Transpiration & Water Loss

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Water Loss

- Typically, 90 to 95% of a commodity is water
- Besides resulting in direct loss of salable weight, it is also an important source of quality loss
  - Appearance quality - wilting, shriveling, accelerated development of injuries
  - Textural quality - loss of crispness, juiciness, etc.
  - Nutritional quality - e.g. vitamins A & C
- Thus, managing water content of commodities is critically important

<table>
<thead>
<tr>
<th>% Water Loss</th>
<th>Potential Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>Increased activity of some cell wall enzyme.</td>
</tr>
<tr>
<td>1</td>
<td>Increased carbon dioxide &amp; ethylene production. Faster ripening, yellowing &amp; abscission. Reduce wound healing (periderm formation).</td>
</tr>
<tr>
<td>2</td>
<td>Reduced turgor. Increased ABA content, reduced susceptibility to chilling injury. Accelerated loss of volatiles.</td>
</tr>
<tr>
<td>3</td>
<td>Reduced severity of certain physiological disorders. Loss of membrane integrity.</td>
</tr>
<tr>
<td>6</td>
<td>Loss of textural quality, e.g., softening, limpness, flaccidity, &amp; loss of crispness &amp; juiciness.</td>
</tr>
</tbody>
</table>
Percent water loss that results in unmarketability

<table>
<thead>
<tr>
<th>Commodity</th>
<th>% Loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asparagus</td>
<td>8</td>
</tr>
<tr>
<td>Brussels sprouts</td>
<td>8</td>
</tr>
<tr>
<td>Cabbage</td>
<td>7</td>
</tr>
<tr>
<td>Celery</td>
<td>5</td>
</tr>
<tr>
<td>Lettuce</td>
<td>3</td>
</tr>
<tr>
<td>Spinach</td>
<td>3</td>
</tr>
</tbody>
</table>

Effects of Water Loss

- Physical Effects
- Economic Effects
- Physiological Effects

Effects of Water Loss

- Physical Effects
  - Reduced turgor pressure from as little as 2% water loss =>
    - Wilting & flaccidity of vegetables
    - Shriveling and wrinkling of fruit
  - Shrinking produce within a package allows it to move/ vibrate during transport = damage

- Economic Effects
- Physiological Effects
Effects of Water Loss

- **Economic Effects**
  - Reduced quality/grade of a commodity reduces its value
  - Commodities are often sold on a weight basis
    - Less weight = lower price

- **Physiological Effects. (% water loss)**
  - Beneficial
    - Reduced symptoms of some physiological disorders (~3%)
    - Probably related to stress response in the plant tissues
  - Detrimental
    - Increased respiration & ethylene production (1%)
    - Reduced periderm formation in some roots and tubers (1%)
    - Faster ripening, yellowing & senescence (1%)
    - Accelerated reduction in volatiles (~2%)
    - Faster loss of vitamins A & C (~4%)
    - Stem end rind breakdown (unknown%)

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**Water - The Molecule**

- O atom covalently bonded by 2H
  - $105^\circ$ bond angle

**Water - The Molecule**

- Polar molecule
  - O atom - partially negative
  - 2H atoms - partially positive
  - Overall - neutral molecule
  - Water's polarity is responsible for many of its unique properties
- Water has one of the highest Dielectric Constants (a measure of a molecule's polarity)

**Hydrogen Bonding**

- Polarity gives rise to Hydrogen Bonds
- H-bonding = the weak electrostatic attraction between partially (+) charged “H” and partially (-) charged “O”
  - Besides water, H-bonds can also form between other molecules with other electronegative atoms (O or N)
**Properties of Water**

- **High Specific Heat (S.H.)**
  1 kcal/kg/°C
  - Lots of energy required to raise the temperature of water 1 °C
- **High Thermal Conductivity (T.C.)**
  5.2 kcal/kg/h/°C
  - Water rapidly conducts heat away from the point of application
  - Disperses heat quickly (reason for effectiveness for hydrocooling)

- **High heat of vaporization** (540 kcal/kg)
  - Water that evaporates (transpiration) absorbs a great deal of heat => cools the plant tissue
- **High heat of fusion** (80 kcal/kg)
  - When water goes from a liquid to a solid, it releases heat energy. Principal behind freeze protection
  - From solid to liquid, water absorbs energy. Added benefit for top-icing

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Kays, 1997

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A-B: 100 kJ (heating ice to 0°C)
B-C: 335 kJ (melting ice @ 0°C)
C-D: 420 kJ (heating liq to 100°C)
D-E: 2,260 kJ (liq-gas @ 100°C)
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The Psychrometric Chart

Liquid – Gas Equilibrium

- Humidity Ratio (HR):
  - Also called the mixing ratio, specific humidity, or absolute humidity
  - Shows the moisture content of the air (= water content mass of water per mass of air)
  - Water vapor is often only = 0.4 to 1.5% of the weight of air
- Vapor pressure:
  - Directly proportional to humidity ratio
  - Shows the partial pressure of water vapor in the air
Relative Humidity

- Relative humidity (RH):
  - Corresponds to the ratio of actual water content of the air to the maximum water content at a given temperature

\[ RH = \frac{VP}{SVP} \times 100 \]

- RH = Relative humidity
- VP = Vapor pressure
- SVP = Saturated vapor pressure (100% relative humidity)
Dew-Point

- Dew-point temperature:
  - Where the horizontal lines intersect the wet-bulb temperature line
  - Represents the point where condensation begins to form as the air is cooled
  - As the air cools, its water-holding capacity decreases until it is no longer able to hold even the water vapor it initially held

Psychrometric Chart

Example

Psychrometric Chart

Example

RH=63.5%
Liquid – Gas Equilibrium

Key concepts
- Maximum air water content (vapor pressure or humidity ratio) increases rapidly with increasing temperature
  - Warm air can hold more water than cold air

Kays, 1997
Liquid – Gas Equilibrium

Key concepts
• When warm, moist air is cooled, RH increases until it reaches its dew-point
• Air cooled below its dew-point begins to lose water as condensation

Kays, 1997

Liquid – Gas Equilibrium

Key concepts
• Placing a cold commodity in a warm room with moist air, cools the air that contacts the commodity to below the dew-point
  – Condensation will form on the commodity surface (AKA “sweating”)

Kays, 1997

Liquid – Gas Equilibrium

Key concepts
• Placing a warm commodity in room with cold, moist air will warm the air contacting the commodity
  – The RH will drop as the air warms because warmer air can hold more water
  – Increased water loss until the commodity is cooled
• Delayed cooling results in greater water loss
Water Loss

- The rate of water diffusion between two points is related to the concentration gradient
  - Greater concentration (or vapor pressure) difference = faster diffusion rate (stronger driving force)
  - VPD (vapor pressure difference) is the driving force of water movement
  - The vertical bars represent VPD between 80% and 100% RH at 0°C & 40°C

Water Loss

- VPD = SVP\text{tissue} - VPair

  - SVP\text{tissue} = Saturation vapor pressure of the air at a given temperature
    - Air within a commodity is nearly saturated (no less than 95%, usually estimated at 100%)
  - VPair = Vapor pressure of the air at a given temperature, pressure & RH

Psychrometric Chart
Water Loss

- For each commodity:
  \[ J = \text{VPD} \times k \]

- \( J \) = rate of water loss
  - e.g., \%/day, gm/h, lb/week, etc.

- \( k \) = proportionality constant
  - Depends on different features of the commodity

Sample Questions

- Calculating RH, dew-point, vapor pressure (humidity ratio) based on wet-bulb & dry-bulb measurements
- How do these change when air is warmed and cooled. When does air lose water or dry commodities out?
- What happens when air moves over refrigeration coils?
- Boundary air layer – effects of wraps, packaging, and air speed

Factors Affecting Water Loss

- Commodity factors
  - Surface to volume ratio
  - Routes of water loss
    - Epidermal cells vs. periderm & other cells
    - Structure of the surface
      - Stomates
      - Lenticels
      - Surface imperfections
      - Cuticular waxes
      - Trichomes
      - Architecture
Factors Affecting Water Loss

- Commodity factors (continued)
  - Physiological state of the commodity
    • Stage of maturity or stage of ripeness – more mature commodities generally loose less water
  - Cultivar
  - Cultural conditions
    • Weather or growing practices

Factors Affecting Water Loss

- Environmental factors
  - Humidity
    • Lower humidity => greater VPD => greater water loss
  - Diffusion shells and air velocity
    • Outside the epidermis, there is a thin layer of air that maintains high humidity (“diffusion shell”). Surface features (e.g. hairs) strongly influence the thickness of this shell
    • Faster air flow => decreases thickness of the diffusion shell => increases water loss
Factors Affecting Water Loss

- Environmental factors (continued)
  - Temperature
    - Higher temperatures => generally greater VPD => greater water loss
  - Atmospheric pressure
    - Lower pressures (high altitudes) increases water loss

Reducing Water Loss

Commodity Treatment

- Addition of water to some commodities (incl. cut flowers, potted plants)

- Careful handling
  - Injury and punctured surfaces greatly increase water loss
  - Proper temperature, R.H., packaging, etc.
Reducing Water Loss
Commodity Treatment

• Rapid cooling & keeping cold

Reducing Water Loss
Commodity Treatment

• Curing of certain root, bulb, and tuber vegetables

Reducing Water Loss
Commodity Treatment

• Waxing and other surface coatings
Reducing Water Loss
Commodity Treatment
• **Use of plastic films (wraps) that act as moisture barriers**

Reducing Water Loss
Commodity Treatment
• **Packaging**
  - Polyethylene or plastic liners
  - Wood or plain fibreboard boxes can absorb water

Reducing Water Loss
Manipulating the Environment
• **Maintaining temperature of refrigeration coils within ±1°C of the air temperature**
  - Larger evaporator coils
• **Minimizing air movement around the commodity & reducing room air exchanges**
• **Addition of moisture to the air (humidifiers)**
Reducing Water Loss
Manipulating the Environment

• Moisture barriers, e.g.
  – In the walls of storage rooms and transport vehicles
  – Polyethylene liners or curtains within shipping containers
• Wet the floor in storage rooms

Reducing Water Loss
Manipulating the Environment

• Use crushed ice in shipping containers and in retail display of commodities that tolerate direct contact with ice

Reducing Water Loss
Manipulating the Environment

• Sprinkle produce with water during retail marketing
  – Can be used on leafy vegetables, cool-season root vegetables, and immature fruit-vegetables (e.g., snap beans, peas, sweet corn, and summer squash)