Respiration
Introduction & Measurement

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Important Organic Compounds
• Four major groups:
  – Nucleic acids
  – Proteins
  – Lipids
  – Carbohydrates
• Also of note are the phenolics

Nucleic Acids
• Genetic information = Polymers of nucleotides
  – RNA = ribonucleic acid
  – DNA = deoxyribonucleic acid

http://www.alzheimers.org/rmedia/IMAGES/high/DNA_HIGH.JPG
Amino Acids & Proteins
- Comprise up to ~ 30% of plant DW
  - Some seeds may have as much as 40% DW protein – storage
- Proteins – important biological polymers
  - Storage proteins
  - Structural components
  - Enzymes

Lipids
- Main membrane constituent
- Long term energy storage
  - Can be converted to carbohydrates in plants via the glyoxylate cycle
- Structural components
  - Cuticle

Carbohydrates
- General formula
  - \((\text{CH}_2\text{O})_n\)
- Primary energy storage compounds
  - Short term storage - sugars
  - Intermediate term storage - starch
Carbohydrates
- Also important structural component
  - E.g. cell walls: cellulose, hemicellulose, & pectin
- Direct products of photosynthesis

Phenolic Compounds
- General classes:
  - lignin, tannins, flavonoids, coumarins, etc.
- Most formed from the amino acid phenylalanine
- Important impacts on produce quality:
  - Lignin (texture)
  - Browning reactions (color)
  - Astringency (taste)
  - Phytoalexins (defense)

Carbon Metabolism
- Carbon cycles through photosynthesis and respiration

\[
\text{Photosynthesis: } \text{CO}_2 + \text{H}_2\text{O} + \text{Energy (light)} \rightarrow \text{Carbohydrates} \]

\[
\text{Respiration: } \text{O}_2 + \text{Carbohydrates} \rightarrow \text{CO}_2 + \text{H}_2\text{O} + \text{Energy (ATP)}
\]
Carbon Metabolism

- Photosynthesis – occurs in chloroplasts (chlorophyll) mostly in the green leaves
- Carbohydrates produced in leaves are translocates throughout the plant (phloem)
- Carbohydrates are oxidized at destination sites to release energy. \( \text{CO}_2 \) & water = RESPIRATION

\[
\text{Sugar} + \text{O}_2 \rightarrow \text{CO}_2 + \text{Water} + \text{Energy} + \text{Heat}
\]

Adenosine Triphosphate (ATP)

- Adenosine triphosphate (-P-P-P)
  - Energy is stored in each P bond
- Intermediate energy molecules
  - analogous to rechargeable batteries

Respiration & Heat

- First Law of Thermodynamics:
  - Energy can not be created or destroyed
  - Thus, total energy at the beginning of a reaction must equal energy at the end
Use of Energy

- During carbohydrate oxidation (respiration), energy (ATP) & heat are produced
  - ATP molecules are intermediate energy molecules that are easily transported within a cell to sites of action
  - At sites of action, ATP is coupled to different processes to "power" them
  - Energy that is not captured as ATP (or other molecule), or is not completely used up in a biological process is lost as heat

Respiration & Heat

- Respiration creates 30 ATP per glucose molecule, but 686 kcal total energy
  - 1 ATP = ~ 12 kcal
  - 12 kcal * 30 ATP = 360 kcal
  - 686 kcal - 360 kcal = 326 kcal lost as heat
- If not removed, lost energy will raise the cell/tissue temperature
  - Heat pumps (refrigeration) move heat from one place to another (e.g., from inside to outside of the rooms)

Thermodynamics - 2nd law

- Entropy (disorder) of a system will always increase with time
- Biological systems are very ordered (low entropy) and maintain their order by making their environment more disordered
  - Organisms expend energy to counteract the natural tendency to disorganize
  - Without a constant energy supply, organisms would disorganize and die
- Living organisms are never at equilibrium
Thermodynamics - 2nd law

• When commodities are detached from the plant, they are severed from their food (energy) supply must live on what they have stored
  – The less reserves they have stored, the shorter their postharvest life

Respiration Overview

• Respiration is composed of three parts:
  – Glycolysis – located in the cytosol
  – Krebs cycle – located in the mitochondria matrix
  – Electron Transport System (ETS) – located on the inner mitochondria membrane
• Respiration is central to overall cell metabolism, such as synthesis of important compounds

“Fuel” for Respiration

• Fuel sources:
  – Starch
  – Sugars (glucose, fructose)
  – Organic acids
  – Sometimes amino acids
  – Sometimes lipids (fats)
**Breakdown of Storage Compounds for Energy Release**

- **“Complex” Storage Compounds**
  - Polysaccharides e.g. Starches
  - Fats & Oils (Triglycerides)
- **“Simple” Storage Compounds**
  - Monosaccharides e.g. glucose (6C)
  - Fatty Acids
  - Amino Acids
- **Smaller Carbon Compounds**
  - Pyruvate (3C compounds)
  - Acetyl CoA (2C compound)
- **Organic Acids**
  - CO₂
  - H₂O

**Electron Transport System (ETS)**

**Breakdown**

- Amylases (& Phosphorylases)
- Lipases
- Proteinase (Proteases)

**Glycolysis**

- **Processing (Glycolysis)**
  - Occurs in the cytosol
  - Converts carbohydrate “fuel” into pyruvate that will be transported to the mitochondria and used by the Krebs cycle
  - Also produces a little ATP (8 per glucose)

**Glycolysis**

- *Glucose* → *Fructose 6-p* → *Fructose 1,6-diphosphate* → *Dihydroxyacetone p* → *
  (2) Glyceraldehyde 3-p* → *
  (2) 1,3-diphosphoglycerate* → *
  (2) 3-phosphoglycerate* → *
  (2) 2-phosphoglycerate* → *
  (2) Phosphoenolpyruvate* → *
  (2) Pyruvate → To Mitochondria & Krebs cycle*
Krebs (or TCA) Cycle
- Furnace & Turbines (Krebs or TCA cycle)
  - Occurs in the mitochondria (powerhouses of the cell)
  - Produces NADH and FADH₂ that are used to make ATP
  - Produces a little ATP directly
  - Produces CO₂

ETS
- Generator (ETS [Electron Transport System])
  - ETS is located on the mitochondrial inner membrane
  - Products from the Krebs cycle are used to make ATP
  - Requires Oxygen (O₂)
    - In the process, electrons are ultimately passed to oxygen (final e⁻ acceptor)
**Anaerobic Respiration**

- Anaerobic respiration = without O₂
  - Also called fermentation
- Without O₂, normal ETS cannot function and the pathways backs up (at pyruvate)
- Glycolysis can still function
  - Pyruvate is shunted off to make Ethanol or Lactic Acid
- Only 2 ATP formed per glucose
  - Compared to 30 in aerobic respiration

**Cyanide Resistant Pathway**

- Many plant tissues have a cyanide resistant pathway (or alternative oxidase pathway)
  - Produces only ~ 1/3 the ATP of the normal pathway (complexes 3 & 4 are bypassed)
  - The loss in efficiency results in much greater heat production
    - In arum spadices, the cyanide resistant pathway increases tissue temperature up to 10°C
- May serve as a stress mechanism to supply carbohydrate metabolites &/or minimize ROS (reactive oxygen species) production
Measuring Respiration

- Measure loss of substrates, or appearance of products
  - Loss of carbohydrates (dry weight)
  - Measure of gas exchange
  - Loss of oxygen (O₂) Ambient concentration = ~21%
  - Appearance of carbon dioxide (CO₂) Ambient concentration ~0.03% (& increasing)
  - Production of heat

Dry Weight Loss

\[
\text{Rate of Dry Wt. Loss} = \frac{\text{Respiration Rate (mg CO₂/kg-hr)}}{1000 \text{ mg/g}} \times \frac{180}{264}
\]

\[
\% \text{ of Dry Wt. Loss per hr.} = \text{Respiration Rate (mg CO₂/kg-hr)} \times 68.2 \times 10^{-6}
\]

- E.g. Onions held at 30°C (respiration = 35 mg CO₂/kg-hr) will loose 1.72% dry wt. per month (30 d)

Measuring Gas Exchange

- Static System
  - Tissue is placed in a sealed container and the loss of O₂ or increase of CO₂ are measured
  - Measure over brief periods so that CO₂ does not accumulate above 0.2% (can inhibit respiration)
**Measuring Gas Exchange**

- **Static System**
  - Easy to use and does not depend on a flow rate. However, any leaks (even small ones) will result in large errors.

- **Flow-Through System**
  - Tissue is placed in a container and a flow of known gases (often air) are passed through.

  - O₂ uptake and CO₂ production is calculated by measuring the concentration differences between the inlet and outlet and knowing the gas flow rate.
  - Small leaks are not critical (due to positive pressure) and gas concentrations are not altered far from ambient.
  - However, it is more involved to set up.
Heat Production

- Newer, more sensitive & precise equipment now allows respiration via this technique