BIOCHEMISTRY: ESSENTIAL MOLECULES FOR LIFE

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1. Introduction to Biochemistry

Biochemistry is the branch of science that explores the chemical processes and substances that occur within living organisms. It is a multidisciplinary science that combines principles from both biology and chemistry. The importance of biochemistry is necessary here to understand about biochemistry (Mougios, 2019).

Importance of Biochemistry (Calderón-Ospina & Nava-Mesa, 2020):

- **Understanding Life Processes:** Actually, biochemistry helps in understanding the fundamental processes of life at the molecular level.
- **Disease and Medicine:** It provides deep understanding into the biochemical basis of diseases and is crucial for drug discovery and development.
- **Biotechnology:** Many techniques are essential in various biotechnological applications, including genetic engineering and protein production.
- **Nutrition:** It also explains the metabolic pathways and nutrient requirements necessary for life.

Basic Building Blocks:

- Molecules of Life: It focuses on essential molecules such as proteins, carbohydrates, lipids, and nucleic acids.
- Proteins: They are made up of amino acids, that are involved in various biological functions. Carbohydrates: In biochemistry, sugars and starches provide energy and structural support.
- Lipids: In biochemistry, fats and membranes play roles in energy storage and cellular structure. Nucleic Acids: In biochemistry, nucleic acids carry genetic information and are vital for inheritance and protein synthesis (Minchin & Lodge, 2019).

Enzymes and Catalysis:

- Enzymes: Proteins operate as biological catalysts, accelerating chemical reactions in cells while remaining unconsumed.
- Importance: Enzymes are crucial for metabolism, allowing cells to perform necessary chemical transformations.
- Specificity and Regulation: Enzymes exhibit specificity for substrates and are regulated to maintain cellular balance.

Cellular Metabolism:

- Metabolic Pathways: Biochemical reactions occur in organized pathways, such as glycolysis and the citric acid cycle, generating energy.

- Energy Currency: Adenosine triphosphate, or ATP, is the energy currency used by cells for both storing and exchanging energy.

Genetic Information and Protein Synthesis:

- DNA Structure: DNA holds genetic instructions.
- RNA and Protein Synthesis: RNA molecules transcribe genetic information and guide protein synthesis through the process of translation.

Biological Membranes:

- Membrane Structure: Membranes are composed of lipids and proteins, providing structural integrity and regulating passage of molecules.
- Cell Signaling: Membranes are essential for cell signaling and communication.

Modern Techniques:

- Biotechnological Advances: Techniques like gene cloning, PCR (polymerase chain reaction), and CRISPR-Cas9 revolutionize biochemistry research (Randazzo et al., 2021).
- Omics Technologies: Genomics, proteomics, and metabolomics analyze large-scale biological data, enabling comprehensive understanding of organisms.

Interdisciplinary Nature:

- Chemistry and Biology: Biochemistry bridges the gap between chemistry and biology, providing a molecular understanding of life processes.

Medicine and Biotechnology: Biochemical knowledge is applied in medicine for diagnostics and therapies, as well as in biotechnological industries.

2. Proteins

Amino acids, the building blocks of life, make up proteins, which are big, complicated molecules. As a result, they are essential to the composition, operation, and control of the body's tissues and organs (LaPelusa & Kaushik, 2020).

Structure of Proteins:

- Amino Acids: Proteins are polymers of amino acids. There are 20 different amino acids, each with a unique side chain (R-group), which gives proteins their diverse functions.
- Peptide Bonds: Polypeptide chains are formed when amino acids are joined by peptide bonds.
- The primary structure of a polypeptide chain is its unique amino acid sequence. The genetic coding dictates this sequence.
- Secondary Structure: Hydrogen bonds between amino acids in the polypeptide backbone stabilise the formation of alpha helices or beta sheets in proteins.
- Tertiary Structure: Interactions between side chains of amino acids cause the polypeptide chain to fold in three dimensions. The protein's distinct form and function are derived from its structure. Quaternary Structure: A functional protein complex is formed when many polypeptide chains, or subunits, come together to form a protein.

Functions of Proteins:

- Enzymes: Proteins function as biological catalysts, accelerating chemical reactions without consuming any energy in the process.
- Structural proteins give cells and organisms structure and support. Collagen found in connective tissues and keratin found in hair and nails are two examples.
- Transport proteins: Help molecules pass through cell membranes (haemoglobin, for example, carries oxygen in blood).
- Hormones**:** Signalling proteins that control a range of physiological functions, including insulin's control over glucose metabolism.
- Antibodies are immune system proteins that identify and eliminate foreign entities, often known as antigens, such bacteria and viruses.
- Receptor Proteins: Located on cell membranes, they receive signals from the environment and facilitate cellular responses.
- Motor Proteins: Enable movement in cells, such as myosin in muscle contraction and kinesin in intracellular transport.

Protein Folding and Misfolding:

- Protein Folding: Proteins must fold into specific three-dimensional shapes to be functional. Proper folding is essential for their biological activity.
- Protein Misfolding Diseases: Improper folding can lead to diseases like Alzheimer's, Parkinson's, and prion diseases, where misfolded proteins aggregate and disrupt cellular functions (Ribarič & Ribarič, 2019).

Protein Synthesis:

- Transcription: The process in which genetic information from DNA is transcribed into RNA.
- Translation: RNA is translated into a specific sequence of amino acids, forming a polypeptide chain. This process occurs in ribosomes.

Protein Regulation:

- Post-translational Modifications: Proteins can be modified after translation, altering their structure and function (e.g., phosphorylation, glycosylation).
- Protein Degradation: Proteins are degraded by proteases when they are no longer needed, regulating cellular processes.

Importance in Nutrition:

- Dietary Proteins: Amino acids, which the body uses to create new proteins, are formed when diet-based proteins are broken down.
- Essential Amino Acids: Certain amino acids need to be taken from the food because the body is unable to synthesise them.

Biotechnological and Medical Applications:

- Biotechnology: Proteins like enzymes are widely used in various industrial processes, including the production of food and pharmaceuticals.

- Medicine: Therapeutic proteins (e.g., insulin) are used to treat diseases, and protein-based drugs are vital in modern medicine

3. Carbohydrates

Carbohydrates are one of the major classes of biomolecules and are essential for life. They serve various critical functions in living organisms and play a central role in energy metabolism. Here are detailed notes on carbohydrates (Gerwig, 2021):

Structure:

Monosaccharides: They are the most basic type of carbohydrates that are incapable of being digested into smaller ones. Galactose, fructose, and glucose are a few examples.

Disaccharides are created when two monosaccharide molecules condense. Glucose + fructose, lactose + galactose, and maltose + glucose are examples of common disaccharides.

Large polymers made up of many monosaccharide units are called polysaccharides. Polysaccharides include cellulose, starch, and glycogen.

Functions:

Energy Source: The body uses carbohydrates as its main energy source. Carbohydrates contain glucose, which is particularly crucial for the synthesis of energy in cells via glycolysis and cellular respiration.

Structural Support: Cells and organisms rely on carbohydrates to maintain their structural integrity. For example, the structural framework of plant cell walls is composed of cellulose.

Energy Storage: Excess glucose is stored in the form of glycogen in animals and as starch in plants. These stored carbohydrates can be broken down to provide energy when needed.

Cell Communication: Carbohydrates on the surface of cells play a role in cell recognition and communication. They are involved in processes such as immune response and cell adhesion. Nucleotide Sugars: Carbohydrates are essential components of nucleotides, which are building blocks of nucleic acids (DNA and RNA).

Types of Carbohydrates:

Simple Carbohydrates: Also known as sugars, these include monosaccharides and disaccharides. They are quickly absorbed by the body and provide rapid energy.

Complex Carbohydrates: Polysaccharides are complex carbohydrates made up of many sugar units. They take longer to break down and provide sustained energy. Examples include starch and dietary fiber.

Dietary Importance:

Sources: Grains, fruits, vegetables, legumes, and dairy products are among the foods that contain carbohydrates.

Dietary fibre is a kind of carbohydrates that the body does not break down. It is crucial for gastrointestinal health, helps with digestion, and gives the stool more volume.

Suggested Intake: Since they give the body energy for a variety of tasks, carbohydrates need to make up a sizeable portion of a diet that is balanced.

Carbohydrate Metabolism:

Glycolysis: The breakdown of glucose into pyruvate, producing ATP and NADH. It occurs in the cytoplasm and is the first step in cellular respiration.

Gluconeogenesis: the production of glucose from precursors that are not carbohydrates. It supports the maintenance of blood glucose levels during fasting.

Glycogenesis and Glycogenolysis: Processes of glycogen synthesis and breakdown, regulating glucose storage and release in the body.

Carbohydrates in Health and Disease:

Blood Sugar Regulation: Insulin, a hormone, helps regulate blood glucose levels. Imbalances can lead to diabetes.

Carbohydrate-Related Disorders: Conditions like lactose intolerance (inability to digest lactose) and celiac disease (gluten intolerance) involve problems with carbohydrate digestion.

Biotechnological Applications:

Biofuels: Carbohydrates derived from plant materials are used in the production of biofuels such as ethanol.

Food Industry: Carbohydrates are used as sweeteners, thickeners, and stabilizers in various food products.

4. Lipids

Lipids are a varied collection of hydrophobic compounds that serve critical roles in cell and organism structure and function. Unlike carbohydrates and proteins, lipids are not defined by a specific chemical structure but by their solubility characteristics (Vázquez et al., 2019).

Types of Lipids:

Fatty Acids: Long hydrocarbon chains having a carboxyl group at the end. In the hydrocarbon chain, saturated fatty acids contain no double bonds, whereas unsaturated fatty acids have one or more double bonds.

Triglycerides are made up of three fatty acids joined together by a glycerol molecule. In adipose tissue, they act as energy storage molecules.

Phospholipids are lipids that are similar to triglycerides but have a phosphate group connected to glycerol. Phospholipids are essential components of cell membranes.

Steroids: Lipids with a characteristic four-ring structure. Cholesterol is a vital steroid found in cell membranes and a precursor for hormones.

Waxes: Esterification of long-chain fatty acids to long-chain alcohols. Waxes are used to waterproof and protect plants and animals.

Functions of Lipids:

Energy Storage: Triglycerides store energy in adipose tissue. They provide a concentrated source of energy, important for organisms with high energy demands.

Structural Component: Phospholipids are the primary constituents of cell membranes, forming a lipid bilayer that separates the cell from its environment.

Insulation: Adipose tissue acts as an insulating layer, helping to maintain body temperature.

Protection: Lipids surround and protect vital organs in the body.

Signaling: Lipids function as signaling molecules (e.g., prostaglandins) that regulate various physiological processes.

Absorption of Fat-Soluble Nutrients: Lipids aid in the absorption of fat-soluble vitamins (A, D, E, and K) in the digestive system.

Lipid Metabolism:

Fatty Acid Synthesis: Cells can synthesize fatty acids from acetyl-CoA. Excess energy is stored in the form of triglycerides.

Fatty Acid Oxidation: Fatty acids are broken down into acetyl-CoA through beta-oxidation, generating energy in the form of ATP.

Cholesterol Metabolism: Cholesterol is synthesized in the liver and is vital for cell membrane integrity. Excess cholesterol can lead to atherosclerosis and cardiovascular diseases.

Health Implications:

Dietary Fats: Different types of dietary fats (saturated, unsaturated, trans fats) have varying effects on health. Unsaturated fats, especially omega-3 and omega-6 fatty acids, are considered beneficial.

Cardiovascular Health: Imbalances in lipid levels, especially elevated LDL cholesterol ("bad" cholesterol), can increase the risk of heart disease and stroke.

Obesity: Excess calorie intake, especially from high-fat diets, can contribute to obesity, a condition associated with various health problems.

Lipids in Biotechnology:

Biodiesel Production: Lipids from plant and microbial sources are used in the production of biodiesel, a renewable energy source.

Pharmaceuticals: Lipid-based drug delivery systems are utilized to enhance the solubility and effectiveness of certain drugs.

5. Nucleic Acids

Nucleic acids are complex macromolecules that carry and store genetic information. They are necessary for the continuation of life and serve as the foundation of heredity. Nucleic acids are classified into two types: deoxyribonucleic acid (DNA) and ribonucleic acid (RNA) (Gautam, 2022).

DNA (Deoxyribonucleic Acid):

Structure: DNA is a double-helix molecule made up of two nucleotide strands. A sugar (deoxyribose), a phosphate group, and a nitrogenous base (adenine, guanine, cytosine, or thymine) make up each nucleotide.

Base pairing is the process by which guanine (G) establishes hydrogen bonds with cytosine (C) and adenine (A) with thymine (T), resulting in complementary base pairs.

Function: All living things, including viruses, rely on DNA for their growth, development, and reproduction. It contains the genetic instructions necessary for these processes.

DNA replication is the mechanism via which DNA copies itself when a cell divides. It guarantees the transmission of genetic information from one generation to the next.

RNA (Ribonucleic Acid):

Structure: Usually composed of ribose sugar and the bases adenine (A), guanine (G), cytosine (C), and uracil (U) rather than thymine (T), RNA is a single-stranded molecule.

Types of RNA:

Transports genetic information from DNA to the ribosome, the location of protein synthesis, via messenger RNA (mRNA).

Transfer RNA (tRNA): During translation, it adds particular amino acids to the expanding polypeptide chain. One of the main parts of ribosomes, which are where protein synthesis takes place, is ribosomal RNA (rRNA).

Function: Gene control, protein synthesis, and other biological functions all depend on RNA. It serves as a messenger, transferring DNA instructions to regulate the production of proteins.

The process of creating an RNA molecule from a DNA template is called transcription. The genetic material from the DNA is transferred to the ribosome via this RNA, known as mRNA.

Genetic Code and Protein Synthesis:

Genetic Code: The amino acid sequence in proteins is determined by the nucleotide sequences found in DNA and RNA. Certain codons, which are three-nucleotide sequences, carry this information in mRNA.

Translation is the process by which a particular sequence of amino acids is synthesised into a polypeptide chain using the information contained in mRNA. This process takes place in ribosomes.

DNA Replication and Repair:

DNA Replication: DNA replication is a significant process that is characterized as semi-conservative; each new DNA molecule is made up of one strand that was synthesized and one strand that was taken from the original molecule.

DNA Repair: The proof-reading systems are present in the cells. They have mechanisms to repair damaged DNA to maintain genetic stability. Therefore, errors in replication or damage due to multiple factors are being corrected (Kumari et al., 2021).

Molecular Genetics and Biotechnology:

Genetic Engineering: It is well known that the techniques such as gene cloning and genetic modification of organisms involve manipulating DNA for various functions, such as medical research, agriculture, and biotechnology.

Genomic Sequencing: It is also important that the determination of complete DNA sequence of an organism of genome is vital for understanding genetic traits and diseases in all species.

RNA World Hypothesis:

It is a world hypothesis that RNA molecules were precursors to this life. It means that they are capable of self-replication and catalysing chemical reactions. It also suggests that RNA, not DNA, was the first genetic material for this life.

6. Summary

In conclusion, the study of biomolecules in biochemistry reveals the intricate chemical processes that govern life. Proteins, carbohydrates, lipids, and nucleic acids are the fundamental building blocks of living organisms, each with unique structures and functions. Firstly, proteins composed of amino acids, are versatile molecules that serve as enzymes, structural supports, transporters, hormones, antibodies, and motor proteins. They play crucial roles in cellular processes and are essential for life. Secondly, carbohydrates including sugars and polysaccharides, are vital energy sources, providing quick energy through simple sugars and sustained energy through complex carbohydrates. They also contribute to structural support, cell recognition, and signalling within the body. Thirdly, lipids encompassing fatty acids, triglycerides, phospholipids, and steroids, fulfill roles in energy storage, cell membranes, insulation, protection, and signalling. They are essential components of cells and have significant implications for health and disease. Finally, nucleic acids such as DNA and RNA, store genetic information and govern the synthesis of proteins. DNA holds the instructions for an organism's development and functioning, while RNA acts as a messenger, transferring genetic information from DNA to proteins. Understanding nucleic acids is fundamental to genetics, evolution, and biotechnological

advancements. Collectively, these biomolecules showcase the complexity and elegance of life's molecular machinery. Biochemical knowledge not only deepens our understanding of biological processes but also underpins advancements in medicine, biotechnology, agriculture, and environmental science. Studying these biomolecules provides invaluable insights into the mechanisms of life, enabling us to unravel the mysteries of living organisms and develop innovative solutions to complex challenges in the world of science and beyond.

Scientific Ethics Declaration

The author say that she is responsible for the scientific, moral, and legal aspects of this chapter, which is published in In Junejo Y (Eds.), *Chemistry for the Life*. ISRES Publishing

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