République Algérienne Démocratique et Populaire
Ministère de l'Enseignement Supérieur
et de la Recherche Scientifique
Université de Tissemsilt
Faculté des Sciences et de la Technologie

Polycopié de cours

Cell Biology

Au profit des étudiants du tronc commun 1ère année (L1).
Domaine des sciences de la nature et de la vie (SNV).

Réalisé par : Dr. CHOUHIM Kadda Mohamed Amine
Dr. ZEMOUR Kamel

Année universitaire : 2023-2024

Table of contents

Table of contents

List of Tables

List of Figures

1. Introduction

Cell biology is the study of cells, which are the basic structural and functional units of living organisms. Cell biologists examine the structure and function of cells, including how they form, divide, differentiate into specialized types, and interact with their environment. All cells share common features like a membrane, DNA, and ability to use energy, reproduce, and respond to signals. But cells also have unique properties that allow them to carry out specific roles in the body. A major focus of cell biology is understanding how differences in cellular structure and composition enable cells to perform specialized functions, such as nerve conduction, hormone secretion, or muscle contraction. By revealing the intricate workings of cells, cell biology provides insight into fundamental life processes and disease mechanisms.

1.1. Kingdom Classification

Biological classification (taxonomy) aims to simplify and order the immense diversity of life into coherent units called taxa that have widely accepted names and whose members share important properties. It synthesizes information concerning a great variety of characters (e.g., morphological; molecular: genes, metagenome, and metabolome; etho-ecological).

One of the earliest systems of classification was proposed by the ancient Greek philosopher Aristotle, who recognized only two kingdoms: animals and plants. Later, in the 18th century, Carolus Linnaeus developed a system of classification that recognized only two kingdoms: animals and plants. In the 19th and 20th centuries, advances in the study of microorganisms, such as **bacteria** and **fungi**, led to the recognition of additional kingdoms. As a result, the five-kingdom classification system was proposed by Robert Whittaker.

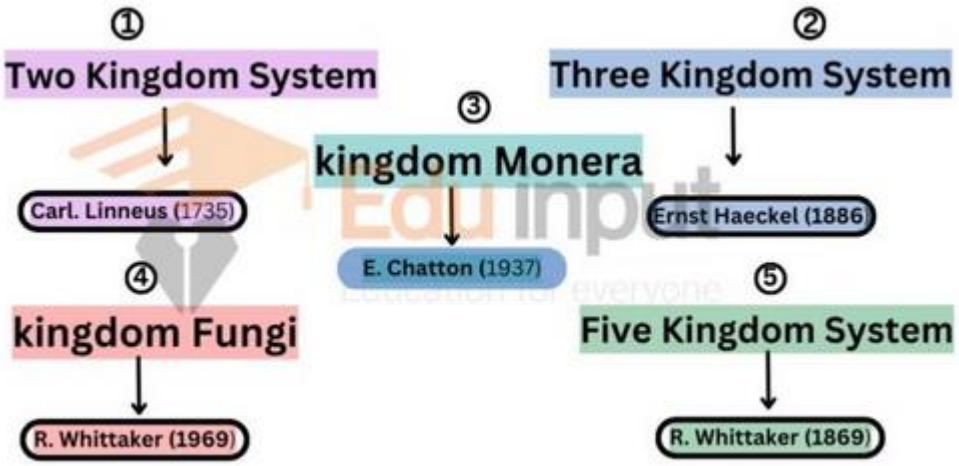

Figure 1. History of 2-5 Kingdom classification system.

1.1.1. Five Kingdom Classification System

Historically, all living things were divided into two kingdoms: plants and animals (or so I was taught). Animals were everything that moved, ate, and grew to a certain size before stopping. Plants were any living organism that did not move or eat and grew continuously. Plantae (plants) Animalia (animals) Monera (monera) (the prokaryotes). Many biologists currently divide Monera into Eubacteria and Archaebacteria.

Kingdoms are subdivided into phyla, which in turn are subdivided into classes, orders, families, genera, and species. A species is a type of organism, like a dog, tiger shark, amoeba, or Acer palmatum (Japanese maple).

Larger organisms are easy to classify, but in a microenvironment it might be difficult. If you've studied biology, describe an individual living item and try to classify it by kingdom.

a. The monera (includes Eubacteria and Archaebacteria)

Individuals are single-celled, have a cell wall, lack chloroplasts and other organelles, and lack a nucleus. Monera are typically quite small, although one variety, blue-green bacteria, resembles algae. They are filamentous and relatively long in length, green, and lack obvious structure inside the cells. There is no evident mechanism of feeding. They either take nutrients via the cell wall or synthesise them through photosynthesis.

b. Protoctista

Kingdom Protoctista comprises the eukaryotic microorganisms and their immediate descendants: all algae, including the seaweeds; undulipodiated mastigote molds, water molds, the slime molds and slime nets; the traditional protozoa; and other even more obscure aquatic organisms. Its members are not animals (which develop from a blastula), plants (which develop from maternally retained plant embryos), or fungi (which lack undulipodia and develop from fungal spores).

c. Fungi

Fungi are multicellular organisms that possess a cell wall, organelles, and a nucleus but lack chloroplasts. They lack movement mechanisms. Fungi come in a variety of sizes, from microscopic to extremely big (such as mushrooms). Absorption is the process by which nutrients are obtained. Fungi obtain the majority of their nourishment from rotting matter.

d. Plantae

Members of the plant kingdom develop from embryos—multicellular structures enclosed in maternal tissue. Because all plants form embryos, they are all multicellular. Furthermore, because embryos are the products of the sexual fusion of cells, all plants potentially have a sexual stage in their life cycle. In the sexual stage, the male cell (sperm nucleus, haploid) fertilizes the female egg (embryo sac nucleus, haploid). Many plants grow and reproduce in ways that bypass the two-parent sexual fusion—all must have evolved from ancestors that formed embryos by sexual cell fusion. Plants are adapted primarily for life on land, although many dwell in water during part of their life history. Plants are the organisms most responsible on land and in shallow marine environments for transforming solar energy, water, and carbon dioxide into photosynthate: food, fiber, coal, oil, wood, and other forms of stored energy. Some half million species of plants have been described. Two great groups—the nonvascular plants (informally called bryophytes, also called Bryata, Pl-1 through Pl-3) and the vascular plants (Tracheata, Pl-4 through Pl-12)—constitute the plant kingdom. The chapter refers to the 12 "phyla" of the plant kingdom, but "division" is the term used by some botanists instead of "phylum."

e. Animalia

The kingdom Animalia is made up of animals. These animals are heterotrophic, meaning they cannot produce their food through the process of photosynthesis or chemosynthesis. Instead, they must obtain nutrients by consuming other organisms, such as autotrophs or decomposing organic matter.

1.1.2. Importance Of Classification Of Animal Kingdom

Animal kingdom classification is critical for understanding the relationships between all living organisms. Species are classified using the Linnaeus approach based on shared traits.

The Swedish botanist Carolus (Carl) Linnaeus devised this method of animal kingdom classification in the early 1700's. The Linnaeus Method, also known as Linnaean Taxonomy, establishes a taxonomic hierarchy and binomial nomenclature, which assigns each animal species a two-word scientific name. This approach of naming animals scientifically is often rooted in Latin and involves combining the genus and species. Humans, for example, are categorised as homo sapiens, but wolves are classed as canis lupus.

The more characteristics that a group of animals shares, the more specific that group of animals is. Each species is classified according to nine branching types. The fundamental way of classifying animals is as follows:

1. Domain.
2. Kingdom.
3. Phylum.
4. Class.
5. Order.
6. Suborder.
7. Animal Families.
8. Genus.
9. Species.

1.2. Cells and Cell Theory

Cell theory, fundamental scientific theory of biology according to which cells are held to be the basic units of all living tissues. First proposed by German scientists Theodor Schwann and Matthias Jakob Schleiden in 1838, the theory that all plants and animals are made up of cells marked a great conceptual advance in biology and resulted in renewed attention to the living processes that go on in cells. The history of cell theory is a history of the actual observation of cells, because early prediction and speculation about the nature of the cell were generally unsuccessful. The decisive event that allowed the observation of cells was the invention of the microscope in the 16th century, after which interest in the “invisible” world was stimulated.

The nature of cellular structure was first recognized by the British scientist Robert Hooke and described in Micrographia (Royal Society, September 1665). The first time the word cell was used to refer to these tiny units of life was in 1665 by a British scientist named Robert Hooke. Hooke was one of the earliest scientists to study living things under a microscope. The microscopes of his day were not very strong, but Hooke was still able to make an important discovery. When he looked at a thin slice of cork under his microscope, he was surprised to see what looked like a honeycomb. Hooke made the drawing in the figure below to show what he saw. As you can see, the cork was made up of many tiny units. Hooke called these units cells because because the cellulose walls of dead cork cells reminded him of the blocks of cells occupied by monks. However, because Hooke's observations were limited by the magnifying power of his microscope, it was difficult for him to learn much about
the internal structure and organization of cells.

Anton van Leeuwenhoek (1632–1723) was a Dutch scientist, known for his work on the development and improvement of the microscope. Leeuwenhoek used double-convex lenses mounted between brass plates and held close to the eye. He viewed objects on pinheads, magnifying them up to 300 times this a lot better than any earlier compound microscopes. He made a powerful single-lens microscope with which he observed many types of cells and tissues and even drew bacteria. From investigating and experimenting with his microscope, Leeuwenhoek became one of the first scientists to refer to living cells when he observed an abundant number of single-celled organisms, which he called animalcules (plants and animals), swimming in a drop of pond water. In 1674, van Leeuwenhoek saw for the first time red blood cells, and spermatozoa. However, Leeuwenhoek's discoveries of bacteria and spermatozoa were more or less ignored for many years.

It was not until 1838 that the botanist Matthias Jakob Schleiden, interested in plant anatomy, stated that "the lower plants all consist of one cell, while the higher ones are composed of many individual cells. When the physiologist Theodor Schwann, Schleiden's friend, extended the cellular theory to include animals, he thereby brought about a rapprochement between botany and zoology. The two scientists clearly stated in 1839 that cells are the elementary particles of organisms in both plants and animals and recognized that some organisms are unicellular and others multicellular.. They are considered the founders of the "cell theory". In 1851, Robert Remak (1815-1865) succeeded in finding that all embryonic cells multiply by division.

Table 1: A brief history of Cell Biology

1642	Death of Galileo Galilei – credited as the father of the scientific method.
1665	Robert Hooke publishes '*Micrographia'.*
1683	Anton van Leeuwenhoek writes to the Royal Society of London describing the presence of 'animalcules' in the plaque of his own teeth. This was among the first descriptions of living bacteria ever recorded.
1776	Lazzaro Spallanzani demonstrates that an organism is derived from another organism.
1831	Robert Brown coins the term 'nucleus'. Brown also discovered Brownian motion.
1838	Matthias Schleiden states that plants are composed of cells.
1839	Theodore Schwann states that animals are composed of cells and that 'the elementary parts of all tissues are composed of cells'
1857	Carl Zeiss sells his first compound microscope.
1876	Ernst Haeckel credited with coining the term 'plastid'.
1882	Walther Flemming introduces the term 'mitosis'.

1898	Carl Benda names ‘mitochondria’ and Camillo Golgi discovered the organelle that bears his name.
1931	Ernst Ruska builds first Transmission Electron Microscope (TEM) at Siemens.
1944	Keith Porter, credited as the father of modern cell biology, and his colleague Albert Claude take first picture of an intact cell with the TEM. Porter coins the term ‘endoplasmic reticulum’. Porter is also responsible for developing the microtome.
1994	Martin Chalfie and colleagues first to use GFP as a marker for gene expression.

1.3. The Origin and Evolution of The Cell

The study of the origin and evolution of the cell is a fundamental aspect of biology and evolutionary science. This research delves into the intricate journey that has led to the development of the complex cellular structures we observe today. It explores the early stages of life on Earth, from the emergence of the first prokaryotic cells to the evolution of eukaryotic cells with their diverse organelles. Through the examination of fossil evidence, molecular biology, and comparative genomics, this research aims to shed light on the fascinating history of cellular life, offering insights into the mechanisms and forces that have shaped the cellular world over billions of years.

The term eukaryote derives from Greek and means true nucleus. The nucleus is indeed one of the most defining features of eukaryotes, a synapomorphy of the group. This is not, however, the only trait setting eukaryotes apart from archaea and bacteria—two distinct groups collectively referred to as prokaryotes. Beyond the nucleus, which harbors linear chromosomes and has characteristic membrane pores, there are many other features that are present in all or almost all eukaryotes and absent from all or nearly all prokaryotes. These include, among others, an intricate endomembrane system differentiated into subcompartments such as the endoplasmic reticulum and the Golgi apparatus, mitochondria, and a complex cytoskeleton able to perform endocytosis and phagocytosis.

Biological information is encoded in genes, which specify the structure of proteins and thereby dictate the organization of cells, forming tissues, organs, and multicellular organisms:

Genes <-> proteins <-> organelles <-> cells <-> tissues <-> organs <-> organisms.

1.4. Cell Types

Cells fall into one of two broad categories: prokaryotic and eukaryotic. The predominantly single-celled organisms of the domains Bacteria and Archaea are classified as prokaryotes (*pro–* = before; *–karyon–* = nucleus). Animal cells, plant cells, fungi, and protists are eukaryotes (*eu–* = true).

All cells share four common components: 1) a plasma membrane, an outer covering that separates the cell's interior from its surrounding environment; 2) cytoplasm, consisting of a jelly-like region within the cell in which other cellular components are found; 3) DNA, the genetic material of the cell; and 4) ribosomes, particles that synthesize proteins. However, prokaryotes differ from eukaryotic cells in several ways.

A prokaryotic cell is a simple, single-celled (unicellular) organism that **lacks a nucleus, or any other membrane-bound organelle**. We will shortly come to see that this is significantly different in eukaryotes. Prokaryotic DNA is found in the central part of the cell: a darkened region called the nucleoid.

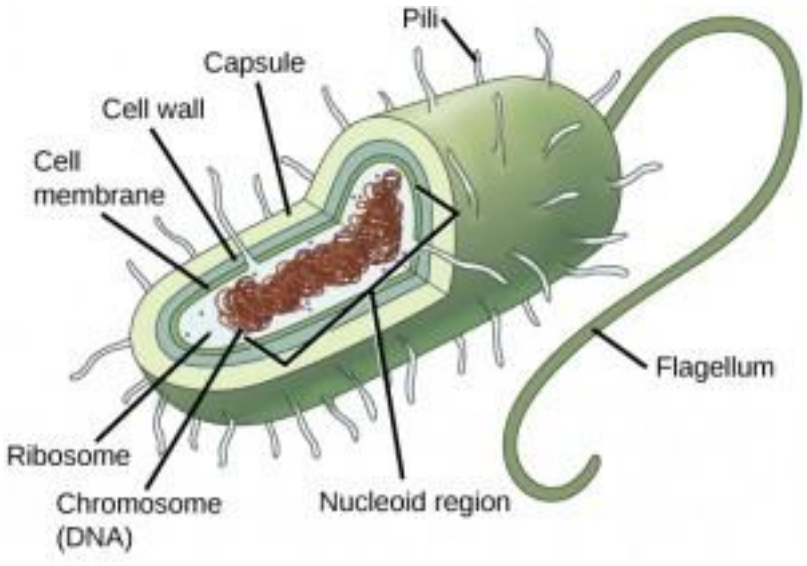

Figure 2. the generalized structure of a prokaryotic cell.

Unlike Archaea and eukaryotes, bacteria have a cell wall made of peptidoglycan, comprised of sugars and amino acids, and many have a polysaccharide capsule (Figure 3.6). The cell wall acts as an extra layer of protection, helps the cell maintain its shape, and prevents dehydration. The capsule enables the cell to attach to surfaces in its environment. Some prokaryotes have flagella, pili, or fimbriae. Flagella are used for locomotion, while most pili are used to exchange genetic material during a type of reproduction called conjugation.

In nature, the relationship between form and function is apparent at all levels, including the level of the cell, and this will become clear as we explore eukaryotic cells. The principle "form follows function" is found in many contexts. For example, birds and fish have streamlined bodies that allow them to move quickly through the medium in which they live, be it air or water. It means that, in general, one can deduce the function of a structure by looking at its form, because the two are matched.

A eukaryotic cell is a cell that **has a membrane-bound nucleus and other membrane-bound compartments or sacs, called organelles**, which have specialized functions. The word eukaryotic means “true kernel” or “true nucleus,” alluding to the presence of the membrane-bound nucleus in these cells. The word “organelle” means “little organ,” and, as already mentioned, organelles have specialized cellular functions, just as the organs of your body have specialized functions.

At 0.1–5.0 μm in diameter, prokaryotic cells are significantly smaller than eukaryotic cells, which have diameters ranging from 10–100 μm (Figure 3.7). The small size of prokaryotes allows ions and organic molecules that enter them to quickly spread to other parts of the cell. Similarly, any wastes produced within a prokaryotic cell can quickly move out. However, larger eukaryotic cells have evolved different structural adaptations to enhance cellular transport. Indeed, the large size of these cells would not be possible without these adaptations. In general, **cell size is limited** because volume increases much more quickly than does cell surface area. As a cell becomes larger, it becomes more and more difficult for the cell to acquire sufficient materials to support the processes inside the cell, because the relative size of the surface area across which materials must be transported declines.

2. Methods of Studying Cells

Cells come in many different shapes and sizes. Prokaryotes are cells without a nucleus or organelles. There are endless subtypes of prokaryotes when looking at all the bacteria, all with unique features and many different eukaryotic cells that can specialise in having a specific function.

So how do we know about all of these features, functions, and subtypes? That's where different methods and techniques of studying cells comes in. Depending on what question we want to answer about a cell, various methods are needed. There is one method nearly everyone knows: cell microscopy. Here we look at cells and cell parts to gather information about them. Depending on those features, the cells work with different types of stains. For example, a different stain is used with fat cells than muscle cells.

2.1. Microscope

A microscope (from Ancient Greek μικρός (mikrós) 'small', and σκοπέω (skopéō) 'to look (at); examine, inspect') is a laboratory instrument used to examine objects that are too small to be seen by the naked eye. Microscopy is the science of investigating small objects and structures using a microscope. Microscopic means being invisible to the eye unless aided by a microscope.

There are many types of microscopes, and they may be grouped in different ways. One way is to describe the method an instrument uses to interact with a sample and produce images, either by sending a beam of light or electrons through a sample in its optical path, by detecting photon emissions from a sample, or by scanning across and a short distance from the surface of a sample using a probe. The most common microscope (and the first to be invented) is the optical microscope, which uses lenses to refract visible light that passed through a thinly sectioned sample to produce an observable image. Other major types of microscopes are the fluorescence microscope, electron microscope (both the transmission electron microscope and the scanning electron microscope) and various types of scanning probe microscopes.

2.1.1.Optical microscopy

Optical microscopy is a technique that uses visible light and a series of lenses to magnify small objects to a level where they can be observed and analyzed. It is a widely used tool in many fields, including biology, material science, and physics, among others.

In an optical microscope, light from a source is focused onto the specimen through a series of lenses, and the light that is transmitted through or reflected by the sample is collected by another set of lenses and directed to the observer's eye or a camera.

Optical microscopes can be used in a variety of modes, including bright-field, dark-field, phase-contrast, and fluorescence microscopy, among others. Each mode provides different types of information about the specimen, such as its shape, texture, composition, and even its behavior under different conditions. Optical microscopy has revolutionized many fields of science and technology, allowing researchers to visualize and understand the structure and function of cells, materials, and devices at the micro- and nanoscale.

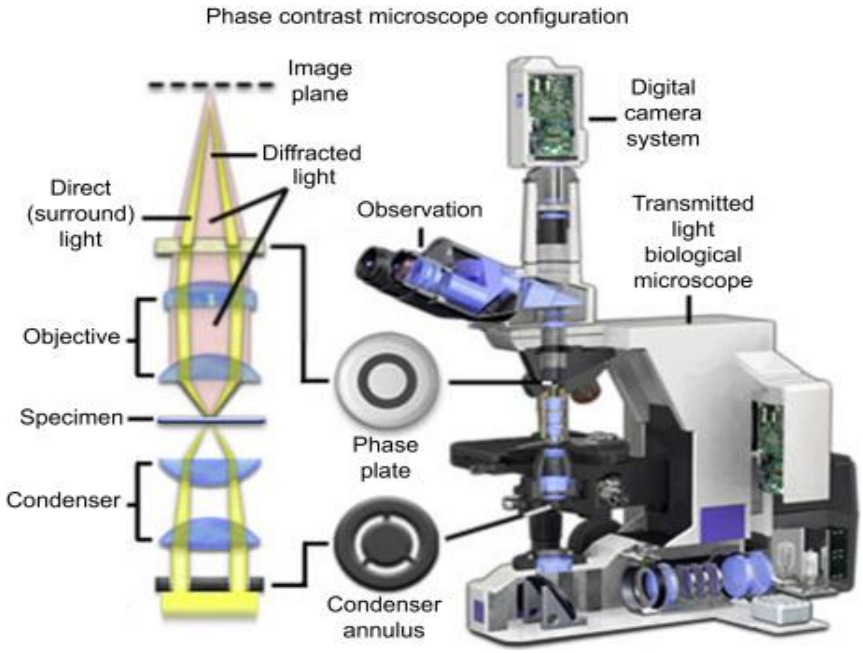

Figure 3. Optical microscopy.

2.1.1.1. Limitations of Optical Microscopy

While optical microscopy is a valuable tool for studying samples at the micro- and nanoscale, it also has several limitations that researchers should be aware of. Some of the main limitations include:

Limited Resolution: The resolution of an optical microscope is limited by the diffraction of light, which means that it cannot resolve details smaller than approximately half the wavelength of the light used. This limits the ability of optical microscopy to observe structures at the nanoscale.

Limited Depth of Field: The depth of field of an optical microscope is limited, meaning that only a narrow section of the sample can be in focus at any given time. This can make it difficult to image thick or 3D samples, and can result in images with blurred or out-of-focus regions.

Limited Contrast: Some samples, particularly those that are transparent or have a similar refractive index to their surroundings, can be difficult to see using optical microscopy. This can limit the ability of researchers to observe and analyze certain types of samples.

Photobleaching and Phototoxicity: Fluorescence microscopy, in particular, can be limited by photobleaching, which is the irreversible destruction of fluorescent molecules due to light exposure, and phototoxicity, which is the damage to living cells or tissues due to prolonged light exposure.

Sample Preparation: Preparing samples for optical microscopy can be time-consuming and may require specialized techniques or equipment. Some samples may also be damaged or altered during the preparation process, which can affect the accuracy and reliability of the observations.

Despite these limitations, optical microscopy remains a valuable tool for many types of research, and new technologies and techniques continue to improve its imaging capabilities and overcome some of these limitations.

2.1.2. Electron Microscope

An electron microscope is a microscope that uses a beam of accelerated electrons as a source of illumination. It is a special type of microscope having a high resolution of images, able to magnify objects in nanometres, which are formed by controlled use of electrons in a vacuum captured on a phosphorescent screen.

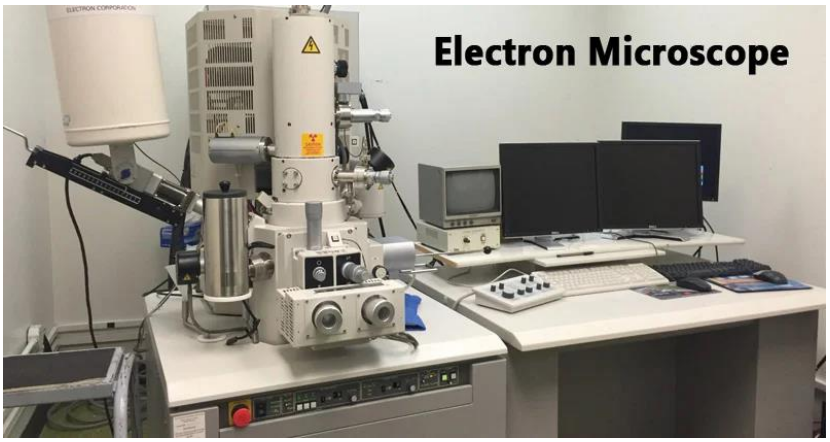

Figure 4. Electron microscope.

Ernst Ruska (1906-1988), a German engineer and academic professor, built the first Electron Microscope in 1931, and the same principles behind his prototype still govern modern EMs.

2.1.2.1.Working Principle of Electron microscope

Electron microscopes use signals arising from the interaction of an electron beam with the sample to obtain information about structure, morphology, and composition.

1. The electron gun generates electrons.
2. Two sets of condenser lenses focus the electron beam on the specimen and then into a thin tight beam.

3. To move electrons down the column, an accelerating voltage (mostly between 100 kV-1000 kV) is applied between the tungsten filament and anode.
4. The specimen to be examined is made extremely thin, at least 200 times thinner than those used in the optical microscope. Ultra-thin sections of 20-100 nm are cut which is already placed on the specimen holder.
5. The electronic beam passes through the specimen and electrons are scattered depending upon the thickness or refractive index of different parts of the specimen.
6. The denser regions in the specimen scatter more electrons and therefore appear darker in the image since fewer electrons strike that area of the screen. In contrast, transparent regions are brighter.
7. The electron beam coming out of the specimen passes to the objective lens, which has high power and forms the intermediate magnified image.
8. The ocular lenses then produce the final further magnified image.

2.2. histochemical methods

Chemical reactions are modifications of tissular molecules that allow them to be colored. There are histochemical procedures for staining carbohydrates, proteins and nucleotides. PAS (Periodic Acid Schiff) is the most popular histochemical technique for detecting free or conjugated carbohydrates that can be visualized when they are relatively abundant in the tissue (Figures 1 and 2). The chemical modification consists in the oxidation by periodic acid of close carbon links that have hydroxyl groups. This reaction forms aldehyde groups that are recognized by the Schiff reactive, providing a brilliant red color. Schiff reactive contains pararosaniline (a component of the basic fuchsin), which has been previously treated with sulfuric acid. PAS technique is able to discriminate different types of carbohydrates by adjusting the procedure.

2.3.immunological methods

Immunological methods in food analysis offer the intrinsic advantage of very high sensitivity and specificity, and of ease of automation. However, interferences from the complex food matrices and the requirement for sample preparation steps contribute to make their application to food analysis less straightforward than in other analytical fields. Most food proteins are excellent antigens both in their native form and in the denatured form that is often obtained from separation procedures. This makes it relatively easy to raise suitable antibodies in any of the animal species commonly used for this purpose. A relatively large number of

antibodies against food proteins are readily available commercially, as are several antibody conjugates useful for quantitative and semiquantitative analysis.

2.4. enzymological methods

Enzymes play a crucial role in all living organisms, being the best chemists that nature has "invented" (from the evolutionary viewpoint, of course). In the last decades these catalysts started to be used more and more in industrial, biotechnological processes, due to the fact that all chemical processes which normally need extreme conditions (high temperature and/or pressure, extremely acidic or alkaline media, etc.) can be done in much milder conditions, at temperatures of 25-40 °C, almost neutral pH, and in water as solvent. Considering the huge number of enzymes known so far and the new ones which are constantly being discovered and characterized in organisms all over the phylogenetic tree (e.g., extremophiles, Archaea, etc), it is no wonder that biotechnologies that use them extensively have grown exponentially in the last period.

In this context, I was delighted to read "Methods to Determine Enzymatic Activity", edited by Alane Beatriz Vermelho and Sonia Couri, which comprises a nice collection of 13 reviews, all of them from Brazilian scientists, dealing with these topics. Each chapter presents in a very nice manner the main reaction(s) catalyzed by the considered enzyme, its sources, purification, characteristics, followed by the detailed description of the assay methods used to determine the activity (as well as inhibition/activation) of these enzymes. Many representatives are taken into consideration, such as pectinases, peroxidases, enzymes with chitinolytic activity, cellulases, amylases, xylanases, lipases, phenoloxidases, transglutaminases, keratinases, peptidases (mainly serine and metallo-proteinases are considered), tannases and ureases. Most of these enzymes have important applications in the food, textile, leather, biofuel production, pharmaceutical, cosmetics, fine chemicals, biomaterials, paper/cellulose, and detergent industries.

3. Plasma Membrane: Structure and Function

Plasma membrane is also referred to as the cell membrane. It is the membrane found in all cells, that separate the inner part of the cell from the exterior. A cell wall is found to be attached to the plasma membrane to its exterior in plant and bacterial cells. Plasma membrane is composed of a lipid layer which is semipermeable. It is responsible to regulate the transportation of materials and the movement of substances in and out of the cell.

In addition to containing a lipid layer sitting between the phospholipids maintaining fluidity at a range of temperatures, the plasma membrane also has membrane proteins. This also includes integral proteins passing through the membrane which act as membrane transporters and

peripheral proteins attaching to the sides of the cell membrane. It loosely serves as enzymes which shape the cell. Plasma membrane is selectively permeable to organic molecules and ions, it regulates the movement of particles in and out of organelles and cells.

3.1.Fluid mosaic model

The description of the structure of plasma membrane can be carried out through the fluid mosaic model as a mosaic of cholesterol, carbohydrates, proteins and phospholipids.

First proposed in 1972 by Garth L. Nicolson and S.J. Singer, the model explained the structure of plasma membranes. The model evolved with time however, it still accounts for the functions and structure of plasma membranes the best way. The model describes plasma membrane structure as a mosaic of components which includes proteins, cholesterol, phospholipids, and carbohydrates; it imparts a fluid character on the membrane.

Thickness of the membrane is in the range of 5-10nm. The proportion of constituency of plasma membrane i.e., the carbohydrates, lipids and proteins vary from cell to cell. For instance, the inner membrane of the mitochondria comprises 24% lipid and 76% protein, in myelin, 76% lipid is found and 18% protein.

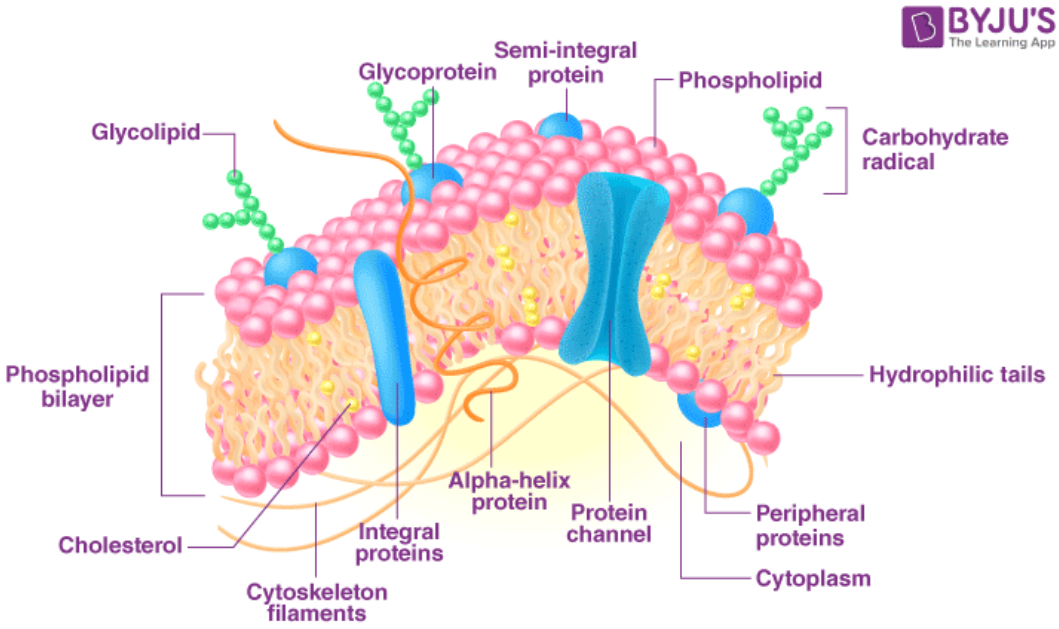

Figure 5. Fluid mosaic model

3.1.1. Phospholipids

The chief fabric of this membrane comprises phospholipid molecules that are amphiphilic. The hydrophilic regions of such molecules are in touch with the aqueous fluid outside and inside the cell. The hydrophobic or the water-hating molecules on the other hand are non-polar in nature. One phospholipid molecule comprises a three-carbon glycerol backbone along with 2 fatty acid molecules associated to carbons 1 and 2, and one phosphate-containing group connected to the third carbon.

This organisation provides a region known as head to the molecule on the whole. The head, which is a phosphate-containing group possesses a polar character or a negative charge while the tail, another region containing fatty acids, does not have any charge. They tend to interact with the non-polar molecules in a chemical reaction however, do not typically interact with the polar molecules.

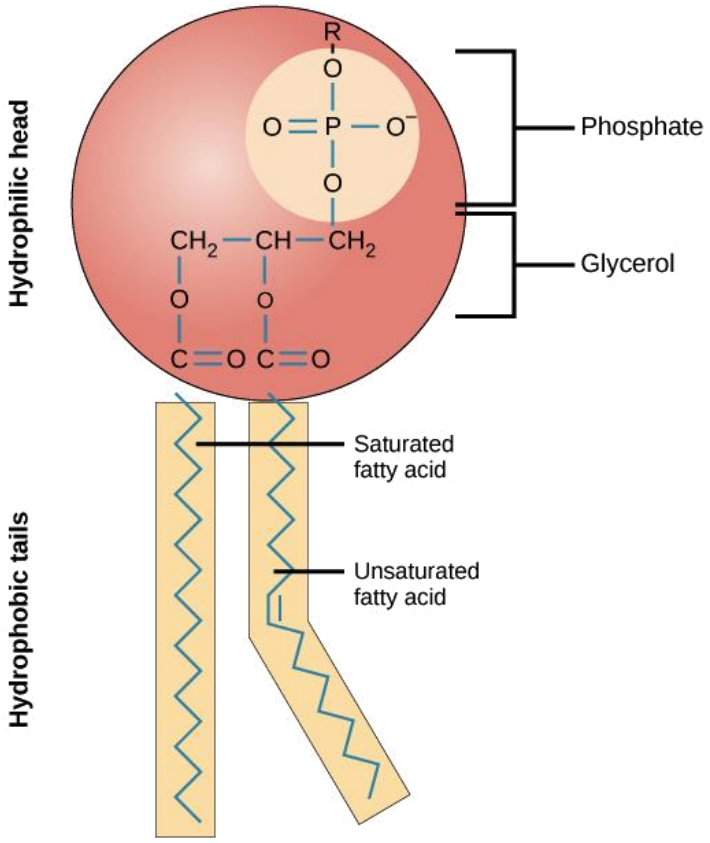

Figure 6. Phospholipids

The hydrophobic molecules when introduced to water, have the tendency to form a cluster. On the other hand, hydrophilic areas of the phospholipids have the tendency to form hydrogen

bonds with water along with other polar molecules within and outside the cell. Therefore, the membrane surface interacting with the exterior and interior of cells are said to be hydrophilic. On the contrary, the middle of the cell membrane is hydrophobic and does not have any interaction with water. Hence, phospholipids go on to form a great lipid bilayer cell membrane separating fluid inside the cell from the fluid to the exterior of the cell.

3.1.2. Proteins

The second major component is formed by the proteins of the plasma membrane. Integrins or integral proteins integrate fully into the structure of the membrane, along with their hydrophobic membrane, ranging from regions interacting with hydrophobic regions of phospholipid bilayer. Typically, single-pass integral membrane proteins possess a hydrophobic transmembrane segment consisting of 20-25 amino acids. Few of these traverses only a portion of the membrane linking with one layer whereas others span from one to another side of the membrane, thereby exposing to the flip side.

Few complex proteins consist of 12 segments of one protein, highly convoluted to be implanted in the membrane. Such a type of protein has a hydrophilic region/s along with one or more mildly hydrophobic areas. This organisation of areas of the proteins has the tendency to align the protein along with phospholipids where the hydrophobic area of the protein next to the tails of the phospholipids and hydrophilic areas of protein protrudes through the membrane is in touch with the extracellular fluid or cytosol.

3.1.3. Carbohydrates

The third most important component of the plasma membrane are carbohydrates. They are generally found on the outside of the cells and linked either to lipids to form glycolipids or proteins to form glycoproteins. The chain of this carbohydrate can comprise two to sixty monosaccharide units which could be branched or straight.

Carbohydrates alongside peripheral proteins lead to the formation of concentrated sites on the surface of the cell which identify each other. This identification is crucial to cells as they permit the immune system to distinguish between the cells of the body and the foreign cells/tissues. Such glycoproteins and glycoproteins are also observed on the surface of viruses, which can vary thereby preventing the immune cells to identify them and attract them.

On the exterior surface of cells, these carbohydrates, their components of both glycolipids and glycoproteins are together known as glycocalyx, which is extremely hydrophilic in nature attracting huge quantities of water on the cell surface. This helps the cell to interact with its fluid-like environment and also in the ability of the cell to acquire substances dissolved in water.

3.2. Structure Of Plasma Membrane – Bio membrane structure

Plasma membrane is a fluid mosaic of proteins, lipids and carbohydrates. The plasma membrane picture provided above shows the detailed structure of the plasma membrane. It is impermeable to ions and water-soluble molecules crossing membranes only through carriers, transmembrane channels and pumps. The transmembrane proteins nourish the cell with nutrients, regulate the internal ion concentration and set up a transmembrane electrical potential. Change in a single amino acid in one Cl^- channel and plasma membrane pump can lead to human disease cystic fibrosis. On the basis of location of the membrane in the body, lipids can make up anywhere from 20-80% of the membrane, the rest being proteins.

It is composed of a phospholipid bilayer, which is two layers of phospholipids back-to-back. Phospholipids are lipids with a phosphate group associated with them. The phospholipids have one head and two tails where the head is polar and water-loving or hydrophilic. Tails on the other hand are nonpolar and water-fearing or hydrophobic.

3.3. Micellar model of Plasma membrane

In 1963, Hilleir and Hoffman suggested that biological membranes can have a non-lamellar pattern. As per them, the plasma membrane has a mosaic of globular subunits referred to as micelles that are densely packed with a central core of lipid molecules with a hydrophilic polar end.

As lipid micelles have a tendancy towards spontaneous linking, they are probable building blocks for membranes. The protein components of the membrane in this model can establish a monolayer on either sides of the plane of lipid micelles.

It is suggested that the gaps between the globular micelles form water-filled pores which are partially lined by polar groups of micelles and partially by polar groups of associate protein molecules.

4. Cytoskeleton and Cell Motility

The cytoskeleton is the network of fibers that runs through the cytoplasm. Its function is to provide mechanical support to the cell and maintain its shape. This function is particularly important for animal cells that lack a cell wall; by anchoring to the cytoskeleton, organelles and certain cytoplasmic enzymes remain in place. The cytoskeleton allows the cell to change its shape; like scaffolding, it can disassemble in one part of the cell and reassemble elsewhere. The cytoskeleton also plays a role in mobility, whether it is the movement of the entire cell or of organelles within the cell. The cytoskeletal fibers not only provide the "skeleton" of the cell but

also its "musculature." The cytoskeleton is also involved in extending the pseudopods ("false feet") of amoebas and in producing cytoplasmic streaming (cyclosis) in many large plant cells. The cytoskeleton provides the "monorails" on which vesicles travel, and its contractile components manipulate the plasma membrane to form food vacuoles during phagocytosis.

4.1.Microtubules

As their name implies, microtubules are small hollow tubes. Microtubules, along with microfilaments and intermediate filaments, come under the class of organelles known as the cytoskeleton. The cytoskeleton is the framework of the cell which forms the structural supporting component. Microtubules are the largest element of the cytoskeleton. The walls of the microtubule are made of polymerizeddimers of α-tubulin and β-tubulin, two globular proteins. With a diameter of about 25 nm, microtubules are the widest components of the cytoskeleton. They help the cell resist compression, provide a track along which vesicles move through the cell, and pull replicated chromosomes to opposite ends of a dividing cell. Like microfilaments, microtubules can dissolve and reform quickly.

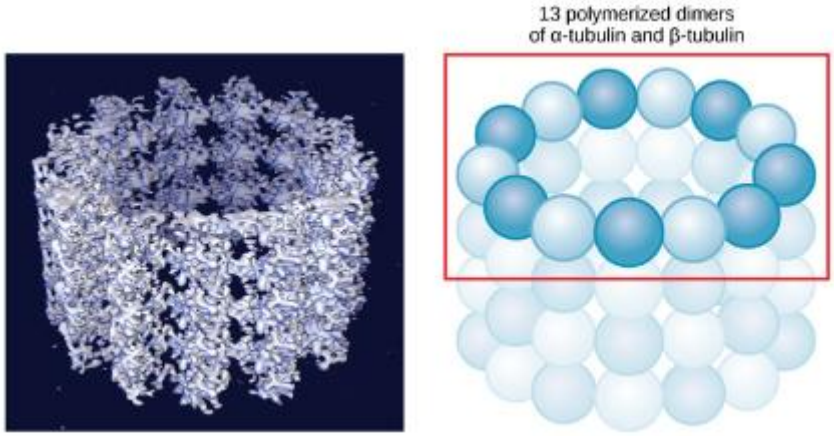

Figure 7. Micrtubule Structure: Microtubules are hollow, with walls consisting of 13 polymerized dimers of α-tubulin and β-tubulin (right image). The left image shows the molecular structure of the tube.

Microtubules are also the structural elements of flagella, cilia, and centrioles (the latter are the two perpendicular bodies of the centrosome). In animal cells, the centrosome is the microtubule-organizing center. In eukaryotic cells, flagella and cilia are quite different structurally from their counterparts in prokaryotes.

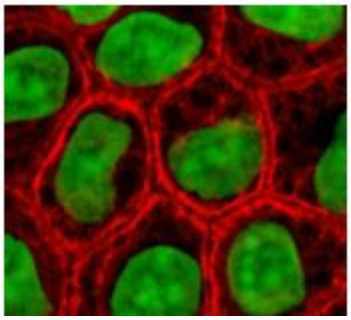

Figure 8. Stained Keratin Intermediate filaments: Keratin cytoskeletal intermediate filaments are concentrated around the edge of the cells and merge into the surface membrane.

4.2. Cilia and Flagella:

Flagella (singular = flagellum) are long, hair-like structures that extend from the plasma membrane and are used to move an entire cell (for example, sperm, Euglena). When present, the cell has just one flagellum or a few flagella. When cilia (singular = cilium) are present, however, many of them extend along the entire surface of the plasma membrane. They are short, hair-like structures that are used to move entire cells (such as paramecia) or substances along the outer surface of the cell (for example, the cilia of cells lining the Fallopian tubes that move the ovum toward the uterus, or cilia lining the cells of the respiratory tract that trap particulate matter and move it toward your nostrils). Despite their differences in length and number, flagella and cilia share a common structural arrangement of microtubules called a "9 + 2 array." This is an appropriate name because a single flagellum or cilium is made of a ring of nine microtubule doublets surrounding a single microtubule doublet in the center.

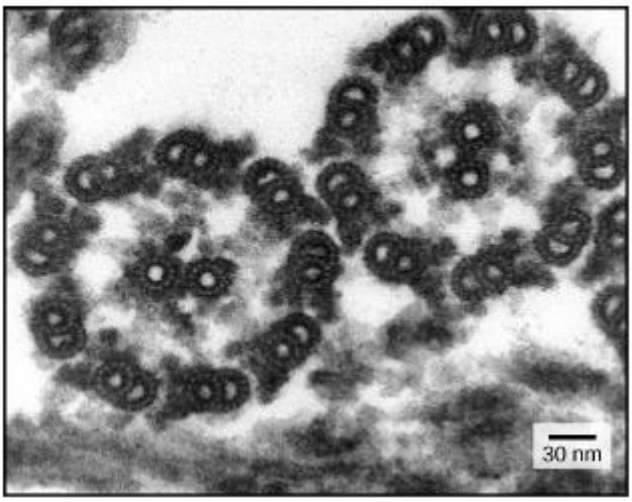

Figure 9. Microtubules are the structural component of flagella: This transmission electron micrograph of two flagella shows the 9 +2 array of microtubules: nine microtubule doublets surround a single microtubule doublet.

4.3. Microfilaments and Movement:

Microfilaments have a cylindrical shape and are composed of actin molecules, a globular protein, which polymerize to form chains. Microfilaments are best known for their role in muscle contraction. Thousands of actin microfilaments are arranged in parallel along the muscle cell, alternating with thicker filaments composed of a protein called myosin. Cell contraction results from the sliding of actin microfilaments against myosin filaments. As concentrated and organized as they are in muscle cells, microfilaments appear to be present in all eukaryotic cells to serve a support function. Actin and myosin aggregates underlie localized cell contractions. In some mobile cells, microfilaments are involved in elongating and retracting pseudopods, allowing the entire cell to move on a surface. In plant cells, microfilaments contribute to cyclosis, a phenomenon in which cytoplasm continually circulates in the space between the vacuole and the plasma membrane.

4.4. Intermediate Filaments

Intermediate filaments get their name from their larger diameter compared to microtubules. Intermediate filaments include various cytoskeletal elements, and their protein composition varies from one cell type to another.

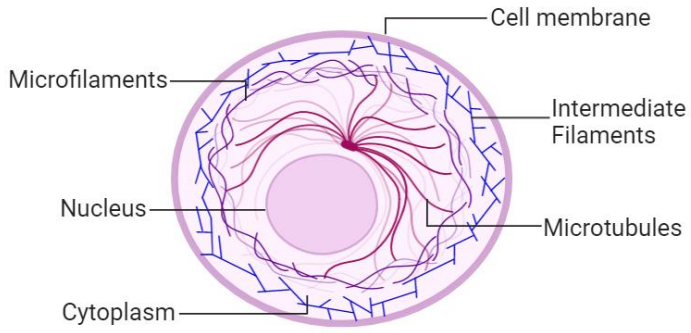

Figure 10. Cytoskeleton Structure and Function.

Unlike microtubules and filaments, intermediate filaments are more stable. It is possible that various types of tension-bearing intermediate filaments make up the entire cytoskeleton.

5. Cellular Adhesion and Extracellular Matrix

Cell adhesion plays a crucial role in facilitating cell communication and regulation, playing a fundamental role in both the formation and upkeep of tissues. The mechanical interplay between a cell and its extracellular matrix (ECM) exerts significant

influence over cell behavior and function. Due to its indispensable role, there is a considerable interest in devising techniques to measure and investigate the properties of cell adhesion

Cell-matrix adhesion is the interaction of a cell with the extracellular matrix, mediated by multi-protein adhesion structures such as focal adhesions, fibrillar adhesions and podosomes.
The ECM is a network of extracellular molecules which are secreted locally to ensure cell and tissue cohesion. The ECM also serves as a reservoir for extracellular signaling molecules that control cell growth, migration, and differentiation. The major classes of ECM molecules are proteoglycans, collagens and multi-adhesive matrix proteins (e.g. laminin, fibronectin). In mammals, the ECM is commonly known as “connective tissue”. ECM components are linked to each other through diverse protein and carbohydrate-binding domains. For stability in tissues, cells are linked to the ECM through cell adhesion receptors (e.g. integrins). A specialized form of extracellular matrix that underlies the basal side of polarized epithelial cell sheets to separate them from the underlying connective tissue is the basal lamina.

Basal laminae (plural) also surround individual muscle cells, fat cells, and cells lining peripheral nerve cell axons (i.e. Schwann cells). The basal lamina is thin and flexible, and is composed of closely packed matrix molecules that lack significant volume. The basal lamina components are synthesized and deposited by the cells on either side: the epithelial cells and the cells within the underlying bed of connective tissue (i.e. fibroblasts). The basal laminae forms a cohesive network and mechanical connection between cells and their external environment. Force-driven signals originating between the basal lamina components (i.e. fibronectin) and linked cell adhesion receptors (i.e. integrins) is communicated to the interior of cells through a mechanotransduction system to influence cell polarity, metabolism, fate, and migration.

6. Chromatin and cell nucleus

Chromatin is found in the nucleoplasm, surrounded by the nuclear envelope. Chromatin is DNA (deoxyribonucleic Acid) and associated molecules involved in DNA organization, primarily represented by histones. DNA is consists of 4 deoxyribonucleotides (abbreviated as nucleotides). Every nucleotide contains a nitrogenous base, a pentose and a phosphate group. The nitrogenous base is either a purine base: adenine (A) and guanine (G), or a pyrimidine base: thymine (T) and cytosine (C) (Figure 1). The pentose is a deoxyribose. Each nitrogenous base is linked to a pentose, resulting in a deoxyribonucleoside. Each deoxyribonucleoside is linked to a phosphate group through the pentose molecule, together forming a deoxyribonucleotide. In this way, DNA contains a chain of nucleotides linked by phosphate groups. This is a single chain, but DNA is made up of two strands, which are paired by the complementarity of the nucleotides.

Chromosome territories. In interphase, each chromosome is found in a limited space within the nucleus, the chromosome territory (Figure 4). These territories are rather spherical, from 2 to 4 μm in diameter, and neighbor territories are only overlapped in the borders (in yeast, however, territories are not so well delimited). Many evidences support that the distribution of these territories in the nucleoplasm is not random. Although the distribution pattern may differ between cell types, differentiation stages, and along the cell cycle, it looks like that the spatial relation between chromatin territories is quite stable in the same cell type. More active territories, i.e. having more intense gene expression, are located toward the center of the nucleus, whereas the less active territories are closer to the nuclear envelope. In general, smaller chromosomes with many genes tend to be inner in the nucleus, while those large chromosomes bearing not too many genes are found peripherally. In the same territory, regions that are replicated during the first part of the S phase (early replication regions) are deeper than those replicated later in the S phase (late replication regions). Moreover, repressed genes have a preference for peripheral positions. It is remarkable that homologous chromosomes occupy separate regions within the nucleus.

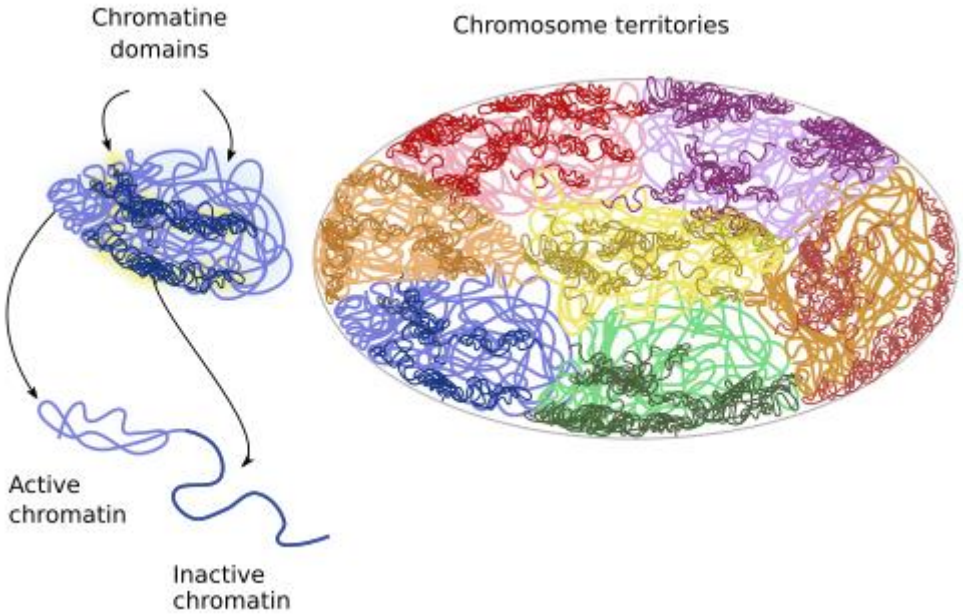

Figure 11. Nuclear organization of chromatin during interphase.

7. Le système réticulum endoplasmique-appareil de Golgi

7.1. Endoplasmic Reticulum (ER):

The endoplasmic reticulum (ER) forms a membranous labyrinth so extensive that it represents more than half of all membrane material in many eukaryotic cells. The endoplasmic reticulum consists of a network of tubules and membranous sacs called cisternae. The membrane of the endoplasmic reticulum isolates the contents of the cisternae from the cytosol. Since it is continuous with the nuclear envelope, the contents of the cisternae communicate with the space between the two membranes of the nuclear envelope.

The endoplasmic reticulum is divided into two regions: rough endoplasmic reticulum and smooth endoplasmic reticulum. Rough endoplasmic reticulum gets its granular appearance from ribosomes that dot the cytoplasmic surface of its membrane. Ribosomes are also found on the cytoplasmic surface of the outer membrane of the nuclear envelope, which is continuous with the rough endoplasmic reticulum. Smooth endoplasmic reticulum lacks ribosomes on its cytoplasmic surface.

7.1.1. Functions of Smooth Endoplasmic Reticulum:

The smooth endoplasmic reticulum is involved in various metabolic processes, including lipid synthesis, carbohydrate metabolism, and the detoxification of drugs, substances, and poisons.

Smooth endoplasmic reticulum plays a significant role in the synthesis of fats, phosphoglycerolipids, steroids, and other lipids. Among the steroids produced by the smooth endoplasmic reticulum are vertebrate sex hormones and various steroid hormones secreted by the adrenal glands.

The smooth endoplasmic reticulum also plays a role in carbohydrate metabolism. Hepatic cells, for example, store carbohydrates in the form of a polysaccharide called glycogen.

7.1.2. Functions of Rough Endoplasmic Reticulum:

The rough endoplasmic reticulum produces proteins that many specialized cells secrete. Proteins destined to become secretion products are synthesized by ribosomes attached to the rough endoplasmic reticulum. When a ribosome synthesizes a polypeptide chain, it enters the membrane of the rough endoplasmic reticulum, likely through a pore. Upon entering the cisterna, the protein folds and assumes its native configuration. Then, with the help of enzymes embedded in the membrane of the endoplasmic reticulum, it covalently attaches to a small polysaccharide to become a glycoprotein, like most secreted proteins.

Once the secretion proteins are formed, the endoplasmic reticulum membrane isolates them from the proteins produced by free ribosomes, which remain in the cytosol. The secretory proteins leave the endoplasmic reticulum packaged in transition vesicles that detach from a specialized region called the transitional endoplasmic reticulum. In addition to participating in the production of secretory proteins, the rough endoplasmic reticulum synthesizes its own membranes by pairing proteins and phosphoglycerolipids. Thus, with the arrangement of appropriate proteins and phosphoglycerolipids, the endoplasmic reticulum proliferates its membrane; this new material can also be transferred in the form of transition vesicles to other organelles with membranes.

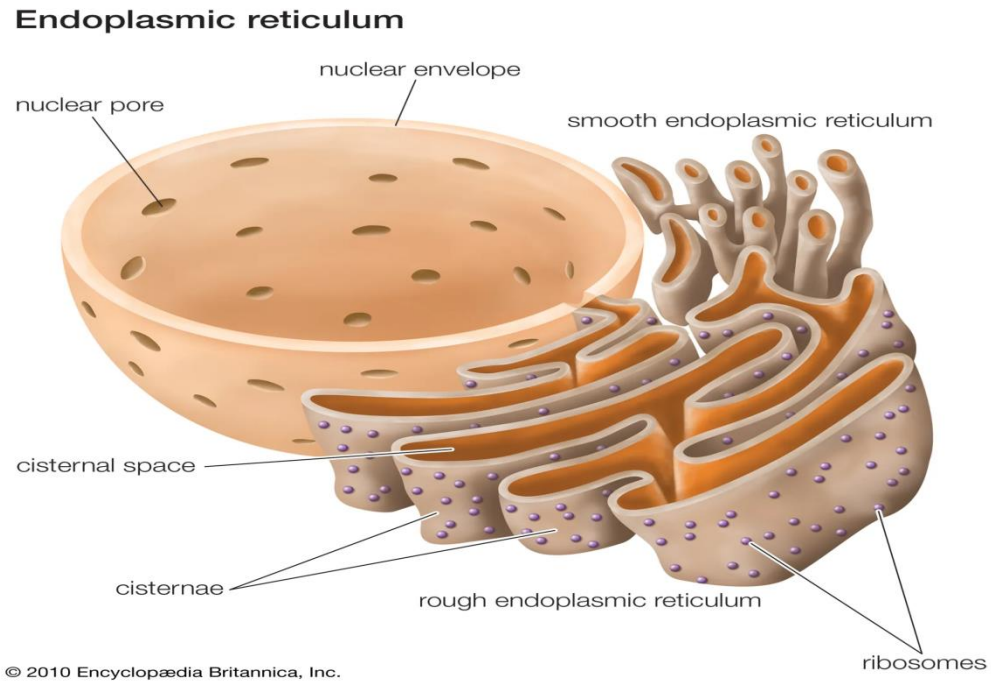

Figure 12. Endoplasmic reticulum.

8. Golgi Apparatus:

After leaving the endoplasmic reticulum, many transition vesicles head to the Golgi apparatus. The Golgi apparatus can be compared to a center for manufacturing, refining, storing, sorting, and shipping. The products of the endoplasmic reticulum are modified and activated there, stored, and then sent to various destinations. As you may have guessed, the Golgi apparatus is particularly extensive in cells specialized in secretion.

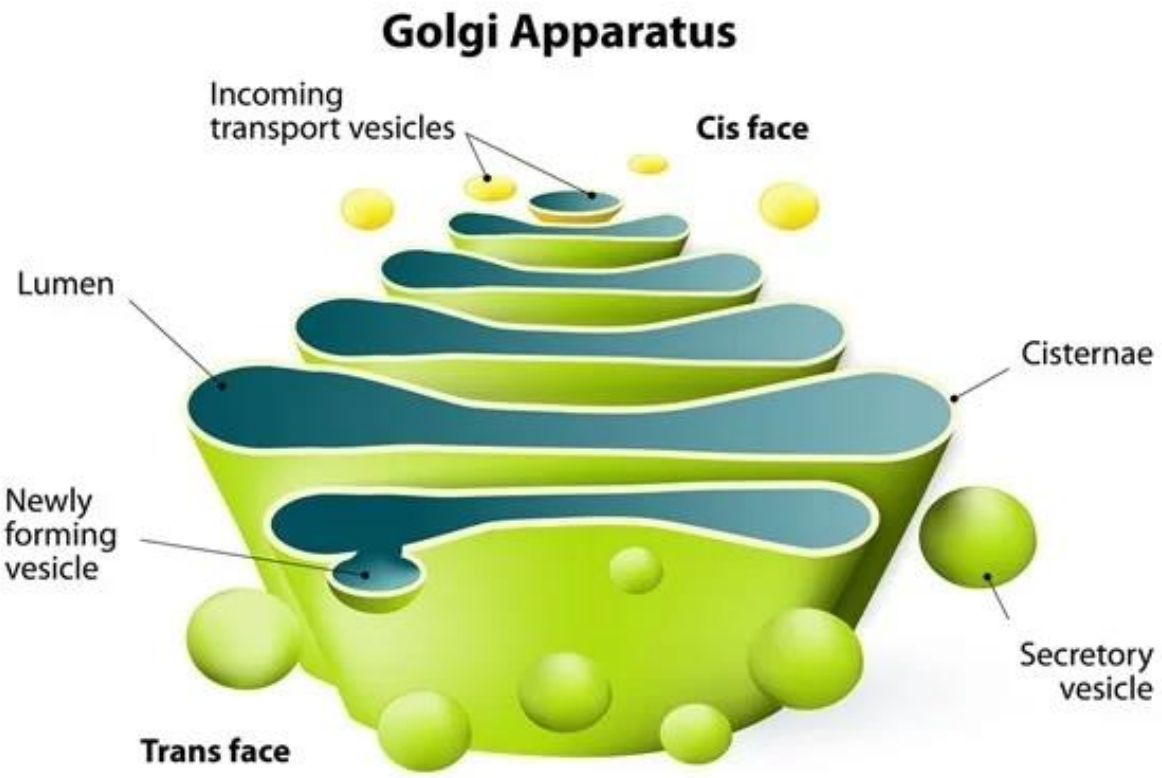

Figure 13. Golgi Apparatus.

9. Lysosomes:

A lysosome is a membrane-bound sac filled with hydrolytic enzymes that digest proteins, polysaccharides, lipids, and nucleic acids. It serves as an animal organelle (not found in plant cells) that protects the cell from damage that would be caused by hydrolytic enzymes if they we Now, the lysosome is a specific type of organelle that's very acidic. So that means that it has to be protected from the rest of the inside of the cell. It's a compartment, then, that has a membrane around it that stores the digestive enzymes that require this acid, low-pH environment. Those enzymes are called hydrolytic enzymes, and they break down large molecules into small molecules. For example, large proteins into amino acids, or large carbohydrates into simple sugars, or large lipids into single fatty acids. And when they do that, they provide for the rest of the cell the nutrients that it needs to... So, for example, if you can't do that, it can't break down large molecules into small molecules. You'll have storage of those large molecules, and this is a disease. There's also another type of lysosome storage disease in which the small molecules that are produced from those large molecules can't get out of the lysosome. They're stored there because the transporters for moving these small molecules out are missing genetically. And finally, one other function of the lysosome is to ingest bacteria so that the bacteria can be

destroyed. So the lysosomes also provide a function against infection, and the cell will often engorge a bacterium and put it into its lysosome for destruction. So here's an important organelle that has function against infection and function in a way in nutrition to break down large molecules into small molecules so that they can be reutilized. re freely circulating in the cytosol.

10. Vacuoles:

Vacuoles and vesicles are both membrane-bound sacs. Larger than vesicles, vacuoles have various functions. We have already discussed nutrient vacuoles, or phagosomes, formed during phagocytosis, and phagolysosomes formed by the fusion of a lysosome and a nutrient vacuole. But the functions of vacuoles do not end there. Many freshwater protists have contractile vacuoles that expel excess water from the cell. Mature plant cells generally contain a large central vacuole surrounded by a membrane, the tonoplast. Vacuoles also serve as the primary reservoir for inorganic ions such as potassium and chloride in a plant cell. Unlike animal cells, plant cells generally do not contain specialized lysosomes; instead, vacuoles function as lysosomal compartments. Vacuoles also serve to isolate intracellular metabolic by-products that would be harmful if they accumulated in the cytoplasm. Some vacuoles contain pigments, such as the red and blue pigments that attract pollinating insects to flower petals. Vacuoles can also protect the plant against predators, as they may contain toxic or unpleasant-tasting compounds. The vacuole plays a crucial role in the growth of plant cells. By absorbing water, it causes cell elongation, allowing the cell to enlarge while saving the production of new cytoplasm.

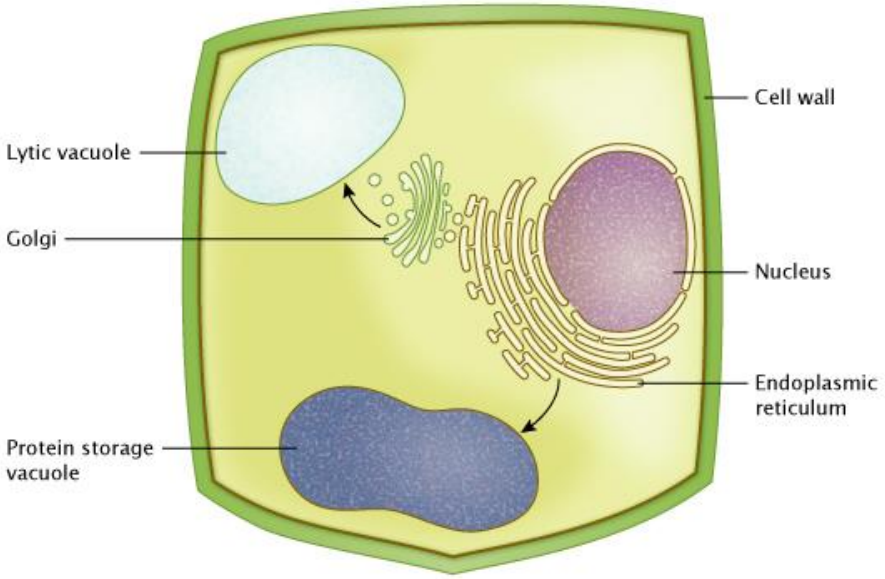

Figure 14. Vacuole.

11.Peroxisomes:

Eukaryotic cells consist of distinct subcellular compartments known as organelles, each dedicated to specific cellular activities. Among these organelles, peroxisomes, discovered relatively recently as major cellular components, have dimensions ranging from 0.1 to 1 µm. These structures are enclosed by a single membrane and lack genetic material. Despite their modest size and basic architecture, peroxisomes exhibit dynamic morphological and metabolic characteristics, playing crucial roles in the developmental processes of both animals and plants. Significantly, a severe disruption in peroxisome biogenesis and function can result in embryo lethality in plants and infant fatality in mammals.

Peroxisomes are specialized metabolic compartments bounded by a single membrane. They contain enzymes that transfer hydrogen from various substrates to oxygen. They are named after the by-product of this transfer, hydrogen peroxide. Peroxisomes in hepatic cells detoxify alcohol and other harmful compounds by transferring hydrogen from these substances to free oxygen.In germinating seeds, lipid-rich tissues contain specialized peroxisomes. These organelles contain enzymes that initiate the conversion of lipids into carbohydrates.

12. Mitochondria:

Mitochondria, found in nearly all eukaryotic cells, are organelles enclosed by membranes. They play a vital role in regulating cellular energy generation, serving as crucial components for sustaining life and controlling the initiation of cell death.

Some cells contain only a single large mitochondrion, but most cells have hundreds or even thousands of them. The number of mitochondria generally depends on the metabolic activity of the cell.

The envelope surrounding the mitochondrion consists of two membranes; each of these membranes is composed of a double layer of phosphoglycerolipids in which a unique assembly of proteins is embedded. The outer membrane is smooth, but the inner membrane is folded upon itself, forming cristae. The mitochondrial membranes divide the mitochondrion into two compartments: the intermembrane space, located between the inner and outer membranes, and the mitochondrial matrix, located within the space defined by the inner membrane. Several metabolic steps of cellular respiration occur in the matrix, where various enzymes are concentrated.

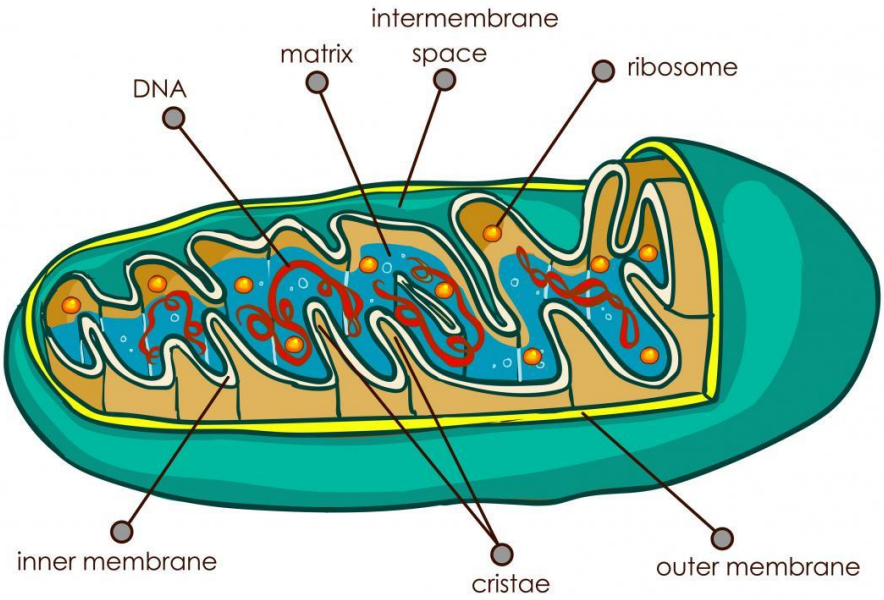

Figure 15. Mitochondria.

13. Chloroplasts:

The chloroplast is a specialized member of a family of plant organelles called plastids. Amyloplasts (also called leucoplasts) are colorless plastids that contain starch, particularly in roots and tubers. Chloroplasts are the place for the major conversion of the sun's radiation energy to chemical energy that is usable by organisms. Theys produce the pigments that give fruits and flowers their orange and yellow hues.

As the site of photosynthesis, the chloroplast is responsible for producing all the biomass in plants. It is also a metabolic center for production or modification of many important compounds, such as carbohydrates, purines, pyrimidines, amino acids, fatty acids, precursors of several plant hormones, and many secondary metabolites. The chloroplast also extensively communicates with other parts and organelles of the cell.

Chloroplasts, on the other hand, contain the green pigment called chlorophyll, along with other pigments, enzymes, DNA, RNA, ribosomes, and other molecules necessary for photosynthesis. As a result, chloroplasts have a degree of autonomy, similar to mitochondria, and can synthesize proteins.

Chloroplasts are biconvex and are found in the leaves and other green organs of plants, as well as in algae. Chloroplasts, amyloplasts, and chromoplasts originate from protoplasts present

in non-specialized cells. During the plant's growth, the fate of protoplasts depends on the position of the cells and the environment in which they live. Under certain conditions, mature plastids change their identity. The contents of a chloroplast are isolated from the cytosol by two membranes separated by a very thin intermembrane space. Inside the chloroplast, there is another membranous network organized into flattened sacs called thylakoids. In some regions of the chloroplast, thylakoids are stacked like poker chips, forming structures called grana (singular: granum). The fluid surrounding the thylakoids is called stroma.

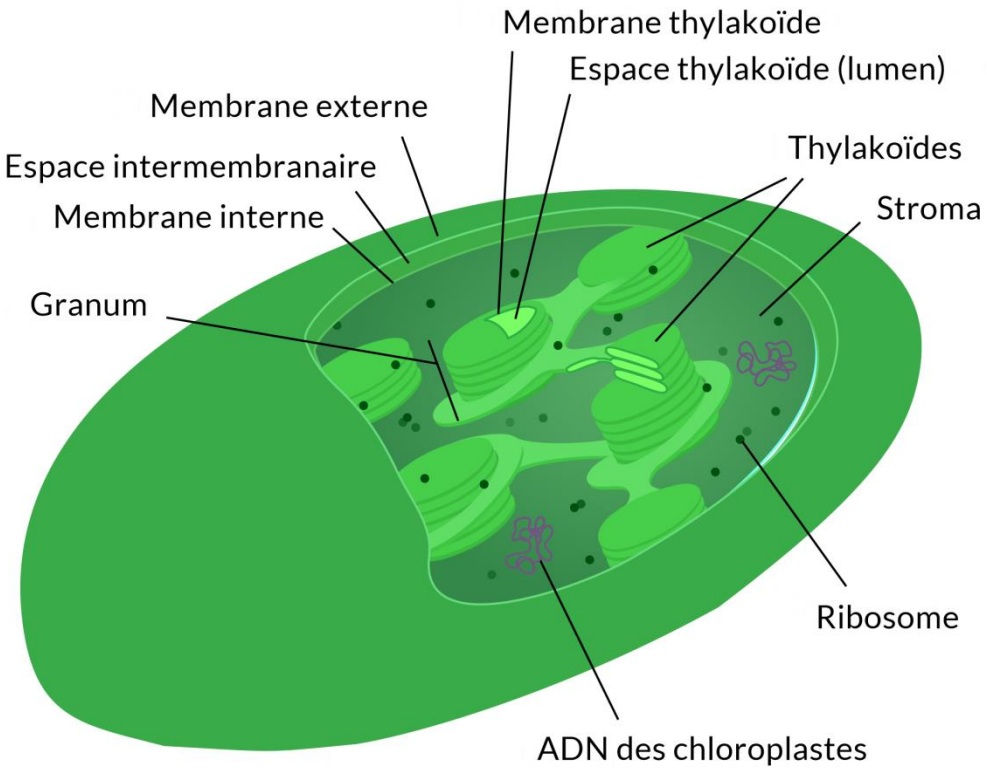

Figure 16. Chloroplast.

References

Aakash.2022. https://byjus.com/neet/plasma-membrane- structure/#Structure%20of%20 Plasma %20Membrane. Consulted on 28/09/2023.

Alberts B., Johnson A., Lewis J., Raff M., Roberts K. and Walter P. 2002. Molecular Biology of the Cell, 4th edition.

Amelia K and Mohd A. 2015. A Review of Cell Adhesion Studies for Biomedical and Biological Applications. International Journal of Molecular Sciences, 16(8), 18149–18184.

Aziz T., Farid A., Haq F., Kiran M., Ullah A., Zhang K., Li C., Ghazanfar S., Sun H., Ullah R., et al. 2022. A Review on the Modification of Cellulose and Its Applications. Polymers, 14, 3206. https://doi.org/10.3390/polym14153206

Bradshaw, R.A. 2016. Encyclopedia of Cell Biology || Kallikrein. , 1, 699–705. doi:10.1016/B978-0-12-394447-4.10090-2

Dall'Agnese A. and Young R. 2023.Regulatory architecture of cell identity genes and housekeeping genes.Trends in Cell Biology. 33(12) : 1010-1013.

Fatma El-Bawab. 2020. Table of classification of Kingdom Animalia. Invertebrate Embryology and Reproduction.103.https://doi.org/10.1016/B978-0-12-814114-4.10000-1

Fletcher, D.A. and Mullins R.D. 2010. Cell mechanics and the cytoskeleton.Nature. 463(7280), 485–492.

Fransen M., Lismont C. and Walton P. 2017. The Peroxisome-Mitochondria Connection: How and Why? Int. J. Mol. Sci. 18, 1126. https://doi.org/10.3390/ijms18061126

Gilpin W., Storm Bull M. and Prakash M. 2020.The multiscale physics of cilia and flagella.Nature Reviews Physics, 2 : 74–88.

Hertzog M. and Erdel F. 2023.The Material Properties of the Cell Nucleus: A Matter of Scale.Cells. 12(15): 1958.

Hooke, R. 1665. Micrographia or some physiological descriptions of minute bodies made by magnifying glasses; with observations and inquires thereupon, J Marthyn & J. Allestry, London.

Hu J, Baker A, Bartel B, Linka N, Mullen RT, Reumann S and Zolman BK. 2012. Plant Peroxisomes: Biogenesis and Function. The Plant cell 24: 2279 –2303.

Hyllner, J., Mason, Wilmut, I. 2015. Cells : from Robert Hooke to cell therapy-a 350 year journey. Philos Trans R Soc Lond B Biol Sci. 370 (1680) : 20150320.

Kao Y.T., Gonzalez K.L. and Bartel B. 2017. Peroxisome function, biogenesis, and dynamics in plants. Plant Physiology, 176(1), 162-177.

Leewenhoeck, A. 1676. Observation, communicated to the publisher by Mr. Antony van Leewenhoeck, in a Dutch letter of the 9 Octob. 1676 here English'd: concerning little animals by him observed in rain-well-sea and snow water; as also in water wherein pepper had lain infused, Philos. Trans. 12 (1676) 821–831.

Lu Y., Liu L.N., Roston R.L., Soll J. and Gao H. 2020. Editorial: Structure and Function of Chloroplasts - Volume II. Frontiers in Plant Science, 11 ,https://doi.org/10.3389/fpls.2020.620152

Lynch, M., Field, M.C., Goodson, H.V, Sazer, S. 2014. Evolutionary cell biology: Two origins, one objective. PNAS. 111 (48) 16990-16994.

Maeshima K., Tamura S. and Shimamoto Y. 2018. Chromatin as a nuclear spring. Biophysics and Physicobiology, 15(0), 189–195.

Margulis L. and Chapman M.J.J. 2009. Kingdoms and Domains. ANIMALIA. 231–377. doi:10.1016/b978-0-12-373621-5.00003-9

Margulis, L., Chapman, M.J. 2009. Chapter Two - kingdom protoctista. Kingdoms and Domains. 117-462.

Osellame L.D., Blacker T.S. and Duchen M.R. 2012. Cellular and molecular mechanisms of mitochondrial function. 26(6) : 711–723.

Pan R, Reumann S, Lisik P, Tietz S, Olsen LJ, Hu J. 2018. Proteome analysis of peroxisomes from dark -treated senescent Arabidopsis leaves. Journal of Integrative Plant Biology 60: 1028 –1050.

Pan Ronghui., Liu Jun., Wang Saisai. and Hu Jianping. 2019. Peroxisomes: versatile organelles with diverse roles in plants. New Phytologist, 225(4), 1410-1427

Paredes, A.M. 2014. MICROSCOPY. Transmission Electron Microscopy. Encyclopedia of Food Microbiology. 711-720.

Pentimalli, F., Giordano, A. 2017. Cell Biology and Genetics. Reference Module in Life Sciences. Elsevier.1-2.

Peter T. S. van der Gulik, Wouter D. Hoff, David Speijer. 2023. Renewing Linnaean taxonomy: a proposal to restructure the highest levels of the Natural System. Biological reviews. 98(2):584-602.

Ribatti, D. 2018. An historical note on the cell theory. Experimental Cell Research.1-4.

Risler T. 2013. Cytoskeleton and Cell Motility. In: Meyers, R. (eds) Encyclopedia of Complexity and Systems Science. Springer, New York, NY. https://doi.org/10.1007/978-3-642-27737-5_112-3

Ruggiero, M.A., Gordon, D.P., Orrell, T.M., Bailly, N., Bourgoin, T., Brusca,R.C., Cavalier-Smith, T., Guiry, M.D., Kirk, P.M. 2015. A Higher Level Classification of All Living Organisms. PLoS One. 10(4): e0119248.

Sabater B. Evolution and Function of the Chloroplast. 2018. Current Investigations and Perspectives. Int J Mol Sci. 19(10): 3095.

Schwann, T. 1838. Ueber die Analogie in der Structur und dem Wachsthum der Thiere und Pflanzen, Neue. Not. Geb. Na. t Heil.

Scott, I., David, C., Logan. 2004. The birth of cell biology.New Phytologist. https://doi.org/10.1111/j.1469-8137.2004.01110.x

Smolyaninov I.I. 2008. Optical microscopy beyond the diffraction limit. HFSP Journal, 2(3), 129-131.

Staffan M.W. 2010. Cell theory, specificity, and reproduction. Studies in History and Philosophy of Biological and Biomedical Sciences 41 (2010), 41(3), 225–231.

Sujatha K., Srividhya V. and Aruna M. 2019. Identification and Classification of Animal Kingdom using Image Processing and Artificial Neural Networks. International Journal of Recent Technology and Engineering. 8(3).4645-4650.

Virchow, R. 1858. Die Cellular Pathologie, Hirschwald, Berlin.

Zeng H. 2022. What is a cell type and how to define it? Cell.185(15): 2739-2755