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BIO 217

General Microbiology

Module 4

BIO 217 (General Microbiology)
Module 4

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Module 4

Unit I Introduction to Systemic Classification of Microorganisms

1.0 Introduction

In order to make sense of the diversity of organisms, it is necessary to group similar organisms together and organise these groups in a non-overlapping hierarchical arrangement. One of the tools needed to perform this grouping is a reliable classification method. The Swedish botanist Carl von Linne or Carolus Linnaeus, as he is often called, developed the first natural classification based largely on anatomical characteristics in the middle of the eighteenth century. The term systematic is often used for taxonomy. However, many taxonomists define systemics in more general terms as "the scientific study of organisms with the ultimate objective of characterizing and arranging them in an orderly manner." Any study of the nature of organisms, when the knowledge gained is used in taxonomy, is a part of systematics. Thus, systematics encompasses discipline such as morphology, ecology, epidemiology, biochemistry, molecular biology and physiology. This unit examines the definition of terms in systematic classification of microorganisms, methods used to classify microorganisms, taxonomic ranks and different characteristics used in classifying microorganisms.

2.0 Objectives

At the end of this unit, you should be able to:

- define the following terms: taxonomy, nomenclature, classification, identification and systemics
- explain the different methods that have been used in classification
- explain the different taxonomy ranks
- explain the different characteristics used in classification and identification of microorganisms.

3.0 Main Content

Definition of Terms

- Taxonomy is defined as the science of biological classification. In a broader sense, it consists of three separate but interrelated parts: classification, nomenclature, and identification.
- Classification – This is the organisation of organisms into progressively more inclusive groups on the basis of either phenotypic similarity or evolutionary relationship. It is the arrangement of organisms into groups called taxa based on mutual similarity.
- Nomenclature – This is the branch of taxonomy concerned with the assignment of giving names to taxonomic groups in agreement with published rules.
- Identification – This is the practical side of taxonomy, the process of determining if a particular isolate belongs to a recognised taxon.

- Systematics - The term systematics is often used for taxonomy. It is the scientific study of organisms with the ultimate objective of characterising and arranging them in an orderly manner.

In practice, the determination of the genes and species of a newly discovered prokaryote is based on polyphasic taxonomy. This approach includes phylogenetic phenotypic and genotypic features.

3.1 The Polyphase Taxonomy

The polyphasic approach to taxonomy uses three kinds of methods: phenotypic, genotypic and phylogenetic for the identification and description of bacteria. Phenotypic analysis examines the morphological, metabolic, physiological and chemical characteristics of the organisms. Genotypic analyses consider comparative aspects of cells at the level of the genome.

These two kinds of analyses group organisms on the basis of similarities. They are complemented by phylogenetic analysis which places organisms in a framework of evolutionary relationships. The habitat and ecology of the organisms is also used in polyphasic taxonomy.

3.2 Methods of Classification

Phenotypic classification: This is the grouping of microorganisms together based on the mutual similarity of the phenotypic characteristics. This classification system succeeded in bringing order to biological diversity and classified the function of morphological structures. Organisms sharing many characteristics make up a single group or taxon.

Phylogenetic classification: Compares organisms on the basis of evolutionary relationships. The term phylogeny refers to the evolutionary development of species. This method is restricted because of lack of good fossil records.

Genotypic classification: Compares the genetic similarity between organisms' individual genes or whole genomes can be compared.

Numeric taxonomy: This is grouping of taxonomic units into taxa on the basis of their character state by numerical methods. Information about the properties of organisms is converted into a form suitable for numerical analysis and they are compared by means of a computer. The resulting classification is based on general similarity as judged by comparison of many characteristics each given equal weight. The result of numerical taxonomic analysis is often summarised with a threadlike diagram called a dendogram.

3.3 Taxonomic Ranks

The classification of microbes involves placing them within hierarchical taxonomic levels. Microbes in each level or rank share a common set of specific features. The highest rank is the domain, and all procaryotes belong to either the Bacteria or the Archaea. Within each domain, each microbe is assigned (in descending order) to a phylum, class, order, family, genus and species.

The basic taxonomic group in microbial taxonomy is the species.

A prokaryotic species is a collection of strains that share many stable properties and differ significantly from other groups of strains.

A strain consists of the descendants of a single, pure microbial culture. Each species is assigned to a genus, the next rank in the taxonomic hierarchy.

A genus is a well-defined group of one or more species that is clearly separate from other genera.

Taxonomy groups of higher rank than genus are listed below:

- **Family:** A group of similar genera
- **Order:** A group of similar families
- **Class** A group of similar orders
- **Phylum:** A group of similar classes
- **Domain:** A group of similar phyla

Microbiologists name microorganisms by using the binomial system of Linneaeus. The Latinised, italicized name consists of two parts. The first part, which is capitalised, is the generic name, and the second is the uncapitalised species name (e.g. *Escherichia coli*). Often, the name will be shortened by abbreviating the genus name with a single capital letter, for example: *E. coli*, *S. aureus* etc.

The species name is stable; however, a generic name can change if the organism is assigned to another genus because of new information. For example, some members of the genus *Streptrococcus* were placed into two new genera. *Enterococcus* and *Lactococcus* based on rRNA analysis and other characteristics.

Bergey's manual of systematic Bacteriology contains the currently accepted system of prokaryotic taxonomy.

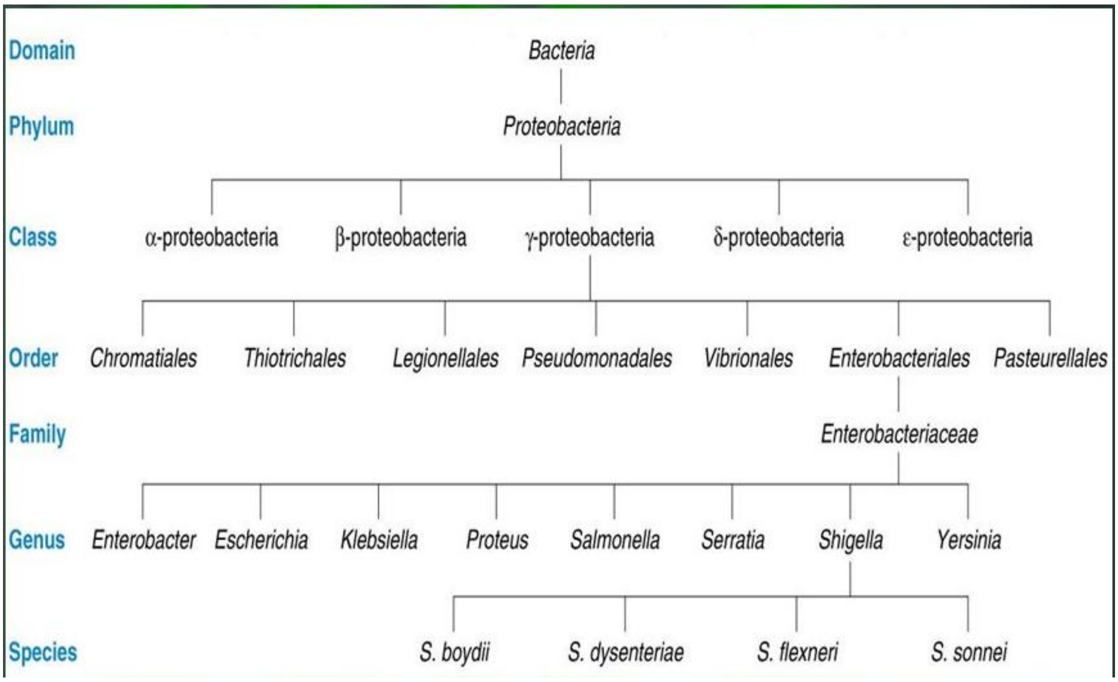

Fig. 1: Hierarchical Arrangement in Taxonomy

Source: Prescott, Harley and Kleins, *Microbiology* by Willey *et al.,* (2008)

3.4 Techniques for Determining Microbial Taxonomy and Phylogeny

Many different approaches are used in classifying and identifying microorganisms. For clarity, these have been divided into two groups: classical and molecular.

Self-Assessment Exercise

i. Define the following terms:
a. Taxonomy
b. Classification
c. Nomenclature
d. Identification and Systematics

3.4.1 Classical Characteristics

Classical approaches to taxonomy make use of morphological, physiological, biochemical, ecological and genetic characteristics. They are quite useful in routine identification and may provide phylogenetic information as well.

Morphological Characteristics
Morphological features are important in microbial taxonomy for many reasons. One, morphology is easy to study and analyze, particularly in eukaryotic microorganisms and the more complex prokaryotes. In addition, morphological comparisons are valuable because structural features depend on the expression of many genes, are usually genetically stable. Thus, morphological similarity is often a good indication of phylogenetic relatedness.

The transmission and scanning electron microscopes, with their greater resolution, have immensely aided the study of all microbial groups.

Table 2: Some Morphological Features Used in Classification and Identification

Feature	Microbial Groups
Cell shape	All major groups
Cell size	All major groups
Colonial morphology	All major groups
Ultrastructural characteristics	All major groups
Staining behaviour	Bacteria, some fungi
Cilia and flagella	All major groups
Mechanism of motility	Gliding bacteria, spirochetes
Endospore shape & location	Endospore-forming bacteria
Spore morphology & location	Bacteria, protists, fungi
Cellular inclusions	All major groups
Colour	All major groups

Used in classifying and identifying at least some bacteria, fungi and protists.

Physiological and Metabolic Characteristics

Physiological and metabolic characteristics are very useful because they are directly related to the nature and activity of microbial enzymes and transport proteins. Since proteins are gene products, analysis of these characteristics provides an indirect comparison of microbial genomes.

Some physiological and metabolic characteristics used in classification and identification are:

- Carbon and nitrogen sources
- Cell wall constituents
- Energy sources
- Fermentation products
- General nutritional type
- Growth temperature optimum range
- Lumniscence
- Mechanisms of energy conversion
- Motility
- Osmotic tolerance

- Oxygen relationships
- pH optimum growth range photosynthetic pigments
- Salt requirements and tolerance
- Secondary metabolites formed
- Sensitivity to metabolic inhibitors and antibiotics
- Storage inclusions.

3. **Ecological Characteristics**

The ability of micro-organisms to colonise a specific environment is of taxonomic value. Some microbes may be very similar in many other respects but inhabit different ecological niches, suggesting that they may not be as closely related as first suspected. Some examples of taxonomically important ecological properties are life cycle patterns, the nature of symbiotic relationships; the ability to cause disease in a particular host; and habitat preferences, such as requirements for temperature, pH, oxygen, and osmotic concentration. Many growth requirements are considered physiological characteristics as well.

Genetic Analysis
Although prokaryotes do not reproduce sexually, the study of chromosomal gene exchange through transformation, conjugation and transduction is sometimes useful in their classification.
Transformation can occur between different prokaryotic species but only rarely between genera. The demonstration of transformation between two strains provides evidence of a close relationship since transformation cannot occur unless the genomes are fairly similar. Transformation studies have been carried out with several genera: *Bacillus, Micrococcus, Haemophilus, Rhizobium* and others. Despite transformation's usefulness, its results are sometimes hard to interpret because an absence of transformation may result from factors other than major differences in DNA sequence.

Plasmids are important taxonomically because they can confound the analysis of phenotype traits. Most microbial genera carry plasmids and some plasmids are passed from one microbe to another with relative ease. When such plasmids encode a phenotypic trait (or traits) that is being used to develop a taxonomic scheme the investigator may assume that the trait is encoded by chromosomal genes.

3.4.2 Molecular Characteristics

Microorganisms have left no fossil record unlike evolutionary biologist studying plants and animals that have drawn from a rich fossil record to assemble a history of morphological changes. In this case, molecular approaches serve to supplement this data, so molecular analysis is the only feasible means of collecting a large and accurate data set from a number of microbes.

Nucleic Acid Base Composition or G.C. Ratios
G+C ratio data are valuable in at least two ways. First, they can confirm a taxonomic scheme developed using other data. Second, G+C content appears to be useful in characterising prokaryotic genera because the variation within a genus is usually less than 10% even though the content may vary greatly between genera.

The GC ratio is the percentage of guanine plus cytosine in an organism's genomic DNA. GC ratios vary over a wide range, with values as low as 20% and as high as nearly 80% among Bacteria and Archaea, a range that is some-what broader than for eukaryotes. It is generally considered that if two organisms GC ratios differ by more than 5%, they will share two DNA sequences in common and are therefore unlikely to be closely related.

Nucleic Acid Hybridisation
The similarity between genomes can be compared more directly by use of nucleic acid hybridization studies.

Nucleic Acid Sequencing
The method uses rRNA from small ribosomal sub units (165 and 185 rRNAs from prokaryotes and eukaryotes, respectively) have become the molecules of choice for inferring microbial phylogenetic and making taxonomic assignments at the genus level. The small subunit rRNAs (SSU rRNAs) are almost ideal for studies of microbial evolution and relatedness because they play the same roles in all microorganisms. In addition, because the ribosome is absolutely necessary for survival and the SSU rRNA are part of the complex ribosomal structure.

Genomic Fingerprinting
A group of techniques called genomic fingerprinting can also be used to classify microbial and help determine phylogenetic relationships. Unlike the molecular analysis so far discussed, genomic fingerprinting does not involve nucleotide sequencing. Instead, it employs the capacity of restriction endonucleases to recognise specific nucleotide sequences.

Amino Acid Sequencing
The amino acid sequences of proteins directly reflect mRNA sequences and therefore represent the genes coding for their synthesis.

The Major Division of Life
The division of all living organisms into three domains – Archaea, Bacteria and Eucarya – has become widely accepted among microbiologists.

DNA-DNA Hybridisation
When two organisms share many highly similar (or identical gene,) their DNAs would be expected to hybridise to one another in approximate proportion to the similarities in their gene sequences. To this way, measurement of DNA-DNA hybridization between the genomes of two organisms provides a rough index of their similarity to each other. DNA-DNA hybridization therefore is useful for differentiating between organisms as a complement to SSU, RNA gene sequencing.

Self-Assessment Exercise
Explain the use of morphological, ecological and molecular characteristics in the classification of microorganisms.

4.0 Conclusion

Systemic classification is the scientific study of organisms, their organisation and arrangement in orderly manner into groups based on their classical and molecular characteristics. This classification is important for the study of the diversity of microorganisms in nature.

5.0 Summary

- Taxonomy is the science of biological classification, is composed of three parts: classification, nomenclature and identification.
- A polyphasic approach is used to classify microorganisms. It makes use of genetic, phenotypic and phylogenetic analysis.
- Methods of classification of microorganisms include phenotypic, phylogenetic, genotypic and numerical taxonomy.
- Taxonomy ranks are arranged in a non overlapping hierarchy.
- The taxonomic ranks are species, genus, family, order, class, phylum and domain.
- Microorganisms are named according to the binomial system.
- The classical approach to determining microbial taxonomy and phylogeny include morphological, physiological, metabolic, ecological and genetic characteristics.
- Molecular techniques used in classification include nucleic acid base composition, nucleic acid hybridization, nucleic acid, sequencing genomic finger printing and amino acid sequencing.

6.0 Self-Assessment Exercise

1. Define the following terms:
   a. Species
   b. genus
   c. Order
   d. class
   e. family
   f. domain,
   g. phylum.
2. Arrange the listed terms in their hierarchical taxonomic levels.
3. Differentiate between phonetic classification and phylogenetic classification.

7.0 References/Further Reading

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Unit 2 Systematic Classification Of Bacteria

1.0 Introduction

The most widely used reference for bacteria classification is Bergey's Manual of Systematic Bacteriology, which is divided into four volumes.

Divisions within Bergey's manual are based on characteristics such as:

- Gram, reaction, cell, shape, cell arrangement, oxygen requirements, motility, metabolic properties. Bacteria are also classified according to the international agreed rules by the international committee on systematic bacteriology. This unit examines the systematic classification of bacteria, the major groups of bacteria and main characteristics of each group.

2.0 Objectives

At the end of this unit, you should be able to:

- identify the major groups of bacteria
- state the major characteristics which set each group apart from others
- Identify important genera within the appropriate group.

3.0 Main Content

3.1 Bergey's Manual of Systematic Bacteriology - Volume I

Ordinary Gram Negative Bacteria

Bergey's Manual of Systematic Bacteriology, Volume I is made up of the ordinary Gram negative chemoheterotrophic bacteria. Many of which have clinical, industrial or agricultural importance. They include:

3.1.1 The Spirochetes

These bacteria have helical shapes. They have the ability to twist and contract their shape (they are flexible). There is presence of a special kind of flagella termed periplasmic flagella or axial fibrils which may be more than one. They are so thin they cannot be easily seen in light microscope. When gram stained, dark field microscope is used to visualise these organisms, they are Gram negative bacteria. Many spirochetes are human pathogens.

Important genera

- Treponema: causes syphilis and yaws
- Borrelia: causes lymes diseases
- Leptospira: causes fever, liver and kidney damages

3.1.2 Aerobic/motile, Helical/Vibrioid Bacteria

They are Gram negative bacteria. The cells are rigid and range from vibrioid (having less than one tumor twist) to helical. They swim by means of polar flagella.

They are aerobic or microaerophilic. Most are harmless saprobes and occur in soil, fresh water or marine environment but a few are parasitic and pathogenic for human animals and other bacteria.

Important Genera

- *Spirillum* - adapted to low concentration of organic matter
- *Azospirillum* - associated with plant roots, nitrogen fixer important to agriculture.
- *Campylobater*- a food poisoning bacteria
- *Bdellovibrio* - Predator on bacteria.

3.1.3 Non Motile Gram Negative Curved Bacteria

These bacteria have rigid cell that are curved to various degrees forming coil, helical spirals and sometime ring, they are not motile. They occur mainly in soil, fresh water and marine environment.

3.1.4 Gram Negative, Aerobic Rods and Cocci

This group of bacteria forms one of the largest and most diverse group of bacteria. They are straight or slightly curved rods, some are cocci. They are a strictly respiratory type of metabolism:

Many industrially, medical, and environmentally important bacteria habitats include soil, water, animal parasites.

Important Genera

- *Pseudomonas*-Opportunistic infections in burns. Aerobic motile with rods with polar flagella. Many may synthesize a yellow green-pigment that fluoresces under UV light. Are resistant to many chemicals and antibiotics.
- *Legionella* - Legionnaire's Disease, fastidiuos organisms found in many environments.
- *Neisseria* - STD mostly of humans and animals
- *Brucella* - Obligate intracellular parasites
- *Bordetella* - Whooping and kernel coughs
- *Francisella* - Tularemia in rabbits, require cysteine.
- *Rhizobium* - A nitrogen-fixing soil bacterium
- *Agrobacterium* - Used to introduce DNA into plants.

3.1.5 Facultatively Anaerobic, Gram-Negative Rods

Many important pathogens, oxidase and a requirement for organic Habitats include soil, plants, and animals, respiratory and intestinal tracts

Many in this group known as 'enterics' found in human intestine)

Important genera: (inhabit intestine of animals) bulky dysentery

Escherichia, Salmonella, Shigella, Klebsiella, Yersina, Vibrio,

Haemophilus, Gardnerella, Pasteurella, Proteus, Seratia

3.1.6 Aerobic, Gram-Negative Rods

Straight, curved and helical rods. They are rigid. They are obligately anaerobic (cannot live in pressure of O_2)

Habitats: Mostly in intestinal traits, some in mouth and genital trait and some of the most common organism in the intestine.

Important genera:

Bacteriodes

Fusobacterium

Leptotrichia

3.1.7 Dissimilatory Sulphate-Reducing or Sulfur - Reducing Bacteria

They have a Gram-negative cell wall.

They are found in anaerobic sediments; reduce oxidised forms of sulphur to H_2S. Dissimilation = nutrition not assimilated but rather excreted. Occur in mud, fresh water, marine or brackish environments.

Important genera: *Desulfovibrio* – vibroid or helical cells.

Desulfococcus

Self-Assessment Exercise

In what way does spirochete differ from other bacteria?

3.2 Bergey's Manual of Systematic Bacteriology - Volume 2

3.2.1 Ordinary Gram- Positive Bacteria

Bergey's Manual of Systematic Bacteriology, Volume 2 is made up of the ordinary gram positive chemoheterotrophic bacteria,many of which have clinical or industrial or agricultural importance. They are:

a. Gram-Positive Cocci. Aerobic/Facultatively Anaerobic Cocci

They possess cytochrome.
They are able to respire with oxygen.
Some can also obtain energy under anaerobic conditions by fermentation.
Members are placed in two families.
Deinococcaceae and Micrococcaceae.

Important genera

1. *Micrococcus*

aerobes or facultative anaerobes that form irregular clusters by dividing in two or more planes.

2. *Streptococcus*
    - aerotolerant anaerobes that obtain energy from fermenting sugars to lactic acid
    - form chains by dividing in one or two planes
    - lack catalase
    - can cause extensive tissue destruction by the release of enzymes that degrade fibrin.
3. *Staphylococcus*
    - common human pathogen
    - responsible for skin abscesses or boils
    - will tolerate and grow in high salt concentrations
    - will rapidly develop antibiotic resistance.
4. Peptococcus
    - obligate anaerobes lack both catalase and enzymes to ferment lactic acid
    - form pairs or irregular clusters
    - can cause many infections.
5. Peptostreptococcus
    a. Aerotolerant Fermentative Cocci

They do not have cytochromes.

They have only a fermentative type of metabolism and do not respire yet they can grow anaerobically or aerobically.

The cells are arranged in pairs, chains or tetrads.

Some representative genera include Streptococcus. Leuconostoc and Pediococcus.

b. Anaerobic Gram-Positive Cocci

These cocci have a fermentative type of metabolism, cells in clusters, tetrads, short or long chains.

3.2.2 Endospore Forming Gram-Positive Bacteria

Most are rod shaped but some are cocci.

Majority are gram-positive but a few species stain gram-negative.

Motility if present is by means of peritrichous flagella.

Some genera included in the group are:

- Aerobic/Facultatively Anaerobic spore forming Rods and Cocci.
- These groups are rod and cocci in shape.
- Two genera found in the group are Bacillus and Sporosarcina.
- Bacillus. They are rod shaped bacteria.

- May form exocellular enzymes that hydrolyse proteins and complex polysaccharides.

- They form endospores which are heat resistant. They are harmless saprobes found in soil, fresh water or sea water. Examples include *B. subtilis, B. cereus* and *B. thuringiensis*.
- Sporosarcina: They are cocci in shape and arranged in tetrads or cubical packets of eight cells. They are widely distributed in fertile soil.

3.2.3 Anaerobic Spore forming Rods

They have a fermentative type of metabolism. They are widely distributed in soil, in marine and fresh water anaerobic sediments. They include *Clostridium* and *Desulfotomaculum*.

3.2.4 Non-Spore Forming Gram Positive Rods of Regular Shape

They are short or long rods in shape.
The group is made of harmless saprobes.
Some are parasitic organisms.

Important Genera

1. Lactobacillus
 foods and cheeses.

2. Listeria
 infection of brain and its membranes, will damage fetus.

3. Erysipelothrix
 red sores in human.

3.2.5 Non-Spore Forming Gram-Positive of Irregular Shape

This group contains a heterogenous variety of bacteria. The few common features are

Straight to slightly curved rods.

1. May be aerobic or facultatively anaerobic.

Some examples of the genera in the group include *Corynebacterium*, *Arthrobacter, Brevibacterium, Micrococcus* and *Cellulomonas.*

Corynebacterium: This genus contains rod shaped cells which are pleomorphic and frequently exhibit club-shaped swellings and a palisade arrangement.

They may be saprobes, pathogens of human and or animals as well as plant pathogens. An example is *C.diptheriae* which causes diphtheria in humans, *C. sepedonicum* which causes ring rot of potatoes.

2. Aerobic/Facultatively Anaerobic Branched Filamentous Rods.

The bacteria of this group form colonies which at first are microscopic in size (microcolonies) and contain branched filamentous cells. As the colonies develop to macroscopic size many of the cells become diphtheroid (like caryobacteria) or cocci in shape. Examples include *Agromyces* and *Arachnia*

3. Anaerobic Non-filamentous or Filamentous

The organisms are either anaerobes or if facultatively anaerobic are preferentially anaerobic. Two of the genera in this group are *Propionbacterium* and *Actinomyces*. They are differentiated by their morphology and by their fermentation end products as determined by gas chromatography.

Important genera

1. Corynebacterium
a. can cause diphtheria.

2. Propionibacterium: anaerobic, causes acne

3. Eubacterium

4. Actinomyces:
   a. branching filamentous soil microbes.

3.2.6 Mycobacterium

They are aerobic bacteria. Their cell walls contain large amounts of lipids. They are made up of a single genus *Mycobacterium* which are slightly curved or straight rods that may show branching.

They are acid fast.

Some are saprophytes, e.g. *M. phlei*

While some are pathogens, e.g. *M.tuberculosis.*

3.2.7 Nocardioforms

They are aerobic bacteria that produce a substrate mycelium i.e. a mat of branching hyphae formed under the surface of the agar medium.

Important genera

- *Nocardia:* pulmonary nocardiosis

- Some pathogens.

Self-Assessment Exercise

- List the group of bacteria placed in Bergey's Manual of Systematic Bacteriology Volume II.
- Differentiate between Staphylococcus and Streptococcus.

3.3 Bacteria with Unusual Properties

The organisms in this volume have unusual properties which are quite different from those in volumes one and two. The anoxygenic phototrophs can be divided into two major groups based on their pigmentation purple bacteria and green bacteria. They occur in anaerobic fresh water or marine environment. They may also occur beneath the surface of shallow aquatic environments rich in organic matter such as stagnant ponds and ditches.

Anoxygenic Phototropic Bacteria

They belong to the order Rhodospirillales. They are Gram-negative and capable of carrying out photolithothrophic or photoorganotrophic type of metabolism. They contain bacteriochlorophyll. Also present in their cells are various water-insoluble carotenoid pigments which can also trap or absorb light energy and transmit it to the bacteriochlorophyll.

The anoxygenic bacteria grow phototrophically only under anaerobic conditions and are incapable of forming O_2 because they possess only photosystems.

Oxygenic Phototrophic Bacteria
They are bacteria that contain chlorophyll. They can use light as an energy source and evolve O_2 in a manner similar to that of green plants. The group include: the Cyanobacteria (blue-green algae).

Gliding, Fruiting Bacteria
Gram-negative, non-phototrophic bacteria
They lack flagella; yet can glide across solid surfaces.
They have a complex life cycle in which the cells swarm together in masses and form fruiting bodies.
The fruiting bodies contain myxo-spores which are shorter and thicker than the vegetative cells.
They are found in surface layers of soil, compost, manure, rotting wood and animal dung.
Constituent genera include *Stigmatella Chondromyes*. They are aerobic or microaerophilic organisms.

They live in soil or water.

Gliding, Non-fruiting Bacteria
Gram-negative non-phototrophic rods, filaments or multicellular trichomes that glide across solid surfaces: fruiting bodies are not produced.

Examples of organisms include *Cytophaga, Flexibacter or Vitreoscilla*

Beggiotoa, Simonsiella,Saprospira and *Thiothrix*.

Sheathed Bacteria
Gram-negative non-phototrophic bacteria that form an external sheath that covers the chain or trichomes.

They inhabit fresh water of marine environments. Among the genera included in this group are *Sphaerotilus, Leptothrix,* etc.

Budding and/or Appendaged Bacteria
They are Gram-negative non-phototrophic bacteria that reproduce asymmetrically by budding and or form prosthecea or stalks (Non- living ribbon-like or tubular appendages that are excreted by the cell).

The organisms range from aerobic to microaerophilic to facultatively anaerobic. Examples include *Hyphomicrobium Ancalomicrobium, Caulobacter*.

Chemolithotrophic Bacteria
Gram-negative non-phototrophic bacteria that obtain energy for carbon dioxide fixation from the oxidation of ammonia, nitrite, reduced sulfur compounds or ferrous iron.

Examples of families in this group are the nitrifying bacteria, the sulfur metabolizing bacteria and the Siderocapsaceae.

Many of these organisms are found in the soil, fresh water and marine environments.

Archaeobacteria
Gram-positive or Gram-negative that are phylogenetically distinct from eubacteria; some produce methane gas; some require unusually high level of NaCl for growth: others are distinguished by their ability to grow at a low pH and a high temperature. Three main categories of archaeobacteria recognised are the methanogens the red extreme halophiles, and the thermo-acidophiles.

Self-Assessment Exercise
List the major group of organism in volume 3 and state the characteristics of each.

3.4 Bergey Manual of Systematic Bacteriology - Volume 4

Gram-positive filamentous bacteria of complex morphology

The organisms in volume IV are aerobic gram positive bacteria which form structures such as mycelium of filamentous hyphae and asexual spores as found in microscopic eukaryotic fungi and have different cell types of cellwalls based on amino acid and sugar composition.

Filamentous bacteria that divide in more than one plane
The hyphae divide not only transversely but also longitudinally to produce cluster or packet of cells or spore; cell-wall type iii; soil organisms, animal pathogens, and symbiotic nitrogen-fixers are represented. The three genera present in this group are *Geodermatophilus*, *Dermatophilus* and *Frankia*.

Filamentous bacteria that form true sporangia
Harmless soil and water organism whose hyphae divide in a single plane; the spores are formed within special sacs; cell-wall type ii or iii

A good example of a genus in this division is *Actinoplanes*.

Streptomyces and related genera
The hyphae divide in a single plane; long chain of conidiospore are formed at the tips of sporogenic hyphae; the organism are mainly harmless soil organism that are noted for production of antibiotics; a few are human or plant pathogen; cell-wall type.

Several genera in this group include *Streptroverticullium*, *Actinopycnidium*, *Actinosporangium* but the most popular of these genera is *Streptomyces.*

Additional Filamentous Bacteria Having Uncertain Taxonomic Placement
The taxonome placement of the bacteria of this heterogeneous group is not yet agreed upon because many of the organisms have unusual and striking morphological or physiological characteristics such as:

1. The extreme halophilism exhibited by *Actinopolyspora.*
2. Formation of heat resistant spores by *Thermoactinomyces* and other unusual properties.

A heterogenic collection of organism whose relationship to the major groups of gram-positive filamentous bacteria is not yet agreed upon; some have remarkable morphological or physiological properties; a few organisms are pathogenic for humans; the cell-wall type vary.

4.0 Conclusion

Division within Bergey's Manual of Systematic Bacteriology Volumes I-IV is based on characteristics such as gram reaction, cell shape, cell arrangement, oxygen requirement motility and metabolic properties.

5.0 Summary

- The Bergey's Manual of Systematic Bacteriology Volume 1-IV is as reference for the classification of bacteria.
- Division is based on characteristics such as Gram Stain reaction, cell shape, oxygen requirement and other properties.
- Bergey's Manual Volume I is made up of ordinary Gram negative bacteria. They include: the spirochetes which have helical shapes, flexible with periplasmic flagella. Important genera include *Treponema* and *Leptospira* Aerobic, motile helical or *vibriod* bacteria with rigid cells and vibriod or helical in shape with polar flagella. Important genera are *Spirillum* and *Azospirillum*.
- Non-motile Gram negative curved bacteria have rigid cell that are curved, they occur in soil, fresh water and marine environment.
- Gram negative aerobic rods and cocci are straight or slightly curved rods; they include *Pseudomonas*, *Nisseria* and other genera.
- Other gram-negative organisms in this group include facultatively anaerobic Gram-negative rods, Aerobic Gram-negative rods, and dissimilatory sulphate-reducing bacteria
- Bergey's Manual of Systematic Bacteriology Volume 2 is made of ordinary Gram positive bacteria among which are Aerobic/facultatively anaerobic cocci.
- Aerotolerant fermentative cocci, Anaerobic Gram positive, cocci.
- Endospore forming gram positive bacteria of regular and irregular shapes and *Mycobacterium*.
- Bergey's Manual of Systematic Bacteriology – Volume 3 is made up bacteria of unusual properties among which are Anoxygenic Phototropic Bacteria, Oxygenic Phototropic Bacteria, Gliding fruiting Bacteria, Gliding Non-fruiting Bacteria Sheathed Bacteria and Building and unappendaged Bacteria.
- Volume IV of Bergey's Manual of Systematic Bacteriology is made up of gram positive bacteria of complex morphology which include filamentous bacteria that divide in more than one plane, filamentous bacteria that form true sporangia, *Streptomyces* and related genera and filamentous bacteria having uncertain taxonomic placement.

6.0 Self-Assessment Exercise

i. What genera of gram-negative bacteria are associated with plants as nitrogen fixers?
ii. Write on systematic classification of Gram-positive cocci.

7.0 References/Further Reading

"Bergey's Manual of Systematic Bacteriology."

Medigan, M.T. *et al.* (2009). *Brock Biology of Microorganisms*. (12th ed.). Pearson Education Inc.

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Unit 3 Systematic Classification of Fungi

1.0 Introduction

The classification of fungi like that of bacteria is described mainly for practical application but it also bears some relation to phylogenic consideration. The nomenclature is binomial, with a generic and specific name (e.g. *Aspergillus niger*). Species are collected in genera, families (suffice-acae), families in order (suffix ales), and order in class (suffix mycetes). Sequence analysis of 185-RNA and certain protein – coding gene has shown that the fungi comprises a monophyletic group with eitht subdivisions. Four of these subdivisions, the *Chytridiomycetes, Zygomycota, Ascomycota* and *Basidomycota* have been recognised as separate groups for some time. The other four – *Uredinomycetes, Ustilaginomycetes, Glomeromycota* and *Microsporidia* have been proposed recently as separate groups. This unit examines the systematic classification of fungi.

2.0 Objectives

At the end of this unit, you should be able to:

- identify the different divisions of fungi
- state the characteristics of each division of fungi and
- State the mode of reproduction of each division of fungi.

3.0 Main Content

Chytridiomycetes or Chytrids
Chytridiomycetes or chytrids are the earliest and the simplest group of fungi. They are unique among fungi because they produce motile zoospore with a single posterior whiplash flagellum. The cell wall is made of chitin. Some exist as single cell while other form colonies with hyphae. Some are free living and found living on plant or animal matter in fresh water, mud or soil. Others are parasitic and infect aquatic plant and animal including insects. They display a variety of life cycles involving both asexual and sexual reproduction. Sexual reproduction usually involves production of sporangiospores from sporagia.

Based on zoospore morphology, the orders with the Chytridiomycetes include the Blastocladiales, Monoblepharidales, Neocallimasticales, Spizellomycetales and the Chytridiales.

3.1 ygomycota

The *Zygomycota* are made of fungi called *Zygomycetes*. They are commonly found in soil and on decaying plant materials. All are multinucleate (*coenocytic*). Asexual spores develop in sporangia at the tip of aerial *hypae* and are usually dispersed by wind. Sexual reproduction produces tough, thick walled zygotes called zygospores that can remain dormant when the environment is too harsh for growth of the fungus. The bread mould *Rhizopus stolonifer* is very common member of this division, the fungus grows on moist, carbohydrate-rich foods such as bread and vegetables.

Self-Assessment Exercise

What feature of Zygomycetes gives this group its name?

3.2 Ascomycota

Members of this group are called Ascomycetes, commonly known as sac fungi. These ascomycetes are large and highly diverse groups of fungi ranging from single-celled species such as yeast (Saccharomyces) to species that are filamentous like *Neurospora*.

The ascomycetes derived their names from the production of asci (singular, ascus) cells in which two haploid nuclei from different mating types come together and fuse, forming a diploid nucleus that undergoes meiosis to form haploid ascopores.

Asexual reproduction in ascomycetes is by the production of conidia formed at the tip of specialised hyphae called conidiospore, an example of fungi in this group is yeast. Cell division in *Saccharomyces cerevisiae* (yeast) occurs by budding. During the budding process, a new cell forms as a small outgrowth of the old cell, the bud gradually enlarges and separates from the parent cell. Sexual reproduction also involves ascus formation with each ascus usually bearing eight haploid ascospores.

3.3 Basidiomycota

The Basidiomycota include the Basidiomycetes, commonly known as club fungi. Examples include jellyfungi, puffballs, toadstools and mushrooms. They are named for their characteristic structure cell, the basidium, which is involved. A basidium is produced at the tip of hyphae and is normally club shaped. Two or more basidiospores are produced by the basidium and basidia may be held within fruiting bodies called basidiocarps. The basidiomycetes affect humans in many ways. Most are saprobes that decompose plant debris, e.g. cellulose and lignin, e.g. *Polyporus squamosus*. Some are used as food, e.g. the mushroom. *Agaricus campestris* while some like *Crytococcus, Neoformans* are important human and animal pathogens.

3.4 Glomeromycota

The glomeromycetes are a relatively small group of fungi with major ecological importance. Only about 160 species of glomeromycetes are currently known. All known species of glomeromycetes form endomycorrhizae, also called arbuscular mycorrhizae with the roots of herbaceous plants. They aid the plant acquisition of materials from the soil. They produce only asexually and are mostly coenocytic in their morphology. There is mutualistic relationship between the fungus, the fungus help protect the plant from stress and deliver soil nutrients to the plant which in turn provides carbohydrates to the fungi.

3.5 Microsporidea

These are tiny (2-5μm), unicellular parasite of animals and protists. They have been considered protists and are sometime cited as such. Molecular analysis of ribosomal RNA and specific protein such as α- and β-tubulin shows that they are most closely related to fungi. However, unlike fungi, they lack mitochondria, peroxisomes and centriols. They are obligate parasites that infect insects, fish and human, in particular they infect immunosuppressed individuals such as those with HIV/AIDS; an example is *Enterocystozoa spp* which causes diarrhea and pneumonia. It reproduces asexually by spore formation.

3.6 Uredinomycetes and Ustilaginomycetes

Both the uredinomycetes and the ustilaginomycetes include plant pathogens causing rust and smuts. Some uredinomycetes include human pathogens. They are often considered basidomycota. Both unlike the basidomycota, they do not form large basidocarps instead small basidia arise from hyphae at the surface of the host plant. The hyphae grow either intracellular or extracellularly in the plant tissue. A good example is *Ustilago maydis,* a common corn pathogen that causes smuts.

Self-Assessment Exercise

State the role of arbuscular mycorrhizae on plants.

4.0 Conclusion

Systematic classification of fungi is based on sequence analyses of 185r RNA and some protein coding genes and on the characteristics of the sexual spores and fruiting bodies present during sexual reproduction.

5.0 Summary

Sequence analyses of 185r RNA and some protein-coding genes show that the fungi comprise a monophyletic group with eight subdivisions.

- Chytridiomycetes are the earliest and simplest group of fungi. They produce motile spores, some are saprobic while some are parasites.
- Zygomycetes are coenocytic (multinucleate) saprobic. They reproduce asexually by spore formation and sexually by fusion of two gametangia to form a zygospore, an example is the bread mould *Rhizopus stolonifer.*
- Ascomycota are known as sac shaped reproductive structure called an ascus. Asexual reproduction occurs by conidia production while sexual reproduction occurs by fusion of gametes.
- Basidiomycota are the club fungi. They are named after their basidium which carries 4 basidiospores. Some are saprobes, while some are pathogens of human and animals.
- Glomeromycota form endomycorrhizae with plants roots. They help to increase nutrient intake in the plants.
- Microsporidia are still sometimes considered as protists but molecular analysis has shown they are most closely related to fungi. They lack mitochondria, centrioles and peroxisomes. They are usually pathogens to insect and those with compromised immunity.
- Uredinomycetes and Ustilaginomycetes are often considered basidiomycetes but they do not form basidiocarp.

6.0 Self-Assessment Exercise

1. What are chytridiomycetes? How do they differ from other fungi?
2. In what structure are the basidiospores formed?

7.0 References/Further Reading

Atlas, R.M. (1995). *Microorganisms in Our World*. Mosby Year Book. Inc.

Medigan, M.T. *et al*. (2009). *Brock Biology of Microorganisms*. (12th ed.). Pearson Education Inc.

Pelczar, M.J., Chan, E.C.S. & Krieg, R.N. (2001). (5th ed.). *Microbiology*. McGraw-Hill.

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Unit 4 Systematic Classification of Algae

1.0 Introduction

Algae are generally classified on the basis of the following characteristics:

- nature and properties of pigment
- chemistry of reserve food products or assimilatory products of photosynthesis
- type and number, insertion (point of attachment), and morphology of flagella
- chemistry and physiological features of cell walls
- morphological characteristics of cells and thalli
- life history, reproductive structures and method of reproduction. This unit examines the systemic classification of algae and the characteristics of the major groups of algae.

2.0 Objectives

At the end of this unit, you should be able to:

- identify the major groups of algae
- state the types of pigment present in each group of algae
- state the major characteristics of each group of algae
- state the mode of reproduction of each group of algae.

3.0 Main Content

3.1 Rhodophycophyta

The Rhodophycophyta, or red algae, are marine forms found in the warmer seas and oceans, but some grow in colder water as well as in fresh water. Most red algae grow in the subtidal (submerged) zone, only a few being able to survive desiccation or exposure. Some species deposit upon their surfaces lime from seawater; ultimately this results in deposition of lime in the ocean and plays a part in the formation of algal reefs. They range from unicellular to multicellular. They are photosynthetic and contain chlorophyll A. Their chloroplast lack chlorophyll B and contain phycobiliproteins. The major light-harvesting pigments of the cyanobacteria, the reddish colour of red algae results from phycoerythrin, an accessory pigment that masks the green colour of chlorophyll. And example is *Gelidium* from which agar is made, *Polysiphonia* and *Chondrus crispus*.

3.2 Xanthophycophyta - The Yellow-Green Algae

These yellow-green algae were once classified with the green algae. However, their pale green or yellow-green colouration indicates that they have a unique group of pigments. They are found more frequently in temperate regions in freshwater and marine habitats, as well as on and in soil. Xanthophytes exist as single cell colonies, and as both branched and unbranched filaments. Motile genera are not common, although, some reproduce asexually by motile reproductive cells (zoospores). Flagella are of unequal lengths.

The xanthophyte walls are typically of cellulose and pectin. The cellular storage product is an oil or (a branched glucan) chrysolaminarin.

Vaucheria, the water felt, is a well-known member of this division and is widely distributed on moist soil and in both quiet and rapidly flowing water. Both freshwater and marine species are known. Zoospores are formed singly in terminal sporangia in asexual reproduction.

3.3 Chrysophycophyta – The Golden Algae

Species of *Chrysophycophyta* are predominantly flagellates; some are amoeboid, with pseudopodia extensions of the protoplasm. The naked amoeboid forms can ingest particulate food with the pseudopodia. Non motile coccoid and filamentous forms are also included in the division.

The chrysophycophyta differ from the green algae in the nature of their pigments, in storing reserved food as oil or chrysolaminarin rather than as starch, and in their frequent incorporation of silica. Most forms are unicellular, but some form colonies. Their characteristic colour is due to the marking of their cholorophyll by brown pigments. Reproduction is commonly asexual (binary fission) but occasionally isogamous. An example is *Ochromonus.*

Self-Assessment Exercise

What are the major characteristics of the Crysophycophyta?

3.4 Phaeoophycophyta – The Brown Algae

These algae are multicellular and contain a brown pigment which gives them their characteristic colour and common name of brown algae, or brown seaweeds. Nearly all are marine dwelling and most frequently, found in the cool ocean waters. They are structurally quite complex, and some – the kelps – are large, the individual plants reaching a length of several hundred feet. Many have holdfasts; and some have air bladders, which give them buoyancy. They reproduce asexually by zoospores and sexually by isogamy and heterogamy. This group includes algae used in commerce, such as the many varieties of kelp. They are used as food for humans, other animals and fish.

3.5 Bacillariophycophyta – The Diatoms

Members of this group are the diatoms, they are found in both fresh and salt water and in moist soil. They are abundant in cold waters. Diatoms are the most plentiful form of plankton in the Arctic. The thousands of species diatoms provide an ever present and abundant food supply for aquatic animals. Diatoms are unicellular, colonial, or filamentous and occur in a wide variety of shapes. Each cell has a single prominent nucleus which is massive and ribbon-like, or smaller lens-like, plastids. They produce shells (cell walls) containing silica, some of which are very beautiful. Shells of diatoms are called **frustules**. Deposits of these shells resulting from centuries of growth are called **diatomite** or **diatomaceous earth.**

3.6 Euglenophycophyta – The Euglenoids

They are unicellular organisms and they are actively motile by means of flagella. They reproduce by cell division. Of particular interest is the genus Euglena, which is representative of a group designated as animals by some zoologists but as plants by many botanists. Euglena is widely distributed and occurs in soil as well as in water, where it often forms a variety film or bloom.

The Euglena is not rigid; it is pliable. There is no cell wall containing cellulose. The outer membrane is an organised periplast. An anterior "gullete" is present even though, no food is ingested through it. Certain species develop a prominent stigma or red eyespot. Contractile vacuoles and fibrils are also present in the cell. All these are animal attributes. On the other hand, the organism carries out photosynthesis. A few types can even ingest particulate food through transient openings adjacent to the gullet. Reproduction is by longitudinal binary fission. Dormant cysts are formed by all types.

3.7 *Chlorophycophyta* – The Green Algae

Members of this large and diverse group of organisms, called **green algae**, are principally freshwater species. They are also found in seawater, and many of them are terrestrial. The cells of the chlorophycophyta have a well-defined nucleus and usually, a cell wall, and the chlorophyll pigments are in chloroplasts, as in higher plants. The majority of green algae contain one chloroplast per cell. It may be laminate, cup-shaped, or reticulate. The chloroplasts also often contain dense regions called **pyrenoids**, on which surface starch granules are formed. Food reserves are stored as starch, a product of photosynthesis. They bear chloroplasts containing chlorophyll A and B giving them their characteristic green colour.

There are many single-celled forms and many colonial types of green algae. Many unicellular green algae are motile by flagella action. Colonial types occur as spheres, filaments, or plates. Some species have special structures called holdfasts, which anchor them to submerged objects or aquatic plants. An example is *Chlamydomonas.*

Chlamydomonas is considered a typical green algae. It is a typical unicellular, motile, green alga and is widely distributed in soils and freshwater. It varies from 3 to 29μm in common forms and is motile except during cell division. Motility is by means of two flagella. Each cell has one nucleus and a single large chloroplast that in most species is cup-shaped, although in some, it may be star-shaped or layered. The cell wall contains cellulose; in many species, an external gelatinous layer is also present. There is some evidence that the red eyespot or stigma in the chloroplast is the site of light perception.

In addition to motile unicellular algae like *Chlamydomonas*, other, non-motile unicellular green algae are widely distributed. One of the most important of these is *Chlorella*, which has served usefully as a tool in many investigations on photosynthesis and supplemental food supply.

Volvox is a colonial green algae which may form water blooms. Its colonies are visible to the naked eye. Each colony contains from 500 to thousands of cells arranged at the surface of a watery colloidal matrix. The individual cells are biflagellate and are morphologically similar to that of chlamydomonas.

Desmids are one of the most interesting green algae found in a wide variety of attractive shapes and designs. Each cell is made up of two symmetrical halves with one or more chloroplasts

Ulethrix is a filamentous form found in flowing streams, attached to wings or stones by holdfasts at the base of the filament.

A very common green alga is *Spirogyra*, a filamentous form seen in the scums that cover ponds and slow-moving water. It is of interest because of its common occurrence and its possession of unusual chloroplasts, which are arranged spirally.

3.8 Cryptophycophyta – The Cryptomonads

The cryptomonads are a small group of biflagellate organisms. They have two unequal flagella, which arise from the base of a groove; both are of the tinsel type, with stiff hairs. The cells are slipper-shaped, flattened into a dorsal-ventral plane, and occur singly. Some forms have a cellulose wall while others are naked, being surrounded only by a plasmalemma with a thin granular material on the outside. There are one or two plastids, with or without pyrenoids, per cell. Food reserve is stored as true starch as well as oil. Asexual reproduction is either by means of longitudinal cell division or the formation of zoospores or cysts. An example is the genus *Cryptomonas*.

3.9 Pyrrophycophyta – The Dinoflagellates

This division includes the dinoflagellates, a diverse group of biflagellated unicellular organisms. The dinoflagellates are so named because of their twirling motion rather than their morphology. These organisms constitute an important component of marine, brackish, and fresh bodies of water. This is another group that has both plant-like and animal-like characteristics. The cells are typically flattened and have a transverse constriction, the girdle, usually around the cell equator. Distinguishing feature of dinoflagellates are that the flagella are inserted in the girdle and that the flagella are arranged with one encircling the cell and one trailing. Hairs project from the flagellar surface. Many dinoflagellates are covered only by a plasmalemma. In some forms, there is a wall made of cellulose. Still, others have a series of cellulose plates within the plasmalemma. These are termed thecal plates and dinoflagellates with them are said to be armored. Dinoflagellates are important constituents of planktons. They are best known as the organisms that produce "red tides", or blooms in which concentration of cells may be so great as to colour large areas of the ocean red, brown, or yellow. Such an organism is *Gonyaulax*. Other marine dinoflagellates such as *Noctiluca* are luminescent. Asexual reproduction takes place by division of the cell.

Self-Assessment Exercise

What are the characteristics of the Chlorophycophyta?

4.0 Conclusion

It can be seen clearly from the different major classes or groups of algae that classification of algae were based on their characteristic coloured pigments and cell morphologies.

5.0 Summary

The Rhodophycophyta – The red algae are found in aquatic habitats. They reproduce asexually by non-motile spores and sexually by the union of well differentiated non-motile male and female germ cells Examples are *Gelidium* and *Polysiphonia*.

The Xanthophycophyta: The yellow green algae are single cells, colonies or filamentous algae that have pale green or yellow green pigmentation and are found in temperate region fresh water and marine habitats. Reproduce asexually by cell division and production of motile spores.

The Phaeoophycophyta: The brown algae are multicellular with brown pigments found most times in marines and reproduce asexually by zoospores and sexually both isogamously and heterogamously.

Bacillariophycophyta: The diatoms are found in both fresh and salt water and in moist soils. They occur in a wide variety of shapes and serve as food for aquatic animals.

Euglenophycophyta: are unicellular organisms that move by means of flagella and reproduce by binary cell division a good example is *Euglena* with animal like and plant like characteristics.

Chlorophycophyta: The green algae may be unicellular, colonies or filament are found in fresh water, see water and terrestrial habitats. They have chlorophyll and other pigments in chloroplasts and have food reserve stored as starch and reproduce by zoospores, fission and other asexual methods.

Cryptophycophyta: The *Cryptomonas* are biflagellate organisms with two unequal flagella food reserved is stored as a true starch as well as oil. Reproduction is either by means of longitudinal cell division or the formation of zoospores or cysts. Sexual reproduction has been confirmed in the genus *Cryptomonas*.

Pyrrophycophyta: The dinoflagellates are a diverse group of biflagellated unicellular organisms with animal-like and plant-like characteristics found in aquatic habitats where they produce "red tides" or blooms which colour large areas of the ocean red, brown or yellow. Asexual reproduction is by division of the cell. Examples are *Gonyaulax* and *Noctiluca*.

6.0 Self-Assessment Exercise

1. What are the characteristics Euglena shares with:
   a. animals?
   b. plants?
2. Write a short note on the Chlorophycophyta.

7.0 References/Further Reading

Medigan, M.T. *et al.* (2009). *Brock Biology of Microorganisms*. (12th ed.). Pearson Education Inc.

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Unit 5 Systematic Classification of Protozoa

1.0 Introduction

Traditionally, the protozoa are grouped together based on general similarities: they lack cell walls, they are colourless and motile, they exhibit a wide range of morphologies and inhabit many different kinds of habitat, and they play major roles in human society and health. The different forms of protozoa have been grouped together not because they are all related in an evolutionary way, but simply for convenience. The old classification schemes of protozoa were based primarily on organelles of locomotion. The major groups are called Phyla (singular, phylum). This unit determines the systematic classification of protozoa and different phyla in which they were placed.

2.0 Objectives

At the end of this unit, you should be able to:

- identify the major phyla of protozoa
- state the characteristics of each phylum
- differentiate between different phyla; and
- List some species found in each group or phyla.

3.0 Main Content

3.1 The Flagellates (Subphylum Mastigophorea)

These protozoa are conventionally divided into two groups: The plant-like forms (class Phytomastigophorea, the phytoflagellates) and the animal-like forms (class Zoomastigophorea, the zooflagellates). Plant-like protozoa usually contain green or yellow chloroplasts as well as flagella and are photosynthetic. The zooflagellates have no chlorophyll and are heterotrophic. All members have one or more flagella. Some have pseudopodia. Asexual reproduction occurs by longitudinal binary fission. A form of multiple fission takes place in some organisms. Encystment is common but sexual reproduction is not.

These organisms are considered as algae by some biologists. Since the zooflagellates have no chlorophyll, they must obtain nutrition heterotrophically. All members of this group have one or more flagella; some members are capable of forming pseudopodia.

3.2 The Zooflagellates (Class Zoomastigophorea)

The Choanoflagellates (order Choanoflagellida) are distinctive in that they are either stalked or embedded in jelly, and each cell has a thin transparent collar that encircles a single flagellum. The collar functions as a food catching device.

Organisms in the order Kinetoplastida are grouped together because of the presence of a kinetoplast (an extra nuclear region of DNA associated with the mitochondrion). The single mitochondrion itself is extensive, traversing the length of the body as single tube, hoop or network of branching tubes. One or two flagella may be present; if there are two, one is either trailing free or attached to the body, with undulating membranes occurring in some cases.

3.3 The Amoebas (Subphylum Sarcodina)

Structure

- Amoebas get their name from the Greek word "amoibe", meaning "change" because their shapes are constantly changing. A typical example is *Amoeba proteus*.
- Amoebas are composed of protoplasm differentiated into a cell membrane, cytoplasm and a nucleus. The cytoplasm shows granules as well as vacuoles containing food, wastes, water, and possibly gases. The outer membrane is selective and permits the passage of certain soluble nutrients into the cell and waste materials out of the cell. Solid food is ingested with the help of pseudopodia. The nucleus functions in reproduction, metabolism and the transmission of hereditary characteristics.
- *Amoeba* reacts to various physical and chemical stimuli in their surroundings. This is an irritability response which is at least superficially analogous to responses of higher organisms to their environment.

Nutrition of Amoeba

- Uses pseudopodia to capture its food.
- Reproduction – amoeba is asexually binary fission.

3.4 The Sporozoa (Phylum Apicomplexa)

They are in constant motion. They move by sending out portions of their bodies in one direction which the whole body follows. They use pseudopodia to capture food. Reproduction is asexually by binary fission. Some have the ability of encysting in unfavourable condition. Most are free living, some are saprophytic; however, one species *Entamoeba histolytica* causes amoebic dysentery in man. All sporozoa are parasitic for one or more animal species. Adult forms have no organs of motility but all are probably motile by gliding at one stage of their life cycle. They cannot engulf solid particles, but feed on the host's cells or body fluids.

Many have complicated life cycles, certain stages of which may occur in one host and other stages in a different host. They all produce spores at some time in their life history. Their life cycles exhibit an alternation of generations of sexual and asexual forms, such that the intermediate host usually harbours the asexual forms and the final host, the sexual forms. Sometimes, humans serve as hosts to both forms.

Toxoplasmosis and malaria are the major human diseases caused by sporozoa. Malaria is caused by *Plasmodium* asporozoa which infect the liver and red blood cells.

3.5 The Ciliates (Phylum Ciliophora)

The ciliates are protozoa with cilia for locomotion. Common examples of the ciliated protozoa are included in the genus *Paramecium*, found in freshwater ponds and lakes where adequate food supplies exist.

Structure/Morphology
Paramecium

- *Paramecium* moves rapidly by rhythmic beating of the cilia.
- Nutrition: *Paramecium* takes in food through a fixed cytostoma at the base of the gullet.
- Excretion is through the contractile vacuole.
- Reproduction – Reproduce asexually by binary fission conjugation may also occur.

Paramecia are microscopic, some, however, are just barely visible to the unaided eye. The outer layer of the cell is less flexible than the outer membrane of the amoeba, and the interior is composed of semifluid, granular protoplasm containing nuclei and vacuoles of several kinds. Paramecia are easily distinguished by their characteristic shape, which has been likened to that of a slipper. The anterior (front) end of the cell is rounded, and the posterior (rear) end is slightly pointed. The entire cell is covered with hundreds of short hair-like projections called cilia, which are the organs of locomotion and also serve to direct food into the cytosome.

3.6 Other Ciliated Protozoa

The ciliated protozoa are represented by many forms other than the paramecia. *Colpoda* is a common freshwater genus. The genus *Didinium* lives on a diet of paramecia, which are captured by a special structure and swallowed whole. The genus *Stentor* comprises large cone-shaped protozoa that move about freely but attach to some object by a tapered lower end while feeding.

4.0 Conclusion

Classification in protozoa is by the use of general characteristics and not as a result of evolution.

5.0 Summary

- Phytomastigophora are divided into two groups. The plant like forms class Phytoflagellates which have chlorophyll and flagella forms, class Zoomastigophora which have no chlorophyll and are heterotrophic.
- The amoebae (subphylum Sarcodina) are constantly changing their shapes and composed of protoplasm differentiated into a cell membrane cytoplasm and a nucleus and feed with the help of the pseudopodia.
- The sporozoa (phylum Apicomplexes) are parasitic for one or more animal species. They feed by the use of pseudopodia and reproduce asexually by binary fission.
- The ciliates (phylum Ciliophora): The ciliates are protozoa with cilia for locomotion.
- Other ciliates include Colpodia and the genera *Didinium* and the genus *Stentor*.

6.0 Self-Assessment Exercise

1. State the two groups of flagellates.
2. Describe the structure of paramecium.

7.0 References/Further Reading

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