Respiration

Internal & Environmental Factors

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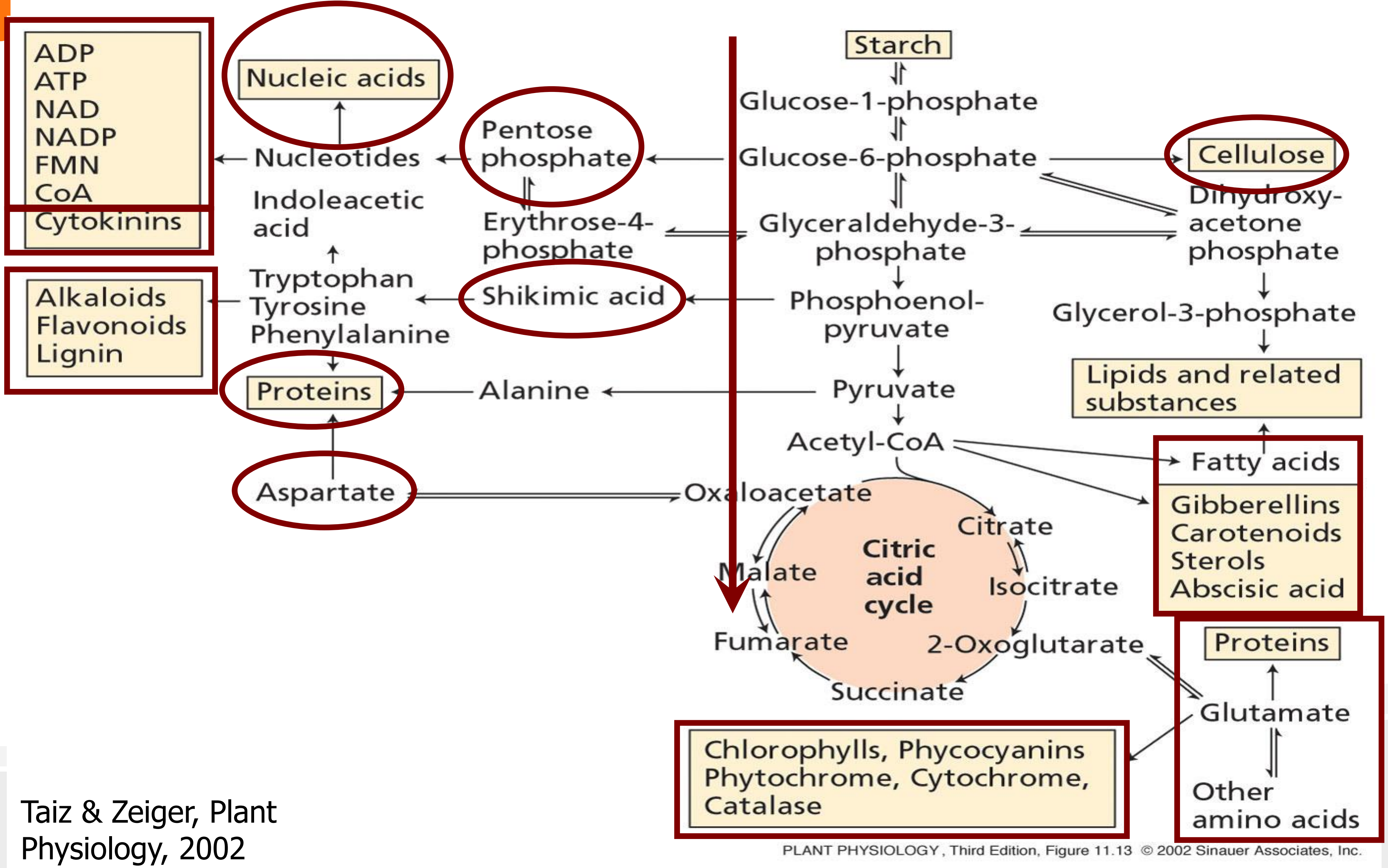
Respiration is tied to many metabolic process within a cell



Taiz & Zeiger, Plant Physiology, 2002

Respiration is tied to many metabolic process within a cell

- Thus:
  - It is an accurate indicator of the general metabolic state of a cell
  - The rate of respiration is influenced by many internal and external factors that affect general metabolism

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Internal Factors

- Genotype of a commodity
- Type of plant part
- Stage of development at harvest
- Respiratory substrate
- Preharvest factors

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Internal Factors

- Genotype of a commodity
  - Between different commodities and within different cultivars of a single species
- Type of plant part
  - E.g. storage organs (potato) have low rates while developing meristems (broccoli) have high rates

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Class	($mg\ CO_2$/kg-hr) at 5 °C (41 °F)	Commodities
Very Low	< 5	Dates, dried fruits and vegetables, nuts
Low	5 - 10	Apple, beet, celery, citrus fruits, cranberry, garlic, grape, honeydew melon, kiwifruit, onion, papaya, persimmon, pineapple, potato (mature), sweet potato, watermelon
Moderate	10 - 20	Apricot, banana, blueberry, cabbage, cantaloupe, carrot (topped), celeriac, cherry, cucumber, fig, gooseberry, lettuce (head), mango, nectarine, olive, peach, pear, plum, potato (immature), radish (topped), summer squash, tomato
High	20 - 40	Avocado, blackberry, carrot (with tops), cauliflower, leeks, lettuce (leaf), lima bean, radish (with tops), raspberry
Very High	40 - 60	Artichoke, bean sprouts, broccoli, Brussels sprouts, cut flowers, endive, green onions, kale, okra, snap bean, watercress
Extremely High	> 60	Asparagus, mushroom, parsley, peas, spinach, sweet corn

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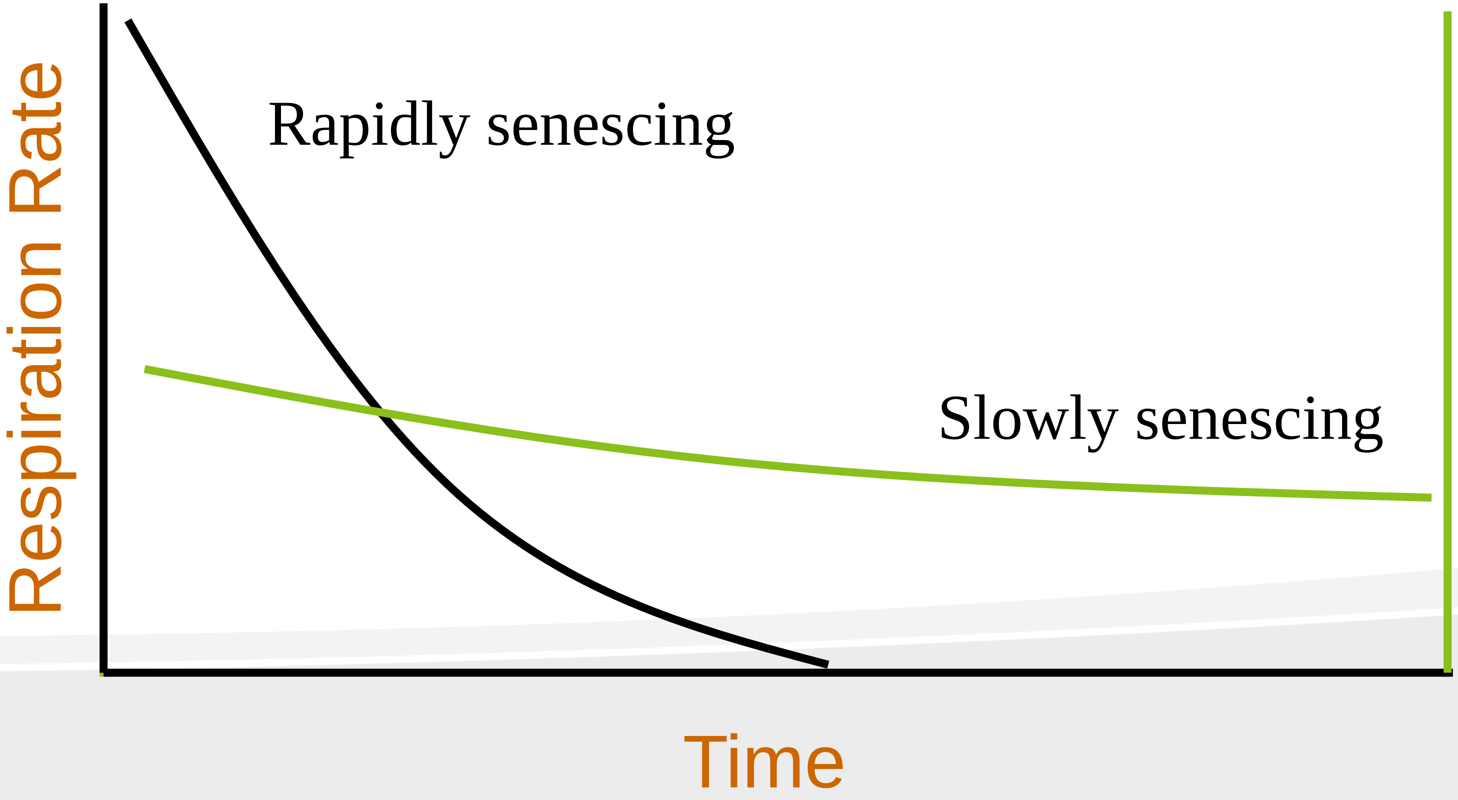
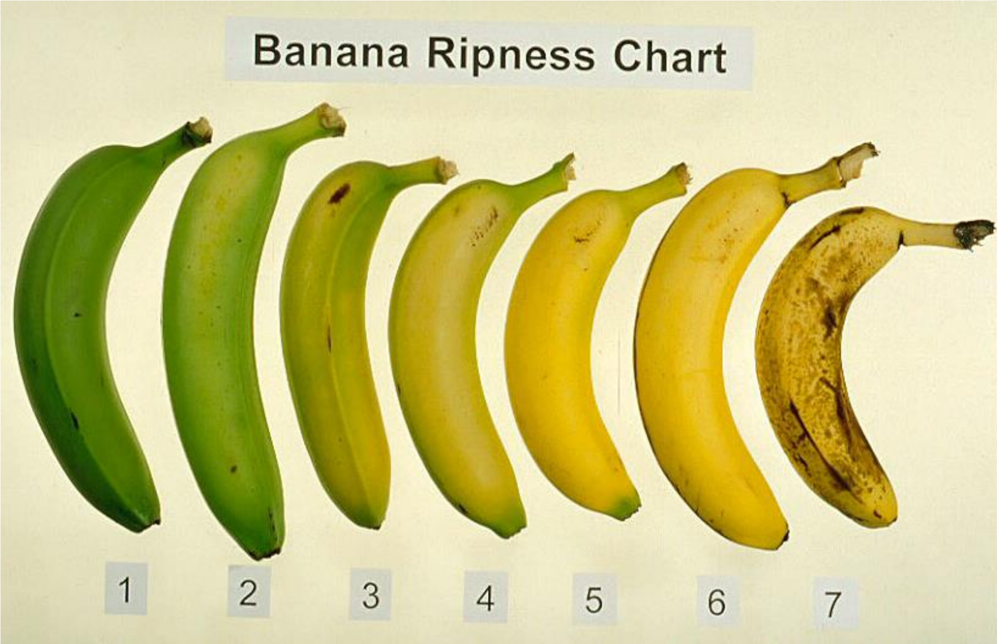
Internal Factors

- Stage of development at harvest
  - Maturing plant organs usually have declining rates of respiration



Climacteric Commodities

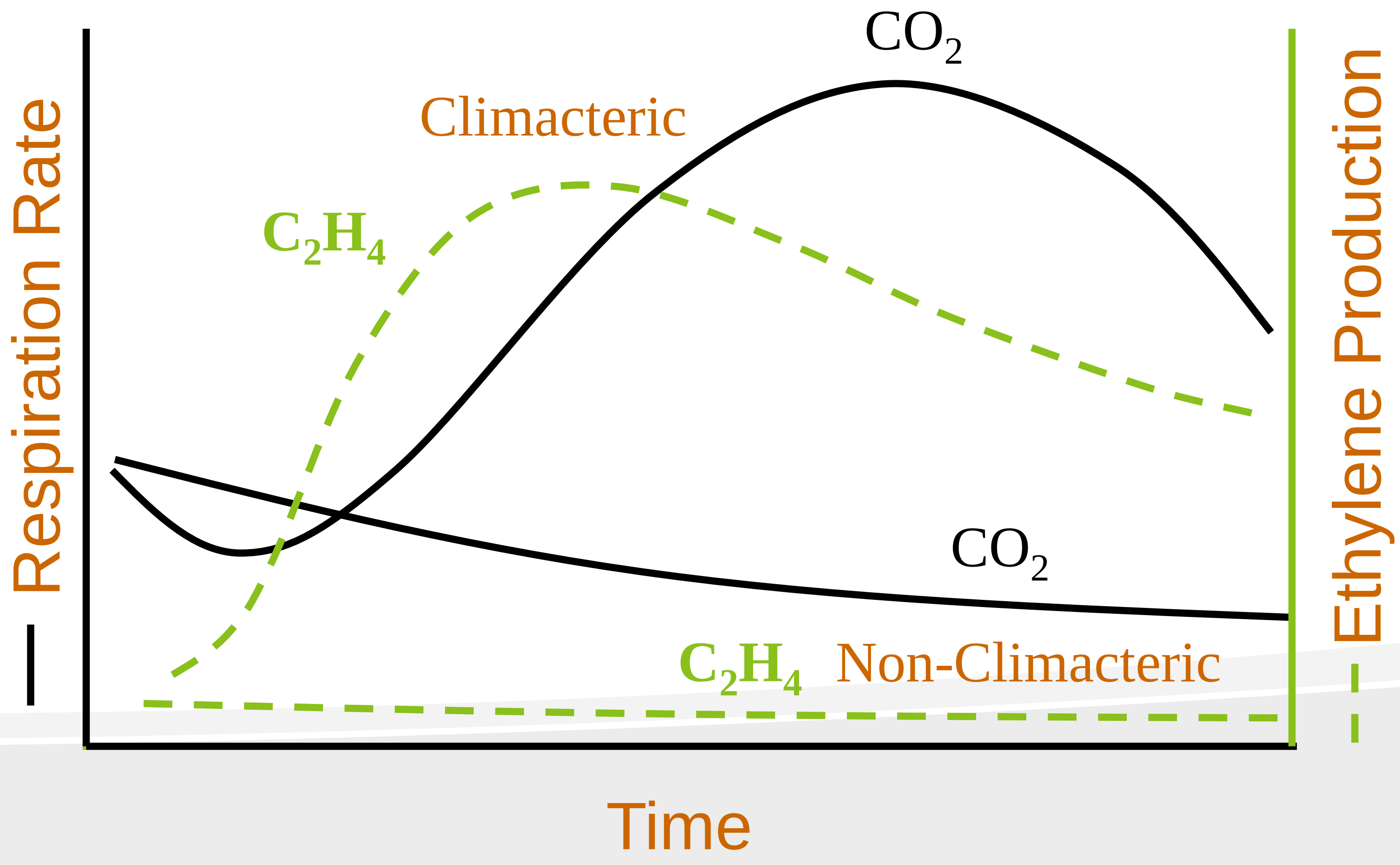
- Have a "ripening phase" (e.g. soften, become sweeter & less acidic, develop characteristic aromas, etc.).



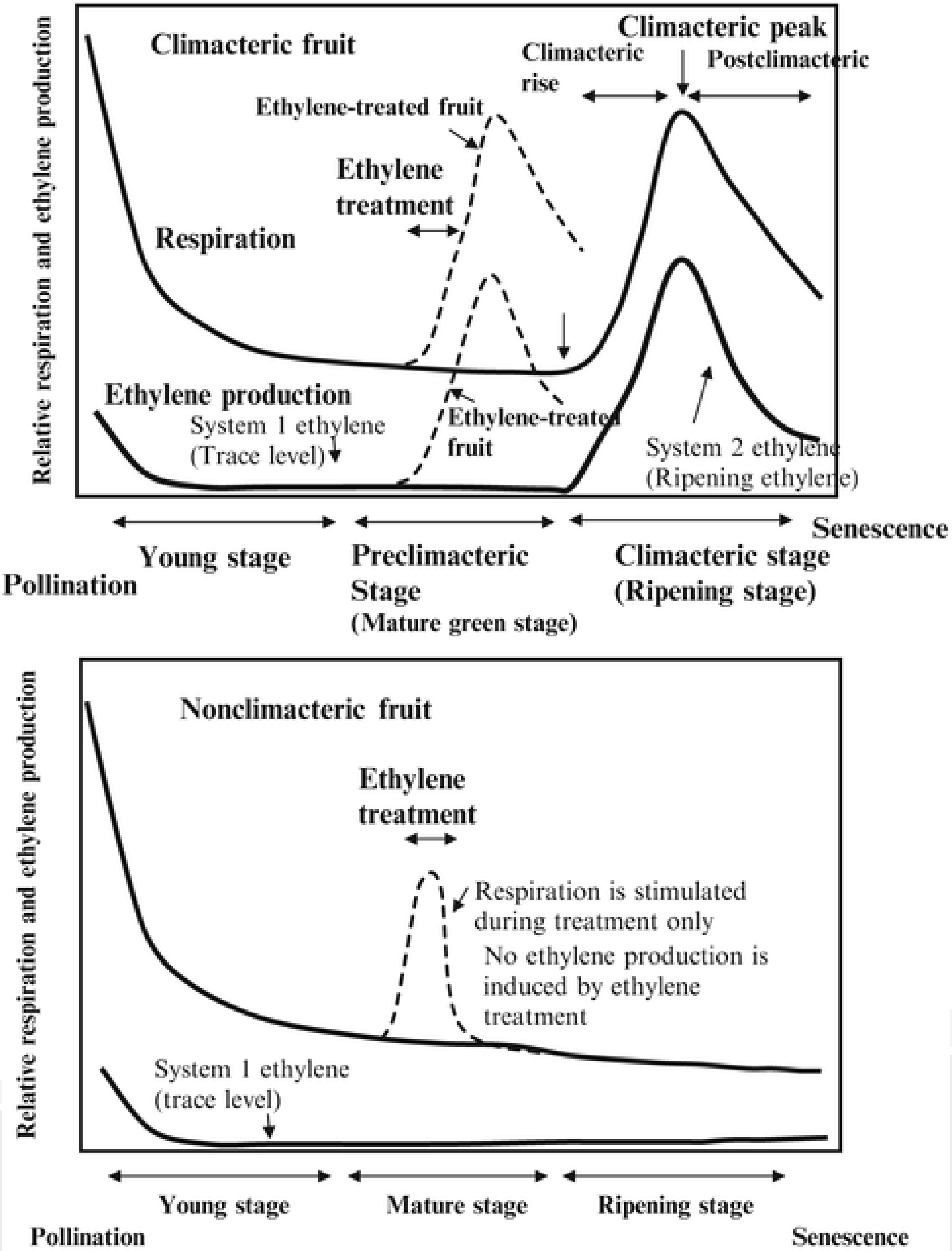
Pictures courtesy Adel Kader and Marita Cantwell, UC Davis

Climacteric Commodities

- Have increased respiration & ethylene production during ripening

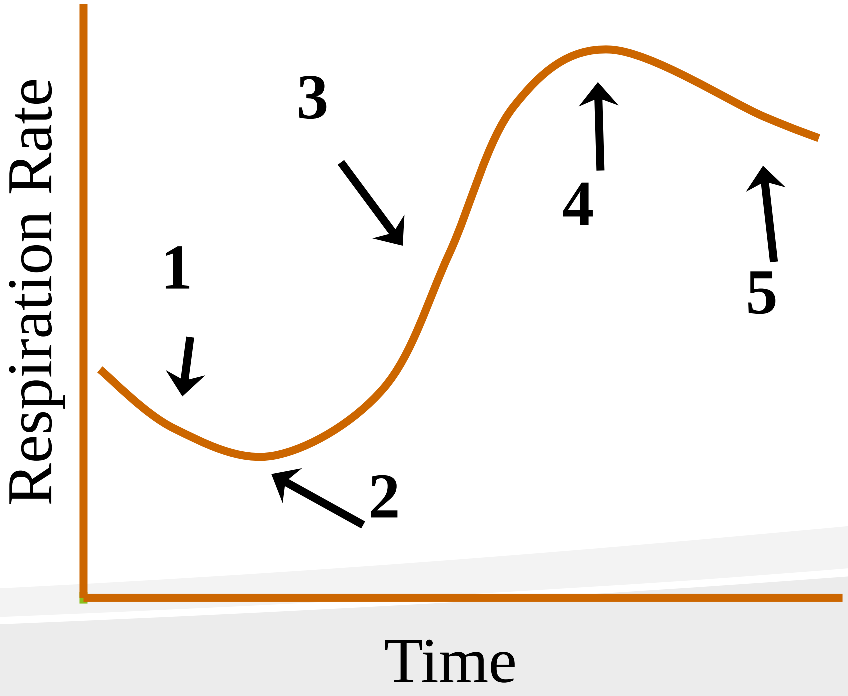


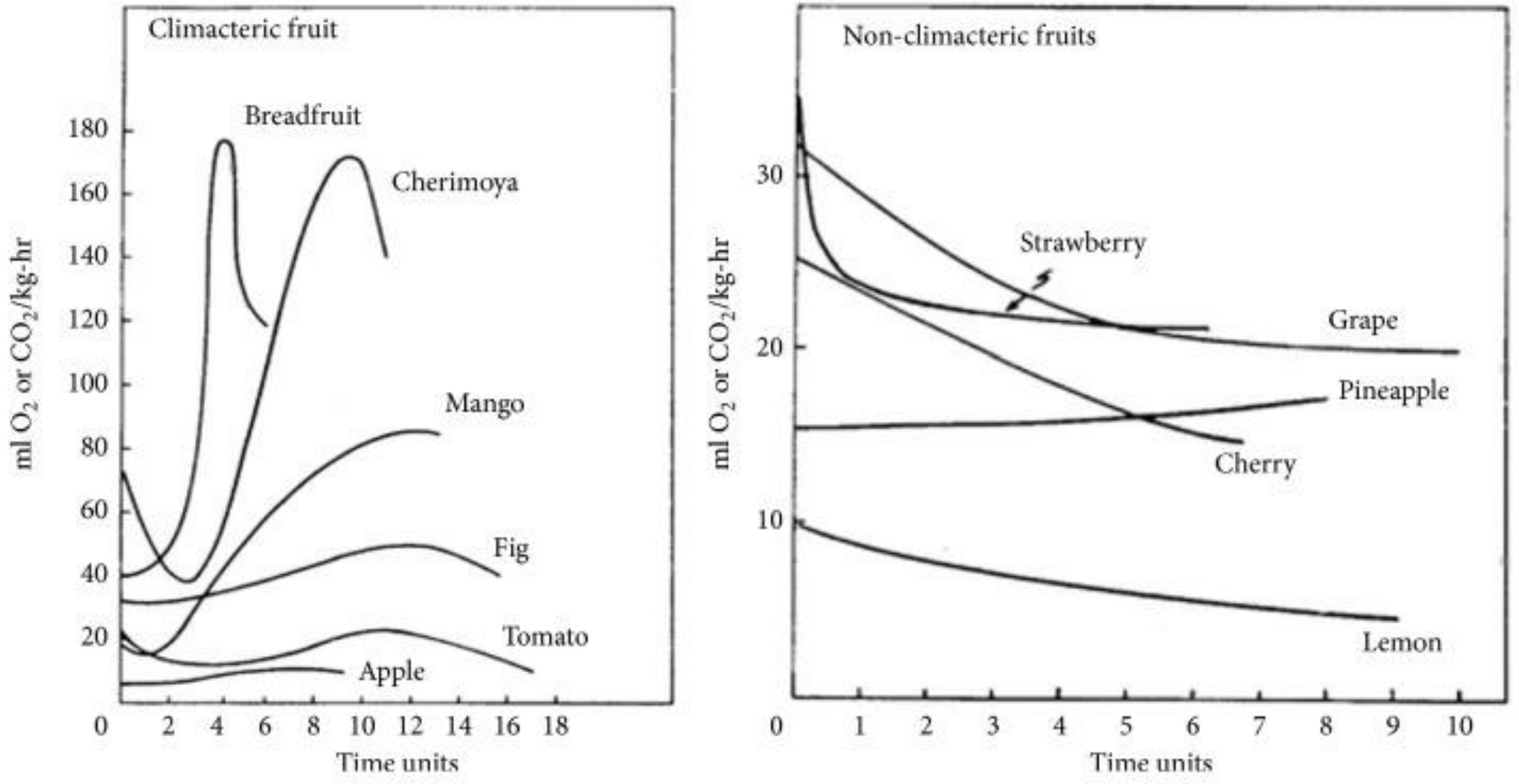
Kubo Y. (2015) Ethylene, Oxygen, Carbon Dioxide, and Temperature in Postharvest Physiology. In: Kanayama Y., Kochetov A. (eds) Abiotic Stress Biology in Horticultural Plants. Springer, Tokyo. https://doi.org/10.1007/978-4-431-55251-2_2



Phases of the Climacteric

1) The preclimacteric
2) The preclimacteric minimum
3) The climacteric rise
4) The climacteric peak
5) The postclimacteric phase





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Climacteric

- Apple
- Apricot
- Avocado
- Banana
- Blueberry
- Breadfruit
- Broccoli
- Carnation
- Cherimoya
- Feijoa
- Fig
- Guava
- Jackfruit
- Kiwifruit
- Mango
- Muskmelon
- Nectarine
- Papaya
- Passion Fruit
- Peach
- Pear
- Persimmon
- Plum
- Quince
- Ranbutan
- Sapodilla
- Sapote
- Soursop
- Tomato

Non-Climacteric

- Cacao
- Carambola
- Cherry
- Cucumber
- Grape
- Grapefruit
- Lemon
- Lime
- Longan
- Loquat
- Lychee
- Olive
- Orange
- Pepper
- Pineapple
- Pomegranate
- Strawberry
- Tamarillo
- Watermelon

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Internal Factors

- Respiratory Substrate – carbohydrates, lipids, and organic acids

$$\text{Respiratory quotient (RQ)} = \frac{[CO_2]\text{ evolved}}{[O_2]\text{ consumed}}$$

  - [ ] indicates moles of each
  - RQ range from 0.7 to 1.3 for aerobic (with O_2) respiration
  - RQ is much greater if tissue goes into anaerobic (without O_2) respiration

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Internal Factors

- Respiratory quotient (RQ) indicates when the cell utilizes different types of substrates for respiration
  - Carbohydrates: RQ = 1
  - Lipids: RQ < 1
  - Organic Acids: RQ > 1

Internal Factors

- Preharvest factors such as:
  - Plant nutrition
    - e.g. nitrogen & calcium
  - Water supply
  - Pruning, training and thinning
  - Insect & Pathogen pressures
  - Climate and weather patterns
    - Temperature
    - Humidity
    - Wind
    - Light intensity, etc.

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Environmental Factors

- Temperature
- Atmospheric composition
  - Oxygen concentration
  - Carbon dioxide concentration
  - Ethylene
- Physical stresses
- Pathogen attack
- Other plant growth regulators
- Radiation
- Light
- Chemical stress
- Water stress

Respiration and Shelf Life

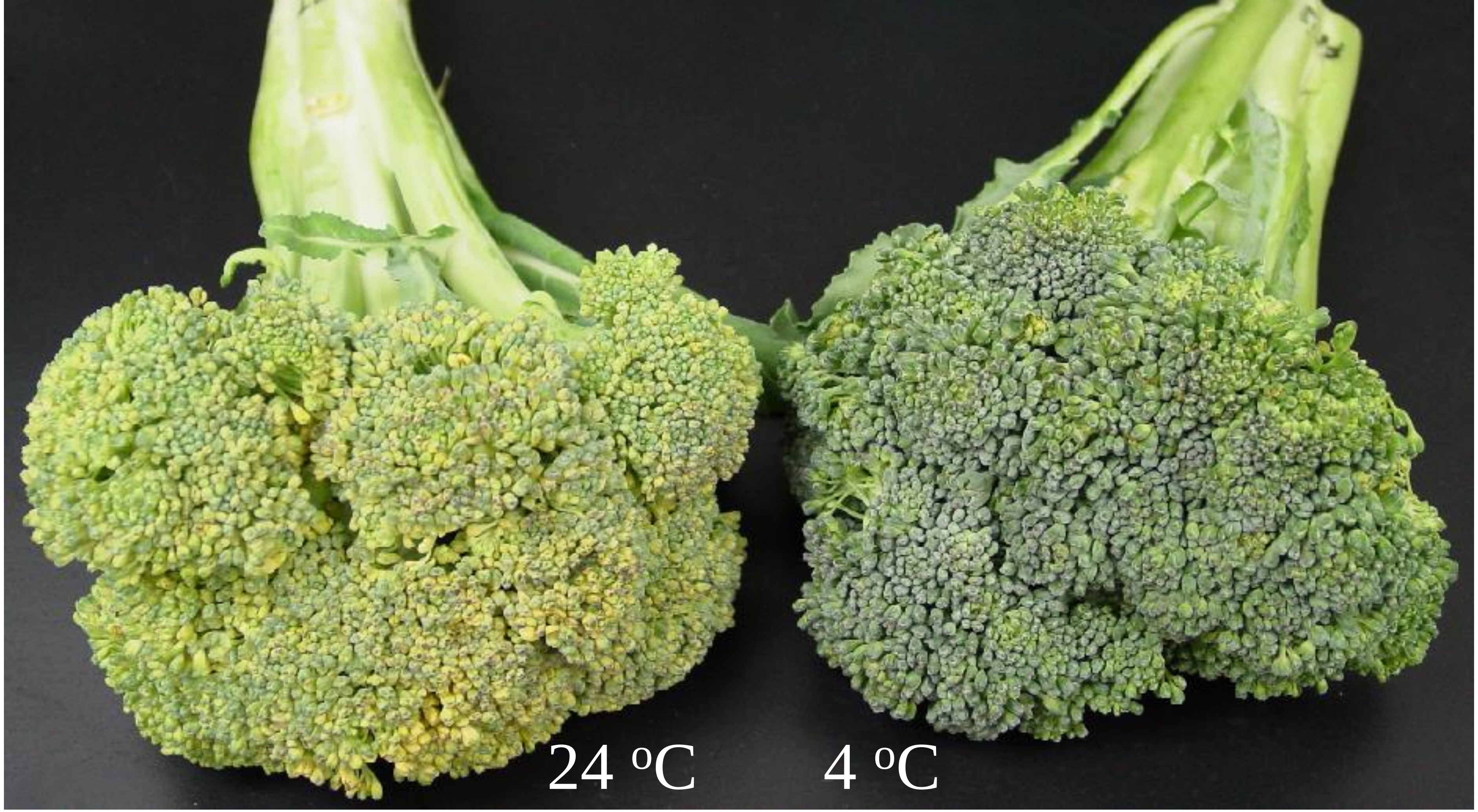
- Respiration rate is inversely related to shelf life

Higher respiration =>

=> Shorter Shelf Life

Environmental Factors
Temperature

- Temperature is the most important factor influencing postharvest life of a given commodity
  - Dictates the speed of chemical reactions (including respiration)
- Typically, for every 10 °C (18 °F) increase, respiration increases between 2 and 4 fold (Q_{10} or Van't Hoff Rule)



Affect of temperature on the quality of broccoli after just 48 h of storage at either room temperature (24°C; 75°F) or in the refrigerator (4°C; 40°F)

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Temperature Coefficient (Q_{10})

$$Q_{10} = \left(\frac{R_2}{R_1}\right)^{\left(\frac{10}{T_2 - T_1}\right)}$$

R_1 = rate of reaction at temperature 1 (T_1)
R_2 = rate of reaction at temperature 2 (T_2)
Temperatures are in ^{o}C

With a 10 ^{o}C Change in temperature => $Q_{10} = \frac{R_2}{R_1}$

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Typical Q_{10} Values

Temperature Range (°C)	Q_{10}
0 – 10	2.5 – 4.0
10 – 20	2.0 – 2.5
20 – 30	1.5 – 2.0
30 – 40	1.0 – 1.5

Temperature effects on shelf-life

Temperature °C (°F)	Q_{10}	Deterioration	Shelf-Life
0 (32)		1	100
10 (50)	3	3	33
20 (68)	2.5	7.5	13
30 (86)	2	15	7
40 (104)	1.5	22.5	4

E.g. grapes at
32C (90F) for 1 h = 1 day at 4C (39F) = 1 week at 0C (32F)

Example of Calculating The Q_{10}

- Say there is a new variety of Grapefruit
- Researchers have determined the following respiration rates at different temperatures:
  - 5 mg CO_2/kg-hr at 0C (32F)
  - 10 mg CO_2/kg-hr at 5C (41F)
  - 15 mg CO_2/kg-hr at 10C (50F)
  - 30 mg CO_2/kg-hr at 20C (68F)
  - 45 mg CO_2/kg-hr at 30C (86F)
  - 55 mg CO_2/kg-hr at 35C (95F)

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Example of Calculating The Q_{10}

- How much additional shelf life would a packinghouse manager expect if they held fruit at 10°C (50°F) compared to 30°C (86°F)?
- First, determine Q_{10} between 10 & 20°C, and between 20 & 30°C

$$Q_{10} = \left(\frac{R_2}{R_1}\right)^{\left(\frac{10}{T_2 - T_1}\right)}$$

If $T_2 - T_1 = 10$ Then

$$Q_{10} = \frac{R_2}{R_1}$$

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Example of Calculating The Q_{10}

- First, determine Q_{10} between 10 & 20C
  - 15 mg CO_2/kg-hr = R_1
    - 10C = T_1
  - 30 mg CO_2/kg-hr = R_2
    - 20C = T_2

$$Q_{10} = \left(\frac{30}{15}\right)^{\left(\frac{10}{20-10}\right)}$$

$$Q_{10} = \left(2\right)^{\left(\frac{10}{10}\right)} = 2^1 = 2$$

Example of Calculating The Q_{10}

- Determine Q_{10} between 20 & 30C
  - 30 mg CO_2/kg-hr = R_1
  - 20C = T_1
  - 45 mg CO_2/kg-hr = R_2
  - 30C = T_2

$$Q_{10} = \left(\frac{45}{30}\right)^{\left(\frac{10}{30-20}\right)}$$

$$Q_{10} = \left(1.5\right)^{\left(\frac{10}{10}\right)} = 1.5^{1} = 1.5$$

Calculated Q_{10} Values for the new grapefruit variety

Temperature Range (°C)	Q_{10}
0 – 10	(you calculate)
10 – 20	2
20 – 30	1.5

Temperature effects on shelf-life

Temperature (°C)	Q_{10}	Shelf-Life
0		
10	3	30
20	2	15
30	1.5	10

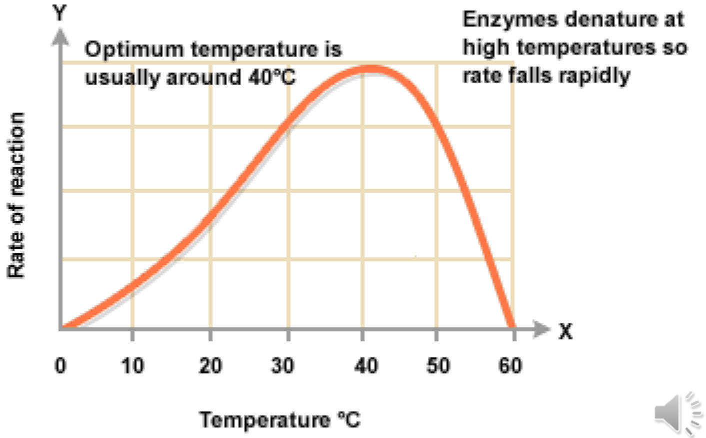
Thus, 10 day at 30C = 15 days at 20C = 30 days at 10C

Low Temperature Injury

- Freezing will kill the tissue
- Chilling sensitive commodities
  - Q_{10} is usually much higher at chilling temperatures. In some commodities, respiration may increase at the lowest chilling temperatures
  - Upon return to non-chilling temperatures, respiration becomes abnormally high and may remain high

High Temperature Injury

- Respiration increase as temperature increases to a point
  - Above that point (tissue & commodity specific) protein denatures and respiration declines rapidly
- Time x Temperature component to thermal cell death
  - Cells can survive short periods at high temperatures (used for some quarantine treatments)



http://www.bbc.co.uk/staticarchive/455e6a42f1b7ab19a1dec6dc9ffb4a849fd4611a.gif

High Temperature Injury

- Heat shock (brief exposure to high, non-lethal temperatures) can protect cells from subsequent high or low temperature stress
  - Induce the production of heat-shock proteins
  - Turns on the antioxidant defense system that counters reactive oxygen species (ROS) that can damage cellular components

Atmospheric Concentration

Oxygen

- Low O_2 concentrations reduce respiration.
  - Below ~2-3% O_2, ETS starts to be inhibited
- If metabolic (ATP) demand is higher than inhibited Krebs cycle and ETS can supply, anaerobic respiration will attempt to satisfy ATP demand
  - Anaerobic respiration only produces 2 ATP per glucose vs. 30 ATP under aerobic respiration = 15 fold greater ATP production under aerobic conditions
  - CO_2 production is faster under anaerobic respiration (at least 15-fold higher!)

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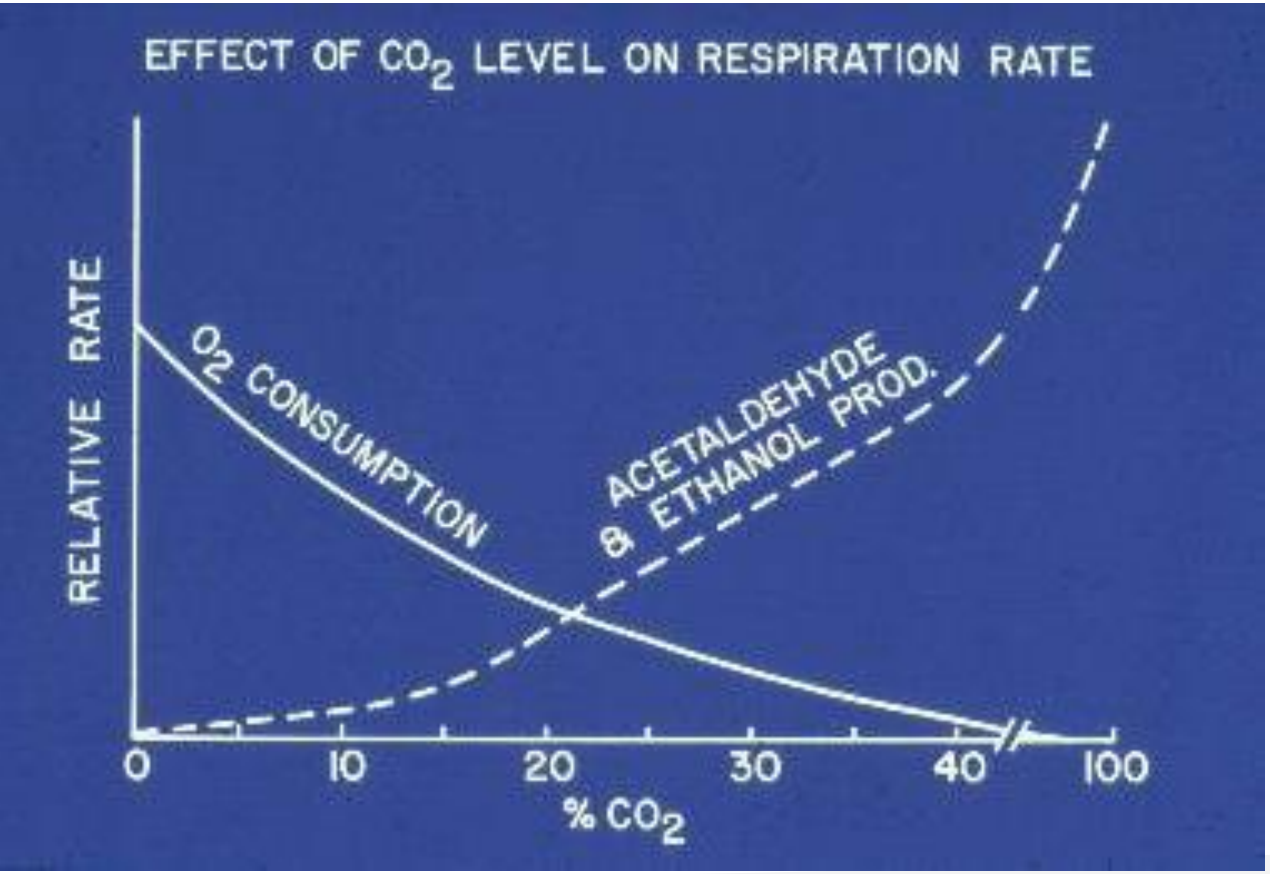
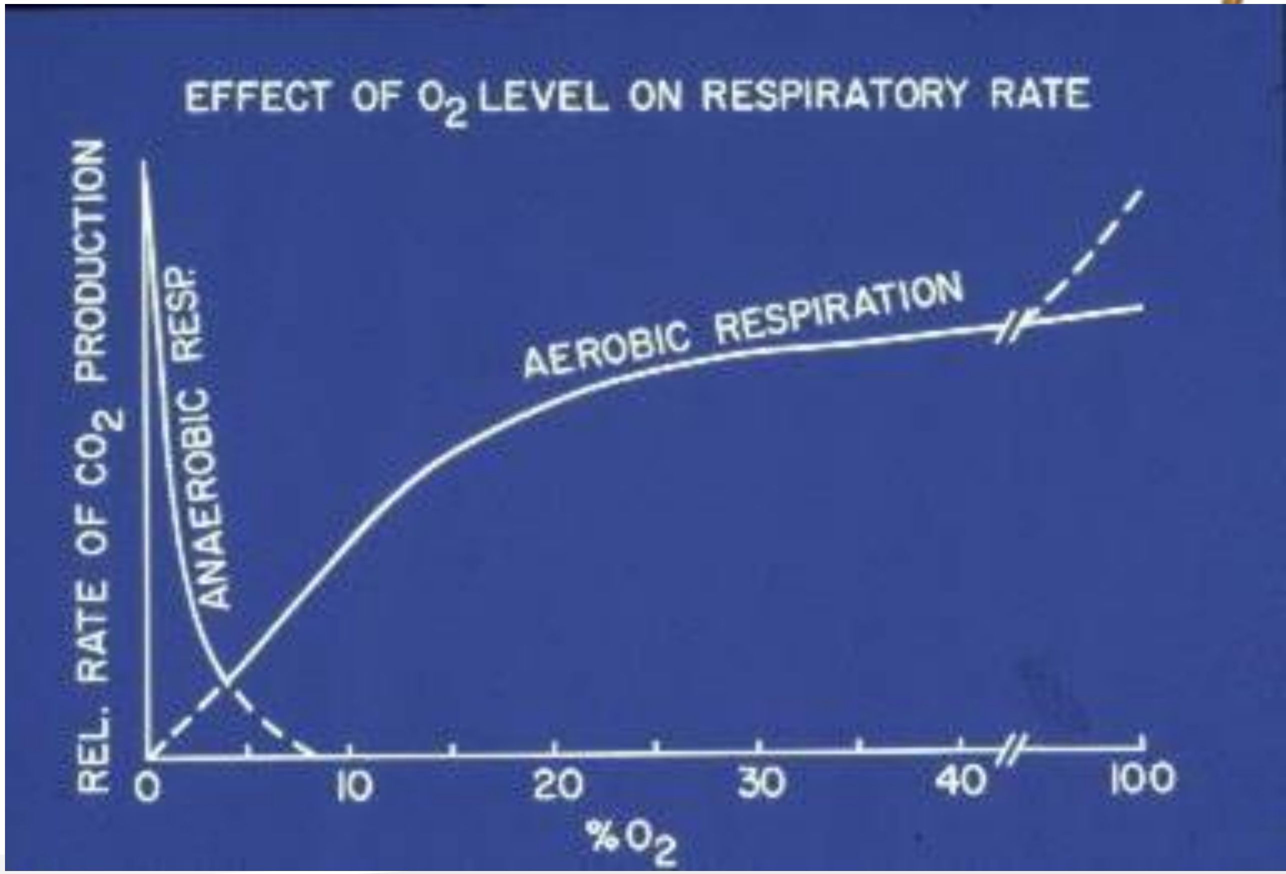
Atmospheric Concentration

Carbon Dioxide

- High CO_2 also reduced respiration
  - Probably by inhibiting decarboxylation during aerobic respiration
- Different commodities vary widely to their ability to tolerate high CO_2 (e.g. lettuce very sensitive vs. strawberries very tolerant)
- As with low O_2 inhibition, if metabolic (ATP) demand is higher than inhibited Krebs cycle and ETS can supply, anaerobic respiration will attempt to satisfy ATP demand

Relationship Between O2 and CO2 Concentrations and Respiratory Metabolism



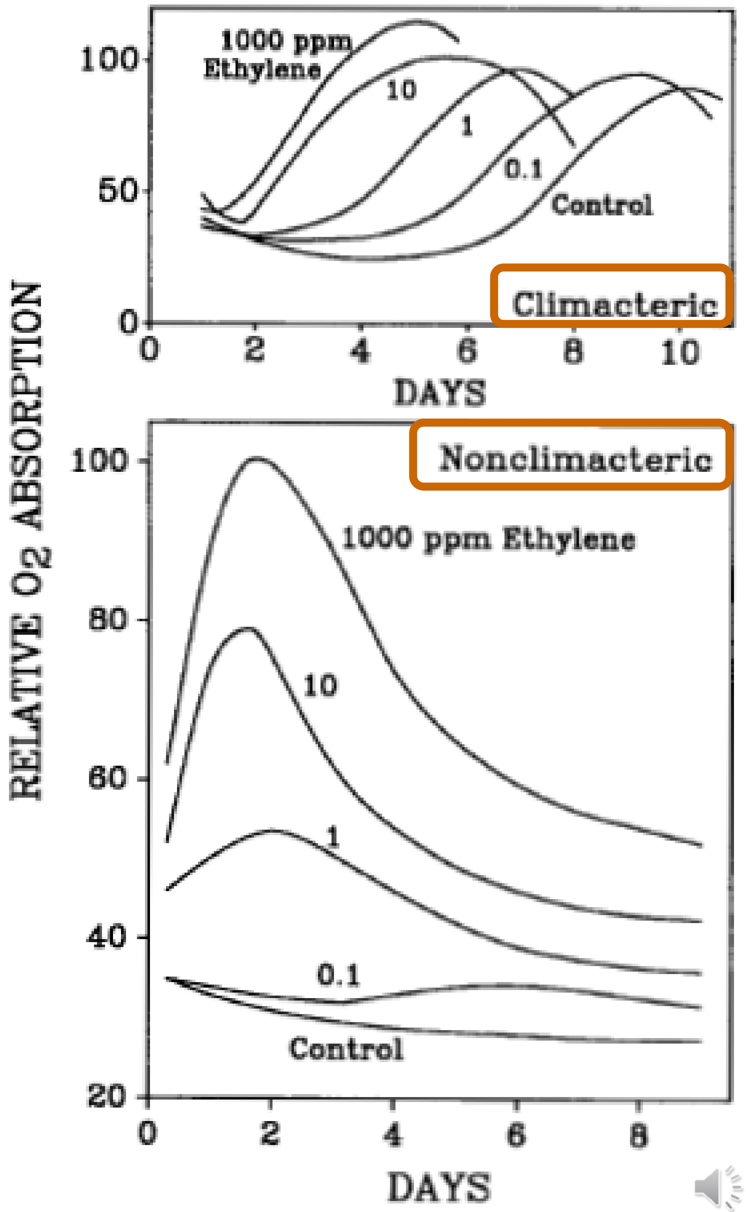


Source: A.A. Kader, UC Davis

Atmospheric Concentration Ethylene

- Climacteric & Non-Climacteric plant organs differ in their response to ethylene in the environment
- Climacteric fruit:
  - Ethylene reduces the time to onset of the climacteric rise (including autocatalytic ethylene production)
  - Concentration of added ethylene has little effect on respiration rate before or during the climacteric

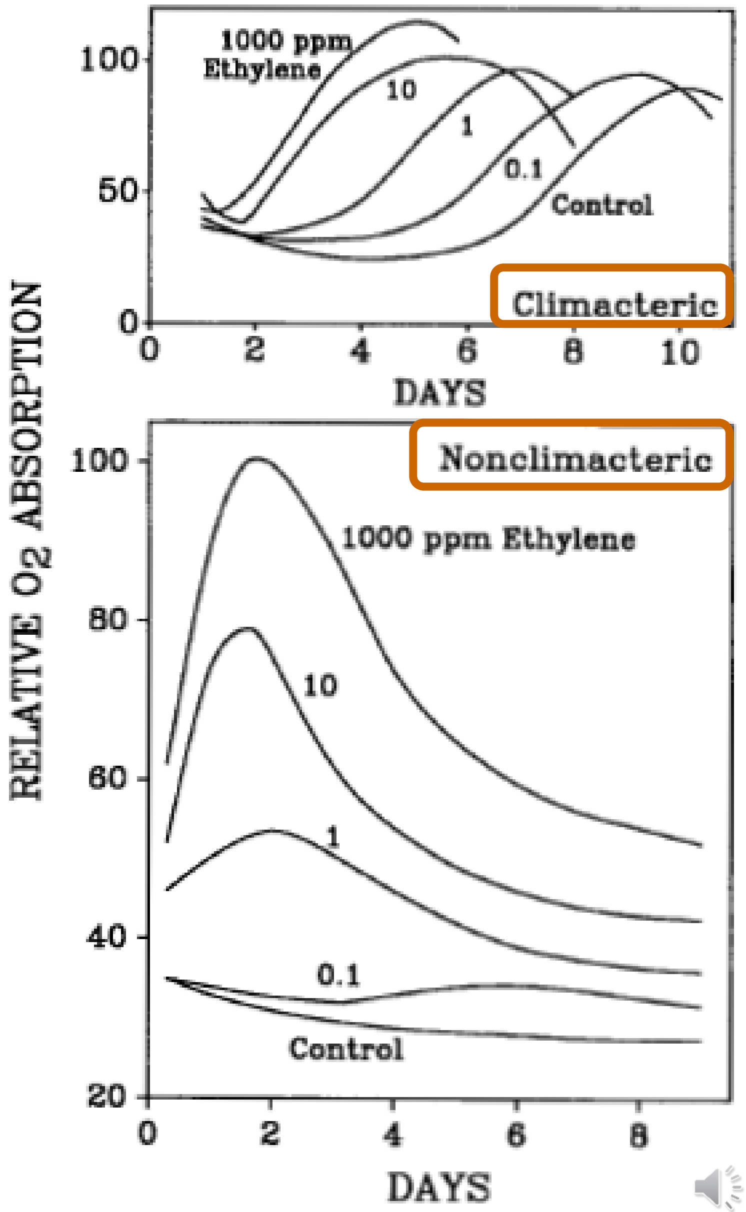
Kays & Paull, 2004, redrawn from Biale



Atmospheric Concentration
Ethylene

- Non-Climacteric fruit:
  - Added ethylene induces a rise in respiration
  - Exposure to greater ethylene concentrations do not change how fast maximum respiration rates are obtained
  - Exposure to greater ethylene concentrations elicit greater rates of respiration
  - Does not induce autocatalytic ethylene production
  - Respiration rates return to normal after ethylene is removed

Kays & Paull, 2004, redrawn from Biale



Physical Stress

- Any type of physical stress can cause respiration and ethylene production to rise quickly in both climacteric and non-climacteric commodities

Courtesy of Steve Sargent

Environmental Factors

- Temperature
- Atmospheric composition
  - Oxygen concentration
  - Carbon dioxide concentration
  - Ethylene
- Physical stresses
- Pathogen attack
- Other plant growth regulators
- Light
- Radiation
- Chemical stress
- Water stress