango (*Mangifera indica*); (d) sunflower (*Helianthus annuus*) and (e) congress grass (*Parthenium hysterophorus*).

16.3 INTERNATIONAL CODE

In Unit 15 you have read about Taxonomic Hierarchy of Biological Classification like taxonomic ranks, taxonomic groups, taxonomic categories etc. A taxon is defined internationally as a taxonomic group or category of any rank. Names applied to different rank of hierarchal categories constitute the concept of nomenclature in taxonomy. The concept of assigning a scientific name to a plant is the initial step at standardising binomial nomenclature. This was based on universal set of rules that govern the application of names of biological organisms.

Such scientific names were very convenient and the idea was universally accepted by the botanists. This means that there have to be international agreements on the issues amongst botanists. For this, International Congresses have been organised from time to time. In these International Congresses, rules have been framed and adopted. These are published in the form of an International Code of Nomenclature. For naming plants including algae, fungi and lichens there is an International Code of Botanical Nomenclature (ICBN). The foundations of International Code of Botanical Nomenclature are found in Linnaeus' *Philosophia Botanica* published in 1751. Another significant work on plant nomenclature was Augustin de Candolle's *Theorie elementaire de la botanique* (1613) wherein he gave detailed rules on plant nomenclature. However, the first organized efforts to develop an acceptable system of nomenclature to be used by all botanists in all the countries were made at the First International Botanical Congress held in 1867 in Paris. At this Congress the *Lois de la nomenclature botanique* (Laws of Botanical Nomenclature) proposed by Alphonse de Candolle (Son of Augustin de Candolle) were adopted with certain modifications: These rules were known as de Candolle rules or Paris code of 1867. You will study more about such codes in next Unit 17.

Besides, there is a Commission on the Nomenclature of Plants and the International Association of Plant Taxonomy (IAPT). For naming bacteria there is the International Code of Nomenclature of Bacteria (ICNB). Viral Nomenclature is governed by the International Code of Viral Nomenclature (ICVN). There is a separate Code of nomenclature for cultivated plants, International Code of Nomenclature for Cultivated Plants (ICNCP). Each Code has different rules of naming of hybrid.

16.4 PRINCIPLES OF BINOMIAL NOMENCLATURE

There are certain basic principles of binomial nomenclature which are as follows:

i) Different nomenclatural systems are independent of each other e.g. though "*CORYDALIS*" is a generic name of plants in the family Fumaricaceae, and "*CORYDALIS*" is also the name of a genus of insects in the Order Megaloptera. Similarly, the name "*CECROPIA*" is used for a genus of showy moths as well as a generic name of a weedy tropical tree of the Family Cecropiaceae. Further, "*PIERIS*" is used as generic name for the cabbage butterfly as well as a shrub belonging to the Family Ericaceae. Although it is permissible in the code it is not desirable to employ the same name for different kinds of organisms of same status of two different systems. This might constitute an obstacle to interdisciplinary understanding.

ii) Within each Code of Nomenclature, each taxon with a particular definition, position and rank can bear only one correct name except in unusual or specified cases.

iii) No two taxa may bear the same name.

iv) Scientific names of taxa are treated as Latin names regardless of their derivation

v) Priority of publication determines the correct usage of a name.

vi) For the categories of order and lower categories, the application of name of taxa is based on nomenclatural types. **Only names have "types".**

vii) Thus, for names of species, the nomenclatural type is an actual specimen – called the "Type specimen". All higher categories DO NOT have type specimens. Instead, the nomenclatural type is another name; for example the name of a species serves as the nomenclatural type for a generic name. Similarly, the name of a genus serves as the nomenclatural type for the name of a family. For example the generic name *Malva* becomes the nomenclatural type for the family name Malvaceae. (In this manner most family names are based on the name of one of the genera classified in the family).

viii) The names contrary to the rules cannot be maintained.

SAQ 1

Choose the correct alternative among the two provided in the parenthesis:

i) A given plant can possess only (one/more) vernacular name(s).

ii) At First International Botanical Congress held at Paris in 1867 the '*lois de la nomenclature botanique*' was proposed by (Alphonse/Augustin) de Candolle.

iii) Scientific name of a taxon is provided in (any/Latin) language.

iv) A plant and an animal (can/cannot) possess similar generic name.

v) (Scientific/Vernacular) name helps to establish affinities between plants.

16.5 BINOMIAL NOMENCLATURE

Nomenclature is allied to taxonomy as it deals with the determination of the correct name to be applied to a known taxon. The use of scientific names rather than of common or vernacular names is an accepted norm today. Since the days of Linnaeus by common accord, no two genera could have the same generic name and no two species within a given genus could have the same specific name.

However, the present system of binomial nomenclature is the result of a historic series of changes that gradually became formalised. The oldest plant names that we use now are the common names prevalent in ancient Greece and Rome. Today, all such names have a Latinized spelling and are treated as Latin regardless of their origin. This is because the use of Latin was in practice in most of botanical publications until the middle of 16th century. Till the middle of 16th century the assignment of names to plants were unregulated. As the number of plants known to botanists increased substantially the need for precise naming systems for plants was realised. However, prior to 1753, often the names comprised of 3 or more words, *polynomials* for example, herbal Clusius (1583) named the willow, as *Salix pumila angustifolia altera*. *Sida acuta* Burm f. was earlier known by a polynomial as : "*Chrysophyllum foliliis ovalis superne glabris parallel strialis subtus tomentosonitidis*".

These were steps in developing modern nomenclature leading to binomial system of nomenclature. Binomial is a Latin term used to denote a combination of two words constituting a name also called binomen, binomial or binary. The system of naming species by means of a generic name plus a specific epithet (often termed trivial name) is known as binomial system of nomenclature. For example we can recollect the scientific name of garden pea as *Pisum sativum* Linn. In this binomial the first word (*Pisum*) designates the genus to which this legume belongs and the second word (*sativum*) to a particular species of that genus. The two words only in this combination (*Pisum sativum* Linn.) constitute the correct (botanical) name of the garden pea.

There is an obvious demerit in tagging specific epithet with the genus to form species name. For example when there is a re-classification due to new knowledge, there could be a transfer of one species from genus "A" to genus "B". With the transfer of a species to a different genus on taxonomist's decision, its name is inevitably changed which in turn disturbs the free flow of information. However, to overcome the confusion so produced, the Code lays certain provisions which should be strictly observed. We can summarise the merits of binomial system as follows:

1) It is simple in its uniformity and very precise. All species are named in this simple uniform manner.

2) It is expandable and can provide names of species which shall be described in future.

3) It provides a summary of affinities for us which acts as an aid to the memory and provides basic information about plant unknown to us.

4) It facilitates talking about groups of species that have certain features in common.

16.5.1 Bauhin

Fig.16.1: Caspar Bauhin

A Swiss botanist **Caspar Bauhin** (1560-1624) (Fig.16.1) published *Pinax Theatri Botanici*, a list of 6000 plants in 1623. *Pinax* provided a much needed synonymy of plant names by listing for each of these plants all the names given to it by various botanists. *Pinax*, thus provided a valuable botanical catalogue of plant names, a kind of register of all kinds of plants known to scientific community at that time.

Bauhin, also used a combination of two words (binomial nomenclature) and appeared to have an understanding of a concept of grouping species to a genus. However, he did not describe the characteristics of the genus. Rather, the genus was described/defined by the characters of the included species. This device helped to simplify the situation of expressing a species but it lacked a system. The generic name often comprised two or three words and the specific epithet was often a long phrase. Casper Bauhin classified plants on the basis of texture and form. The binary nomenclature with which Linnaeus is usually credited was founded by Bauhin more than a century before its use by Linnaeus. Bauhin had also published earlier in 1620 a collection, *Prodromus Theatri Botanici*. In the next subsection we are going to discuss the works of Linnaeus.

16.5.2 Linnaeus

Almost a century after Bauhin, the great Swedish naturalist Carolus Linnaeus (1707-1778) introduced a revolutionary system for naming a plant, the **binomial nomenclature**. His contribution was hailed by his contemporaries as 'epoch' in the field of science. His work proved to be culmination of an attempt to create a workable system of identification and classification of plants. His binomial system of nomenclature of a plant was 'precise' and 'referable'. Referable means. "The name of the species immediately indicated the genus into which it is classified". The scientific name of each species is restricted to two Latin words, no matter in what country it was first found or in what language it was first described. This use of a universal language of binomial nomenclature helped to avoid ambiguity of meaning for varied local or vernacular names and conveyed the same information about the species in question to scientists throughout the world.

Why is Latin the language of botanical nomenclature?

- Latin is not spoken in many parts of the world. Hence its vocabulary does not change in different parts of the world. It thus serves as a universal language.

- Latin grammar has definite rules, and thus can be used for deriving botanical names of plants from any language. For example the generic name *Putranjiva* (Family Euphorbiaceae) is derived from Sanskrit, and the name *Mangifera* is derived from Tamil.

- A large amount of ancient botanical literature was published in Latin. (Like Sanskrit, Latin was the language of scholars). Many names used in the past continue to be used even today.

- The Latin or Latinized form of scientific names that have been universally used is a direct result of the fact that most publications of natural history were written in Latin known as the language of the scholars of the day.

- It is a rich source of the roots from which scientific names (that would be specific and exact in meaning) can be made.

The singular contribution of Linnaeus has been to combine a *specific* epithet with a generic name to make a scientific name - a binomial.

His epoch-making work was published in a 2-volume catalogue for plant identification - ***Species Plantarum*** (1753). In these volumes each plant had a generic name followed by a polynomial descriptive phrase. This descriptive phrase was intended to serve as a definition (description) of the species-analogous to our dichotomous keys.

Before Linnaeus, the genus *Mentha* was identified to be of two prominent kinds : *Spearmint* and *Pepper mint*. And, they were described as the following:

Spearmint : *Mentha floribus spicatus foliis oblongis serratus* (Mentha with flowers in spike, leaves oblong, saw-toothed)

Peppermint : *Mentha floribus capitalus foliis lanceolatis serratus subpetiolatus* (Mentha with flowers in head, leaves lace-shaped, saw toothed, with very short petioles)

Species : Species is like the word 'sheep: spelled same singular and plural. There is no such thing that a plant or an animal 'specie'. Since Linnaeus's time, a species is defined as a "population of individuals capable of freely interbreeding in nature, but not generally interbreeding with members of another species".

Linnaeus in *Species Plantarum* used Latin for names and for phrases whenever necessary to reflect relationship by placing one or more species to a genus. He limited each Latin phrase to a maximum of 12 words and in the margin next to the phrase - he listed a single word with the genus. This word in the margin he referred to as 'trivial' name. This 'trivial' name when suffixed to a genus concerned formed a 'binomial'. The trivial name thus is the "specific epithet". Let us take the example of mints mentioned above. Linnaeus described them as:

Trivial name **Generic name**

- *spicata* : *MENTHA floribus spicatus foliis oblongis serratus* = (*Mentha spicata*)
- *piperata* : MENTHA *floribus capitalus foliis lanceolatis serratus subpetiolatus*. = (*Mentha piperita*)

Some other examples:

CUSCUTA **(Genus)**

Trivial name **Binomial name**

- *europa* : *CUSCUTA floribus feffilius* = (*Cuscuta europa*)
- *americiana* : *CUSCUTA floribus pendicularis = (Cuscuta americana)*

HYPECOUM **(Genus)**

Trivial name **Description**

- *procumbens* : *HYPECOUM filiquis arcualis compreffis articularis*
- *pendulum* : *HYPECOUM filiquis cernius teretibus cylindricis*
- *erectum* : *HYPECOUM filiquis erectis teretibus tortulofis*

Accordingly, the 3 species of the genus ***Hypecoum*** would be : *H. procumbens*; *H. pendulum*, and *H. erectum* respectively. Linnaeus in his 2-volume catalogue of *Species Plantarum* listed, described all the known plants of the time and provided binomials for each of them. May 1, 1753 the day of publication of *Species Plantanum* has been chosen by ICBN as starting day of binomial nomenclature. For his monumental work he is aptly and fondly known as "Father of Plant Taxonomy" (box 16.1).

Box 16.1: Carolus Linnaeus (1707-1778)

Carl von Lineé (Latinized as *Carl Linnaeus*), the father of Plant Taxonomy (Fig.16.2) was born in Rashult, Sweden in 1707. He joined University of Lund in 1729 under the influence of Dean, Olaf Celsius. Professor Celsius introduced Linnaeus to Professor Rudbeck, a botanist. On an expedition to Lapland, in 1732, he increased his knowledge of natural history. In 1735 he moved to the Netherlands and finished his Medical degree at University of Harderwijk. In Netherlands, he became personal physician of a wealthy banker, George Clifford. Clifford had immense interest in botany and horticulture. He became a patron of Linnaeus.

Three years later, Linnaeus travelled extensively in Europe and returned to Sweden in 1738 and published a number of books on Natural History. He met a number of famous Naturalists of his time including John Frederick Gronovius, Herman Boerhaave from Netherlands, Professor S.S. Dillen and Sir Hans Sloane in England, and de Jussieu brothers in France.

After practising medicine on his return to Sweden, he became Professor of Medicine and Botany at the University of Uppasala in 1741 a position he held till his death in 1778.

In his works Linnaeus used the works of Bauhin, Cesalpino, Ray, Tournefort, and others and put together a synthesis of their ideas. His prominent students were : Peter Kalm; Frederick Hasselquist; Peter Forskål; Peter Thunberg; and Daniel Solander. Linnaeus work was sold by his widow in 1783 to J.E. Smith, an English botanist, and one of the founders of Linnean Society of London. The herbarium of Linnaeus is now stored in the Linnean Society, Burlington House, Piccadilly, U.K.

His famous works are :

Critica Botanica 1727

Hortus Uplandicus 1730

Systema Naturae 1735

Hortus Cliffortianus 1737

Genera Plantarum 1737

Classes Plantarum 1738

Philosophia Botanica 1751

Species Plantarum 1753

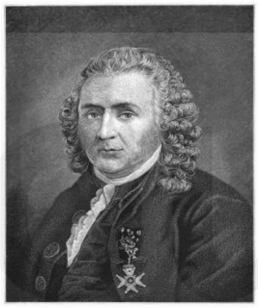


Fig.16.2: Carolus Linnaeus

SAQ 2

Fill in the blank(s) with appropriate word(s) :

i) *Pinax theatric botanici* was written by …………. ……………

ii) *Species Plantarum* was authored by ………… ……………..

iii) …………. ……………. is regarded as father of plant taxonomy.

iv) Trivial name when suffixed to a genus constitutes a …………..

v) The binomial nomenclature as proposed by Linnaeus is both ………. and …………. .

16.6 SUMMARY

In this unit you have studied that:

- Systematic botany is field of science that involves identification, classification and nomenclature of plants. Nomenclature is primarily concerned with providing a Latin name to the plant and determination of the correct name of a known plant according to a nomenclature system.

- Any given plant can have one or more common or vernacular name(s), but only one scientific name - a binomial name.
- Prior to Carl Linnaeus's time, a given plant was known by a polynomial name. It consisted of a generic name followed by a phrase of many words that described its morphological characteristics.
- A Swiss physician and botanist Casper Bauhin (1560-1624) published a list of more than 6000 plants - *Pinax Theatri Botanici*. This *Pinax* was a catalogue of plant names along with all the synonyms for each of the listed plants.
- Bauhin used a combination of two-words to name a plant. However, he did not describe the characteristics of a genus (generic name).
- Carl Linnaeus, a Swiss naturalist, Professor of botany and medicine introduced the concept of - Binomial Nomenclature. According to him, each plant name shall be of 2 words - binomial/binary. Consisting of a generic name followed by a specific epithet. No two different kinds of a plant shall bear the same/similar binomial.
- Author of 2-volume work, "*Species Plantarum*" (1753), Linnaeus is regarded as 'Father of Plant Taxonomy'.

16.7 TERMINAL QUESTIONS

1. "Vernacular name(s) is/are not scientifically appropriate". Discuss.
2. What is the significance of Paris Code of 1867?
3. What is meant by polynomial? Explain with the help of any 2 examples.
4. Discuss the contributions of Casper Bauhin in the field of plant nomenclature.
5. "Carolus Linnaeus is aptly referred to as father of plant taxonomy". Explain.

16.8 ANSWERS

Self-Assessment Questions

1. i) More

   ii) Alphonse

   iii) Latin

   iv) cannot

   v) Scientific

2. i) Casper Bauhin

   ii) Carolus Linnaeus

   iii) Carolus Linnaeus

   iv) binomial

   v) precise, referable

Terminal Questions

1. Refer section 16.2
2. Refer section 16.3
3. Refer sections 16.5
4. Refer sub-section 16.5.1
5. Refer sub-section 16.5.2

Acknowledgement of Figures

Figure 16.1 : https://images.app.goo.gl/QjS4NvJUVYpT8j5j7

Figure 16.2 : https://images.app.goo.gl/7QDHmWXvsMYTh818A

UNIT 17

SCIENTIFIC NAMING OF PLANTS: NOMENCLATURE

Structure

17.1 INTRODUCTION

Man has always been a nomenclaturist. He gives names to plants, animals and objects. For centuries, such names were long, descriptive and unwieldy. Casper Bauhin (1560-1624) devised a plan of adopting two names for each plant. Swedish naturalist, C. Linnaeus (1707-1778) undertook a task of classifying and naming in a methodical manner the whole living world. This led to the dual-name system of naming species being permanently established. It was mandated that every living organism has to be distinguished and designated by a name. A formal system based on which such names are assigned is called Nomenclature. According to Albert E. Radford (1986) "Taxonomist as a nomenclaturist names a new taxon and determines the correct name for old taxa that have been remodelled, divided, united, transferred, or changed in rank according to the International Botanical Code; they also determine the correct name for a specimen according to an identification or classification system." For example, the botanical name of white oak would be *Quercus alba* L., but that of sweet pea would be *Pisum sativum* L.

This Unit will help you to understand the code that deals and determines the laws, provisions and rules for nomenclature of plants.

Objectives

After studying this unit you should be able to:

- ❖ know the history of plant taxonomy, with special emphasis on plant taxonomy in ancient India;
- ❖ know the necessity for a suitable scientific code for nomenclature of living organisms;
- ❖ identify the basic principles that govern the International Code of Nomenclature for algae, fungi and plants;
- ❖ name and describe prominent laws and provisions that govern this code;
- ❖ describe with suitable examples the rules for Nomenclature that govern: Rank; Typification; Priority; Valid publication; Author citation and Retention and Rejection of scientific names.

17.2 COMMON NAME: ITS PROBLEMS

You may often be wondering why I should learn the valid, scientific botanical names of the plants. Why cannot we refer the plants by the so called, vernacular names that all of us so commonly know. Let us discuss the problems with the common names of the plants and also the advantages of adopting the Latin, scientific names for them.

The problems

1) Names in common languages are ordinarily applicable in only one language, they are not universal. Also, all the species of plants known to man do not have vernacular names.

2) Common names do not provide scientific information that a Latin name does. The later assigns a species to a genus; a genus to a family, a family to an order and so on......

3) It is frequently observed that a given plant may be known by different vernacular names in different localities and people may not even know that all of them are referring to a same plant.

   Example :

   - ***Aegle marmelos*** is *wood apple* in English; *sriphal* in Hindi; *bael* in Bengali; *vilvamaram* in Tamil and *bilamu* in Telugu.
   - ***Oryza sativa*** is *paddy* in English; *dhan* in Hindi; *bhat* in Marathi; *chaval* in Pubjabi; *Vari* in Telugu
   - ***Rhus vermix*** is known as poison sumac; poison dogwood; poison elder; and swamp-sumac in different places;
   - *Ipomoea* is ‘morning glory’ in USA but called ‘woodbine’ in Scotland.
   - ***Convallaria majahis*** is called lily of the valley in England, muguet in France, landysh in Russia and mailblume in Germany.

4) Similarly a given vernacular name could actually belong to a number of plants with totally unrelated genera.

- Let us consider the vernacular name 'Oak, the common name of genus *Quercus*. However, tanbark Oak is *Lithocarpus;* poison oak is *Rhus*; silk oak is *Grevillea,* and jerusalem oak is *Chenopodium*.
- the name pine is loosely referred to a variety of genera such as: *Pinus*, *Araucaria*, *Agathis* or *Casuarina* in different places.

5) It is also possible that two different plants are known by a common vernacular name.

eg.*Caltha palustris* (family- Ranunculaceae) in North America has a vernacular name cowslip. However, *Primula veris* (family-Primulaceae) in UK is also having a same vernacular name i.e., cowslip.

Another example is of *Hyacinthoides non-scripta* (family- Asparagaceae in North America is commonly known as blue bells whereas in Scotland plant *Campanula rotundiflora* (family-companulaceae) is also famously known as blue bell.

The Advantages of Scientific names

1) The principal purpose of a scientific name is to act as an easy means of reference.

2) It also aids in communication (like your name and surname....).

3) It is unambiguous and universal in application

4) Their usage avoids the use of a descriptive phrase (s) every time one wishes to refer to an object or a group of objects. If you were to observe *Campanula* plant in a park, probably you would say. "I saw a *Campanula* plant today". or would you prefer to say, I saw some plants with blue-elongated- bell-shaped flowers in groups at the end of long stalks which had parallel sided leaves almost a foot long, all springing from the ground levels, in the park today"?

Why Latin?

The International Code of Nomenclature mandates that all the botanical names shall be in Latin, and also to have a Latin name for any new taxon published. Latin is preferred choice of language because:

1) Latin is a dead language and its usages and interpretations are less prone to changes;

2) Latin is specific and exact in meaning, *aphylla* is leafless; *aquatica* is for in water; *magnus* means large; *nigra* for black; *alba* for white, any plant growing on ground is *terrestris*; *palustris* refers to marshy, swampy habitat; etc.;

3) It follows grammatical sense of words. The end-suffix of epithets provides reference to gender eg., *-um* (neuter), - *a* (feminine) and *us* (masculine). For example, *sativum*, *sativa* and s*ativus*; etc.

4) Latin has Roman alphabets, which a majority of languages follow.

17.3 NOMENCLATURE: THE CODE

The principal mandate of the nomenclature code is to assign a botanical name to every living (extant) or fossil (extinct) organism that are historically treated as plants. These include land plants, blue green algae, true fungi, other fungi, photosynthetic protists or even taxonomically related non-photosynthetic groups. In fact, many of these groups are not phylogenetically related, yet, the International Code of Botanical Nomenclature (ICBN) deals with them since they were historically treated as plants. Photosynthetic bacteria, however, are coded both by International Code of Botanical Nomenclature (ICBN) and International Code of Nomenclature of Bacteria (ICNB). Some protists are named both according to ICNB and International Code of Zoological Nomenclature (ICZN). Thus, some organisms have two names, from two different codes. Greuter *et. al*., (1997) have prepared a draft of a future universal code encompassing all forms of life, termed BioCode. Cantino and Queiroz (2004) have proposed a separate code using phylogenetic approach for higher land plant taxa, termed PhyloCode.

The first organized efforts towards the standardisation of naming of plants were made at First International Botanical Congress held at Paris, in 1867. Since then such Congresses are held periodically to review and standardise the botanical code for nomenclature. Since VII International Botanical Congress held at Stockholm (1950), successive editions of the code have been published as ICBN. However, in Melbourne, Australia (2011) the title has been changed to International Code of Nomenclature for algae, fungi and plants. The abbreviation shall be ICN for algae, fungi and plants.

After every six years, The International Botanical Congress discusses all suggestions for improving the Code of Nomenclature. All changes accepted and approved by the Congress, are incorporated into a New Code. This new code supersedes (replaces) the existing (all previous) Codes.

The XIX International Botanical Congress) was held at Shenzhen, China in 2017, and the new Code (called The Shenzhen Code) was published in 2018.

The Code Volume comprises:

- Preamble
- Division I – Principles
- Division II – Rules and Recommendations
- Division III – Provisions for the Governance of the Code
- Appendix-I to VIII
- Glossary of terms used in the Code.

Some major deviations in ICN for algae, fungi and plants from earlier ICBN versions are:

1) acceptance of certain forms of electronic publications;

2) option of using English as an alternative to Latin for description/diagnosis of new taxa of non-fossil organisms;

3) the requirement for registration as a prerequisite for valid publication of a new name of fungi;

4) abolition of the provision for separate names for fungi with pleiomorphic life histories; and

5) abandonment of morphotaxon concept in the nomenclature of fossils. (The details of some of these provisions, you shall learn further in this unit).

17.4 LAWS AND PROVISIONS

Some of the salient features of preamble of ICN for algae, fungi and plants are as follows:

1) Biology requires a precise and simple system of nomenclature that is used in all countries. It includes, on one hand the terms that denote the ranks of taxonomic groups or units and on other hand the scientific names that are applied to the individual taxonomic groups. The purpose of giving a name to taxonomic groups is not to indicate its characters or history, but to supply a means of referring to it and to indicate its taxonomic rank.

   This **Code (The International Code of Nomenclature for algae, fungi and plants)** aims at (i) the provisions of a stable method of naming taxonomic groups, (ii) avoiding and rejecting the use of names that may cause error or ambiguity also, (iii) to avoid the useless creating of names.

2) Algae, fungi and plants are the organisms covered by this code (*The 'word organism' applies only to the organism covered by the code i.e. those traditionally studied by botanists, mycologists, and phycologists*).

3) The Principles form the basis of the system of nomenclature governed by the **Code**.

4) The detailed provisions are divided into the rules, which are set out in the Articles and Recommendations. There are examples provided in the Code to illustrate rules and recommendations.

5) The object of the rules is to put the nomenclature of the past into order and to provide for that of the future; names contrary to a rule cannot be maintained.

6) The Recommendations deal with subsidiary points, to bring about uniformity, clarity especially in future nomenclature.

7) The provisions regulating the governance of this **Code** form its last Division (Div. III).

8) The provisions of this **Code** apply to all organisms, traditionally treated as algae, fungi, or plants, whether fossil or non-fossil, including blue-green algae, chytrids, oomycetes, slime moulds, and photosynthetic protists with their taxonomically related non-photosynthetic groups (excluding *Micro sporidia*). Provisions for the names of hybrids appear in Appendix 'I'.

9) Names that have been conserved or rejected, suppressed works, and binding decisions are given in Appendices II-VIII.

10) This edition of the **Code** supersedes all previous editions.

The **Six** principles that define the **Code** are:

I. The nomenclature of algae, fungi and plants is independent of Zoological and Bacteriological nomenclature. This code applies equally to names of taxonomic groups treated as algae, fungi and plants, whether or not these groups were originally so treated,

II. The application of names of taxonomic groups is determined by means of nomenclature types,

III. The nomenclature of a taxonomic group is based upon priority of publication.

IV. Each taxonomic group with a 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. The rules of nomenclature are retroactive unless expressly limited.

Let us now study these principles in some detail in next sub-section 17.5.

17.5 RULES

17.5.1 Ranks of Taxa

- The taxonomic group of any rank will be referred to as taxa (singular taxon).
- Every individual organism is treated as belonging to an indefinite number of taxa of consecutively subordinate rank, among which the rank of species is the lowest.
- The principal ranks of taxa in descending sequence are:

  - Kingdom (*regnum*)
  - Division or phylum (*divisio* or *phylum*)
  - Class (*classis*)
  - Order (*ordo*)
  - Family (*familia*)
  - Genus (*genus*), and
  - Species (*species*).

  Here, we can write that Magnoliophyta is a taxon at the rank of a Division; Rosales is a taxon at the rank of an Order, Poaceae is a taxon at the rank of a Family; *Triticum* is a taxon at the rank of a Genus and so on. Thus, each species is assignable to a genus, each genus to a family and so on..............

- Species and the subdivisions of a genus must be assigned to a genus, while infraspecific taxa must be assigned to a species because their names are in combinations.

- The principal ranks of hybrid taxa (nothotaxa) are nothogenus and nothospecies. The ranks are same as genus and species. The prefix 'notho' indicates the hybrid character.

- The taxa are classified hierarchically by rank, wherein higher rank is inclusive of all lower ranks. For example, all the species, genera, families, orders, classes, division of plants shall be included in the highest ranked taxon, the Kingdom Plantae.

- The secondary ranks of taxa in descending sequence are tribe (*tribus*) between family and genus; Section (*section*) and Series (*series*) between genus and species and variety (*varietas*) and form (*forma*) below species.

A prefix 'sub' is added to the taxon of a rank to create greater number ranks eg., an organism may thus be assigned to the taxa of the following ranks (in descending order) See Table 17.1.

Scientific name of any organism is a binomial (binary combination). It consists of two parts: genus name and a specific epithet, eg. *Pisum sativum*, Zea *mays*, *Oryza sativa*. The first part of a binomial, *Pisum*, is genus (Latin for "birth/origin") and is always capitalized. The second name of the binomial '*sativum*' is a specific epithet. Species in Latin means 'appearance'. It would be incorrect to say, that scientific name of sweet pea is *sativum*. The correct name would be *Pisum sativum*. It could also be written as *P.sativum*, but only after the first generic name is spelled out in its entirety, otherwise it could be confused, say with *Passiflora*, or *Parthenium*.

Further, taxonomic ranks are assigned specific – 'suffixes' under the code. With the help of the suffix one can find/observe the equality as well as the hierarchy of any taxon. For example, a family rank taxon has a suffix -'aceae', while an order rank taxon has a suffix - ales. Thus, we can say, that

- Rosales and Asterales are taxa of the rank Order and are equivalent;

- Malvaceae and Poaceae are taxa of the rank Family and are equivalent. However,

- Rosales and Poaceae are two taxa of two different ranks, and that Rosales taxon is at higher rank than the taxon Poaceae.

Table 17.1 Taxonomic Ranks of Land plants

S. No	Taxonomic Rank	Latin	Abbreviation	Ending	An Example
1.	Kingdom	*regnum*	*reg.*	Various (-bionta)	**Plantae**
2.	Subkingdom	*subregnum*	*subreg.*	various	

3.	Phylum = Division	*phylum*	*diviso*	-phyta	**Magnoliophyta**
4.	Sub- phylum- Sub- division	*sub phylum = subdivisio*	*subdivision = subdiviso*	-phytina	Magnoliophytina
5.	Class	*classis*	*cl.*	-opsida	Asteropsida
6.	Sub class	*subclassis*	*subcl.*	-idae	Asteridae
7.	Order	*ordo*	*ord.*	-ales	**Asterales**
8.	Suborder	*sub ordo*	*subord.*	-ineae	Asterineae
9.	Family	*familia*	*fam.*	-aceae	**Asteraceae**
10.	Sub family	*subfamilia*	*subfam.*	-oideae	Asteroideae
11.	Tribe	*tribus*	*tr.*	-eae	Heliantheae
12.	Subtribe	*subtribus*	*subtr.*	-ineae	Helianthineae
13.	Genus	*genus*	*gen.*	(various)	***Helianthus***
14.	Subgenus	*subgenus*	*subg.*	(various)	*Helianthus* subg. *Helianthus*
15.	Section	*section*	*sect.*	(various)	*Helianthus* sect. *Helianthus*
16.	Subsection	*subsection*	*subsect.*	(various)	
17.	Series	*series*	*ser.*	(various)	*Helianthus* ser. *Helianthus*
18.	Sub series	*subseries*	*subser.*	(various)	
19.	Species	*species*	*sp.*	(various)	*Helianthus annuus*
20.	Sub species	*subspecies*	*subsp.*	(various)	*Helianthus annuus* subsp. *annuus*
21.	Variety	*varietas*	*var.*	(various)	*Helianthus annuus* var. *annuus*
22.	Sub variety	*subvarietas*	*subvar.*	(various)	
23.	Form	*forma*	*f.*	(various)	*Helianthus annuus* f. *annuus*.
24.	Sub form	*sub forma*	*subf.*	(various)	

- Table lists principal ranks of taxa in descending order:
- Starting with kingdom and with forma/subforma at the end.

SAQ 1

Choose the correct alternative among the two provided in the parenthesis:

i) A scientific name always has (advantages/disadvantages) over a vernacular name.

ii) ICN mandates that all botanical names be given in (Latin/English).

iii) The binomial scientific name has taxonomic ranks with (variable/fixed) ‘suffixes’.

iv) The taxonomic rank class is designated with the suffix (opsida /ales) at the end.

17.5.2 Typification

The 2nd principle of ICN for algae, fungi and plants stipulates that every scientific name must be associated with an “element” known as nomenclature type = type. Thus, every name is based on a TYPE. At the same time, it is important to remember that ONLY NAMES HAVE TYPES. In the case of the name of a species, it is almost always a single specimen on a “standard herbarium sheet”. However, the Melbourne Code 2011) permits, w.e.f. 01.01.2012 the type specimen to be in a Portable Document Format (PDF) published in a publication with an International Standard Serial Number (ISSN) or International Standard Book Number (ISBN).

For names of all other ranks, the “type” IS NOT an actual specimen, but it is another name. Thus, the name of a species serves as the TYPE of the name of a genus; for example – the name *Poa annua* Linn. is the nomenclatural TYPE of the generic name *Poa* Linn. This implies that *Poa annua* Linn. is the FIRST named species of the genus *Poa* Linn. In the same manner, the name of a genus serves as the TYPE of the name of a family. Thus, the name *Poa* Linn. serves as the TYPE of the family Poaceae. This ‘type’ acts as a reference for comparison when the identity of a specimen is to be established beyond doubt. Further, the TYPE method is important when there is a change in taxonomic position or rank due to different reasons.

Different Kinds of “Types”

A) Types mentioned at the time of publication of a name by an author:

1. **Holotype:** A holotype is the specimen/illustration upon which a name is based. It is the specimen originally used/designated by the author, at the time of valid publication. It serves as definitive reference source for any questions of identity or nomenclature.

   It is recommended that the holotype be deposited in a public herbarium/collection centre where it is available for reference. In fact, an indication of a deposit site of a holotype is one of the criteria for valid publication of a name. Being very valuable, it is mostly kept in a safe custody.

2. **Isotype:** An isotype is a duplicate specimen of a holotype. It is collected almost at the same time as holotype, by same individual and from the same individual plant/population. It serves as a reliable duplicate(s) of same taxon. It may be distributed to other herbaria for identification or reference.

3. **Syntype:** When an author uses two or more elements from A SINGLE COLLECTION to name a new species, **but does not designate any one of them as the Holotype, and refers to all the specimens/ elements as TYPES,** then these are collectively known as **Syntypes.** They all have the same nomenclatural status. **Any one of them can be selected to serve as the Lectotype** (described below)**.**

4. **Paratype:** A paratype is a specimen that is cited in the valid publication but is not a holotype, isotype or a syntype. It is a specimen from another collection/other location different from the place where the TYPE material was collected.

B) Types designated later:

5. **Lectotype:** A lectotype is a specimen is selected from the **original material** when a holotype is lost/missing/destroyed. It is one of the many specimens of the original material. It is selected (usually later) to serve as the TYPE in place of the Holotype.

   A lectotype must be selected from among the isotypes, paratypes or syntypes , if these are available. If a lectotype is selected from the Isotypes, it is often called an “Iso-Lectotype”; and if a Paratype is selected to serve as the Lectotype, it is called a “Para- Lectotype”. Similarly, if a Syntype is selected to serve as the Lectotype, it is called a “Syn-Lectotype”.

6. **Neotype:** A neotype is any specimen that is derived/selected from non-original collection to serve as the type as long as all the materials (Holotype, Isotype/s & Paratype/s) on which the name was originally based are missing.

17.5.3 Principle of Priority and its Limitations

Priority

The 3rd Principle of **code** governs the principle of priority. The guiding principle is that each family or a taxon of lower rank can bear only **one** correct name. Let us discuss some of the prominent aspects of this principle.

1) When two or more competing possibilities for a correct name exist, then the one published **first** is treated as the correct name eg.

   (a) “The genera *Mimulus* and *Diplacus* were validly named in years 1753 and 1838 respectively. However, when two of them were merged to form one genus, the name *Mimulus* prevailed over *Diplacus* as it was published earlier”.

   (b) “When *Aesculus* L. (1753), *Pavia* Mill. (1754), *Macrothyrus* Spach (1834), and *Calothyrsus* Spach (1834) are referred to a single genus, the correct name is *Aesculus*.” as it was published earlier.

2) In case when the name has been conserved under the principle "*nomina conservanda*", its name shall prevail. The use of alternative of the eight of the following families indicated as "nom alt." (*nomen alternatum*) is authorized

Compositae (nom. alt.; Asteraceae; Type: *Aster* L.);

Cruciferae (nom. alt.; Brassicaceae; Type: *Brassica* L.);

Gramineae (nom. alt.; Poaceae; Type: *Poa* L.);

Guttiferae (nom. alt.; Clusiaceae; Type: *Clusia* L.);

Labiatae (nom. alt.; Lamiaceae; Type: *Lamium* L.);

Leguminosae (nom. alt.; Fabaceae; Type: *Faba* Mill.);

Palmae (nom. alt.; Arecaceae: Type *Areca* L.);

Umbelliferae (nom. alt.; Apiaceae; Type: *Apium* L.);

When the Papilionaceae is regarded as family distinct from the remainder of the Leguminosae, the name Papilionaceae is conserved against Leguminose."

3) A name has no priority outside the rank in which it is published.

eg. "*Magnolia virginiana* var. *foetida* L. (1753) when raised to specific rank is called *M. grandiflora*. L. (1759), not *M. foetida* (L.) Sarg. (1889)."

4) For any taxon below the rank of genus, the correct name is the combination of the final epithet of the earliest legitimate name of the taxon in the same rank with the correct name of the genus or species to which it is assigned.

eg. "When transferring *Serratula champaepeue* L. (1753) to *Ptilostemon* Cass., Cassini illegitimately named the species *P. muticus* Cass. (1826). in that genus, the correct name is *P. champaepeue* (L) Less. (1832).

5) An autonym is treated as having priority over the name of the same date and rank which upon their valid publication established the autonym.

eg. " *Heracleum sibiricum* L. (1753) includes *H. sibiricum* sub sp. *lecokii* (Godr. & Gren) Nyman (1879) and *H. sibiricum* subsp. *sibiricum* automatically established at the same time. When *H. sibiricum*, so circumscribed is included in *H. sphondylium* L. (1753) as a subspecies, the correct name of that subspecies is *H. sphondylium* sub sp. *sibirium* (L) Simonk, and not *H. sphondylium* subsp. *lecokii*."

6) For the purpose of priority, names of fossil taxa (diatom taxa accepted) compete only with names based on fossil type.

Limitations

1) Valid publications of names for organisms of different groups are treated as beginning from following dates which are given in Table 17.2.

Table 17.2: Valid Publication Dates for some Organisms.

S. No	Group of Organisms	Rank	Beginning date
1.	Spermatophyta Pteridophyta	Genus and below	1st May, 1753
2.	Spermatophyta Pteridophyta	Suprageneric names	4th August, 1789
3.	Musci (except Sphagnaceae)		1st January, 1801
4.	Sphagnaceae and Hepaticae	Genus and below	1st May, 1753
5.	Sphagnaceae and Hepaticae	Suprageneric names	4th August, 1789
6.	Fungi		1st May, 1753
7.	Algae (with some exceptions) a) Nostocaceae- homocysteae b) Nostocaceae-heterocysteae c) Desmidiaceae d) Oedogoniaceae		1st May, 1753 1st Jan., 1892 1st Jan., 1886 1st Jan., 1848 1st Jan., 1900
8.	Fossil organisms (except diatoms)		31st Dec., 1820

2) The group to which a name is assigned as mentioned in Table 17.2 is determined by the accepted taxonomic position of the type of the name, e.g., "The genus *Porella* and its single species *P. pinnata* were referred by Linnaeus (1753) to the Musci; Since the type specimen of *P. pinnata* is now accepted as belonging to the *Hepaticae* (Hepaticopsida), the names were validly published in 1753."

3) For nomenclature purposes, a name is treated as pertaining to a non-fossil taxon unless its type is fossil in origin.

4) Generic names that appear in Linnaeus's *Species Plantarum* ed. 1(1753) and ed. 2 (1762-1763) are associated with the first subsequent description given under those names in Linnaeus's *Genera Plantarum* ed. 5 (1754) and ed. 6 (1764). The spellings of the generic names are included in *Species Plantarum*, ed.1, is not to be altered because different spelling has been used in *Genera Plantarum*, ed. 5.

5) The code provides in Appendix II-IV, list of the names of families, genera, and species that are conserved (*nomina conservanda*). Similarly, Appendix III & IV of the code provides the list of conserved names for subdivision a genus of an intraspecific taxon. Such names are legitimate even though initially they may have been illegitimate. This provision provides for the stability of nomenclature.

6) A name may be conserved in order to preserve a particular spelling or gender. A name so conserved is to be without change of date to the author who validly published it, not to the author who later introduced the

Nomina conservanda (singular:Nomen conservandum) is a Latin term which means a name to be conserved

Nomen rejiciendum (pl. *Nomina rejicienda*) is a Latin term which means a suppressed name or a name rejected in favour of a particular conserved name.

conserved spelling or gender. e.g., the spelling *Rhodymenia* used by Montagne (1839) has been conserved against the original spelling *Rhodymenia*, used by Greville (1830). The name is to be cited as *Rhodymenia* Grev (1830).

7) Till 1980, the Principle of Priority was STRICTLY APPLIED FOR NAMES OF SPECIES ONLY. Names of genera and families could be used AGAINST the Principle of Priority by applying or using the rule of "*Nomina Conservanda".*

8) An important amendment to the ICBN was made at the International Botanic Congress held in Sydney (Australia) in 1981. For the first time, the taxonomists accepted to allow binomials (i.e. names of species) to be used AGAINST THE PRINCIPLE OF PRIORITY BUT ONLY FOR "NAMES OF SPECIES OF MAJOR ECONOMIC IMPORTANCE".

Concept of Homonym

Homonyms are defined as names spelt in an identical manner but based on different types. Thus, when two taxonomists publish the same name BUT for two different plants, only ONE plant can HAVE IT AS THE CORRECT NAME. As per ICN of algae, fungi and plants, of two or more homonyms, only the oldest is valid and all others are illegitimate. This means, the oldest name (based on the date of its publication, and according to "The Principle of Priority)" shall be accepted as the correct name. The other name (published later) HAS to be rejected. It is called a "LATER HOMONYM". For example, in1831 Bunge named a plant *Viburnum fragrans* Bunge. He overlooked the fact that in 1824 Loiseleur had already provided a valid name *Viburnum fragrans* Loisel. to another plant BUT based on a different type specimen for a very different species of the genus. Thus, *Viburnum fragrans* Bung. (1831) is a later homonym of *V. fragrans* Loisel. (1824) and as such is illegitimate and rejected. Now, if Bunge's specimen must be renamed; it has to be next oldest validly published legitimate name. It happens to be *Viburnum farreri* Stearn (1966). Here, the name published by Bunge in 1831 is illegitimate but later published 1966 Stearn's nomenclature is valid.

The citation is written as:

Viburnum farreri Stearn 1966

Syn. *Viburnum fragrans* Bunge (1831). nom. illegit. non Loisel (1824)

Thus, in the above example, an organism has two names, one valid and other illegitimate. They are termed synonyms.

eg. *Malva rosea* L. was changed to a distinct genus *Althea* by Cavanilles. So, the correct name is *Althea rosea* (L) Cav, hence, *Malva rosea* L. is a synonym.

eg. *Magnolia insignis* Wallich (1824) is a synonym of *Manglieta insignis* (Wall.) Bl. because Blume in 1829 assigned genus *Magnolia* to genus *Manglieta* and republished valid new name.

Significance of synonyms

Although synonyms are not considered valid names, they are/remain as a source of information in literature. They provide a synthesis of our knowledge of plants concerned.

17.5.4 Publication of Names: Effective and Valid

All names have to be properly published according to the Rules of Nomenclature if they are to be accepted and used in taxonomy. The ICN for algae, fungi and plants provides specific requirements for the proper publication of names. Only names published according to the rules CAN ENTER BOTANICAL NOMENCLATURE. Some important requirements for publishing names are:

1) Name (of a taxon) must be effectively published in a scientific journal or a botanical publication (such as a Flora) which is commonly accessible to the botanists. Only names published in this manner are termed EFFECTIVE and can enter botanical nomenclature. The name should NOT be published in a local magazine, or a non-scientific publication or a newspaper.

2) Name must also be published in a correct form, properly Latinised with rank indicated, eg. *sp. nov*. or *gen*. *nov*. (New species/ new genus respectively) the correct form published is known as admissible name.

3) The name must be published with a Latin description or diagnosis or with a reference to an earlier validly published name. Thus, the description can be in English if the publication is on or after January 1, 2012, BUT a brief Latin description should be provided. This must mention the salient features that make the new taxon different from the other related taxon. It should be accompanied by a detailed description in vernacular language.

4) Thus, names effectively published AND accompanied by a Latin description/Latin diagnosis are accepted as **valid names.**

5) Nomenclature must be included for the rank of species and below.

6) The ‘type’ reference and its location must be mentioned/indicated. It should include the acronym of Index Herbariorum, (Holmgreen *et. al*., 1990). From 1st January, 2012 the type can be made available on a PDF.

7) A term, **protologue**, is used to include everything that is associated with a name as its valid publication. It includes: description/diagnosis; illustration; reference; synonym; geographical data; citation of specimen, discussion, comments etc.

8) A full citation of a scientific name includes: its authorship; journal; volume; page number; date of publication; the full citations are listed in International Plant Names Index, and are available on website (http//www. ipni.org.).

Some recommendations associated with valid publications are as follows:

a) For organisms other than vascular plants, a single figure showing details that aid identification is admissible.

b) The description of any new taxon should mention the points in which the taxon differs from its other related taxon. eg., *Eunotia gibbosa* Grunow (1881), a name of a diatom was validly published by provision of a figure of a single valve.

c) The authors of a new taxon should not adopt a name that has been previously but not validly published for a different taxon.

d) In describing/diagnosing a new taxon author should provide, when possible, figures with details of structures as an aid to identification. The figures should be properly and clearly scaled.

e) In event of a publication of a new parasitic organism (especially fungi), it should always be accompanied by the name of host, by their scientific name and not by the common name.

Some examples of valid/invalid publications:

a) The names *Kedarnatha* P.K. Mukh and Constance (1986) and *K. sanctuarii* P.K. Mukh and Constance (1986), were published simultaneously in a paper where in the later was designated as a new single species of the new genus. Both were considered valid, although the Latin description was provided only under generic name.

b) *Panax nossibiensis* Drake (1896) was published as a plate with proper analysis. It was held as a valid publication. (An analysis is a figure or group of figures commonly separate from the main illustration of organism showing details aiding identification with/without a separate caption).

c) *Egeria* (Neraud in Gautichaud voy. uranie, Bot 25-28, 1826) was published without a description or a reference. Thus, is *nomen nudum* (not validly published). Therefore, it is rejected.

d) Binary designation for six species of '*Suaeda*' includes *S. baccata* and *S. vera*. They were published with description and diagnosis by Forsskalii (1775), but he provided no description of diagnosis for the genus, *Suaeda*, all of them, therefore, are invalid names and are rejected.

17.5.5 Author Citation

Original Author

In publications, particularly those dealing with taxonomy and nomenclature, it may be desirable to cite the author(s) of the name concerned.

eg. Rosaceae Juss.,

Rosa L.

Rosa gallica L.

Rosa gallica var. *eriostyla* R. Keller

Rosa gallical L. var. *gallica*

In above examples Juss., L., R. Keller are abbreviations representing the original authors who validly published these taxa.

Thus, the person/s who individually/jointly name a new taxon and publish the name according to the Rules of Nomenclature is/are referred to as the author/s of the botanical name.

When a name has been published jointly by two authors, names of both should be cited. Linked by means of the word "*et*" or by and if the authors are more than two, then the citation should be restricted to that of first one followed by *et*. *al*.,

e.g 1) *Didymopanax gleasonii* Britton et Wilson, or

Didymopanax gleasonii Britton & Wilson

2) *Streptomyces albo-niger* Hesseltine, J.M. Porter, Deduck, Hanck, Bohonos & J.A. Williams should be cited as- *Streptomyces albo-niger* Hesseltine *et*.*al*.,

Name proposal

When a name has been proposed but not validly published by one author and is validly published subsequently and ascribed to him by another author, the name of the former author followed by connection word "*ex*" may be inserted before the name of the publishing author(Table17.3).

eg. *Havetia plexitis* Spruce ex. Planchet Triana

Publication

When a name with a description/diagnosis (reference/description/diagram) supplied by one author is published in a work by another author, the word '*in*' should be used to connect the names of two authors. In such cases, the name of the authors who supplied the description/diagnosis is more important and should be retained (when it is desired to abbreviate such a citation).

eg. *Viburnum ternatum* Rehder *in* Sargent.

Rank Alteration

When a genus or a taxon of lower rank is altered in the rank but retains its name or epithet, the author who first published it as a legitimate name or epithet (author of basionym) must be cited in parenthesis followed by the author who made the alteration.

eg. *Medicago polymorpha* var. *orbicularis* L. was raised to the rank of species by Allioni changed as: *Medicago orbicularis* (L) All.

Table 17.3: List of some celebrated authors and abbreviations associated with them.

Name of the Author	**Abbreviation**
Carlos Linnaeus	L.
Augustin Pyramus de Candolle	DC
Andrien de Jussieu	A. Juss
Robert Brown	R.Br
Burman filius	Burm f.
J.B.P.A. de Monet ,chevalier de Lamarck	Lam.
Joseph Dalton Hooker	Hook.

17.5.6 Retention, Choice and Rejection of Names

With the introduction and application of code of nomenclature, especially the principle of priority, names are frequently altered or replaced by new names. This leads to some degree of instability to nomenclature. Whenever, such a situation arises, a petition is made before the International Botanical Congress to resolve, recommend, retain or reject a given name of a taxon. Such a change of a name, if done, is termed as **taxonomic revision**.

A taxonomic revision becomes necessary when:

- a taxon is transferred to another taxon,
- when two or more taxa are merged into same rank,
- a rank of a taxon is altered.

It is by applying the **Code**, that a name is either retained or rejected. Let us, study some examples where situations have been rectified.

Following such amendments, three categories which govern such retentions and rejections of names at various ranks of taxa are formed. These are:

1) *Nomina familiarum conservanda*
2) *Nomina generica conservanda et rejecienda*
3) *Nomina specifica conservanda et rejecienda*

Example 1: A genus *Carduus* (family: Asteraceae) is split into two genera *Carduus* and *Cirsium* of same rank. The genus *Carduus* is retained.

Example 2: A genus *Haplopappus* (family: Asteraceae) is split in 5 genera : *Haplopappus*; *Ericameria*; *Hazardia*; *Happlopappus*; and *Isocoma*. When a large genera (taxon) is split into two or more smaller taxa of same rank, the terms *sensu lato* (*s.l.*) and *sensu stricto* (*s.s./s. str.)* are introduced, to distinguish the more inclusive (unsplit *Haplopappus*/taxon) as *s.l.* and less inclusive taxa (other four in this example as *s.s*. Here, *Haplopappus s.l.* has more number of species than any of other 4 taxa.

Example 3 : The family Liliaceae is split into four families: Liliaceae *s.s.;* Melanthiaceae; Phiesiaceae, and Smilacaceae. Here, three more taxa at family rank are created the original taxa Liliaceae *s.l.* retained but as Liliaceae *s.s.*

Example 4: The families Apocynaceae and Asclepiadaceae are merged but the taxon name Apocynaceae is retained. The merged taxon is larger (inclusive) and thus written as Apocynaceae *s.l.*, in contrast to pre-merged taxon Apocynaceae *s.s*.

Example 5: When two taxa of generic rank are merged.

Diplacus and *Mimulus* are merged as *Mimulus*; the *Diplacus* is rejected and *Mimulus* is retained. And, all the species of *Diplacus* are transferred to *Mimulus* (*Mimulus s.l*).

Example 6: The taxon of species rank, *Eruca sativa* was downgraded to the rank of subspecies of *Eruca vesicaria*. It is validly written as *Eruca vesicaria* sub sp.*sativa*. Here, taxon *Eruca* at genus rank is retained; *sativa* at species rank is rejected.

The code mandates that:

1) When two or more names compete, the earliest must be retained unless contrary is indicated or one of the competing names is listed in the principle of priority.

Example 1: Rafinesque named a genus rank taxon, *Alocasia,* but did not designate 'type'. Later G. Don in 1839 validly named it *Alocasia* (Schott) G Don. Hence, latter is retained and authorship of Rafinesque is rejected (defying priority principle).

Example 2: Since, the 'type' was not designated for genus, taxon, *Piaropus* Rafinseque (1836), it stands rejected name in favour of *Eicchornia* Kunth (1842) though published later.

Example 3 : Both the taxon *Triticum astivum* L. (1753) and the taxon *Triticum hypernum* L. (1753) were published in Species Plantarum by Linnaeus. However, since the former was published in Vol. I and the latter in Vol. II., the taxon *T. aestivum* is retained and *T. hypernum* is rejected.

2) Some conserved names for taxa have no *rejicienda* because they were conserved explicitly to conserve a type. For Example: 8 families and a sub family name (see 17.5.3) under the rule *nom*. *alt*. (*Nomen alternatum*).

nomina rejicienda(Singular: *nomina rejiciendum*:is a latin term which means suppressed name or a name rejected in favour of a particular conserved name.

3) A name of taxon may be ruled as rejected if it does not include its 'type'. A name thus rejected or its basionym (if it has one) be treated as *nomina rejicienda*. Also, all combination(s) based on them also stand rejected.

4) Autonyms, i.e., those taxa that are automatically created at the rank of intrafamilial, intrageneric or interspecific have no authorship to be retained as valid, since 'type' remains the same.

Example 1 : Taxon *Lotus stripulans* is split into two varieties: *L stripulans* var. *Ottleyc* Isley and *L. stripulans* var. *stripulans*. The later has no authorship but the 'type' remains of original *L. stripulans*. So, both the varieties are retained.

Example 2: When a taxon at subfamily rank Euphorbiodeae is created out of the family rank taxon Euphorbiaceae and as is based on the type genus *Euphorbia*- subfamily euphorbiodeae is not rejected.

5) Tautonyms are binomials (names of species) where both the genus and specific epithet are similarly spelt. They are rejected by the **Code**.

Example: *Malus malus*; *Helianthus helianthus; Linaria linaria*.

However, when republished validly, as *Helianthus helianthoides*, the name is accepted. It is NO LONGER a Tautonym, because the specific epithet DOES NOT has the same spelling as the generic name.

Tautonyms are also created when some genus rank taxon are transferred to another taxon.

Example: Nees renamed *Justicia adhatoda* as *Adhatoda adhatoda*, making the changed taxon as tautonym, and was rejected. However, Nees, republished the new taxon as *Adhatoda vasica* Nees, it was retained.

6) Paratautonym, are almost similar to tautonyms, but the specific epithets are slightly different from generic names. By pronunciation they seem similar but by spellings they are not. These are accepted and retained as valid.

Examples: *Cajanus cajan;*

Sesbania sesban

7) Taxon transfer (basionym): When a taxon of lower rank than genus is transferred to another taxon with or without alternation of rank but retaining the name or its epithet, the author who first published this as a legitimate name or epithet (author of basionym) must be cited in parentheses followed by the author who made the alternation (the author of combination).

Example: In *Cheiranthus tristis* L. Robert Brown transferred genus *Cheiranthus* to genus *Matthiola* along with its species *tristis*. The new valid name would be: *Matthiola tristis* (L). R. Br.

SAQ 2

Fill in the blanks with suitable words/terms.

i) A syntype is a specimen which was cited ……………… the designation of the holotype.

ii) According to the principle of …………………, each taxon can only bear ………….. correct name.

iii) Although ……………… are not considered ………. names, they are an important source of information to taxonomists.

iv) The periodical meetings of ……………… ……………. …………… recommend changes of names of plants, it any.

17.6 SUMMARY

In this unit you have studied that:

- Taxonomists name a new taxon and determine the correct name for old taxon that has been remodelled, divided, united, transferred or changed in a rank in accordance with a *Code*.

- International Code of Nomenclature (ICN) for algae, fungi and plants lays the guidelines that govern all the aspects of nomenclature – it is called *Code*.
- *Code* also determines the correct name of a specimen according to an identification or classification system. It replaces and discourages the usage of common/vernacular names of the taxon.
- *Code* is governed by Laws, and Provisions.
- Principally, the *Code* lays down the rules that determine: ranks of taxa; typification; principles of priority and its limitations; effective and valid publication; author citation; retention and rejection of names, etc.
- International Botanical Congress at their periodical meetings recommends the changes, if any to the code. The last IBC (The XIX International Botanical Congress) was held at Shenzhen, China in 2017, and the new Code was published in 2018.

17.7 TERMINAL QUESTIONS

1. Why is there a need to have valid, scientific botanical names of plants?
2. What is ICBN? Why is the abbreviation now changed to ICN for algae, fungi and plants?
3. Discuss the six principles of the Code.
4. Explain different "types" to compare the specimens for their identification.
5. Give any one example to explain the concept of homonyms.
6. What are valid/publications? Explain by taking any one example.

17.8 ANSWERS

Self-Assessment Questions

1. i) advantages;

   ii) latin;

   iii) fixed;

   iv) opsida

2. i) prior to/before;

   ii) Priority, one;

   iii) Synonyms, valid;

   iv) International Botanical Congress.

Terminal Questions

1. Refer to section 17.2
2. Refer to section 17.3
3. Refer to section 17.4
4. Refer to sub section 17.5.2
5. Refer to sub section 17.5.3
6. Refer to sub section 17.5.4

UNIT 18

SYSTEMS OF CLASSIFICATION

Structure

18.1 INTRODUCTION

In Unit 11, you have studied about history and concepts of plant taxonomy. Now, you will study about the development of systems of classification of angiosperms. The development of angiosperm classification has been one of the most fascinating subjects. Plants have been known to man from times immemorial and remained intimately associated with human life. As the number of plant known to men increased, the necessity to organise them was felt and perhaps earliest classification came into existence. The story reflects a study of sequential events about contribution made by several eminent scholars, botanists and thinkers from time to time. As a matter of fact, plants are classified basically in the same way as are the non-living objects, primarily on the basis of various characters; For example, one can classify library books by titles, disciplines, contents, or by names authors. In the same manner, the knowledge of morphology, embryology, palynology, cytology, biochemistry, physiology, molecular biology and phylogeny have contributed to the concept of plant classification.

In this Unit you will study about various types of plant classifications, their basis and evaluate them on the parameters of merits and demerits.

Objectives

After studying this unit you should be able to:

- appreciate the importance of classification of plants;
- differentiate between artificial, natural and phylogenetic systems;and
- describe the historical background, outline, basis of classification, merits and demerits of the various systems of classification, especially the ones proposed by Linnaeus; Bentham and Hooker and Engler and Prantl.

18.2 AIMS AND TYPES OF CLASSIFICATIONS

In this section you will study about the aims and principal systems of plant classification.

18.2.1 Aims of Plant Classification

What are the aims of classification? What role does plant classification play in plant systematics?

An ideal classification should:

1) Establish and determine position and rank for a new taxon.

2) Determine the correct position and rank for old taxa that have been remodeled, divided, united, transferred or changed in rank;

3) Provide a system that expresses these relationships in practical or natural way;

4) Develop system(s) of classification; and

5) Determine the group to which new species belongs to in a system of classification.

In addition, a good and successful classification should be comprehensive, consistent, and compatible with other systems. It should be able to incorporate new knowledge and techniques to provide a “more meaningful” understanding of the system. A student of plant classification at present times should be well-versed with traditional knowledge, modern mathematics and computer applications.

It is practically impossible for anyone to study all the plants of the world, even if one spends a whole life. But it is important to understand them. Thus, it is necessary to place them into small or large groups on the basis of their similarities and differences. This is, in essence the significance of classification. Plant classification provides a system to place the plants in a hierarchy of taxa of different ranks such as: **division**; **class**; **order**; **family**; **genus**; and **species**. Each rank is inclusive of the rank below (refer unit 17). It is important and essential to provide at least a taxon to each rank. During classification, the given group of plants is placed in different hierarchical ranks. This is based on different parameters such as phenetic similarities; phylogenetic relationship or artificial criteria.

Basically there are three kinds of classification: **artificial, natural** and **phylogenetic.**

18.2.2 Types of Classification

It is said "each one of us is a taxonomist from cradle to grave". For example, we tend to identify, name, describe and classify almost everything we come across. We classify: food we eat; clothes we wear; beverages we drink; home-purchases we do; games we play; work we do. We would like to grade objects, such as varieties of apples or mangoes; kinds of fabrics; means of transport etc. To summarise, we use some or other principles of taxonomy for whatever we do. Scientists, philosophers, thinkers, and naturalists in past too have made attempts to observe, describe, preserve, name and classify various kinds of plants.

A classification could be categorised as: **empirical** or **rational**. An empirical classification is the one which has nothing to do with the properties of the objects it classifies. For example: listing of plants alphabetically. On the other hand, a rational classification could be: **practical**, **artificial** or **natural**. A practical classification is based on the "utility" principle. For example, medicinal plants, food plants, herbals, vegetables and fruits etc. Such classification is of no taxonomic value. Earliest classifications were artificial, based on extreme discretion of the taxonomist. Its principle objective was to make some order out of a chaos. Earlier workers had to start from a scratch. There were millions of organisms, and many people did not know them. They had insufficient data, and even the concept of taxa/species was unknown. As more and more plants were discovered and as data became voluminous, the concept of 'natural kinship'; 'natural relationship' and 'unifying principle' took roots. This led to the development of Natural classification.

In post Darwin period natural classification gave way to phylogenetic classifications based on 'evolutionary kinship'. Artificial classification resulted in formation of **monothetic groups** of plants. Herein, members of the group were placed together based on a unique set(s) of characters called **monothetic set**. The premise was that all the character(s) are to be present in all the members of the group **or** individual character out of the set could be present in other group but not all the characters of the group e.g. monandria or diandria of Linnaeus (see 18.3). These monothetic groups did not exhibit any natural relationship among its members and resulted in serious errors. However, keys for identification were easy to prepare.

In the **polythetic group concept**, the organisms were placed together with a larger number of shared attributes and no single character was considered essential to the group. For example: Members of family Rubiaceae are characterized by the following characters: opposite leaves; interpetiolar stipules; connate petals and inferior ovary. However, within Rubiaceae, genus *Galium* has whorled leaves; genus *Agrostemma* possesses free petals; and ovary in genus *Gaertnera* is superior. But, all three of them are placed in family Rubiaceae because they share a large number of other characters common to Rubiaceae. Can you provide another example?

All classification systems are transient in nature. They are subject to continuous modifications and improvements. The most modern, phylogenetic systems are evolved from earlier classical and natural systems of classification. Let us discuss 3 principal systems of classification of plants.

Artificial Classification

- When plants are classified using some arbitrary or easily observable characteristics, the classification is called artificial.
- Almost all of the earliest descriptions and classifications of plants can be classified as artificial. The most prominent and ancient among them are the contributions of: a) **Theophrastus** of Eresus's *Historia Plantarum* (c. 350 B.C and 287 B.C); b) **Gaius Plinius Secundus**, **Pliny the Elder**; *Historia Naturalis* (77 A.D); and c) **P. Dioscorides** *De Materia Medica*. Later among prominent contributors of 16th and 17th centuries A.D. are : 1) **Andrea Caesalpino's** *De Plantis* (1583); 2) **Caspar Bauhin's** *Pinax Theatri Botanici* (1623) and *Prodromus Theatri Botanici* (1618) 3) **John Ray's** *Methodus Plantarum Nova* (1682) and *Historia Plantarum* (1704); 4) **Joseph Pitton de Tournefort's** *Elements de botanique* (1694) and *Institutions Res Herbariae* in 1700. The most prominent and epoch making contribution of **Carolus Linnaeus**, a Swedish doctor and botanist is the *Species Plantarum* (1753) ,the father of plant taxonomy.

The advantages of an artificial classification are as follows:

- Identification made easy.
- Poorly known plants can be definitely placed.
- Such a classification is stable and not altered by availability of increased knowledge.

However, an artificial classification has numerous **disadvantages**, such as:

- It may not place together plants similar in their hereditary constitution.
- It may group together unrelated plants closely.
- It conveys only a very limited amount of information about its members.
- There is no scope of incorporating any additional information about its members.
- It possesses very little or no predictive value.
- It does not throw light on evolutionary relationships among members.

Natural Classification

Natural systems of classification reflect the situations as they might have existed in nature. They take into account the sum of all characters of its members. This clearly means that all the plants existing today are related and should be grouped together to form a natural group based on the principle of "unifying features of the group".

It is also called alpha, classical or descriptive classification:

Bernard de Jussieu in mid 18^{th} Century tried to classify the plants at Royal Gardens, Paris. He developed a system of classification which is in fact the first natural system of classification.

The classifications proposed by 1) Michel Adanson (*Families des Plantes*, 1763), 2) **Antonie Laurent de Jussieu** (*Genera Plantarum*, 1789); 3) **Robert Brown** (*Prodromus floral Novae Hollandial*, 1827); 4) Augustin Pyrame de Candolle (*Regni Vegetabilis*, 1824-73; 5) **John Lindley** *(Introduction to natural System of Classification,* 1830;. *The Vegetable kingdom*, 1846); and 6) **Stephan Endlicher** (*Genera Plantarum*, 1841) are some of the excellent examples of natural systems of classification. The classification proposed by **George Bentham** and **Joseph Dalton Hooker** in their famous publication *Genera Plantarum* (1862-1883) is discussed in detail in section 18.4.

The **advantages** of a natural classification are as follows:

- It groups together plants that are most alike in their hereditary constitution.
- Mostly, the plants grouped together are closely related to each other.
- It provides a great deal of information about its members.
- It provides a high predictive value.
- There is an ample scope to incorporate additional information about its members.

The **disadvantages** of a natural classification could be:

- Identification of plants may be difficult.
- Placing of poorly known plants may be uncertain or even impossible.
- It is liable to change with increase in our knowledge.
- It is based on 'overall' similarity among members rather than 'evolutionary kinship' among them.
- This system is also an extension of artificial system since it is also based on some selected characters only.

Phylogenetic Classification

The publication of Darwin's **"Theory of Evolution"** (1859) provided a new understanding of natural relationships. It emphasised the need to understand the relationships in evolutionary terms. Therefore, many natural classifications began to be designed with a 'new parameter', i.e. "evolutionary history or phylogeny". This led to the development of **Phylogenetic Classifications.**

Phylogenetic systems of classification are those where the plants are classified according to their evolutionary tendencies. It may be pointed out clearly that due to incomplete fossil records it is not possible to claim a system as a perfect phylogenetic one. The phylogenetic classification is usually designed on the basis of natural classification. Thus there is an overlapping in practice.

The classifications proposed by 1) **August Wilhelm Eichler** (*Blüthendiagramme*, 1875-1878); 2) **Alfred Barton Rendle** (*Classification of Flowering Plants*, 1904, 1925, 1930); 3) **Charles Edwin Bessey** (*The Phylogenetic Taxonomy of Flowering Plants,* 1915); 4) **Richard von Wettstein** (*Handbuch der Systematischen Botanik*, 1901); 5) **John Hutchinson** (*The Families of Flowering Plants,* 1973); 6) **Arthur Cronquist** (*Integrated System of Classification of Flowering Plants*, 1981); 7) **Rolf Dahlgren** (*A Revised System of Classification of Angiosperms*, 1980) are some of the most famous phylogenetic systems of classification of plants. Almost all of them are related to plants belonging to angiopserms.

The classification discussed in detail in this Unit was proposed by two German botanists, **Adolph Engler** and **Karl A.E. Prantl** in their famous publication *Die Natürlichen Pflanzenfamilien* (1887-1915). They provide a classification system for all plants ranging from algae to angiosperms.

SAQ 1

a) Fill in blanks with appropriate word(s) :

i) Plant classification provides a system to place the plants in hierarchy of taxa of different………………………..

ii) Plant classification establishes and determines ……….. and ……….

iii) Natural system of classification reflects the situation as they might have existed in ………………

iv) The classification system proposed by Takhtajan is an example of ……………. system of classification.

v) In post-Darwinian period ………….. system of classification gave way to …………….system of classification.

b) Segregate the system of classification proposed by the following botanists into the categories: artificial; natural, or phytogenetic.

i) Stephan Endlicher

ii) Charles Edwin Bessey

iii) Joseph Pitton de Tournefort

iv) Michel Adanson

v) Arthur Cronquist

vi) Andrea Caesalpino

c) List any two advantages and two disadvantages of an artificial system of classification.

18.3 LINNAEUS'S: ARTIFICIAL SYSTEM OF CLASSIFICATION

We will discuss here in detail the classification as proposed by Linnaeus (Fig18.1) as a representative of artificial classifications in plants.

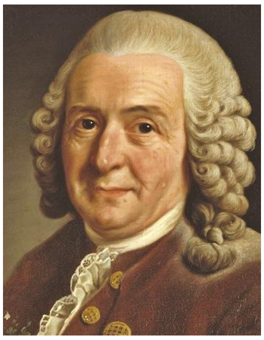


Fig.18.1: Carolus Linnaeus.

Linnaeus followed Tournefort in arrangement of plants in the classification and introduced further modifications and ideas of his own. But his classification was artificial because he has considered only one major character as an aid for delimitation of taxa from each other, irrespective of their relationship.

Linnaeus classified the plant kingdom into 24 classes in his famous work '*Genera Plantarum*' (1737) and '*Species Plantarum*' (1753). In *Species Plantarum*, he diagnosed nearly 6000 species under 1000 genera. This work is still considered to be the most important in the botanical world.

18.3.1 Basis and Outline

Linnaeus classified all the flowering plants under 23 classes on the basis of floral characters, which included:

1) Number of stamens present in a flower.
2) Insertion of floral parts into the thalamus.
3) Arrangement, adhesion and distribution of stamens.
4) Nature of anther and filaments and their arrangement.

All non-flowering plants were placed in the 24th class in his classification system.

The classification proposed by Linnaeus is based on the following:

	Artifical character(s)	Class
i)	Number of Stamens	(I-XIII)
ii)	Size of Stamen	(XIV-XV)
iii)	Cohesion of filaments into bundles	(XVI-XVIII)
iv)	Cohesion of anthers	(XIX)
v)	Stamens adnate to ovary	(XX)
vi)	Distribution of sex in plants	(XXI-XXIII)
vii)	Plants without flowers	(XXIV)

The outline of the classification proposed by Linnaeus is as under :

Class I	Monandria	- One Stamen e.g. *Canna, Salicornia*
Class II	Diandria	- Two stamens e.g. *Olea*, *Veronica*
Class III	Triandria	- Three stamens e.g. *Triticum*, *Oryza*
Class IV	Tetrandria	- Four stamens e.g. *Protea, Galium*

Class V	Pentandria	- Five stamens e.g. *Ipomoea, Campanula*
Class VI	Hexandria	- Six stamens e.g. *Narcissus, Lilium*
Class VII	Heptandria	- Seven stamens e.g. *Trientalis, Aesculus*
Class VIII	Octandria	- Eight stamens e.g. *Vaccinium*, *Dirca*
Class IX	Enneandria	- Nine stamens e.g. *Laurus, Butomus*
Class X	Decandria	- Ten stamens e.g. *Rhododendron, Oxalis*
Class XI	Deodecandria	- Eleven to Nineteen e.g. *Asarum*
Class XII	Icosandria	- Twenty or more stamens attached to Calyx e.g. *Opuntia*
Class XIII	Polyandria	- Twenty or more stamens attached to receptacle e.g. *Tilia, Ranunculus*
Class XIV	Didynamia	- 2 stamens short and 2 long, e.g. *Mentha*
Class XV	Tetradynamia	- 2 stamens short and 4 stamens long e.g. *Brassica*
Class XVI	Monadelphia	- Stamens forming one bundle only, e.g. *Hibiscus*
Class XVII	Diadelphia	- Stamens forming 2 bundles , e.g. *Pisum*
Class XVIII	Polyadelphia	- Stamens forming many bundles e.g. *Bombax*
Class XIX	Syngenesia	- Anthers are fused but filament are free (Syngenesious condition) e.g. *Helianthus*
Class XX	Gynandria	- Stamens adnate to the gynoecium e.g. *Dendrobium*,
Class XXI	Monoecia	- Plants monoecious, male and female flowers are borne on the same plant e.g. *Cucurbita, Morus*
Class XXII	Dioecia	- Plants Dioecious, male and female flowers are borne on different plants e.g. *Carica*
Class XXIII	Polygamia	- Plant Polygamous, male, female and bisexual flowers are borne on the same plant e.g. *Mangifera*
Class XXIV	Cryptogamia	- Flowers concealed e.g. Algae, Lichen, Fungi, Musci (Moss), Filicinae (Fern) etc.

Linnaeus, therefore, never asserted that system proposed by him was perfect and natural. Later in his life he started pointing out that instead of one, a group of characters should be taken into consideration.

The evolutionary concept was not clear during Linnaeus period and Darwin's theory of evolution was brought to light nearly a century later than Linnaeus. Despite several limitations, Linnaeus has contributed excellent knowledge of living kingdom.

18.3.2 Merits

The identification of most of the plants of that period became very easy through this classification because it was:

1) simple;
2) practical; and
3) easy.

18.3.3 Demerits

1) Arranged plants into 24 admittedly artificial classes.
2) It is based on only stamen characters or sexual characters, but other important morphological characters are not taken into account.
3) Affinity or phylogenies among plants are not proposed.
4) Closely related plants are placed far apart and quite different species placed together.
5) A large number of different kinds of cryptogams (as we know today) are placed in one common class.

18.4 BENTHAM AND HOOKER'S NATURAL SYSTEM OF CLASSIFICATION

After Linnaeus, the interest of botanists was the expansion of taxonomic knowledge through the exploration of vegetation. At the same time, they started realising the existence of natural affinity amongst plants. Several approaches were made towards the construction of natural system of classification reflecting the natural relationship of individuals.

Our National Herbarium (Central National Herbarium at BSI, Kolkata) is also arranged according to Bentham and Hooker system. It was established by William Roxburgh in 1795.

Based on the general principle of **Form-relationships,** the most popular of the natural systems of classification was proposed by two British Botanists (Fig.18.2) George **Bentham** (1800-1884) and **Sir Joseph Dalton Hooker** (1817-1911). Hooker being the Director of Royal Botanic Gardens, Kew, had all the facilities at his disposal. Bentham and Hooker published the monumental work **"*Genera Plantarum*"** (1862-1883). This work included names, accurate description and classification of all the seed plants known at the time (nearly 97,205 species). The term **family** was designated as **order** and the term **"Order"** was named as **Cohort**. This system of classification is adopted in most of the Commonwealth countries including our country. In all 202 families (orders) were recognized in this system. The starting family in this classification is Ranunculaceae and Poaceae is the last family.

18.4.1 Basis and Outline

As pointed out earlier, this system is mainly based on the principle of **"Form-relationships"**. Thus the various genera were grouped under orders and different orders under Cohorts on the basis of overall similarities and differences. A few orders could not be satisfactorily accommodated in any

Cohort. They were treated as anomalous orders (***Ordines Anomali***) such as Moringaceae, (common name Sajna, Drumstick tree) under cohort Moringeae.

The salient features of classification are given below:

Fig.18.2: George Bentham and Sir Joseph Dalton Hooker.

1) Phanerogams (Flowering plants or seed plants) were classified into 3 classes namely, i) Dicotyledons, ii) Gymnosperms and iii) Monocotyledons.

   This division is based on reticulate venation versus parallel venation, 4-5 merous flowers versus 3-merous flowers, 2-cotylodons versus 1-cotyledon in seed in Dictoyledons and Monocotyledons respectively. They have placed Gymnosperms in between the Diocots and Monocots as the group Gymnosperms possess naked seeds. Dicots are further split into 3 subclasses:

2) Class Dicots is further split into 3 subclasses:

   a) sub class : Polypetalae,

   b) sub class : Gamopetalae, and

   c) sub class : Monochlamydeae

   This division is based mainly on the presence or absence of petals, and their fusion. For example, in sub class Polypetalae the petals are present but free whereas in sub class Gamopetalae the petals are fused. On the other hand in sub class Monochlamydeae, no distinct petals are present but perianth is present which may be 1 or 2 seriate.

3) The sub class Polypetalae is further classified into 3 series

   a) series : Thalamiflorae,

   b) series : Disciflorae, and

   c) series : Calyciflorae

   This splitting is mainly based on the position of ovary in relationship to thalamus.

4) The series Thalamiflorae has 6 Cohorts (present day's Orders) and 34 orders (present day's families). The starting cohort is Ranales and Ranunculaceae as the starting or the first order. The last or the sixth cohort is Malvales with Tiliaceae as the last order of this series.

5) The series Disciflorae which possesses a well developed disc with superior ovary has 4 cohort and an anamolous cohort namely *Ordines Anomali*. The total number of orders in this series is 23. The starting cohort is Geraniales with Linaceae as the starting order whereas *Ordines Anomali* is the ending cohort and Moringaceae as the last order.

6) In the series Calyciflorae perigynous or epigynous flowers are found which have 5 cohort and 27 orders. The starting cohort being Rosales with Connaraceae as the starting order whereas the last or the ending cohort is Umbellales and Cornaceae as the ending order.

7) The sub class Gamopetalae where the petals are fused is divided into 3 series, namely : i) Inferae, ii) Heteromerae, and iii) Bicarpellatae

This splitting is mainly based on the number and position of carpels. For instance in the series, Inferae, as the name indicates, bicarpellary, syncarpus, inferior ovary is present, whereas in the case of Heteromerae, the carpels are always more than two. On the other hand, in series Bicarpellatae, it is always bicarpellary,syncarpous with superior ovary. The total number of cohort in Gamopetalae is 10, 3 in series Inferae, 3 in series Heteromerae and 4 in Bicarpellatae. Whereas out of a total of 45 orders, 9 are in series Inferae, 12 in series Heteromerae and 24 in series Bicarpellate.

The outline of the system can also be represented graphically.

OUTLINES OF THE SYSTEM OF CLASSIFICATION OF BENTHAM & HOOKER (1862-1833)* SEED PLANTS OR PHANEROGAMS

- DICOTYLEDONS
  - Polypetalae
    - Series I Thalamiflorae
      - Order 1. Ranalaes
      - Order 2. Parietales Cruciferae
      - Order 3. Polygalineae
      - Order 4. Caryophyllineae
      - Order 5. Guttiferales
      - Order 6. Malvales Malvaceae
    - Series II Disciflorae
      - Order 1. Geraniales
      - Order 2. Olacales
      - Order 3. Celastrales
      - Order 4. Sapindales
    - Series III Calyciflorae
      - Order 1. Rosales Leguminosae
      - Order 2. Myrtales
      - Order 3. Passiflorales Cucurbitaceae
      - Order 4. Ficoidales
      - Order 5. Umbellales
  - Gamopetalae
    - Series I Inferae
      - Order 1. Rubiales
      - Order 2. Asterales Compositae
      - Order 3. Campanales
    - Series II Heteromerae
      - Order 1. Ericales
      - Order 2. Primulales
      - Order 3. Ebenales
    - Series III Bicarpellatae
      - Order 1. Gentianales
      - Order 2. Polemoniales Solanaceae
      - Order 3. Personales
      - Order 4. Lamiales
  - Monochlamydeae
    - Series 1. Curvembryeae
    - Series 2. Multiovulate aquaticae
    - Series 3. Multiovulatae Terrestres
    - Series 4. Microembryeae
    - Series 5. Daphanales
    - Series 6. Achlamydosporeae
    - Series 7. Unisexuales
    - Ordines anomali
- GYMNOSPERMAE
- MONOCOTTYLEDONS
  - Series 1. Microspermae
  - Series 2. Epigynae
  - Series 3. Coronarieae Liliaceae
  - Series 4. Calycineae
  - Series 5. Nudiflorae
  - Series 6. Apocarpae
  - Series 7. Glumaceae

8) The series Inferae has 3 cohorts namely Rubiales, Asterales and Campanulales. The starting order is Caprifoliaceae while the ending or terminating order is Campanulaceae.

9) The series Heteromerae also has 3 cohorts viz. Ericales, Primulales and Ebenales. The starting order is Vacciniaceae whereas the last order is Styraceae.

10) The series Bicarpellatae has 4 cohorts namely Gentianales, Polemoniales, Personales and Lamiales. Further, the first 2 cohorts i.e. Gentianales and Polemoniales have actinomorphic flowers while Personales and Lamiales are characterised by zygomorphic flowers. The starting order is Oleaceae while the last or ending order is Labiatae or Lamiaceae. The order Plantaginaceae has been accommodated under series *Ordines Anomali*.

11) The subclass Monochlamydae is divided into 7 series and one series as Ordines Anomali. The starting series being Curvembryeae with Nyctaginaceae as the starting order whereas the ending series being *Ordines Anomali* with Ceratophyllaceae, a hydrophytic order, as the ending order.

12) The Class Gymnospermae is placed in between the Dicots and Monocots with 3 orders namely Cycadaceae, Coniferae and Gnetaceae.

13) The Class monocotyledons is divided into 7 series. The starting one being Microspermae with Hydrocharitaceae as the starting order. The order Orchidaceae is also included in the series, whereas the last series being, Glumaceae with Gramineae (Poaceae) as the last order.

18.4.2 Merits

The merits of this system are:

- Careful observation and original description of the genera from living specimens or from herbarium sheets form a fine taxonomic judgment and set a standard for generic description.
- The system is easy to work out and most suitable for all practical purposes or in other words it is quite easy to identify the plants up to family level with the help of this system.
- The geographical distribution of most of the genera included in the system is given.
- Up to date and authentic information is given in the system. Further, Royal Botanic Garden, Kew, is keeping it up to date by the publication of Index Kewensis regularly at the intervals of every 5 years.
- Although the system is not phylogenetic, but the position of Ranales (as the starting order of the system) is according to the modern concept of evolution.
- The position of Monocots after Dicots is also logical and in accordance with the modern concept of evolutionary trends.

18.4.3 Demerits

There are several demerits or shortcomings of the system namely:

- The position of Gymnospermae in between Dicots and Monocots is not logical and appropriate.

- The establishment and demarcation of Polypetalae and Gamopetalae as natural groups creates confusion in some cases. For example, certain members of Cucurbitaceae have gamopetalous conditions but in this system Cucurbitaceae has been placed in Polypetalae. In the treatment of Gamopetalae and Asteraceae, regarded as the highest evolved family has been placed in the beginning of the group and thus the position of Asteraceae is not at all justified according to modern evolutionary trends.

- The consideration of Monochlamydae as a separate and reduced group is not logical because by doing so the otherwise regarded as closely related families such as Chenopodiaceae could not be placed near Caryophyllaceae.

- Similarly, the inclusion of Orchidaceae in Microspermae, the starting series of Monocots is not in accordance with the recent evolutionary trends. The family Orchidaceae is considered as one of the most evolved families in Monocots and so it should not be placed as the starting family.

18.5 ENGLER AND PRANTL'S SYSTEM OF PHYLOGENETIC CLASSIFICATION

Heinrich Gustav Adolf Engler (1844-1930), Professor of Botany, University of Berlin, Germany, proposed a phylogenetic system of classification in a book entitled *Syllabus* (1892). Soon after, Engler in collaboration with **Karl Anton Prantl,** (Fig. 18.3) another German Botanist, published a monumental work entitled **"*Die-Natürlichen Pflanzenfamilien*"** (1887-1915) having 23 volumes, **Hans Melchior** published the revised (13^{th}) edition of *Syllabus der Pflanzenfamilien* in 1964 with a number of modifications in this system.

As a whole 303 families of flowering plants were recognised in this system.

18.5.1 Basis and Outline

Unisexual, naked-flowers arranged in a Catkin inflorescence and wind pollinated was considered as the lowest grade of floral organisation by Engler and as such is called **Englerian concept.** The next stage of evolution in flower is followed by the appearance of 1-seriate perianth leading to 2-seriate condition along with bisexual condition.

The outline and basis of classification of Engler and Prantl's system is given below :

1) Plant Kingdom has been divided, into XIII Divisions in the original classification. [This was revised by Melchior (1964) and the total Divisions are now XVI. In the revised classification (by Melchior, 1964), there is (1) an increase in the number of Divisions for the Algae; (2) Bryophytes and Pteridophytes have been classified in two separate Divisions; and (3) Gymnosperms and Angiosperms have also been classified into separate Divisions.]

2) In the original classification, Divisions I to XI deal with Bacteria, different types of Algae and Fungi.

3) The XIIth Division was named *Embryophyta Asiphonogama* (plants having an embryo **but no pollen tube**) and included the Bryophytes and Pteridophytes

4) The XIIIth Division was named *Embryophyta Siphonogama* (plants having an embryo **and a pollen tube**) It is divided into 2 sub-divisions based on the naked and enclosed ovules, that is

   i) Gymnospermae (Plants with naked ovules)

   ii) Angiospermae (Plants with enclosed ovules)

5) The sub-division Gymnospermae has been divided into 7 orders, the starting one being Cycadofilicales, the most primitive one where as the ending order is Gnetales, an advanced group of Gymnosperms.

6) The sub-division Angiospermae has been split into two

   i) Class Monocotyledonae, and

   ii) Class Dicotyledonae

   This division is mainly based on the striking differences between Monocots and Dicots such as the venation of leaf, trimerous flowers in Monocots whereas tetra-pentamerous flowers are present in Dicots; single cotyledon (Monocots) or two cotyledons (Dicots) in the seed.

Fig.18.3: Engler and Prantl

7) The Monocotyledons are further divided into 11 Orders and 45 Families (14 Orders and 53 Families after the revision by Hans Melchior, 1964). The first or the starting Order is Pandanales which possesses naked, unisexual flowers with Typhaceae as the starting family. The last order is Microspermae with Orchidaceae as the last family.

8) The Dicotyledons are divided into 2 subclasses namely :

   i) Archichlamydeae, and

   ii) Metachlamydeae/Sympetalae

   This division is mainly based on the condition of perianth: 1-seriate or 2-seriate and their fusion. For example, in Archichlamydeae the flowers may be naked or have a 1-seriate perianth, followed by 2-seriate perianth where the petals are mostly free (that is polypetalous condition). While in the case of Sympetalae, (as the name indicates), the 2-seriate perianth having the petals fused (that is gamopetalous).

9) Archichlamydeae has 33 Orders and 186 Families (37 Orders and 227 Families after the revision by Hans Melchior, 1964). The first or the starting order being Verticillatae and Casuarinaceae as the starting family followed by some other Orders and Families without perianth or reduced perianth. This is followed by a 1-seriate perianth and ends with Orders and Families having a 2-seriate perianth. The last Order being Umbelliflorae with Cornaceae as the last family.

10) Sympetalae which is also named as Metachlamydeae has 11 Orders in all with 52 Families (11 Orders and 64 Families after revision of Hans Melchior, 1964). The first or the starting Order being Ericales with

Clethraceae as the starting family. The last or ending order of Sympetalae is Campanulales with Asteraceae or Compositae as the last or ending family and that is very rightly placed because this family is considered as the highest evolved family among Dicots.

The outline of the system can also be represented in the form of a chart.

System of Classification Engler and Prantl

Division I
II
III
-
-
XIII Embryophyta Siphonogamia

Gymnospermae	Angiospermae		
1. Cycadofilicales	Monocots	Dicots	
2.	11 Orders	44 Orders	
3.	45 Families	258 Families	
4.	1. Pandanales		
5.	Typhaceae		
6.	2.	Archichlamydeae	Sympetalae
7. Gnetales	3.	33 Orders	11 Orders
	4.	186 Families	52 Families
	5.	1- Verticillatae	1. Ericales
	6.	2-	- Clethraceae
	7.	3-	-
	8.	4-	-
	9.	5-	-
	10.	-	-
	11. Microspermae	-	-
		-	-
		-	-
		-	11. Campanulales
			Asteraceae
		33 - Umbelliflorae	
		Cornaceae	

18.5.2 Merits

After going through the details of the system of classification proposed by Engler and Prantl we are in a better position to discuss the merits of the system, which are as follows:

1) Although, Engler himself did not consider the system as a true phylogenetic one but the arrangement of Order and Families in the system is mostly according to evolutionary tendencies.

2) The system deals with all groups of Plant-Kingdom ranging from Bacteria, Algae, Fungi, Bryophyta, Pteridophyta, Gymnosperms and Angiosperms. The system provides modern keys for the identification of each group of plants.

3) The position of Gymnosperms before Angiosperms is very accurate and is in perfect accordance to the modern concept of evolution.

4) The position of Asteraceae (Compositae) as the ending family of Dicots is very logical and accurate because it is proved beyond doubt that this family is the highest evolved family of Dicots and thus its position is fully justified.

5) Similarly, the position of Orchidaceae as the ending family of Monocots is also very accurate as this family is considered as one of the highest evolved family of monocots.

6) Anatomical data were taken into consideration in this system of classification for the first time.

18.5.3 Demerits

There are some shortcomings or demerits of the system. The important demerits are as under:

1) The concept of primitive flower (unisexual, naked, catkin) is against the modern concept of evolution. However, Melchior (1964) now places dicotyledons prior to monocotyledons.

2) Monocots are regarded more primitive than Dicots. This concept is not in agreement with modern concept of evolution.

3) Amalgamation of Apetalous families to form Archichlamydeae is not desirable as it has resulted in the formation of an unmanageable large group with 33 Orders and 186 families.

4) The system is not of much practical utility.

Box18.1 : Takhtajan's System of Classification

Another important phytogenetic system was proposed by Armen Takhtajan, the famous Russian Palaeobotanist working at Komarov Botanical Institute, St. Petersburg, Russia.

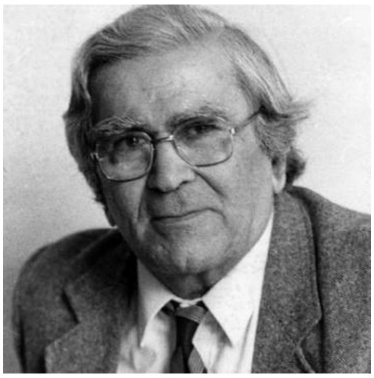


Fig. 18.4: Armen Takhtajan

For the first time he proposed the system in 1942 mainly based on the structural types of gynoecium and placentation. Afterwards, he put forward a modified system in 1954 in Russian language and then the translated version of English in 1958. This modified system was mainly based on phylogenetic principles. Soon after he made another attempt to revise the system of classification in the light of evolutionary trends in angiosperms, which appeared in 1964. This, too, was not the last word and Takhtajan again revised and updated version of his system which appeared in 1997 (**Diversity and Classification of Flowering Plants**). Before we take into account the outline of the system, it seems proper to point out the important and significant points as new terms were employed by Takhtajan in his system:

i) Magnoliophyta (Angiosperms) are regarded to be **monophyletic** in origin.

ii) Magnoliopsida (Dicotyledons) are considered as a **primitive** group than Liliopsida (Monocotyledons).

Outline of Takhtajan's. System of Classification

(Takhtajan, 1997)

1) Magnoliophyta (Angiosperms) has been divided into 2 classes viz.,

   i) Magnoliopsida (Dicots) and

   ii) Liliopsida (Monocots)

2) Magnoliopsida (Dicots) is further divided into 11 subclasses, 55 super orders, 175 orders and 458 families; estimated genera 10, 000, species 1,90.000.

   The 7 subclasses are as follows:

   1. Magnoliidae
   2. Nymphaeidae
   3. Nelumbonidae
   4. Ranunculidae
   5. Caryophyllidae
   6. Hamamelididae
   7. Dilleniidae
   8. Rosidae
   9. Cornidae
   10. Asteridae
   11. Lamiidae

3) Liliopsida (Monocots) is divided into **6** subclasses, **16** super orders, 57 orders and 131 families; estimated genera 3000, species 60,000.

   The 6 subclasses are as follows:

   1. Liliidae
   2. Commelinidae
   3. Arecidae

4. Alismatidae
5. Triurididae
6. Aridae

Takhtajan has accepted main divisions and sub-divisions as classes and sub-classes almost similar to classification given by Bentham and Hooker. In the Hooker's system the larger taxa are natural since their status is ascertained on the basis of large number of characters. But so far as further sub-groupings like series (Thalimiflorae, Disciflorae, and Calyciflorae etc. and several orders and families are concerned,one can easily spot out that more or less only one character is chosen as basic criterion in categorisation making it more artificial. Takhtajan introduced modifications at such levels. A critical examination of Takhtajan's classification shows that it is of considerable merit since he has made use of maximum data available through morphology, cytology, palynology, anatomy, embryology, cytogenetics, biochemistry and palaeobotany in the construction of taxa of various ranks.

SAQ 2

a) State whether the statement provided is true or false by placing **T** for true or **F** for false in the parenthesis.

i) The term cohort in Bentham and Hooker's classification is equivalent to the term order. [ ]

ii) Engler and Prantl's system of classification is based on the principle of form-relationship. [ ]

iii) The series Thalamiflorae belongs to subclass Gamopetalae. [ ]

iv) In Engler and Prantl's system of classification Gymnosperms are placed prior to Angiosperms. [ ]

b) Choose the correct alternative from the provided :

i) Engler and Prantl assumed catkin-type of inflorescence as most (advanced/primitive) in their system of classification.

ii) (Melchoir/Bessey) revised the classification proposed by Engler and Prantl.

iii) Metachlamydeae of Engler and Prantl is synonym with sub class (Archichlamydeae/Sympetalae).

iv) (Cryptogamia/Monandria) is the 24th class in the classification proposed by Linnaeus.

v) *Species Plantarum* (1753) is authored by (Linnaeus/ Engler and Prantl).

vi) Series Inferae, Heteromerae, Bicarpellatae are placed in the subclass (Gamopetalae/Calcyflorae) by Bentham and Hooker.

18.6 SUMMARY

In this Unit you have studied that:

- Classification of plants is the basic method employed by us to organize the plant world.
- An ideal classification aims to: establish and determine position, rank, of a new taxon and determine the correct position for old taxa; provide a relationship among plants in practical and natural way.
- A classification is regarded as good and successful if it is comprehensive, consistent, and compatible with other systems.
- It should be able to get modified with new knowledge and techniques.
- The various systems of classification are grouped into artificial, natural and phylogenetic ones.
- The system proposed by C. Linnaeus is one of the best examples of artificial system of classification. Linnaeus recognized 24 classes in his system of classification. His system of classification includes all kinds of plants including cryptogams.
- In natural system of classification, two British botanists Bentham and Hooker proposed a system of classification, which is chiefly based on the Form-Relationship. A total of 202 families were recognized in this system. The starting family being Ranunculaceae and Poaceae (Graminae) being the ending family of the system. French Botanists, Bernard de Jussieu, and Antonie Laurent de Jussieu; and A.P. de Candolle, have also proposed natural system of classifications of plants.
- Phylogenetic system of classification is those where plants are grouped according to their evolutionary and genetic affinities. The most popular under this category is the system of classification proposed by two German Botanists, Engler and Prantl.
- In Engler and Prantl's system of classification, unisexual, naked flowers in catkin are considered as the most primitive type of flowers. In this system the position of gymnosperms just before the angiosperms is an important point of merit. As a whole, 303 families of flowering plants are recognized in this system.

18.7 TERMINAL QUESTIONS

1. Point out the merits and demerits of Bentham and Hooker's classification of plants.
2. Write short notes on :
   a) Polypetalae
   b) Embryophyta Siphonogamia
3. "Classification systems are transient in nature" comment.
4. Differentiate between artificial, natural and phylogenetic system of classification of plants.
5. Discuss the demerits of Linnaeus's system of classification of plants.

18.8 ANSWERS

Self-Assessment Questions

1. a) i) ranks

   ii) position, ranks

   iii) nature

   iv) phylogenetic

   v) natural, phylogenetical

   b) Artificial : Andrea Caesalpino; Joseph Pitton de Tournefort

   Natural : Michel Adanson; Stephen Endlicher

   Phylogenetic: Arthur Cronquist; Charles Edwin Besse

   c) Refer to section 18.2.2

2. a) i) T; ii) F; iii) F; iv) T

   b) i) primitive

   ii) Melchior

   iii) sympetalae

   iv) cryptogamia

   v) Linnaeus

   vi) Gamopetalae

Terminal Questions

1. Refer to Section18.4
2. Refer to a) Section 18.4.1; b) Section 18.5.1
3. Refer to Subsection 18.2.2
4. Refer to Subsection 18.2.2
5. Refer to Section 18.3.3

Acknowledgement of Figures

Figure 18.1	https://images.app.goo.gl/UKdzNRVscPzUXDwH8
Figure 18.2	http://lh3.ggpht.com/-OG82aI2AzIM/U42JmQZEcJI/AAAAAAAABmk/T7IYVRG8lE4/Bentham%252520and%252520Hooker.png?imgmax=800
Figure18.3	https://images.app.goo.gl/me51XAfzFudXR6dN7
Figure18.4	https://www.google.com/search?q=takhtajan&source=lnms&tbm=isch&sa=X&ved=2ahUKEwiWgd-

UNIT 19

BIOMETRICS, NUMERICAL TAXONOMY

Structure

19.1 INTRODUCTION

In this Unit we will describe numerical taxonomy and its applications. Numerical taxonomy is one of the modern approaches to synthetic taxonomy. It was developed in the late 1950s as a part of multivariate analyses. Interestingly, this approach was accompanied with the parallel development of computers. We will also describe about, its principle, various steps used, procedure used and its advantages. We will also touch upon the biometrics.

Objectives

After studying this Unit, you should be able to:

- define numerical taxonomy ;
- know various principles of numerical taxonomy ;
- make a list of the procedures adopted in numerical taxonomy; and
- appreciate the advantage and applications of numerical taxonomy.

19.2 BIOMETRICS

The term Biometrics is derived from the Greek words -*bio* (life) and -*metrics* (to measure). Biometrics is a term that encompasses -the application of modern statistical methods to the measurements of biological objects.

A number of biometric systems are commercially available for human recognition. However, there is no such biometric system for plant recognition. Interestingly, there are many characteristics that are uniquely identifiable at a species level, and these can be easily measured. Biometrics can be strengthened by adding reference images of new plant species to the database or by adding mere reference images of existing species. This is an upcoming study in the area of plant taxonomy which is gaining importance.

19.3 NUMERICAL TAXONOMY

The book "Numerical Taxonomy" by P.H.A. Sneath and R.R. Sokal (1973, W.H. Freeman, San Francisco) provides valuable information relating to the aims, the principles, the methods and results of numerical taxonomy.

Taxonomy today is, in many details, different from what it was a generation ago. The use of computers by taxonomists has established an interesting modern trend called **Numerical Taxonomy** or **Taximetrics**. Mathematical and statistical evaluation of taxonomic information and computation of this data has provided taxonomists with new approaches to understand classification.

The computation of data by evaluating numerically the affinity or similarity between organisms and then ordering them into taxa takes very little time, probably a few seconds. However, the preparation of the data in a suitable form for input into the computer is a very tedious task requiring painstaking examination and recording of information.

The use of computers in numerical taxonomy has made it possible to compare a large number of characters from many organisms with relative ease. After comparisons of the organisms they are grouped according to overall similarity or dissimilarity and wherever necessary presented graphically.

In this section, you will study about the fundamentals of numerical taxonomy; know the principles and important terms used in this science; and understand the procedures adopted by numerical taxonomists in arriving at a classification.

In Block 4, Unit 18, you had studied that organisms are classified on the basis of evidence obtained from their characters. You have also studied that different kinds of classifications can be designed by using a few or many characters. M. Adanson (1763) proposed that a classification should use a vast range of characters covering all aspects of the plants, and in construction of a classification all characters must be given equal importance. This idea forms the basis of modern numerical taxonomy, also called Neo-Adansonian Taxonomy. So far as the character number is concerned there is no limitation but larger the number better is the approach for generalisation of the taxa. You should remember that numerical taxonomy is not a totally new approach, but it is an organised method of evaluating data with computers in an objective and repeatable manner enabling comparison of many characters from many populations of plants.

19.4 CHARACTERS

The proper selection of characters is a critical point in the application of numerical taxonomy. Certain characters are clearly disqualified for numerical taxonomy and these are listed by Sokal and Sneath (1963) as inadmissible characters. According to these authors it is undesirable to use the following:

i) attributes which are not a reflection of the genotypes of the organisms themselves;

ii) any property which is a logical consequence of another, either partly or wholly; and

iii) characters which do not vary within the entire sample of organisms.

The authors also suggest that to be qualified as an admissible character the following attributes are important:

i) It should be inherent in the organism and should neither be susceptible to environmental changes, nor affected by experimental uncertainties;

ii) It must be of some diagnostic value;

iii) It cannot be sub-divided; and

iv) The character that is selected must show variation among the taxa under comparison.

19.5 PRINCIPLES OF NUMERICAL TAXONOMY

Numerical taxonomy is based on the following 7 principles.

1. The greater the content of information in the taxa of a classification is, and the more characters on which it is based, the better a given classification will be.

2. Every character is of equal weight in creating natural taxa.

3. The overall similarity between any two entities is a function of their individual similarities in each of the many characters for which they are being compared.

4. Distinct taxa can be recognised because correlations of characters differ in the groups of organisms under study.

5. Phylogenetic inferences can be made from the taxonomic structure of a group and from character correlations, given certain assumptions about evolutionary pathways and mechanisms.

6. Taxonomy is viewed and recognized as an empirical science.

7. A classification is based on phenetic similarity.

SAQ 1

State whether following statements are True or False.

i) Computers are not used in numerical taxonomy. [ ]

ii) Modern numerical taxonomy is also called Neo-Adansonian taxonomy. [ ]

iii) Characters should be chosen which do not occur anywhere in the entire sample of organisms. [ ]

iv) For creating natural taxa every character should be of equal weightage. [ ]

19.6 PROCEDURES ADOPTED BY NUMERICAL TAXONOMISTS

Numerical taxonomy is a new method of organising data that may prove helpful in better understanding of relationships. The number of characters studied in numerical taxonomy is usually about 50-100 from approximately the same or greater number of organisms. It is presumed that the greater the number of characters the more valid the classification is. You have already studied about the property of good characters. Since numerical taxonomy is an operational science, the procedure is divided into a number of repeatable steps, allowing the results to be checked at every step.

19.6.1 Choice of Units to be Studied

Choice of units to be studied (Character weighing): The first step is to decide what kind of units to study. In numerical taxonomy, the basic unit of study is called the "operational taxonomic unit" (OTU). Thus the OTU can be an individual plant if the taxonomist is studying a single population of plants to find out the range of variations in its characters. Similarly, you may treat an entire population of plants as an OTU if you are studying a single species represented by different populations existing in nature; or the OTU may be different species when a genus is being evaluated. Therefore, in numerical taxonomy, the OTU varies with the material being studied, and this helps the taxonomists in making an objective study.

19.6.2 Character Selection

Character selection: After selecting the OTU's, it is necessary to select characters by which they are to be classified. By experience, you will learn that characters which vary greatly amongst the OTU's are clearly more useful in numerical taxonomy; and we know that as many characters as possible may be used. Preferably a minimum of 60 and generally 80 to 100 or more characters are needed to produce a fairly stable and reliable classification. The selected characters have then to be coded or given some symbol or mark. There are 2 methods of coding taxonomic information.

19.6.3 Coding of Characters

The huge amount of data handled in numerical taxonomy makes computers essential. Therefore, the data on the characters of the OTU's must be suitably coded. The selected characters have then to be coded or given some symbol/mark so that the data can be computed. For this purpose, a general listing of all the characters is very helpful. Secondly, it is important to treat all characters as having equal importance (equal weighting/ "*a priori weighting*") as this is also one of the 7 principles of numerical taxonomy.

There are two ways/methods of coding taxonomic information for the purpose of numerical taxonomy:

a) Binary coding or two-state coding

This is the simplest form of coding adopted in numerical taxonomy where the characters are divided into (+) and (**-**) or as 1 and 0. The positive characters are recorded as + or 1 and the negative characters as – or 0. It is possible to use this method of coding for all characters studied. In case a particular character is not present in an OTU being examined, the symbol or code NC is used, indicating that there is no comparison for that character. However, we find that by using this method of coding, we tend to increase our work because there are large variations in the plant, and very often a single character such as colour of flower can be represented in a wide range. We can have white, pink, red, yellow and other colours in roses. If we are to use this data in a binary coding, then we will have to use each colour as a character and it would be coded as + or -, as the case may be.

b) Multi-state coding

An alternative method would be to use multi-state coding where a single character can be coded in a number of states, each being represented by a numerical symbol or code (e.g. 1, 2, 3, 4, 5,. .. .) depending on the range of variation. Thus, if we again look at the colour of the rose flower, we can give different codes to different colours such as white = 1, pink = 2, red = 3, yellow = 4, and so on. Besides qualitative characters such as colour of flower, type of placentation, etc, multistate coding is also useful for quantitative characters such as plant height, leaf length, leaf breadth, and other characters involving measurements. A code is prepared for the range of variation and appropriate symbols are allotted to each unit in the range.

c) Preparation of data matrix

The data obtained by scoring the characters in the OTU's are then presented in a table as a data matrix giving the OTU's on one side of the table and the codes for different characters against each OTU. Thus, if one has studied 25 OTU's and has scored 75 characters from each; the data matrix will contain 25 × 75 = 1875 units of information. This large unit of information in the data matrix necessitates the use of computers to help the taxonomists to digest the knowledge quickly. It is also important to remember that computer programmes are based on mathematical equations and computer language and the data matrix is essential for this purpose. In addition, the next step in numerical taxonomy is entirely dependent on the data matrix.

The information is then presented a **t** × **n** table or data matrix consisting of OTU's scored for **n** characters (Table 19.1).

Table 19.1: Coded data (t × n table)

Characters (n) (1-12)	Taxa OTU's			
	A	**B**	**C**	**D**
1.	+	+	-	NC
2.	+	+	+	+
3.	+	+	+	-
4.	-	+	NC	NC
5.	+	+	+	+
6.	+	+	-	+
7.	+	+	-	NC
8.	NC	-	+	+
9.	+	+	+	+
10.	+	+	+	-
11.	+	NC	-	NC
12.	+	+	+	-

(After Sneath, 1962, in Microbial Classification, edited by Ainsworth and Sneath)

19.6.4 Measurement of Similarity

Overall similarity(s) is calculated by comparing each OTU with every other and is usually expressed as a percentage, 100 percent S for identity and 0 percent S for no resemblance. A similarity table or matrix is then constructed by tabulating the S coefficients for each one of the OTU's (Fig. 19.1). The most commonly used method of determining similarity/resemblance is to calculate the "**simple matching coefficient"**. This computation was first used by Sokal & Michener in 1958, and it is based on a very simple mathematical formula as follows:

$$\text{Simple matching coefficient } (S_{sm}) = \frac{\text{matches}}{\text{matches} + \text{mismatches}}$$

$$\text{Or} \quad \frac{m}{m+u}$$

It is more convenient to record similarity as a percentage. Thus, the formula would be modified as follows:

$$S = \frac{m}{m+u} \times 100$$

The data on percentage similarities of all the OTU's against all other OTU's can be calculated in this manner. Thus when one OTU is compared with itself, the similarity will always be 100%.

On the other hand, when no single character is common between two OTU's, the similarity will be 0%. Therefore, by comparing each OTU with all the other OTU's, it is possible to obtain a large amount of information on the similarities/dissimilarities among the units investigated.

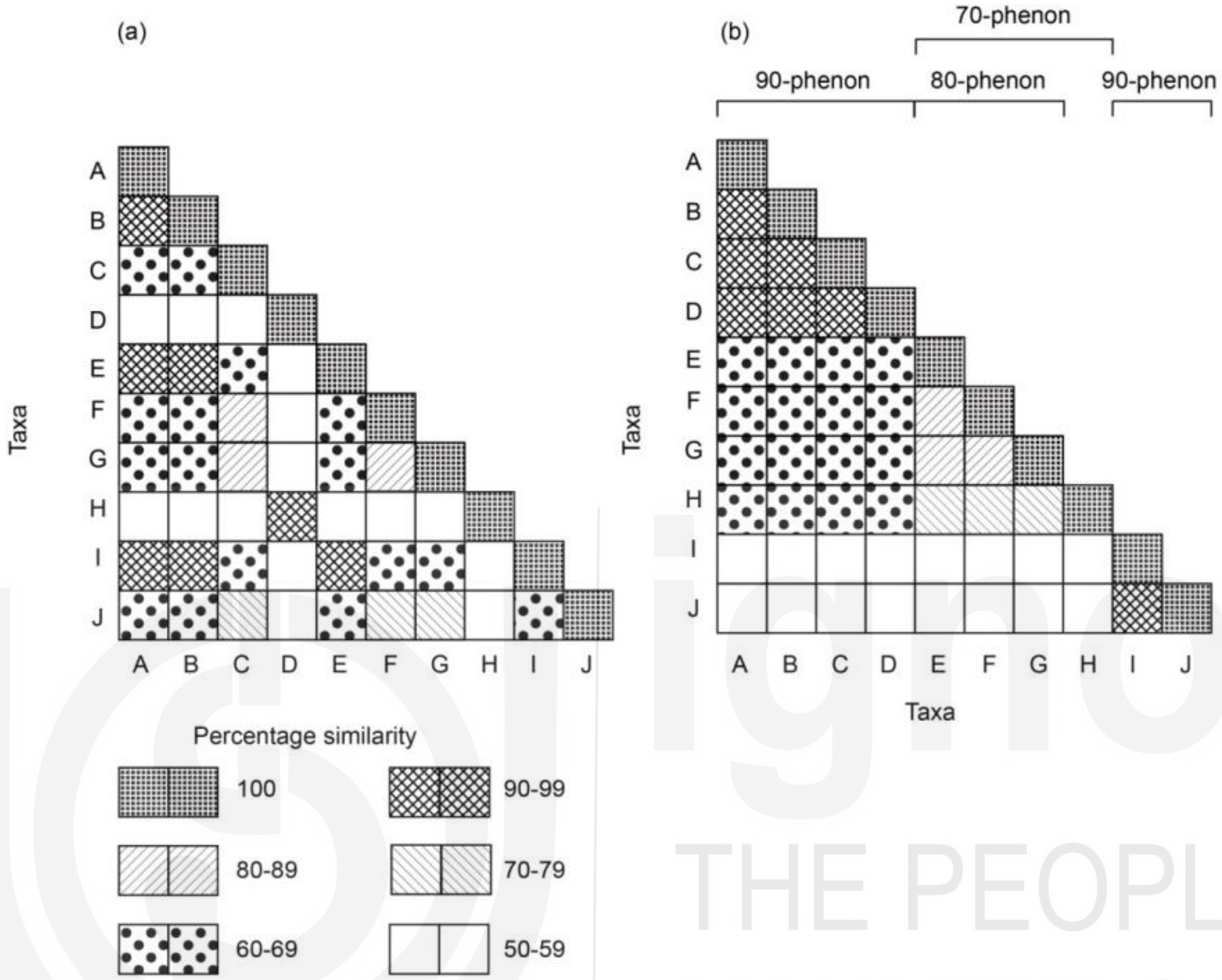


Fig. 19.1: a) Schematic diagram showing a matrix of hypothetical similarity coefficient between pairs of group (taxa); the magnitude of the coefficient is shown by the depth of shading. b) The same coefficient arranged by placing similar taxa next to each other; this gives triangle of high similarity values. Phenons are groups by desired rank (After Sneath 1962, Microbial classification).

19.6.5 Cluster Analysis

After making a similarity table, it is rearranged so that OTU's whose members have the highest mutual similarity are brought together. This can be done by several methods and related taxa or groups are generalized. These clusters are called **phenons** and can be arranged hierarchically in a tree diagram or dendrogram (Fig. 19.2).

The groups or clusters thus generalized may be treated as equivalent to the categories having ranks in classical taxonomy, such as the genus, family, order, etc. A problem faced by many taxonomists is whether there is any equivalence between the ranks in different taxonomic groups of organisms. Is a family of flowering plants, for example equivalent in any sense to one of algae, or other organisms? To overcome this problem, numerical taxonomists have advocated a new terminology.

Here, the term “phenon” is introduced and the particular phenons are designated by numerical prefixes (e.g., 80 similarity) showing the level of resemblance by which they are defined

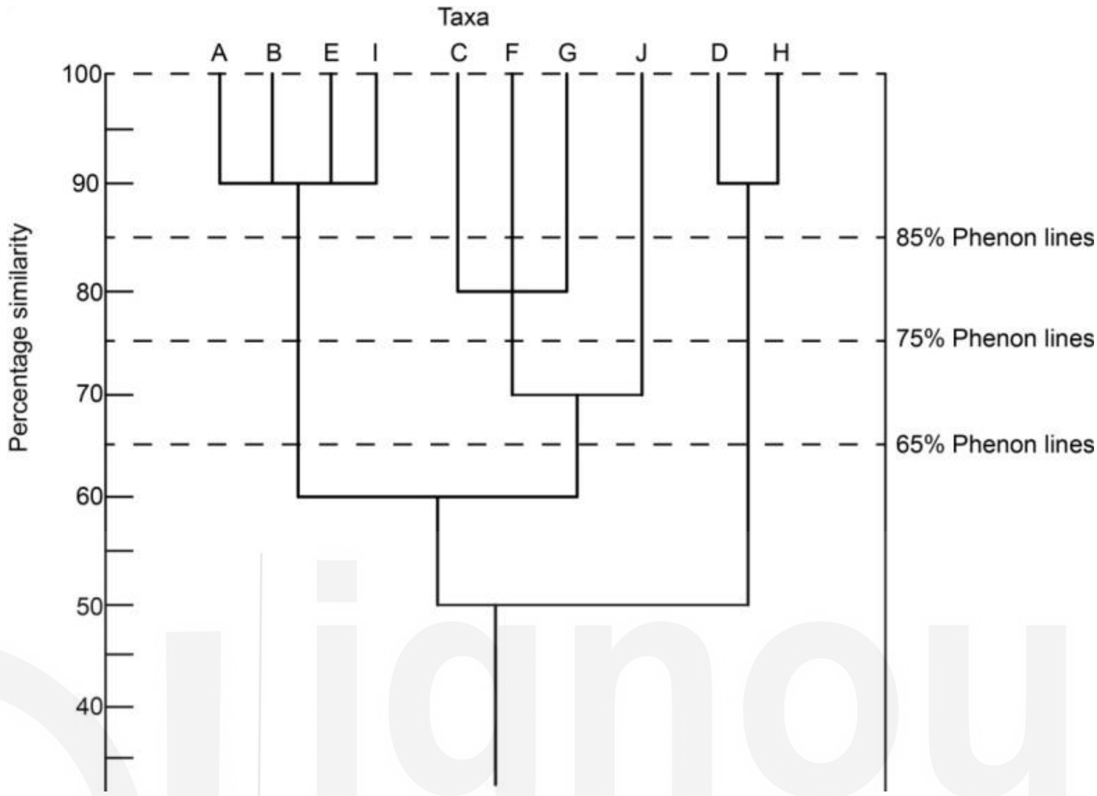


Fig. 19.2: A dendrogram representing the hypothetical hierarchy of group (taxa) obtained from Fig 19.1. The ordinate indicates magnitude of similarity coefficient at which stems join to form higher ranking groups. Horizontal delimit groups of equal rank (per cent phenon lines). (After Sneath, 1962) Microbial Classification, edited by Ainsworth and Sneath. University of Cambridge).

The delimitation of the phenons is done by drawing horizontal lines across the dendrogram at a chosen similarity value. Such a dendrogram will have reference to a given study only, and cannot be generalized. Thus, phenons will be arbitrary and relative to groups within the limits of only one analysis.

Of the numerous numerical taxonomic studies, the reclassification of the dicotyledons by Young arid Watson (1970) serves as a good example. They studied 83 characters from morphology and anatomy in 543 genera and computed this information to classify these angiosperms. The computer-based classification was in many ways similar to other traditional classification, as well as in some ways different. However, the different genera were clearly distinguishable into distinct categories on the basis of the nature of the ovule into crassinucellate (ovules with a massive nucellus) and tenuinucellate (ovules with a small amount of nucellus). In view of these, some taxonomists are of the opinion that numerical taxonomy may never replace traditional methods as standard procedure. It would, however, be successful where other methods have failed or are laborious or otherwise difficult to apply. The most important contribution of numerical taxonomy has been to help taxonomists analyse their methods, data, and conclusions more logically and objectively.

SAQ 2

i) Define numerical taxonomy.

ii) What is meant by 'operational taxonomic unit' (OTU)?

iii) Describe how similarity is measured.

19.7 ADVANTAGES OF NUMERICAL TAXONOMY

Sneath and Sokal (1973) have mentioned the following advantages of numerical taxonomy:

1. In comparison with the classical taxonomy, the data in numerical taxonomy are collected from more variety of sources, such as morphology, physiology, phytochemistry, cytology, proteins, etc.

2. Through numerical taxonomy, much taxonomic work can be done by less highly skilled workers.

3. Numerically coded data may be used easily for the creation of keys, maps, descriptions, catalogues, etc. with the help of existing electronic data processing system in herbaria and other taxonomic institutions.

4. Because the numerical methods are more sensitive in delimiting taxa, they provide better keys and classification systems in comparison to classical taxonomic methods.

5. The quality of classical taxonomy is improved by numerical taxonomy as more and better described characters are used in the latter.

6. Numerical taxonomy has suggested several fundamental changes in the classical principles of taxonomy in general and classification system in particular.

7. Number of the existing biological concepts have been reinterpreted in the light of numerical taxonomy

19.8 APPLICATIONS OF NUMERICAL TAXONOMY

Some of the examples of the application of numerical taxonomy are listed below:

1. Numerical methods are used considerably to study the similarities and dissimilarities in bacteria, and other microorganisms.

2. Numerical taxonomy is used for delimitation of several angiospermous genera like *Solanum* (Soria and Heiser, 1961), *Oryza* (Morishima and Oka, 1960), etc.

3. Several angiospermous taxa have been re-classified using numerical methods.

4. Sneath and Sokal (1973) have mentioned several examples of the application of numerical taxonomy in several angiosperm genera, viz. *Apocynum*, *Crotolaria*, *Curcurbita*, *Chenopodium*, *Oenothera*, *Salix*, *Zinnia*, barley cultivars, maize cultivars, wheat cultivars, etc.

19.9 SUMMARY

- Biometrics is a new area of research in plant taxonomy
- Numerical taxonomy is a mathematical and statistical evaluation of taxonomic information and computation of the data has given new approach to understand classification
- Proper selection of characters is an important feature in the application of numerical taxonomy.
- It is based on seven principles
- Basic unit in the study of numerical taxonomy is selection of operational taxonomic units (OTUs) which varies with the material being studied.
- There are two methods of coding taxonomic information: Binary coding and multi-state coding.
- Cluster analysis of OTUs are done and arranged hierarchically in a tree diagram or dendogram.
- Numerical taxonomy has several applications such as bacterial classification, reclassification of several angiospermic taxa etc.

19.10 TERMINAL QUESTIONS

1. Why numerical taxonomy is also called Neo-Adansonian taxonomy?
2. Briefly describe the procedure adopted by Numerical taxonomists.
3. Differentiate between binary coding and multi-state coding.
4. Mention two uses of a data matrix in numerical taxonomy.
5. What is ‘cluster analysis’ and how is this arrived at in numerical taxonomy?
6. Describe applications of numerical taxonomy.

19.11 ANSWERS

Self-Assessment Questions

1. i) F; ii) T; iii) F; iv) T
2. i) Numerical taxonomy is a branch of modern approach to synthetic taxonomy. It was developed in the late 1950s as a part of multivariate analyses and in parallel with the development of computers.

ii) 'Operational Taxonomic Unit' or OTU is the basic unit of study in numerical taxonomy. It can vary with the nature of the material being investigated as well as the purpose of the investigation.

iii) Refer to subsection 19.6.4 Measurement of similarity.

Terminal Questions

1. Numerical taxonomy is also Neo-Adansonian taxonomy because it is based on the same basic taxonomic principles formulated by M. Adanson in the 18^{th} century.

2. Carefully read the Section 19.6 and rewrite the procedure in your own words.

3. Binary coding is two-state coding according to which every character studied can be analysed in 2 states viz. present (+) or absent (-); whereas multi-state coding analyses more than two states in which a particular character exists and each state is given a definite symbol or code.

4. The data matrix basically presents taxonomic information in tabular from for all the OTUs examined and all the characters studied. It also provides information for clustering of the OTUs.

5. A cluster analysis is a process by which the OTU s are sorted out to form groups or cluster on the basis of their overall similarity. Similarity or dissimilarity coefficients are calculated by comparing each OTU with every other OTU and this is represented as a percentage. This information is used for cluster analysis in numerical taxonomy.

6. See Section 19.8

UNIT 20

CLADISTICS

Structure

20.1 INTRODUCTION

In the earlier Units of this Block you have studied the taxonomic concepts that differentiate the living organisms as species and other taxonomic ranks. Unit 20 specifically deals with the schemes and principles that govern the classification of these taxa as Natural, Artificial, Phylogenetic, etc. Systematics is the branch of biology that attempts to understand the genealogical relationship underlying organic diversity and also constructs classifications of living things. There is a diversity of opinion on how genealogy and taxonomy are related. Three prominent views are:

1) Numerical taxonomy aims to ascertain the overall similarity among the organisms using objective, quantitative and numerous characters, regardless of descent. Proposed by Sokal and Sneath, this view is termed 'phenetic' by the German American biologist, Ernst Mayr, as this approach relies directly on the overall similarity of the phenotypes.

2) Classification that emphasized phylogeny-based sister- group relationships or the Phylogenetic Systematics was proposed by Hennig and later termed **Cladistics** by Ernst Mayr. This approach involves the construction of phylogenetic trees to graphically depict the relationships between organisms. Cladistics is based on shared derived characters (synapomorphies) between related groups.

3) Mayr suggests that the classification should be based both on cladistics and phenetics and be termed "Evolutionary Taxonomy".

In this Unit, we will discuss, compare and understand the concepts of phenetics and cladistics.

Objectives

After studying this Unit, you should be able to:

- ❖ define the phenetics, cladistics and the associated terms;
- ❖ construct and analyse phenograms;
- ❖ differentiate between different kinds of clades;
- ❖ build and interpret the cladograms;
- ❖ compare the relative merits and demerits of classification systems based on principles of similarities vs. descent.

20.2 PHENOGRAMS

The term **phenetics** (as proposed by Robert Sokal and Peter Sneath in 1963), is based on the Principles of Numerical Taxonomy. In this scheme, weightage is given to "overall similarity" of character(s) used. Most of the presently used systems of classifications have been established on phylogenetic principles, but largely founded on phenetic (structural) relationships. Taxa (2 or more) with similar structural characters are called **phenetic groups**. From a given group to taxa, the phenetic groups can be expressed and analysed through a branching diagram, the **phenogram** (syn: dendrogram).

Since phenetics uses "overall similarity" between taxa in question, for a construction of a phenogram, one has to identify taxa (to be classified) and the character(s) to be compared. The taxa in question (operational taxonomic units-OTUs) need to be organized into groups based on their overall similarity .At the end, the hierarchical pattern of grouping is expressed as a branching diagram or phenogram ,without implying any evolutionary relationships.

For example:

Let us presume, you are constructing a phenogram for the taxa, **W**, **X** and **Y**, by comparing their characters 1, 2 and 3.

- The characters could be (i) qualitative; easily distinguishable morphological features, such as: leaf; petiole; flower; inflorescence, or fruit types,(ii) It could be number, color, of petals, etc. or,
- The characters could be quantitative viz., length of the leaf, area of leaf, height of the plant etc.

Next step would be depiction of a **character** x **taxon matrix** in a tabular form (Fig. 20.1).

	1	2	3
W	yes	yes	yes
X	yes	no	no
Y	no	no	no

Fig. 20.1: A Character-Taxon matrix.

In the character- taxon matrix, tabulate the presence or absence of a character in the given taxon as symbol respectively. This matrix also provides the basic data to construct a phylogenetic tree or cladogram (to be discussed later). The given Figure 20.1 suggests that taxa 'W' has the presence of all characters 1, 2 and 3, while taxa 'Y' has none of these. In the taxa 'X' only the character '1' is present while '2' and '3' are absent. A simple analysis of this "character-taxon matrix", data suggests that taxon 'W', which possesses all the 3 characters is distinctly different from the other two taxa 'X' and 'Y'. Otherwise taxa 'X' and 'Y' are similar or closer in not possessing the characters 2 and 3. The phenogram based on these similarities of characters is provided in Figure 20.2. The diagrammatic representation in phenogram suggests that taxa X and Y are much closer to each other than either of them is to the taxon W.

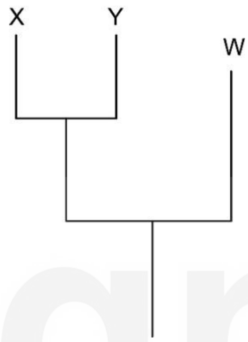


Fig. 20.2: A Phenogram.

A phenogram can also exhibit a number of taxa relationships based on a larger number of characters (figure 20.2). More the characters, better is the analysis.

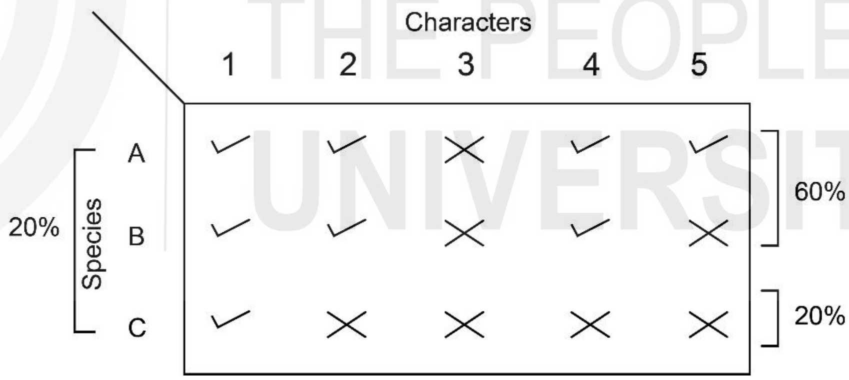


Fig. 20.3: Character-Taxon Matrix for 3 taxa and 5 characters.

Let us, now try to find out the overall similarities between species from a "character x taxon" matrix given in Figure 20.3. The figure provides the matrix for a set of 5 characters for the species (taxa) A, B and C. You can analyse the matrix as follows:

i) Species A and B have 3 out of 5 similarity of characteristics, i.e. they have overall 60 percent similarity (for the characters 3, 4 and 5).

ii) Species A and C have only 1 out of 5 similar characters will have overall similarity of 20 percent (for the character 2).

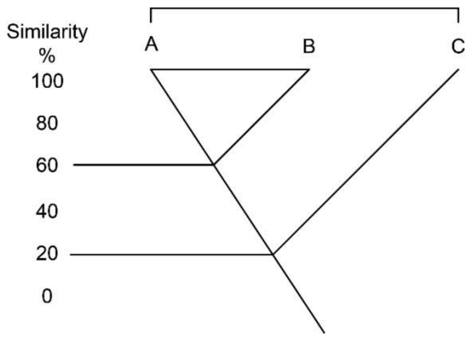
iii) Species B and C also possess overall 20 percent similarity of character (for the character 1). The percent similarities between taxa A, B and C have been depicted in Fig 20.4 a.

Based on the percent similarity Fig. 20.4 b provides the phenogram for the above character-taxon matrix.

Percent Similarity

	A	B	C
A	—	60	20
B		—	20
C			—

(a)



(b)

Fig. 20.4: (a) Percent similarity; (b) Phenogram.

The key to graphical representation of overall similarities and phenetic construction in the form of a phenogram involves the following steps:

1) Choice of unit, the Operational Taxonomic Unit (OTU). An OTU varies with the material being used. It could be a plant, an entire population, a single species and different species of a genus and so on. In the figures 20.1 and 20.2 these characters are represented by W, X, Y and A, B, C respectively.

2) Once an OTU is selected, it is important to select the characters (attributes) to be matched. It is through the choice of character(s), the phenetic relationships are/can be established. While choosing the character(s), some common precautions that need to be followed are:

   - it should be an unit character,
   - it should be heritable,
   - it must not be susceptible to environmental modifications,
   - selected characters should be from all parts of the life cycle.

   In addition, a large number of characters should be used which could be qualitative or quantitative.

3) Once the characters are selected, each of them should be expressed in binary form, with a clear-cut demarcation of contrasting pairs, e.g. leaf present or not: long or broad; petals: 4 or 5; inflorescence: raceme or cyme etc. Each of these binary pairs be allocated the signs (+) or (-); or (1) or (0). If a particular character in an OTU is absent, it is labelled NC (no comparison). These characters are coded in the form of a "character x taxon" matrix. This matrix does not show any hypothetical ancestor, as no *a priori* hypothesis of evolutionary direction (polarity) is made.

   Next step would be preparation of **n** x **t** table to document the data collected for the analysis. Here, '**n**' represents the character and the symbol '**t**' represents the OTU. Figures 20.1 and 20.3 are n x t tables.

4) If a character possesses multiple states, convert them into a series and each state of the series is treated as a character. e.g., if the color of petals could be red, yellow or blue, then red could be 1, yellow 2 and blue as 3.

The following steps are common in all phenetic studies:

1. A data matrix is first constructed by listing the character states (in coded numerical form) for all the selected characters among all of the organisms or taxa under study.
2. The collected information is then converted into a measure of similarity (called similarity coefficient) between every pair of taxa.
3. Taxa are finally clustered based on their **similarity coefficient** so that those with higher similarity are placed together in a tree (called a **phenogram**).

For the measurement of similarity of the phenetic characters between taxonomic entities refer section 19.6.3 of Unit 19 in this block.

Let us take a hypothetical example to understand the various steps involved in constructing a Phenogram:

1. Consider five species of a herbaceous flowering plant (Taxon A, B, C, D, and E).

Ten characteristics along with their character states are listed below:

1.	Plant Habit	(Herb or Shrub)	+/-
2.	Leaf Shape	(Elliptic or Linear)	+/-
3.	Bract	(Present or Absent)	+/-
4.	Flower	(Complete or Incomplete)	+/-
5.	Flower Color	(Red or Yellow)	+/-
6.	Petal Number	(Five or Four)	+/-
7.	Stamen Number	(Four or Two)	+/-
8.	Stamen Position	(Free or Adnate)	+/-
9.	Pollen Surface	(Spiny or Smooth)	+/-
10.	Carpel Number	(Three or Two)	+/-

The above information is recorded in the form of a table or a character-taxon matrix (Fig. 20.5). In numerical taxonomy and cladistics it is commonly converted to a **numerical code**.

Characters

Taxa	1	2	3	4	5	6	7	8	9	10
A	+	+	+	+	+	+	+	+	+	-
B	+	+	+	-	-	+	+	+	-	-
C	+	+	+	+	-	+	+	+	-	+
D	+	+	-	-	-	+	-	-	-	-
E	+	+	-	-	-	-	+	-	-	-

Fig. 20.5: Character-taxon matrix for five taxa and ten characters.

2. Calculation of similarity between each pair of taxa by either **Simple Matching Similarity Coefficient** or by **Coefficient of overall similarity** (S_{jk}). Simple matching similarity coefficient is the ratio of the number of matches between the two taxa to the total number of characters. The percentage of characters shared by the two taxa can be calculated by multiplying the coefficient by 100.

Let us view the simple matching similarity between the two taxa A and B (Fig. 20.6):

	Characters									
Taxa	1	2	3	4	5	6	7	8	9	10
A	1	1	1	1	1	1	1	1	1	0
B	1	1	1	0	0	1	1	1	0	0
C	1	1	1	1	0	1	1	1	0	1
D	1	1	0	0	0	1	0	0	0	0
E	1	1	0	0	0	0	1	0	0	0

Fig. 20.6: Simple matching similarity between taxa A and B.

3. Arrange the similarity matching in the form of a ***similarity matrix****.*

Taxon A and taxon B show a similarity matching of 7/10 or 0.70.
Similarly, the matching coefficients of all the taxa are represented in Fig. 20.7.

	A	**B**	**C**	**D**	**E**
A	-				
B	0.7	-			
C	0.7	.08	-		
D	0.4	0.7	0.5	-	
E	0.4	0.7	0.5	0.8	-

Fig. 20.7: Matching coefficients of taxa A, B, C, D and E.

4. Apply clustering strategy to the similarity matrix : The similarity table shows that two groups viz., B-C and D-E share 80% (0.8).So these taxa are the most similar set of plants and are therefore, linked first at 80%.

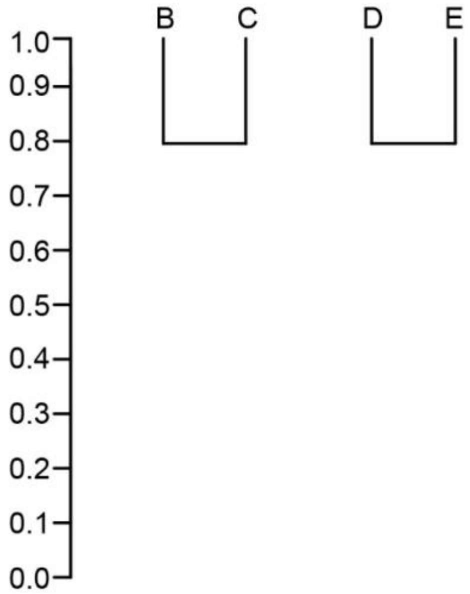


Fig 20.8: First step in construction of hierarchical classification.

Construct a hierarchical classification by the order in which the taxa are united to form a new taxon. A phenogram (Figs 20.8, 20.9 and 20.10) denotes the classification where the phenetic distance is represented on a scale of similarity (from 0 to 1).

5. Consider and link the next most similar taxa from the similarity table**.** You can see that 70% is the next highest cluster. But now the question is - should we join A to B-C; or D-E to B? If we join A to B and C it will cluster with the B-C group at 70%:

   A-B=0.7
   A-C=0.7
   average = 0.7+0.7÷0 = 0.7

But if we wish to join B to the D-E cluster we must also include C as it is already joined to B: Thus

D-B = 0.7
D-C = 0.5
E-B = 0.7
E-C = 0.5
average = 0.7 + 0.5 + 0.7 + 0.5 ÷ 4 = 0.6

A is the next best as it actually joins at a higher with more overall similarity to the BC cluster:

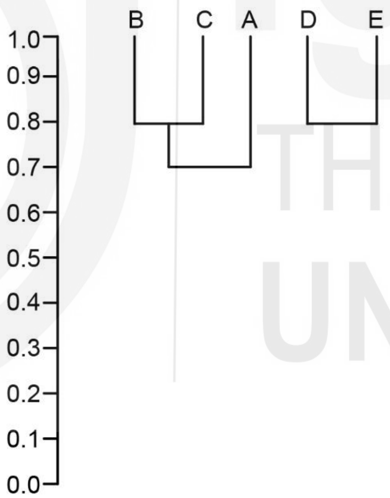


Fig. 20.9: Second step in construction of hierarchical classification.

Now the D-E cluster must be linked to the A-C-B cluster as there is a 0.7 similarity between B and DE (see Fig .20.7). This is done by finding the average similarity between D and E and each of the three taxa in the A-B-C cluster:

A-D = 0.4
B-D = 0.7
C-D = 0.5
A-E = 0.4
B-E = 0.7
C-E = 0.5
Total = 3.20
Average = 3.2 ÷ 6 = 0.53

Then the A-B-C cluster and D-E are linked at 0.53 to complete the phenogram.

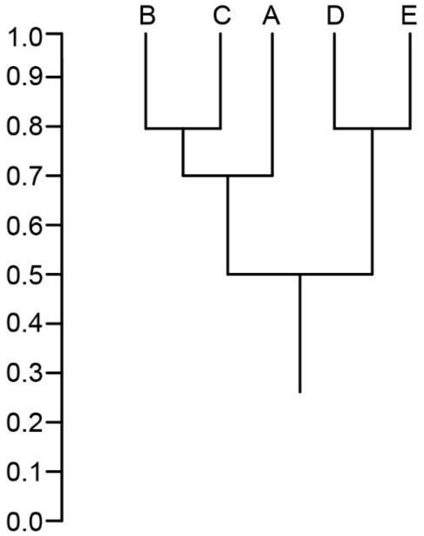


Fig. 20.10: The final phenogram.

You will appreciate those phenetic classification groups' taxa on the basis of overall similarity which may not be useful in phylogenetic systematics.

SAQ 1

In the following statements fill in the blanks with appropriate word/s:

i) Taxa with structural similarities are the …………….. groups.

ii) A character-taxon matrix depicts the percent …………. between the taxa regardless of any ……………….. relationships.

iii) Taxon A and Taxon B showing a similarity matching coefficient are linked ……………… in a phenogram.

iv) The selected characters are expressed as ……………. and then allotted …………… before they are coded in the form of a ………………..

20.3 CLADOGRAMS

Ever since Charles Darwin proposed the principles of evolution, a major topic of interest to a biologist has been to determine life's history of descent. This can be determined by studying both living and fossil organisms. Among all these organisms, a branching pattern can be used as a basis of system of classification that directly reflects the genealogical history. These branching patterns may reflect on or help deduce collective genetic changes that have occurred in populations through the passage of time.

Cladistics (Greek *kládos* = branch) or phylogenetic systematics is a system which classifies organisms on the basis of shared ancestry. Unlike phenetics (section see 20.2), where the organisms are assigned to a taxa (group of genus, families…) on the basis of morphological similarities, cladistics attempts to develop a classification of living and extinct organisms based on evolutionary ancestry. Cladistics places more emphasis on objective, quantitative analysis, evolution and geneaology In contrast to subjective use of characters in the phenetics and traditional biological taxonomy. The term *phylogenetic systematics* was introduced by a German Entomologist Willi Hennig in 1966. The term **clade** was introduced by Julian Huxley in 1958, while Cain and Harrison in 1960 introduced the term **cladistics**. Mayr in 1965 used the term **cladist**. In literature the term ‘phylogenetics is often used synonymously with cladistics’.

20.3.1 Definition and Terminology

Prior to construction of a cladogram (from Greek *kládos* "branch" and *gramma* "character"), you should get familiar and with a variety of terms that are commonly used in cladistics.

Cladogram: It is a tree-like relationship diagram that graphically represents a hypothetical evolutionary process. Cladograms are subject to revision as additional data becomes available. It can be falsifiable. A cladogram uses lines that branch off in different directions ending at a *clade*, a group of organisms with a last common ancestor.

Let us for example look at figure 20.11. Blackberry, raspberry and cherry, all belong to family Rosaceae. All of them possess fleshy fruits, termed drupes. However, a number of small fruits are present as cluster in black berry and raspberry. Cherry drupes are larger and single. The given evolutionary tree suggests that blackberry and raspberry are closely related to each other (on the basis of fruit-characteristics) than either of them is closely related to cherry. It can also be interpreted that blackberries and raspberries are probably derived from a more recent common ancestor. It can also be said that these two are sister (closely related) groups. This conclusion can be substantiated by other evidences from phytochemistry and DNA sequencing studies.

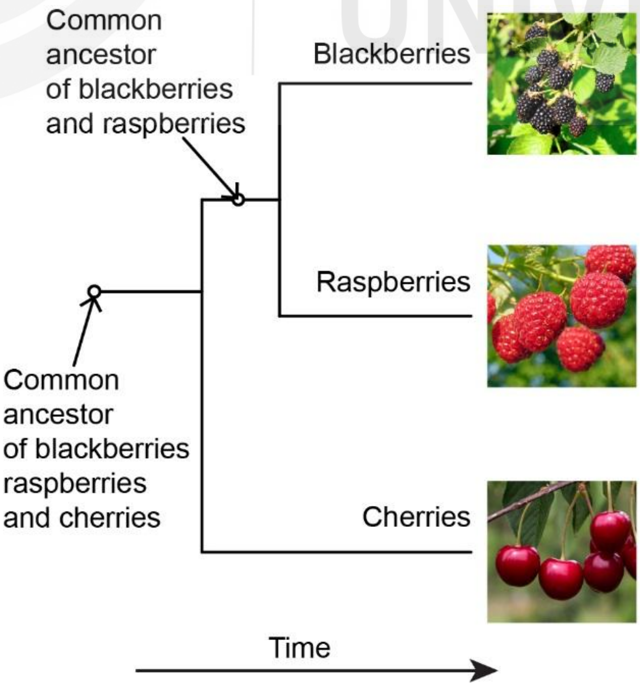


Fig. 20.11: A phylogenetic tree depicting three groups in the rose family (from Judd *et al*. 2016)

Clade: A clade is group consisting of a species (extant/extinct) and all its descendents. It is a single branch on a tree of life. It is the only acceptable unit in cladistics. It is always monophyletic i.e. it has only one ancestor. The ancestor could be actual or even hypothetical. It generally has a binary (two-way) inner node. The two taxa on either side of the split are called ‘sister-taxa’ or ‘sister groups’, e.g. Raspberry and Blackberry.

Cladogenesis: It is an attempt to determine the branching pattern in evolution. These patterns are determined by using derived (*apomorphic*) character states of the character involved.

Character : It is any heritable character that is employed to compare and determine the evolutionary state. For example, petal color, number of anthers, plant habit, pollen-grain morphology. It could be from any field of biology viz: morphology, anatomy; embryology; ultrastructure; paleontology; ecology; molecular biology. It is very important to choose proper character(s) to compare one organism to another. What constitutes the similarity of a character? It can be similar in position in two given organisms, may possess similar morphology and anatomy, or is linked by intermediate forms.

Character-state: It represents two or more forms of a character. For example: if the character is **fruit type** its character-states could be: berry, drupe, capsule etc. Petal colour is a character whereas white, red, purple, yellow, and blue petals represent character-states.

Homology and Homoplasy: It is hypothetically presumed that in *homology* similar character/character-states have common evolutionary origin. Due to common ancestry, the two homologous taxa have possibly shared common/ similar gene-pool. Determination of homology is indeed a very challenging aspect. It is normally determined on the basis of direct similarities via gradation of series.

However, *homoplasy* (analogy) is a collective term used for non-homologous similarities. It is also described as the presence of similar character or character-state in two organisms by independent origin. It is believed to occur by *parallelism* or *convergence* (independent evolution of similar features or characters in two or more different lineages), or even by *reversal* (losing of the derived feature and restoration of the original ancestral one).

Morphocline: It is also termed as *transformation-series*. Once the character and character-states are selected, they are arranged in a sequence/series. This series is called a morphocline.

eg., Character : Ovary position on a thalamus

Character-state: Inferior, superior, half-inferior half superior.

Morphocline : Superior $\longrightarrow$ Half inferior $\longrightarrow$ Inferior, or

Inferior $\longrightarrow$ Half superior $\longrightarrow$ Superior

This series is only a postulate. One character with two character states **A** and **B** will have just one morphocline **A** $\longleftrightarrow$ **B.** If there are only **three** character-states **A** and **B**, and **C**, the morphocline could be postulated as:

A $\longleftrightarrow$ B $\longleftrightarrow$ **C**

B $\longleftrightarrow$ **A** $\longleftrightarrow$ **C**

A $\longleftrightarrow$ **C** $\longleftrightarrow$ **B**

The direction of arrow ($\longrightarrow$) represents the direction of evolutionary change. These possible directions could vary and increase substantially if one increases the number of characters/character-states.

Apomorphic vs. Plesiomorphic characters:

A primitive, ancestral character/character-state is called *plesiomorphic*. In contrast, an advanced, derived character/character-state is called *apomorphic*. Pleisomorphy being an ancestral trait is “homologous” within a particular group of organisms. The taxon retains this trait throughout evolution and therefore cannot be used as a diagnostic or defining character for the group. On the other hand, apomorphy is a “novel evolutionary” trait which is unique to a particular species and all its descendents. It can therefore be used as a defining character for a species or group in evolutionary terms. To determine branching pattern in evolution apomorphic character/character-states are of no value in producing a branching pattern. In fact, only derived character states shared by two or more taxa are cladistically informative.

When two or more taxa share similar derived plesiomorphic characters, the taxa are called *synapomorphies*. On the other hand, *autapomorphies*, i.e., singular taxon possessing derived characters are of no value in cladistics.

Different types of phylogenies describing varied patterns of ancestral and derived traits are graphically represented in Fig. 20.12 below:

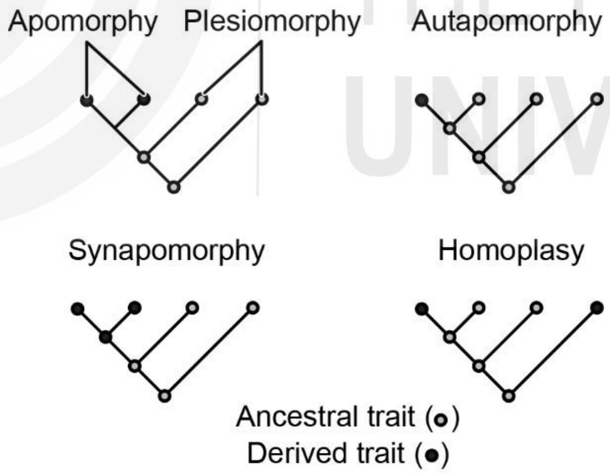


Fig. 20.12: Different phylogenies.

Polarity: The principle of polarity is to designate relative ancestry to the character states of morphocline. A change in the character-state represents a heritable evolution (plesiomorphic). It also involves a permanent change from a pre-existing structure to new features (apomorphic). It can also be written as:

Plesiomorphic $\longrightarrow$ Apomorphic features

Ancestral $\longrightarrow$ Derived features

Primitive $\longrightarrow$ Advanced features

Since the monoclines are thought to be represent evolutionary changes, and each character may have been evolved from the other, let us again look at the example of three character states with reference to ovary position mentioned in the subtitle morphocline above. If we assume that superior ovary is primitive (plesiomorphic) the resultant morphocline can be represented as superior (**0**) ($\longrightarrow$ half-inferior (**1**) $\longrightarrow$ inferior (**2**). Thus we have assigned polarity by designating the relative ancestry to the superior character state (**0**) of a morphocline. Likewise, after the determination of polarity, it is possible to have the following nine morphoclines for this three-state character:

$0 \longrightarrow 1 \longrightarrow 2$	$1 \longrightarrow 0 \longrightarrow 2$	$2 \longrightarrow 0 \longrightarrow 1$
$0 \longrightarrow 2 \longrightarrow 1$	$1 \longrightarrow 2 \longrightarrow 0$	$2 \longrightarrow 1 \longrightarrow 0$
$1 \longleftarrow 0 \longrightarrow 2$	$0 \longleftarrow 1 \longrightarrow 2$	$0 \longleftarrow 2 \longrightarrow 1$

Assignment of numerical values to the selected characters and character states helps in the tabulation in the character taxon matrix. The establishment of polarity of a morphocline is an important step in the preparation of a cladogram.

Monophyletic groups: To prepare cladograms, monophyletic groups (clades) are required. The monophyletic groups can be defined objectively through identifying synapomorphies. A monophyletic group is the one which comprises a given species and all of the descendents of that species. A common ancestor for all of these organisms is the branch point above the root of the tree, known as the **most recent common ancestor (MRCA).** These trees can be horizontal and vertical arrangements (Fig. 20.13a), or diagonal arrangements (Fig.20.13b),. The two arrangements are however, identical.

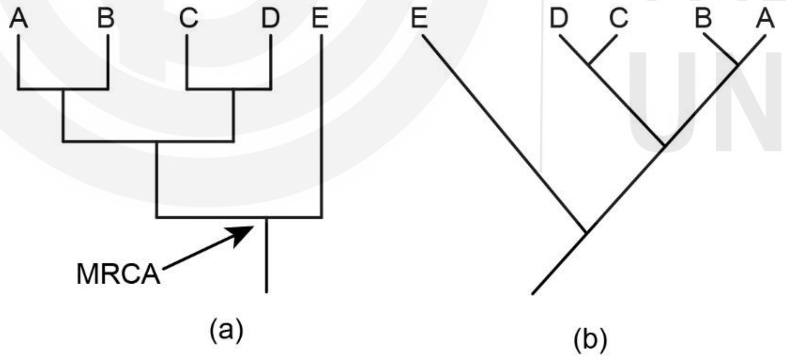


Fig. 20.13: a) Vertical; and b) Diagonal arrangement of trees showing hypothesized relationships between A, B , C, D and E.

Paraphyletic groups: In phylogenetics, a group of species is said to be paraphyletic if the group contains its most recent common ancestor, but does not contain **all** the descendents of that ancestor.

How to identify monophyletic taxa? Let us look at the figure 20.14. Out of the three taxa (1), (2) and (3), hypothetical common shared ancestry could be between (1) and (2), (1) and (3) or (2) and (3). From the figure, one can derive that (1) and (2) are sharing common ancestry, and are thus monophyletic taxa.

Another method is to cut this tree at different places. Only one cut, the 'cut 1' in the figure separates (1) and (2), but and an additional cut 'cut 2' is necessary to remove (1) and (3).

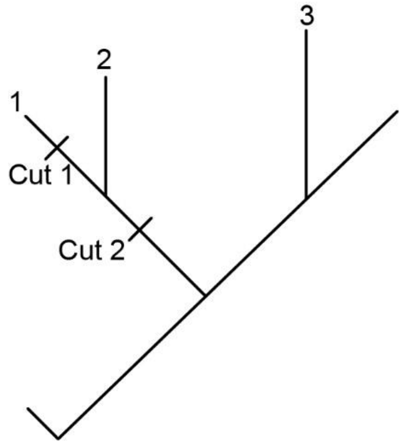


Fig. 20.14: Identification of monophyletic groups.

The principle is, whatever remains after one cut has common ancestor. In this example, thus (1) and (2) are monophyletic groups. When a cladogram involving a large number of taxa is involved, a network of such monophyletic groups is to be identified.

Polyphyletic groups: A group comprising members from separate evolutionary lines is called polyphyletic (Fig. 20.15).

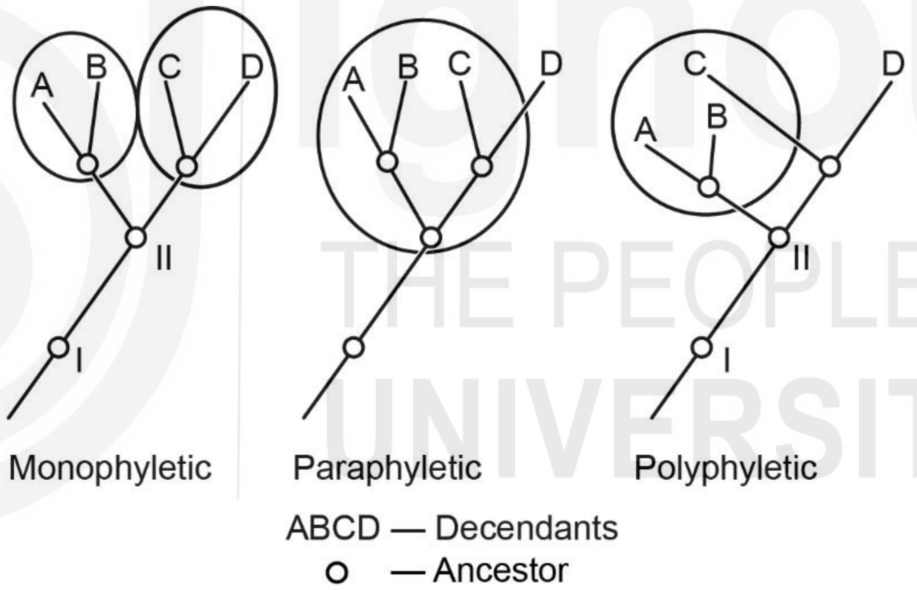


Fig. 20.15: Concept of monophyletic, paraphyletic and polyphyletic groups.

1. Groups A, B and C, D are monophyletic : each arising from a common ancestor at II,

   Groups A, B, C and D are also monophyletic: as their common ancestor is at I,

2. Groups A, B and C are paraphyletic : descendent D is also a common ancestor at II, but is outside the group.

3. B and C are polyphyletic as they are arising from different ancestor at II

Out-Group Comparison : Out-Group taxon employment in construction of a cladogram to determine the ancestral conditions (characters) is an important method. An out-group of one or more species are related to, but not within, the taxon under study.

Parsimony: In constructing a cladogram, a single dichotomous branching pattern is selected, from amongst many possible, to assign ancestral relationship, involving least character changes according to the principle of Parsimony.

For two taxa, there is only one kind of cladogram (Fig 20.16 a).

For three taxa, three possible dichotomies are possible (Fig. 20.16 b-d).

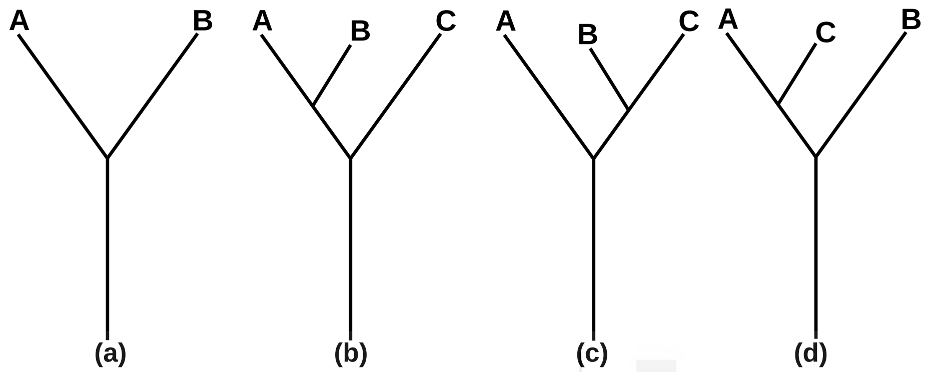


Fig. 20.16: The possibilities increase with increase in number of taxa incorporated.

Dendogram : A broad term used for the diagrammatic representation of a phylogenetic tree.

Phylogram : A phylogenetic tree that has branch lengths proportional to the amount of character change.

Chronogram : A phylogenetic tree that explicitly represent evolutionary time through its branch length.

Cladogram : A phylogenetic tree formed using cladistic method. It represents only a branching pattern, the branch length do not represent time or relative amount of character change.

20.3.2 Types of Clades

A clade is a hypothetical construct based on experimental data which represents a monophyletic group, consisting of an ancestor and all its descendents. Clades are formed using multiple (can be more than 100) of traits from a number of species/specimen/statistically derived to find most likely phylogenetic tree for the group (Figs 20.17 a, b).

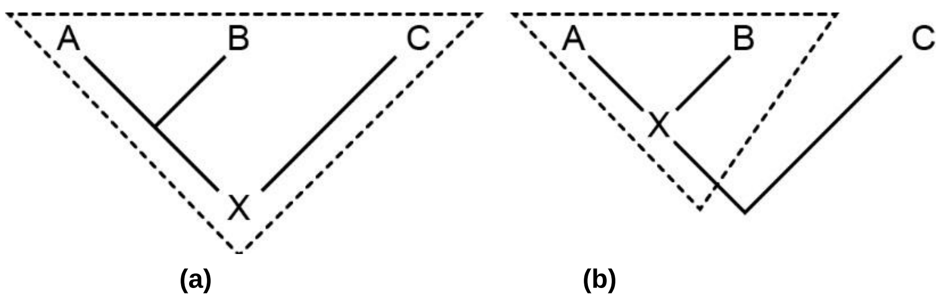


Fig. 20.17: Phylogenetic trees showing clades demarcated by dashed lines. Each clade has an ancestor X. a) Clade includes X, A, B and C. b) Clade includes X, A and B under another hypothesis.

Clades can be classified in 3 major ways:

A) **Node-based :** It is also called Crown-based. The most recent common ancestor (MRCA) of A and B (could include C, D……..), and all its descendents of that ancestor . In Figure 20.18 a, A and B are the descendents of MRCA.

B) **Branched-based:** It is also known as stem-based. Here, all the organisms, or species that share a most recent common ancestor (MRCA) with A (may include B, D……). or organism C (may include X, Y, Z……) In Figure 20.18 b, A species share MRCA with B and C.

C) **Apomorphy-based :** The first organism or species to possess apomorphies **M** (N etc…) inherited by A (B etc.) and all its descendents. The first ancestor A to possess derived trait **M** homologously (synapomorphically) within A, and all descendents of that ancestor (Fig. 20.18 c).

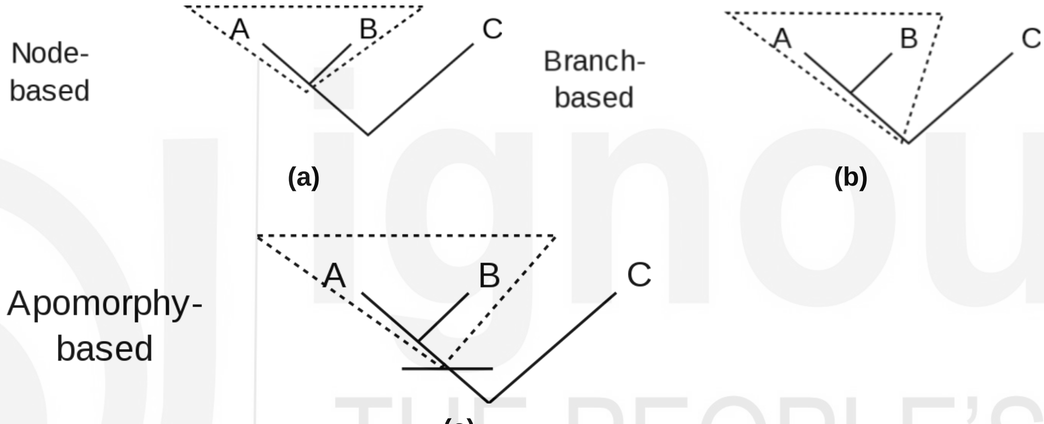


Fig: 20.18: Types of clades. (a) Node-based; (b) Branched-based; (c) Apomorphy-based.

20.3.3 Building and Interpretation of Cladograms

Building of a cladogram

1) Select characters and character states for study. Use as many of these as possible. It should include morphological, anatomical, chemical, DNA nucleotide sequences, amino acid sequences etc. Conserved characters belonging to floral parts are best suited features of consideration.

2) Determine the polarity of the chosen characters plesiomorphic vs. apomorphic ones. The following criteria could provide some guidance to choose polarity.

   a) The initial step in basic cladistic analysis is to determine which character states are primitive and which are derived. Features characteristic of early phases or development are considered primitive eg., free petals are plesiomorphic, while fused petals are apomorphic;

   b) Examine character associations if A$\longrightarrow$B, then most characters associated than the most primitive members of B should appear more like A;

c) If a taxon that is not a member of the group of organisms being classified has a character state that is the same as some of the organisms in the group, then that character state can be considered to be plesiomorphic. The outside taxon is called the *outgroup* and the organisms being classified constitute the *ingroup*. Select an out group, for references for comparative purposes. If a character present in outgroup as well as in the ingroup, then character is all probability to be treated as plesiomorphic.

d) Study of fossils.

3) Score the selected taxa for each character-taxon-character (**n** x **t**) matrix.

4) Run a computer analysis. (There are many excellent programmes such as:

PAUP, PHYLIP, Hennig 86 and Mac Clade.

5) Analyse the cladogram. The computer generates the cladogram that fits the data. The best tree is selected based on:

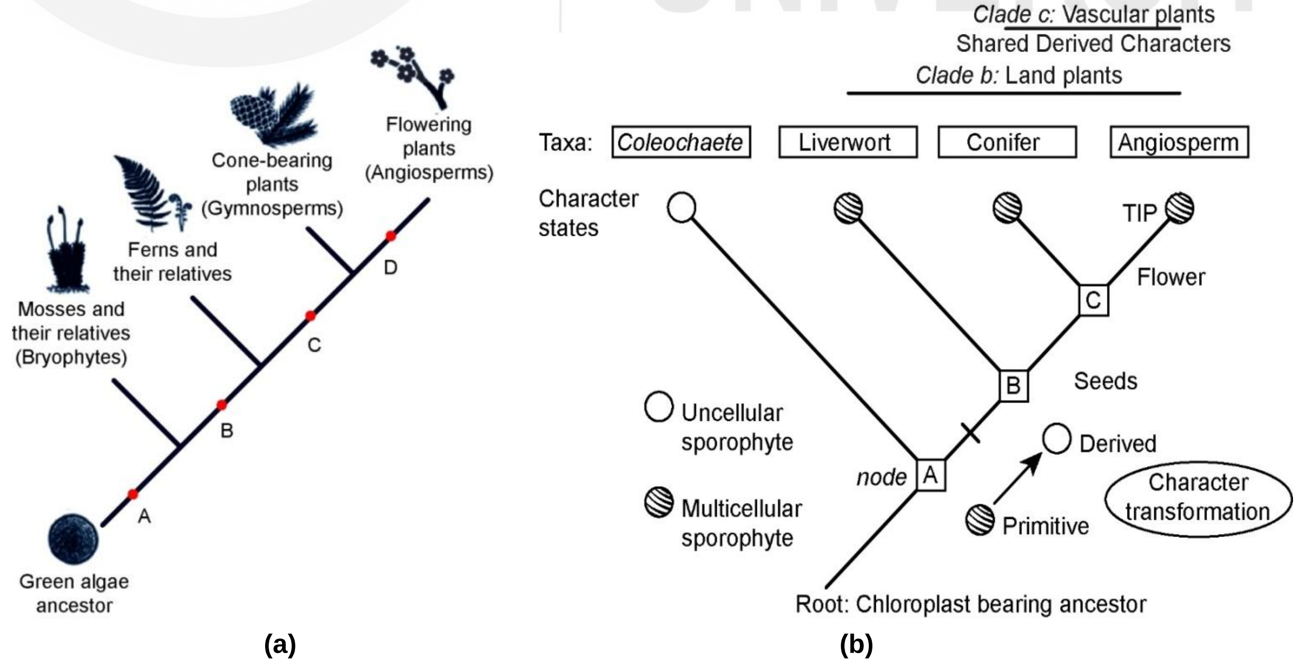
a) Parsimony principle

b) Minimum distance methods

c) Maximum likelyhood method.

6) Select the best tree (consensus and monophyletic)

Cladograms are also constructed by grouping organisms based on their shared derived characteristics. You must have seen a general phylogenetic tree for angiosperms in other units of taxonomy (Fig.20.19 a). How did we arrive at this conclusion? Let us take an example of a simple cladogram to make you familiar with the cladistic vocabulary (Fig. 20.19 b).



Figs 20.19: a) A general phylogenetic tree for flowering plants; b) Cladistic vocabulary used while constructing a cladogram.

You are familiar that the land plants are characterized by vascular tissue. If we chart a phylogenetic tree in a time scale from the ancient to the recent, a hypothetical ancestor having chloroplasts constitutes a *root.* At the branching point or *node* **A,** the “multicellular sporophyte” character constitutes an *autapomorphy*(a distinctive derived trait unique to a taxon or group) for clade B (i.e., land plants). Interestingly, the same character of multicellularity is a *synapomorphy* (shared derived character stage) at node **B** and clade **C** (vascular plants).

At node **B**, this very character of multicellular sporophyte becomes *symplesiomorphic* **(**shared ancestral character state shown by two or more taxa) for conifers and angiosperms. Flower is a derived character which is absent in conifers but present in angiosperms (constitutes the TIP).So the clade **B** (land plants) possesses multicellular sporophyte while the clade **C** by vascular tissue too.

Let us now consider the methodology of cladogram construction in details:

Example

a) Characters and taxa are tabulated in the form of a matrix(Fig. 20.20) :

Chracter.

× = Present

- = Absent

<u>Taxa</u> Character(s)	1	2	3	4
A	×	×	×	×
B	-	×	×	×
C	-	-	×	×
D	-	-		×

Fig. 20.20: Character-taxon matrix for a Venn diagram.

b) Draw a Venn diagram as shown in Fig. 20.21. Start with a character that is shared by all the taxa on the outside. Only those set of characters are needed to be written inside each box.

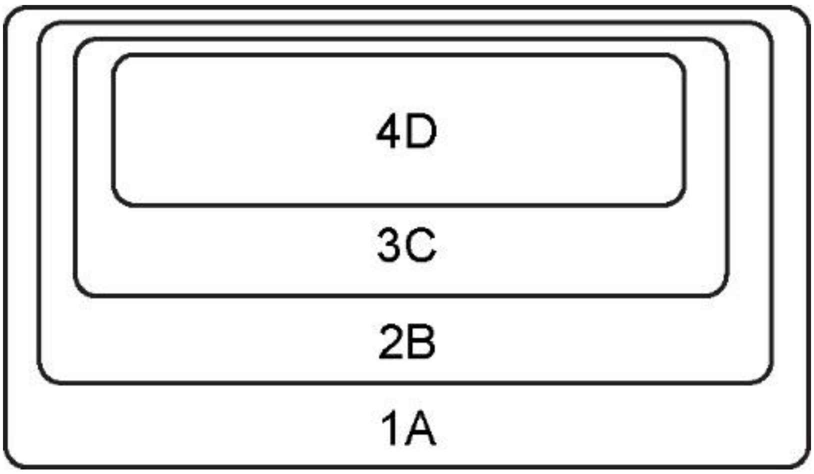


Fig. 20.21: Venn diagram of the Character–taxon matrix given in Fig 20.20.

c) Convert the Venn diagram into a cladogram (phylogenetic tree) as depicted in Fig.20.22.

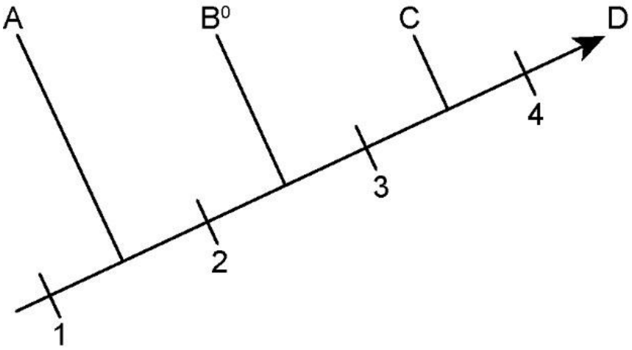


Fig. 20.22: A cladogram illustrating hypothesized evolutionary relationships of the four imaginary species. The numbered lines indicate synapomorphies.

Interpretation of Cladogram

1) Once a cladogram is generated, it looks a tree. It exhibits patterns of shared ancestry between lineages.

2) When an ancestral lineage splits (mostly binary): the speciation is indicated due to the 'arrival' of some new trait (plesiomorphic) (Fig. 20.20)

3) Each lineage has unique traits to itself alone and traits that are shared with other lineages

4) Draw a Venn diagram. Start with the character that is shared by all the taxa on the outside. Inside each box, write the taxa which have only that set of characters.

5) Convert the Venn diagram into a cladogram.

Let us revisit Venn-diagram method to construct a cladogram with another example.

1) Let the OTU's be: Green alga (A); Bryophytes (B); Pteridophytes (C); Gymnosperms (D); Dicotyledons (E); and Monocolyledons (F). Let (G) be some hypothetical out group with ability to photosynthesize.

2) Let the characters under consideration be : starch as food reserve (1); presence of embryo (2); lignifications (3); seed formation (4); triple fusion (5) and one cotyledon per embryo; (6) Scattered vascular bundles.

The **character x taxon matrix** is tabulated in Fig. 20.23:

	Taxa Character(s)	1	2	3	4	5	6
Chracter	A	+	-	-	-	-	-
(+) = Present	B	+	+	-	-	-	-
(-) = Absent	C	+	+	+	-	-	-
	D	+	+	+	+	-	-
	E	+	+	+	+	+	-
	F	+	+	+	+	+	+
	G	-	-	-	-	-	-

Fig. 20.23: A character-taxon matrix.

Based on the above matrix, a Venn-diagram is made (Fig. 20.24):

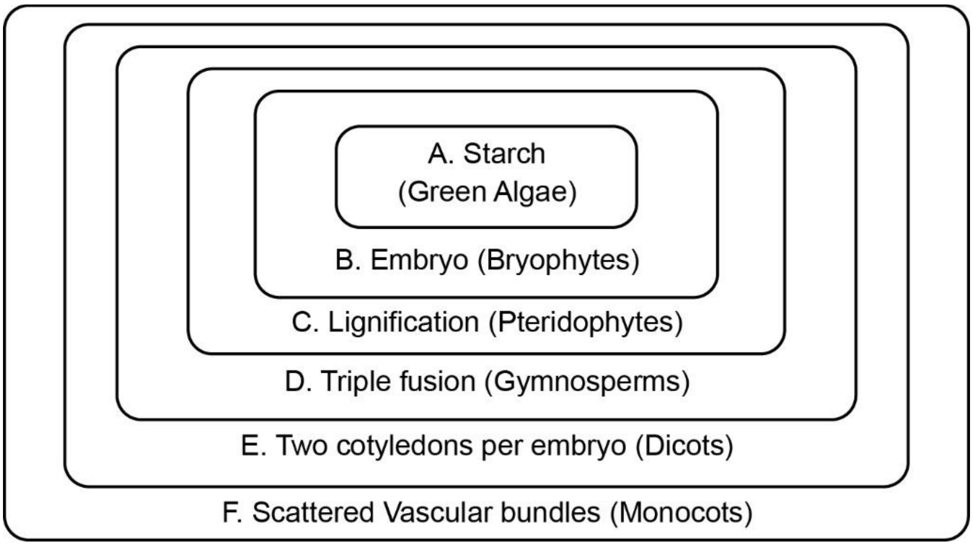


Fig. 20.24: Venn-diagram is made for the matrix in Fig. 20.21.

A cladogram (phylogenetic tree) can now be made (Fig 20.25), based on the Venn diagram:

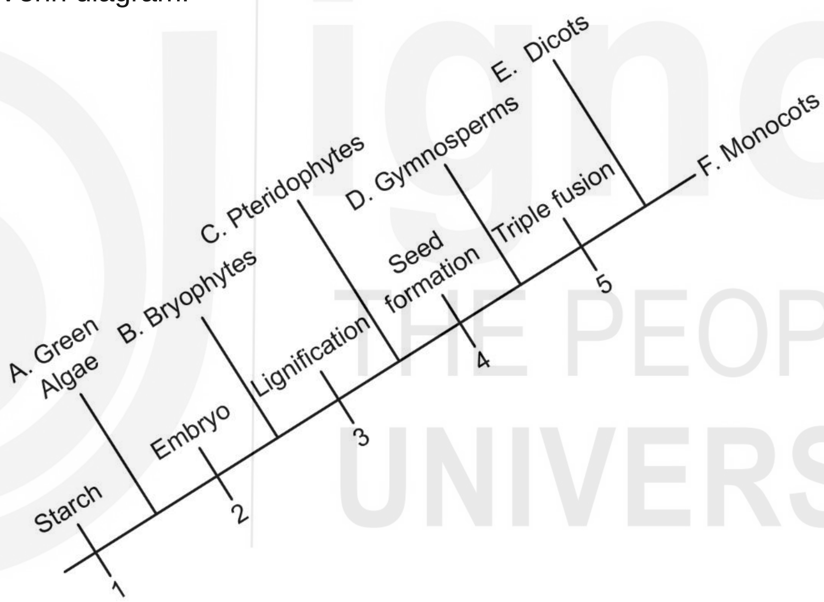


Fig. 20.25: A cladogram based on Venn-diagram.

Finally, you must by now be in a position to appreciate the difference between a phenogram and a cladogram. Let us construct a cladogram by considering the character-taxon matrix data in Fig. 20.5 which we had used earlier for making a phenogram (section 20.2).

Taxa	1	2	3	4	5	6	7	8	9	10
A	+	+	+	+	+	+	+	+	+	-
B	+	+	+	-	-	+	+	+	-	-
C	+	+	+	+	-	+	+	+	-	+
D	+	+	-	-	-	+	-	-	-	-
E	+	+	-	-	-	-	+	-	-	-

Let us rescore this character chart by coding the derived character states (apomorphies) as 1 and the primitive states (Plesiomorphies) as 0.

The chart Fig. 20.26) now reads as follows:

	Characters									
Taxa	1	2	3	4	5	6	7	8	9	10
A	1	1	1	1	1	1	0	1	1	0
B	1	1	1	0	0	1	0	1	0	0
C	1	1	1	1	0	1	0	1	0	1
D	1	1	0	0	0	1	1	0	0	0
E	1	1	0	0	0	0	0	0	0	0
Out	0	0	0	0	0	0	0	0	0	0

Fig. 20.26: Modified matrix with primitive and derived characters.

Following the method of Hennigian argumentation (proposed by Hennig). We consider the information provided by each character one at a time and construct a cladogram (Fig. 20.27):

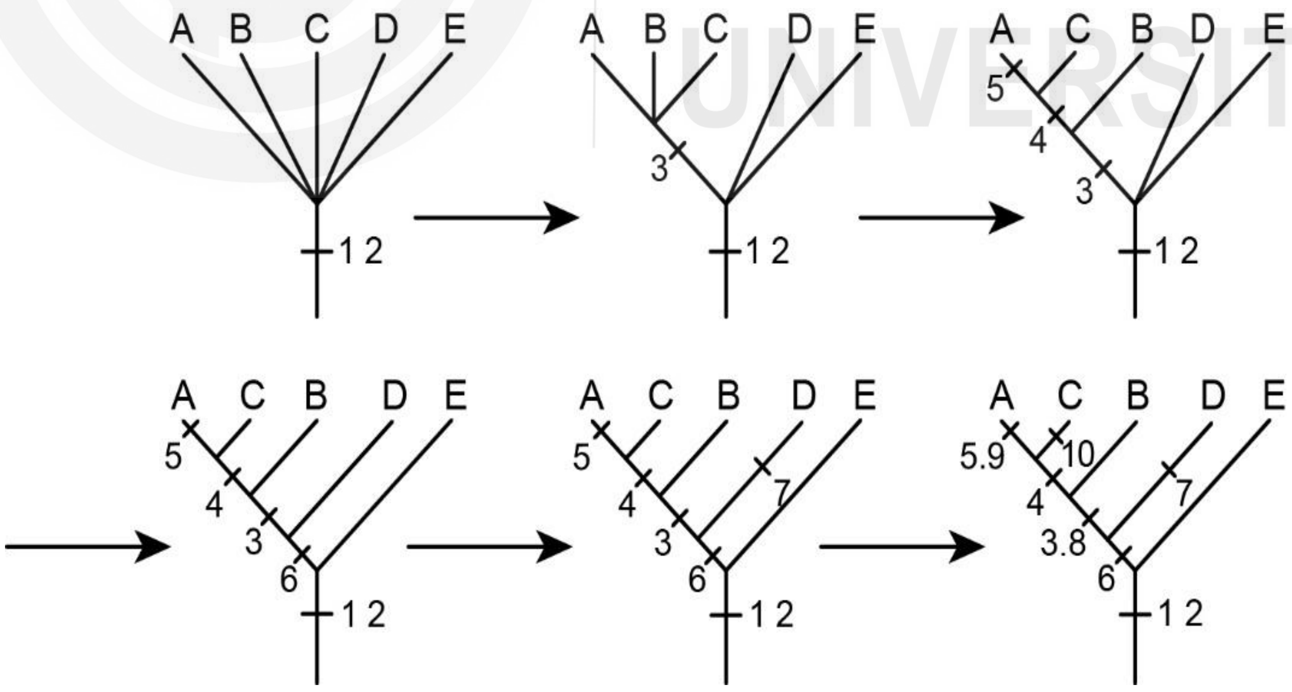


Fig: 20.27: Step by step construction of a cladogram.

In conclusion, the following cladogram (Fig.20.28) illustrates the evolutionary events occurring within the major extant groups of plants:

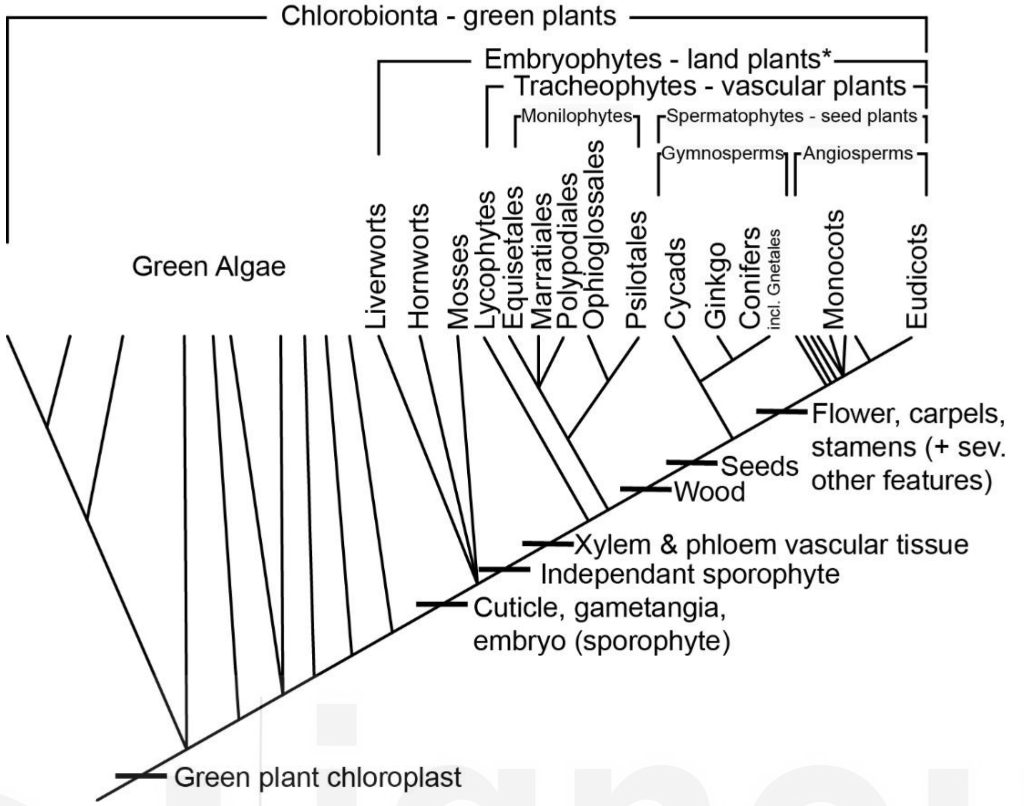


Fig. 20.28: Simplified cladogram (evolutionary tree) of the green plants, illustrating major extant groups and evolutionary events (or "apomorphies," notated by thick hash marks). *Embryophytes are treated as "plants". (From Simpson, 2010).

Comparison of phenetics and cladistics

- Phenetics uses overall similarity using as many characters as possible, each one equally weighed. Cladistics uses only phylogenetically informative characters.
- Phenetics-based classification is subjective whereas cladistics is firmly objective and reproducible (repeatable).
- Cladistics can help deduce bio-geographical history, whereas phenetics does not.
- Cladistics can provide clue to past evolutionary events, and phenetics helps to find similarity.
- Phenetic classification is less flexible than cladistics. The latter is variable and falsifiable (depending upon apo-plesiomorphic choices of character).

SAQ 2

Fill in the blanks:

i) A group of organisms with a last common ancestor in a cladogram denotes a ………………… .

ii) Two similar derived characters evolving independently in each species are …………….. .

iii) …………………….. are the taxa showing similar derived plesiomorphic characters.

iv) ………………… designates relative ancestry to the character states of morphocline.

v) A group comprising members from separate evolutionary lines is …………….. while the …………. group contains its most recent common ancestor and not all the descendents of that ancestor.

20.4 SUMMARY

- Classification systems of plants have undergone a change from natural-artificial to phylogenetic.
- Phenetics is primarily based on the principle of overall similarity among organisms. It encompasses incorporation of objective quantitative and qualitative characteristics. It is an extension of numerical taxonomy.
- The diagrammatic representation of phenetic classification is called phenogram.
- Phylogenetic systematics is called cladistics and the evolutionary tree of life generated by its study is called cladogram.
- A cladogram consists of clades, nodes, internodes, out-groups, and hypothetical taxonomic units.
- Cladistics is primarily based on the principles of descent of the character or character-states evolving from ancestral, plesiomorphic ones to derive, apomorphic ones.
- Study of cladistics involves the understanding of meanings of character, character-state, homology, homoplasy, morphocline, Monopoly and paraphyletic, polarity, parsimony and many other related terms.
- Clades could be node-based, branched-based,or apomorphy-based.
- Computer analysis is involved in the development of cladograms, which are reproducible but also falsifiable.

20.5 TERMINAL QUESTIONS

1. Differentiate Questions

   i) Apomorphic and plesiomorphic characters.

   ii) Polarity and morphoclines

   iii) Monophyletic and polyphyletic groups

   iv) Cladogram and Phenogram

   v) Operational Taxonomic Unit and node

2. Define

   i) Parsimony

   ii) Chronogram

   iii) Branch-based clade

   iv) Character-taxon matrix

20.6 ANSWERS

Self-Assessment Questions

1. i) phenetic

   ii) similarity, evolutionary

   iii) first

   iv) binary, signs, matrix

2. i) clade

   ii) homoplasic

   iii) synapomorphies

   iv) polarity

   v) polyphyletic, paraphyletic

Terminal Questions

1. i) See Subsection 20.3.1

   ii) See Subsection 20.3 .1

   iii) See Subsection 20.3 .1

   iv) See Subsection 20.3 .1

   v) See Subsection 20.3 .1 and 20.3.2

2. i) See Subsection 20.3.1

   ii) See Section 20.2

   iii) See Subsection 20.3.2

   iv) See Subsection 20.3.3

GLOSSARY

Analysis : A figure or group of figures showing details aiding identification, with or without a separate caption.

Autonym : An automatically established name in which a generic name or specific epithet is repeated as the final epithet (in subgenus or subdivision or infra specific taxon); does not require authorship; has same 'type' as that of genus/species.

Basionym : The legitimate, previously published name on which a new combination/name of a new rank is based.

Binomial : A two-word combination of scientific name of a plant. The first word represents the genus and the second word is the specific epithet.

Cf : Confer; compare to.

Clade : It is a hypothetical construct based on experimental data. It is a monophyletic group, consisting of a common ancestor and all lineages that arise from this common ancestor.

Cladistics : The branch of systematics that helps understand relationships of taxa based on the pattern of shared derived character states (synapomorphies). Also called phylogenetics.

Cluster analysis : A presentation that produces a hierarchial classification of entities (taxa) based on the similarity matrix.

Cohort : The term order renamed by Bentham and Hooker.

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Comb. Nov : new combination; *combanatio nova*.

Conserved name : (*nomen conservandum*) : A name of a taxon rules as legitimate and with precedence over other specified name even though it may have been illegimately published or lack priority.

Data : Documentation of the character to a taxon.

Descent : Transfer of genetic material from parents to offspring over time.

Diagnosis : A statement of that which in opinion of its author distinguishes a taxon from other taxa; a must for a valid publication of a name.

Epithet : Used for words in combination other than the generic name and any rank-denoting term; hyphenated words are equal to one word.

Epitype : A specimen/illustration selected to serve as interpretative type when holotype/lectotype/neotype are not available for identification.

Et	:	and.
Ex	:	from.
Ex-type	:	A living isolate obtained from the type of a name when this is a culture permanently preserved in a metabolically inactive state.
Gen.nov.	:	genera nova; proposed new genus.
Holotype	:	The one specimen/illustration used by the author, or designated by the author as the nomenclature type.
Homonym	:	A name spelled exactly like another name published for a taxon of the same rank based on a different type.
Hypothetical out group	:	An hypothetical ancestor based on outgroup information, used to root the resulting network.
Iapt	:	International Association of Plant Taxonomy.
Icbn	:	International Code of Botanical Nomenclature.
Icnb	:	International code of Nomenclature of Bacteria.
Icncp	:	International code of Nomenclature of Cultivated Plants.
In ed	:	*in editus*; not validly published.
Internode	:	Hypothetical last common ancestral population that speciated (i.e. split) to give rise to two or more daughter taxa.
Isoepitype	:	A duplicate specimen of epitype
Isolectotype	:	A duplicate specimen of lectotype
Isoneotype	:	A duplicate specimen of neotype
Isonym	:	The same name based on the same type, published independently at different times, perhaps by different authors.
Isosyntype	:	A duplicate of syntype.
Isotype	:	A duplicate of hototype
Legitimate name	:	A validly published name that is in accordance with the rules.
Monothetic	:	Groups whose all members share an individual character.
Monothetic	:	Groups whose all members share an individual character.
N.v.	:	*non-vascus*; not seen
Node	:	Hypothetical ancestor; present at the base of a clade.

Nom. Alt. : *nomen alternativum* : alternate name.

Nom. Cons : *nomen conservandum* : conserved name.

Nom. Nov. : *nomen novum* : replacement name.

Nom. Nud. : *nomen nudum* : A designation of new taxon published without a description or diagnosis/reference.

***Nom.* Rej** : *nomen rejiciendum* : suppressed name.

Nothogenus : A hybrid genus.

Nothospecies : A hybrid species.

Nothotaxon : A hybrid taxon.

Otu : The Operational Taxonomic Unit. It is an individual taxon/large group.

Out group : Organisms considered not the part of the group in question, nonetheless related to the group.

Paratype : Any specimen cited in the protologue which helps to define the actual representation of the scientific name of species that is neither the holotype nor an isotype, or a syntype.

Paris code : System of nomenclature adopted at the first International Botanical congress held in 1867 at Paris. The laws which were proposed by Alphonse de Candolle were adopted at this Congress and are also known as de Candolle's Rules of 1867. aff.: "related to'. *affne*.

Phenetics : Grouping of taxa by overall similarities regardless whether these share common ancestry or not.

Phylogenetic systematics : Biological systematics which classifies living organisms on the basis of shared ancestry. The focus is on evolutionary relationships.

Phylogeny : The evolutionary history or pattern of descent of a group of organisms.

Polythetic : Groups whose members share large number of characters.

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Priority : A right of precedence by the date of valid publication.

Root : Basal node of a cladogram.

S.l. : *sensu lato*; in broad sense.

S.s. : *sensu strict;* narrow sense.

Sp. Nov	**:**	*species nover*; new species.
Stat. Nov	**:**	A name at a new rank.
Syntype	**:**	Any specimen cited in the protologue when there is no holotype, or any of two or more specimens cited in the protologue.
Systematics	**:**	The science of the organismal diversity. It includes discovery, description and interpretation of biological diversity, including predictive classification.
Tautonym	**:**	A binary designation in which the specific epithet exactly repeats the generic name.
Taxon. (taxa)	**:**	A taxonomic group at any rank.
Type	**:**	nomenclature type.
X	**:**	hybrid.