Lecture 5: Basic Plant Biochemistry: Carbohydrates, Proteins, Nucleic Acids and Secondary metabolites

Reference texts for this lecture:
Biology, 6th edition by Campbell and Reece
Introduction to Botany by Murray Nabors
In this lecture we will deal with essential and useful biological macromolecules. However, water is important in ways which helps in either synthesis of these compounds or functioning (directly or indirectly). So let’s know about water first before we proceed to biological macromolecules.

**Water**: One liquid that allows us to live

Why astronomers are searching for evidence of water in other planets?

Because water is the substance that makes possible life as we find it on earth.
Life on earth began in water and evolved there for 3 billion years before spreading onto land.

70-95% of a cell is water

Three quarters of earth’s surface is submerged in water

Water can exist in three states of matter: Ice, liquid and water vapor

Though water is common, it is an exceptional substance with several extraordinary properties.

1. The polarity of water molecules results in hydrogen bonding $\text{H}_2\text{O}$ – two hydrogen atoms joined to one oxygen atom by single covalent bonds
Oxygen regions of the molecule partially negative (δ-)
Hydrogen region partially positive (δ+)
This results in hydrogen bonding.
Hydrogen bonds play important role in macromolecules
2. Cohesion of water makes it a highly structured liquid

The hydrogen bonds hold the water molecules together resulting in a phenomenon called cohesion. Cohesion contributes to transportation of water from roots to tips of plants/tress against the gravity.
The transportation of water is also supported by another force called adhesion, the clinging of water to the xylem vessels, the tissue involved in transportation of water and minerals.

**Surface tension:** Is a measure of how difficult it is to stretch or break the surface of a liquid. It is related to cohesion. Water has a greater surface tension than most other liquids. Because of this, some animals can stand, walk or run on the water without breaking the surface.
3. Water moderates temperatures on earth:

Earth receives so much of solar radiation and it results in lot of heat. Water absorbs the heat with only slight change in its own temperature. This is because of high specific heat of water

4. Evaporative cooling: As water evaporates, the surface of the liquid that remains behind cools down. This is due to water’s high heat of vaporization (quantity of heat required to convert 1 gram of liquid to gaseous state). E.g. evaporation/transpiration in plants keep microclimate cool

5. Oceans and lakes don’t freeze solid: This is because ice floats on water and also ice is poor conductor of heat. Ice floats on water because its density is less than that of water.
6. Water is the solvent of life: There is no solvent better than water.

Hydrophilic substances: Substances that have an affinity for water
Hydrophobic substances: Substances that do not have an affinity for water
BIOLOGICAL MACROMOLECULES

The four main classes of large biological molecules are:
1. Carbohydrates
2. Lipids
3. Proteins
4. Nucleic Acids

These macromolecules, except lipids, are polymers of repeating units called monomers.
Monomers also have other functions of their own.

In all these macromolecules, polymers are formed by the same mechanism.
Monomers are connected by a reaction in which two molecules are covalently bonded to each other through loss of a water molecule. This is called condensation reaction (specifically dehydration reaction).

Polymers are disassembled to monomers by hydrolysis, a process that is essentially the reverse of the dehydration reaction.
Variations in living beings reflects variations in these polymers

**Carbohydrates:** They include sugars and their polymers

Simple sugars are monosaccharides

<table>
<thead>
<tr>
<th>Triose sugars ( (C_3H_6O_3) )</th>
<th>Pentose sugars ( (C_5H_{10}O_5) )</th>
<th>Hexose sugars ( (C_6H_{12}O_6) )</th>
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<tbody>
<tr>
<td><strong>Aldoses</strong></td>
<td><strong>Ketoses</strong></td>
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<tr>
<td><strong>Glyceraldehyde</strong></td>
<td><strong>Dihydroxyacetone</strong></td>
<td><strong>Ribulose</strong></td>
</tr>
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<td><strong>Ribose</strong></td>
<td><strong>Ribose</strong></td>
<td><strong>Fructose</strong></td>
</tr>
<tr>
<td><strong>Glucose</strong></td>
<td><strong>Galactose</strong></td>
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</table>
Disaccharides are double sugars
Polysaccharides are polymers of sugars.

Some polysaccharides act as storage molecules e.g. starch in plants; is a polymer of glucose

Glycogen is a storage polysaccharide in animals; is also a polymer of glucose
Some polysaccharides act as structural polysaccharides e.g. cellulose
- Is a major component of cell wall in plants
- Is a polymer of glucose
- The most abundant organic compound on earth

On a global scale, plants produce about 100 billion tons of cellulose per year
Cellulose is a polymer made up of β-glucose monomers, which are linked together by β-1,4-glycosidic bonds. These molecules form microfibrils in the plant cell wall, contributing to the rigidity and strength of the plant structure. Each microfibril is composed of cellulose microfibrils, which are typically 0.5 μm in length.
Cellulose and Starch both are polymers of glucose. What is the difference between them?

They differ in the forms of glucose.
**Chitin** is one more structural polysaccharide. 
**e.g.** Arthropods (insects, spiders, etc.) use chitin to build their exoskeleton- A hard case that surrounds the soft parts of an animal. 
Chitin is also used to make strong and flexible surgical thread that decomposes after the wound or incision heals.
**Lipids:** All lipids share one important character; they have either little or no affinity to water (hydrophobic) - Smaller than other major macromolecules - Highly varied group in form and function - Include fats, phospholipids, waxes, some pigments and steroids

**Fats:**
“Friends with little consumption; Enemies with over consumption
- Store large amounts of energy
- Are constructed from two kinds of smaller molecules: Glycerol and fatty acids.

Glycerol is an alcohol with 3 carbons
Fatty acid- has a long carbon skeleton with 16 or 18 carbons and carboxyl group attached at one end
Saturated fat and fatty acids: have no double bonds between the carbon atoms composing the chain. E.g. stearic acid

Unsaturated fat and fatty acids: have double bonds between the carbon atoms composing the chain. E.g. oleic acid
- Unsaturated fatty acids are better for health compared to saturated fatty acids
- Unsaturated fatty acids can be converted to saturated fatty acids by hydrogenation e.g. peanut butter, margarine

**Phospholipids:**

Major component of cell membrane in all organisms.
- Phospholipids show ambivalent behavior toward water
  - Their heads; hydrophilic in nature
  - tails; hydrophobic in nature

- Most of the membranes are made up of phospholipid bilayer

- This bilayer forms a boundary between the cell and its environments
Phospholipid bilayer
Proteins:
The term ‘protein’ is derived from Greek word ‘proteios’ meaning “first place”
- Account for > 50% of the cell’s dry weight
- Involved in almost everythin organisms do

Proteins have diverse functions;
- Structural support
- Storage
- Transport of other substances
- Signaling from one part of the organism to another
- Movement
- Defense against foreign substances
- Enzymes or biocatalysts
For diversity in functions of Proteins diversity in their three dimensional shape or conformation is important

A polypeptide is a polymer of amino acids connected in a specific sequence
Though proteins are polymers of amino acids (monomers), they are not polymers of a single monomer like carbohydrates. E.g. starch- a polymer of glucose only

In addition, the order of the amino acids in a sequence is important to give specific three dimensional structure

All amino acids possess an Amino group and a carboxyl Group.
20 amino acids are commonly found in nature:
<table>
<thead>
<tr>
<th>Polar</th>
<th>Acidic</th>
<th>Basic</th>
</tr>
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<tbody>
<tr>
<td>Serine (Ser)</td>
<td>Aspartic acid (Asp)</td>
<td>Lysine (Lys)</td>
</tr>
<tr>
<td>Threonine (Thr)</td>
<td>Glutamic acid (Glu)</td>
<td>Arginine (Arg)</td>
</tr>
<tr>
<td>Cysteine (Cys)</td>
<td></td>
<td>Histidine (His)</td>
</tr>
<tr>
<td>Tyrosine (Tyr)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Asparagine (Asn)</td>
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<td></td>
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<td>Glutamine (Gln)</td>
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Among 20 amino acids, some are called essential amino acids; because human body can not make them and they must be obtained from the diet e.g. Methionine, valine (9 total)

Rest of the amino acids are non-essential because human body can synthesize them

Amino acids in proteins are connected by covalent bonds called ‘Peptide bond’. Hence the name polypeptide
Four levels of protein structure:
1. **Primary structure**: refers to its unique sequence of amino acids
2. **Secondary structure:** Most proteins have segments of their polypeptide chain repeatedly coiled or folded in patterns that contributes to protein’s overall conformation. These folds are collectively referred to as secondary structure.
3. **Tertiary structure**: Superimposed on the patterns of secondary structures is a protein’s tertiary structure, consisting of irregular contortions from interactions between side chains of amino acids.
4. **Quaternary structure**: Some proteins consist of two or more polypeptide chains aggregated into one functional macromolecule. Quaternary structure is the overall protein structure that results from aggregation of these polypeptide subunits.
Factors determining Protein’s conformation:
• Sequence of the polypeptide e.g. sickle cell disease is due to change in only one amino acid.
• Physical and chemical conditions of protein’s environment like pH, temperature, salt concentration, etc.

Under some conditions, proteins undergo denaturation where in they unravel and lose their conformation. This loss in the conformation may lead to loss in their function.

**Nucleic Acids:**

- Are informational polymers and are basis of inheritance.
- two types a. DNA   b. RNA
- Both are polymers of nucleotides
- Here also specific sequence is important
- Sequence of amino acids in a protein is determined by nucleotide sequence of the gene coding for the protein
DNA and proteins are used as evidence for evolutionary relationships

<table>
<thead>
<tr>
<th>Species</th>
<th>Number of amino acid differences in beta chain of hemoglobin compared to human’s</th>
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</thead>
<tbody>
<tr>
<td>Human</td>
<td>0</td>
</tr>
<tr>
<td>Gorilla</td>
<td>1</td>
</tr>
<tr>
<td>Gibbon</td>
<td>2</td>
</tr>
<tr>
<td>Rhesus monkey</td>
<td>8</td>
</tr>
<tr>
<td>Mouse</td>
<td>27</td>
</tr>
<tr>
<td>Frog</td>
<td>67</td>
</tr>
</tbody>
</table>
Secondary Metabolites:

- Important secondary metabolites are Phenolics, Alkaloids, terpenoids
- Are not essential for basic plant growth and development but help plants in surviving e.g. Protection from herbivores and diseases

Phenolics: Made mainly from the amino acids phenyl alanine and tyrosine.
Major types of phenolics and their functions

a. **Lignins;** strengthen cell walls and repel herbivores

b. **Flavonoids** e.g. anthocyanin, the pigment seen on red grapes, apple, red and pink flowers
Flavonoids
- Commonly found in fruits and vegetables
- Deter herbivores
- Attract pollinators
- Prevent bacterial decay
- Can be used to preserve leather e.g. tannins
- In medicine, to help control and prevent cancer and cardio-vascular diseases and as antiviral agents e.g. lycopene from tomato

C. Allelopathics: compounds secreted by plant roots which inhibit neighboring plants and hence reduces competition for light, nutrient and space.
Alkaloids:
- Made from several amino acids
- Serve primarily to protect against herbivores
- Medically useful because of their neurological effects and effects on cell division
  e.g. caffeine, heroin, nicotine, etc

Terpenoids (terpenes): Protect plants from herbivores and diseases
1. Astronomers are searching for evidence of water in other planets because

a. To drink water whenever astronauts feel thirsty should they visit them

b. To cool the space shuttle

c. Water is the substance that makes life possible

d. To replenish water resources on earth when they get exhausted
2. Transportation of water in plants from roots to tip of plants/trees is due to which of the properties of water

a. Cohesion

b. Adhesion

c. Surface Tension

d. All the above
3. Carbohydrates are polymers of

a. Sugars

b. Amino acids

c. Nucleotides

d. Water molecules
4. Starch is a

a. Monosaccharide
b. Disaccharide
c. Trisaccharide
d. Polysaccharide
5. Which of the following can affect protein’s conformation
   a. pH
   b. Temperature
   c. Salt concentration
   d. All the above
6. Secondary metabolites

a. Not essential for growth and development

b. Protect plants against herbivores

c. Protect plants against diseases

d. All the above