CYTOPLASM

The fraction of protoplasm in between cell membrane and nuclear membrane is termed **cytoplasm**. It is living, viscous (semi-fluid, jelly-like) substance of changing consistency, composed of highly complex and specialized molecules that exhibits certain physical and biological properties. The cytoplasm is found universally in all prokaryotic and eukaryotic cells. The cytoplasm contains **organelles** (Gr. *organon*=instrument) like mitochondria, plastids, Golgi complex (dictyosomes), endoplasmic reticulum, microbodies, etc.; particulate organs performing specialized functions, the **ribosomes**; and **matrix** (L. womb) now called **cytosol**, a transparent, semi-fluid, colloidal area free from the organelle. However, the electron microscope has revealed the presence of tubular and rod-shaped structures known as **microtubules** and **microfilaments** respectively in the cytoplasmic matrix. The cytoplasmic matrix is the most important part of the cell. Most of the metabolic and biosynthetic activities of the cell such as glycolysis occur in cytoplasmic matrix. Also the colloidal properties of the cell such as sol-gel transformations (viscosity changes), intracellular motion (cytoplasmic streaming), amoeboid movements, spindle formation and cell cleavage, depends mostly on the cytoplasmic matrix. Also it is the site of many fibrillar differentiations found in the cells, for example, cellulose fibrils, microtubules and microfilaments.

Ultrastructure of Cytoplasmic Matrix

Under electron microscope, the cytoplasmic matrix appears homogeneous or finely granular and it has low electron density. In some cells fine filaments of less than 100 A° organized in parallel array are observed. These are considered to be concerned with phase reversal property (solation or gelation) of the cytoplasm. With improved techniques it has been found that the macromolecular organization, e.g., those of protein molecules of the cell matrix, varies in different cells and also in different region of the cell matrix. These structural proteins form a network in which polypeptide chains may be held together by cross-linkages of hydrogen bonds or van der Waals forces. Changes in strength of these cross-linkages are considered to be responsible for **phase reversal**, i.e., gelation or solation in a particular region of protoplasm.

Chemical Nature of Cytoplasmic Matrix

Chemically the cytoplasmic matrix is composed of many different types of inorganic chemical compounds and organic chemical compounds.

i. Inorganic Chemical Compounds

The inorganic chemical compounds are water and inorganic elements. Water is the main inorganic component of the cytoplasmic matrix and constitutes about 90% of the total weight of the system, however it varies in different parts of plant, for example in woody parts it is 50%, 85-95% in succulent parts, 95-98% in hydrophytes, and only 10% water contents are found in dry seeds. The water is found as free water (about 95% of total water in the cell) which act as solvent and dissolve compounds present in the matrix, and **bounded water** (about 5%) that is linked to the compounds present in the matrix such as proteins, etc.

About 36 elements occur in different percentage in the matrix that takes part in various metabolic reactions of the living system. The predominant elements are **oxygen**, **carbon**, **hydrogen** and **nitrogen**. In addition Ca^{2+}, P, Cl, S, K^{+}, Mg, Na, I_2, Fe are also found in certain quantities. These are called **macroelements** and take part in synthesis of macromolecules of the living system. For example, the Mg is necessary for synthesis of chlorophyll as it occupies the center of the chlorophyll molecule, P as H_2PO_4 is one of the main component of nucleic acids (DNA & RNA) and ATP. and Ca^{2+} is an important constituent of plasma membrane and also constituent of calcium pectate which form middle lamella. Similarly certain elements, for example Cu, Co, Mn, Zn, Mo, Bo, Si, etc are present in minute quantities (in traces, about 0.756%). These are called **microelements** and most of these acts as **cofactors**.

ii. Organic Chemical Compounds

The most commonly found organic compounds of the matrix are proteins, carbohydrates, lipids, nucleic acids, growth hormones, and porphyrins.

a. **Proteins:** Proteins are one of the major constituents amounting to about 40-60% of the total dry weight (minus water) of the matrix. Most of the protein content of the matrix is in the form of globular proteins, but in certain physiological activities fibrillar structures may arise, e.g., development of microtubules responsible for formation of spindle during cell division. In addition enzyme proteins that are about 20-25% of the total protein contents of the cells are present in the cytoplasmic matrix. The enzymes catalyze important reactions such as glycolysis and activation of amino acids for protein synthesis. The soluble proteins form colloidal dispersions, therefore the colloidal nature of the matrix is largely due to presence of proteins. Also the proteins act as buffers and prevent changes in cellular pH.

b. **Carbohydrates:** Carbohydrates are main source of energy for all living organisms and they form about 12-14% of the total dry weight of the matrix. Green plants and certain microbes (bacteria, cyanobacteria) have the ability to synthesize carbohydrates. The most common **monosaccharides** of the matrix are pentoses, the riboses and deoxyriboses, and hexoses – glucose (most common and primary source of energy for the cell), fructose and galactose. The most abundant **disaccharide** of the plant cells is sucrose and chief **polysaccharides** are cellulose and starch (amylose and amylopectin). The sugars are translocated in the plants in the form of sucrose usually. The cellulose play an important structural role as it is main constituent of the cell wall.

c. **Lipids:** About 12-14% of total dry weight of the matrix is **lipids**. These are organic compounds insoluble in water but soluble in organic solvent such as chloroform, benzene, etc. These are important constituents of cellular membranes, hormones, and vitamins formed in the cytoplasmic matrix. The lipids occur in the form of natural fats, fatty acids, phosphatides, waxes and steroids. The phospholipids are main components of unit biological membranes along with proteins. The lipids are also an important source of energy for the cells.

d. **Nucleic acids:** Nucleic acids are complex macromolecules of immense biological importance. They control hereditary and most important biosynthetic (protein synthesis) activities of the cell. Two types of nucleic acids occur in the cells, the DNA and RNA, however cytoplasmic matrix contains RNA only. Transfer RNA is present as soluble factor of the matrix and plays an important role in protein synthesis. It collects and carries the amino acids to the ribosomes for linking to produce a polypeptide.

e. **Growth Promoting Hormones:** Many different growth-promoting hormones are found in cytoplasmic matrix. These are organic compounds synthesized in one part of the plant and transported to another part where these cause physiological responses. Five groups of well-known plant hormones are found in plant cells. These are **auxins**, **giberellins**, **cytokinins**, **abscisic acid** and **ethylene**.

f. **Porphyrins:** Porphyrins (Gr. *porphyra*=purple) are cyclic compounds formed by four pyrrole rings [$(CH)_4NH$] linked by methylene bridges. The most common porphyrins found in matrix of plant cells are **carotenoids**. The important carotenoids found in the matrix are alpha-, beta-, y-carotenes, xanthophylls and anthocyanins. The porphyrins link with metals and proteins to form another important pigments of plant cell, the **chlorophylls**. The carotenoids and chlorophylls absorb light energy, which is converted into chemical energy and is utilized by the cells for their biochemical activities.

g. **Vitamins:** Vitamins are organic compounds of diverse nature required for growth and reproduction of cells in minute quantities. The most important role of the vitamins is perhaps their capacity to work as **coenzymes**. Important vitamins of the matrix are **NAD** (nicotinamide dinucleotide), **FAD** (flavin adenine dinucleotide), **Co A** (coenzyme A), **NADP** (nicotinamide adenine dinucleotide phosphate), etc.

Physical Nature of Cytoplasmic Matrix

In past many workers tried to explain the physical nature of the matrix. According to some investigators the matrix is composed of a network of fibers (**reticular theory**). **Butschili** (1892) proposed that matrix consists of many droplets or alveoli just in the same way as droplets in an emulsion (**alveolar theory**). **Altmann** (1893) suggested that the matrix is composed of many granules of various sizes called **bioplasts** (**granular theory**). But most recently, electron microscopic studies have revealed that cytoplasmic matrix is a **true solution as well as a colloidal system**. The solvent in the solution part of the cytoplasm is water whereas the solutes of biological importance are glucose, amino acids, fatty acids, electrolytes, minerals, vitamins, hormones, etc. The colloidal system of the protoplasm consists of a liquid phase in the form of water and dispersion phase is composed of macromolecules like proteins, nucleic acid and carbohydrate molecules. The colloidal phase of the matrix shows **phase reversal**, i.e., it may occur either in semi-solid state (**gel phase**) or liquid state (**sol phase**), and both these phases are interchangeable due to physiological and biochemical activities of the cell.

There are vast areas of interface between some of the macromolecules, especially enzymes, and the cytoplasmic solutions in which they are suspended. All the biochemical activities of the cell are catalyzed at these interfaces and microscopic surfaces in cytoplasm influence many physiochemical activities of the cell. The special physical nature of the matrix is caused by membranes and by particles larger than atoms, small molecules and ions, but too small to settle out by gravity. When these larger particles are suspended in water, they sometimes form glue therefore these are termed as **colloids** (Gr. *kolla*=glue). The cytoplasmic matrix exhibits almost all properties of colloids, therefore physical nature of the matrix is largely properties of colloids. These include: Tyndall effect, Brownain movements, surface tension, intracellular motion or cyclosis, pH and buffer nature, and adsorption.

i. **Tyndall Effect:** When colloidal particles are observed in a light microscope by strong illumination from one side, these appear as points of light because these scatter light. John Tyndall noticed this phenomenon first, therefore it is called Tyndall effect. The soluble fraction of the cytoplasm exhibits this phenomenon indicating the presence of colloidal particles in it.

ii. **Brownian Movements:** Robert Brown, a Scotish botanist, in 1927 discovered that colloidal particles seem to dance around with many random hops per second. These movements were called Browninan movements. These were found to be due to bombardment of different sides of colloidal particles by water molecules.

These movements keep colloids from settling. The disperse phase of protoplasm shows Brownian movements depicting the colloidal nature of the protoplasm.

iii. **Surface Tension:** The molecules at the surface of a liquid are being continuously pulled into the liquid by the cohesive forces. Therefore, the molecules are held together to form a membrane. The force by which the molecules are bound is called the surface tension. The cytoplasmic matrix being a liquid possess the property of surface tension. The proteins and lipids of matrix have less surface tension, therefore these occur at surface and form the membrane; whereas other chemical substances present in the cytoplasm, e.g., sodium chloride (NaCl), have hight surface tension and are found in deeper part of the matrix.

iv. **Cyclosis (Intracellular Motion):** During cyclosis the cytoplasm is generally reduced to a layer next to cell wall and continuous currents can be observed that displace chloroplasts and other cytoplasmic granules. The cyclosis occurs due to phase reversal colloidal property of the protoplasm. The cyclosis usually occurs in sol phase and is affected by hydrostatic pressure, temperature, pH, viscosity, etc. Amoeboid movements (in fungi) also depends upon cyclosis directly.

v. **pH and Buffer Nature of Matrix:** Different pH have been recorded in the cell in different regions. For example, the pH of vacuolar sap is either basic or acidic whereas the pH in aqueous nucleoplasmic matrix ranges from 7.6 to 7.8. The pH of the protoplasm is liable to constant changes due to production of acids and bases during the metabolic processes occurring in the cell protoplasm. The cytoplasm contain buffering systems such as carbonate-bicarbonate systems which help in maintaining the pH of the cell protoplasm constant.

vi. **Adsorption (L. ad=to + sorbex=to draw in):** The tendency of molecules or ions to adhere to the surface of certain solids or liquids is known as adsorption. Since it is a surface phenomenon, therefore colloidal particles with their large surface areas show better adsorptive capacity. The reactions of life occur on surfaces. The protein molecules with their large surfaces provide adsorptive surfaces in the protoplasm. This colloidal property also helps the cytoplasmic matrix to form the protein boundaries.

Biological Properties of Cytoplasmic Matrix

The cytoplasmic matrix exhibit following biological properties:

i. **Irritability:** The irritability is the fundamental and inherent property of the matrix. It possesses sensitivity to stimulation, ability to transmission of excitation, and ability to react according to stimuli. The heat, light, chemical substances and other factors stimulate the cytoplasmic matrix to contract.

ii. **Conductivity:** The process of conduction or transmission of excitation from the place of its origin to the region of its excitation is called **conductivity**. The matrix of nerve cells possesses the property of conductivity.

iii. **Movement:** The cytoplasmic matrix can perform movement due to cyclosis. The cyclosis depends on the age, water contents, hereditary factors and composition of the cell.

iv. **Metabolism:** The matrix is seat of various chemical activities. These activities may be either constructive or destructive in nature. The constructive processes such as biosynthesis of proteins, lipids, carbohydrates and nucleic acids are called **anabolic processes**; while the destructive processes such as oxidation of food molecules are known as **catabolic processes**. The anabolic and catabolic processes are collectively called **metabolic processes**.

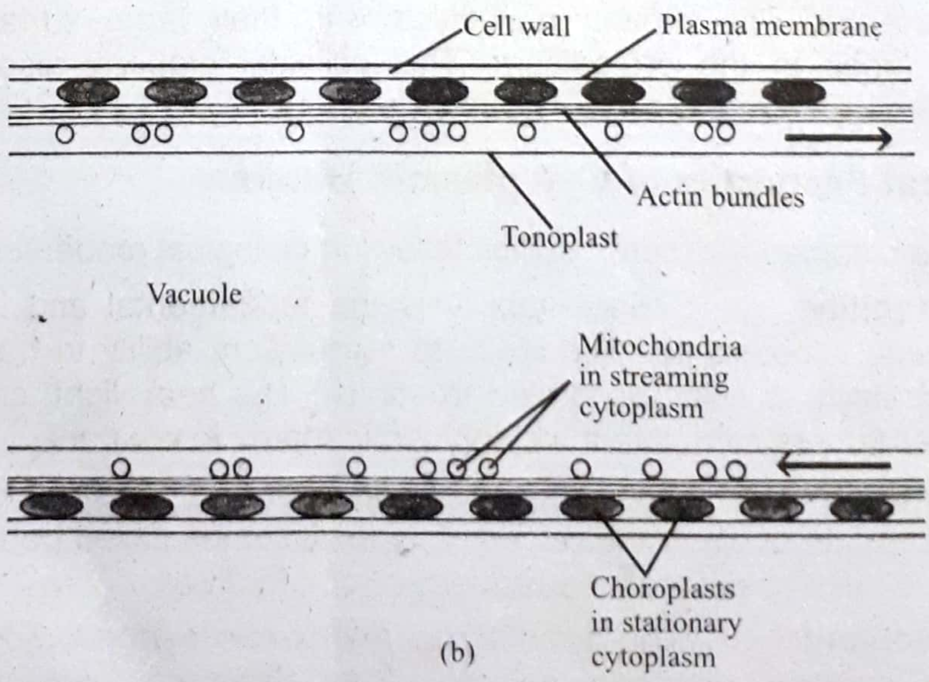
v. **Growth:** Due to the secretory or anabolic activities of the cell, new protoplasm continuously increases in its volume. The increase in the volume of the matrix of the cell leads to growth of the cell.

Cytoplasmic Streaming

In a living plant cell, the cytoplasm is frequently in motion. The organelles, as well as various substances suspended in the cytosol, can be observed being swept along in an orderly fashion in the moving currents. This movement is known as **cytoplasmic streaming** or **cyclosis**, and it continues as long as the cell is alive. Cytoplasmic streaming facilitates the exchange of materials within the cell and between the cell and its environment.

Much of our understanding of cytoplasmic streaming comes from work on giant cells of green algae such as *Chara* and *Nitella*. In these cells, the chloroplast containing layer of cytoplasm borders the wall and is stationary. Spirally arranged bundles of actin filaments extend along the cells forming distinct tracks that are firmly attached to the stationary chloroplasts. The moving layer of cytoplasm occurs between the bundles of actin filaments and the tonoplast and contains the nucleus, mitochondria and other cytoplasmic components. The generating force necessary for cytoplasmic streaming comes from an interaction between actin and myosin (a protein molecule with an ATPase-containing head that is activated by actin. Apparently the organelles in the streaming cytoplasm are indirectly attached to the actin filaments by myosin molecules, which use energy released by ATP hydrolysis to walk along the actin filament, pulling the organelles with them. Streaming always occur from the minus to the plus ends of the actin filaments, all of which are similarly oriented within a bundle.

(a)



(b)