Storage of Perishables

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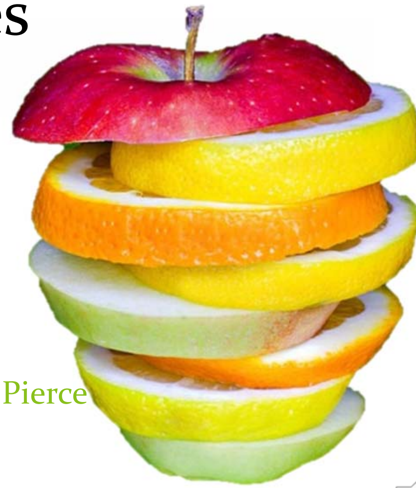

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Part I. Why We Need to Store Perishables

- Historically for winter storage
- Year-round demand for fresh fruits and vegetables
- Spread production peaks
  - Maximize profits
  - Reduce waste
- Long distance transportation is a kind of storage

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Part II. Techniques for Storage

1. On the plant storage
2. Field Storage
3. Common Unrefrigerated Storage
4. Refrigerated Storage
5. Modified and Controlled Atmosphere Storage

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1. On the Plant Storage

- Possible for crops with long harvest windows, *e.g.*, citrus, underground storage organs
- Overcomes need for capital investment in storage buildings
- Reduces storage problems, *i.e.*, water loss, storage rots, *etc.*
- Problems with idle land and natural disasters

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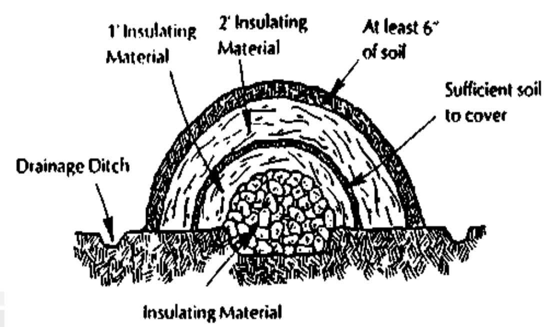
2. Field Storage (clamps)

- Piles of commodity covered with straw and soil (insulate and waterproof)
- Traditional storage method
  - Need ventilation
  - Used for potatoes, *etc.*



Kitinoja and Kader. 2003. Small-scale postharvest handling practices.

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3. Common Unrefrigerated Storage

- One step up from field clamps
- Insulated, often partly underground buildings
- Takes advantage of cool (nonfreezing) average temperatures
- Used for cabbage, potatoes and apples
  - Night air storage: Store opened at night to take advantage of cool night air. Well insulated with a ventilation system

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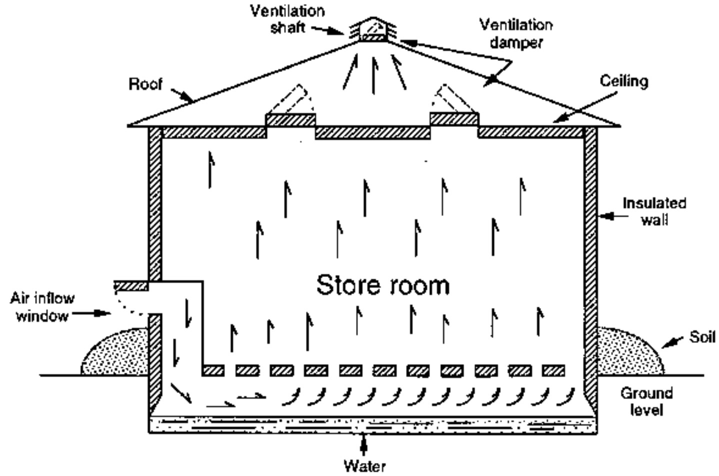
Common Storage with Ventilation



Source: S.K. Lee, Seoul National University, Korea

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4. Refrigerated Storage

- By far the most important worldwide
- Refrigeration plant (how the air is cooled)
  - Ice or cold water
  - Evaporative cooling (can cool to 1-2°C above the wet bulb temperature)
  - Mechanical refrigeration

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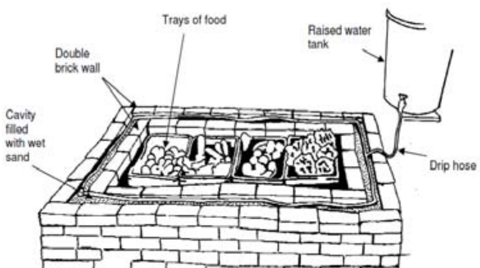
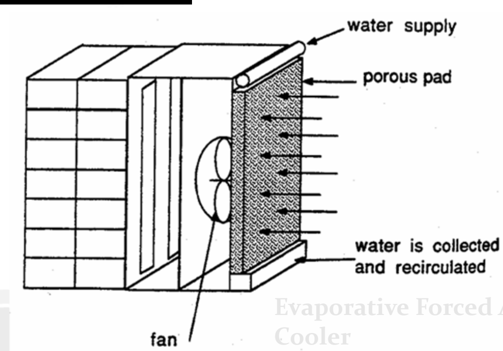


Evaporative Cooling Static System

Being promoted recently as the “ZECC” (Zero Energy Cool Chamber)



Evaporative Forced Air Cooler

FAO, Postharvest Manual, 2004

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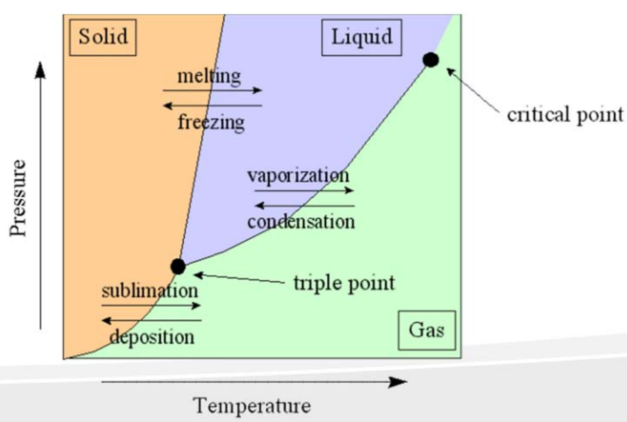
4. Refrigerated Storage: Mechanical refrigeration

- Materials can exist as liquid or gas at the same temperature depending on the pressure (see phase diagram)



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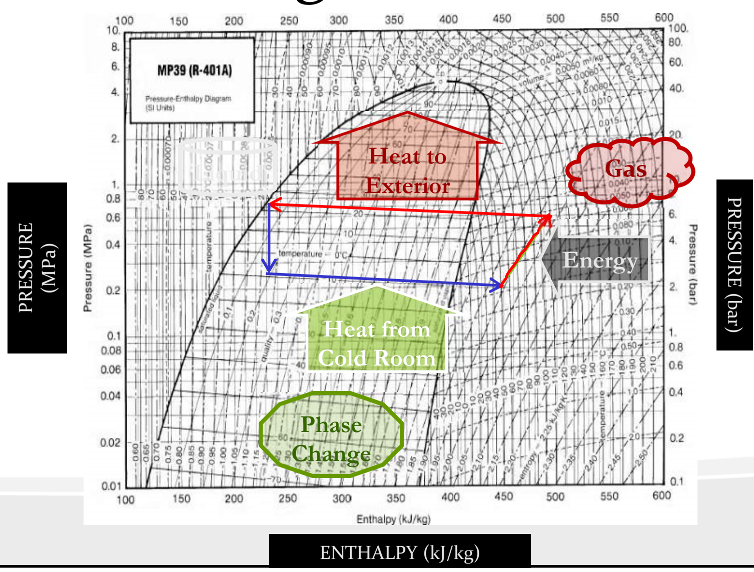
4. Refrigerated Storage: Mechanical refrigeration



- Energy required for conversion from liquid to gas produces cooling
- Work is done to compress the refrigerant gas; heat is released

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4. Refrigerated Storage: Mechanical refrigeration

- A continuous loop with a high pressure side and a low pressure side separated by a compressor and expansion valve (see schematic)
- Evaporator coils (low pressure side) cool air as vaporized refrigerant boils
- Compressed refrigerant (high pressure side) is cooled by air or water in a condenser

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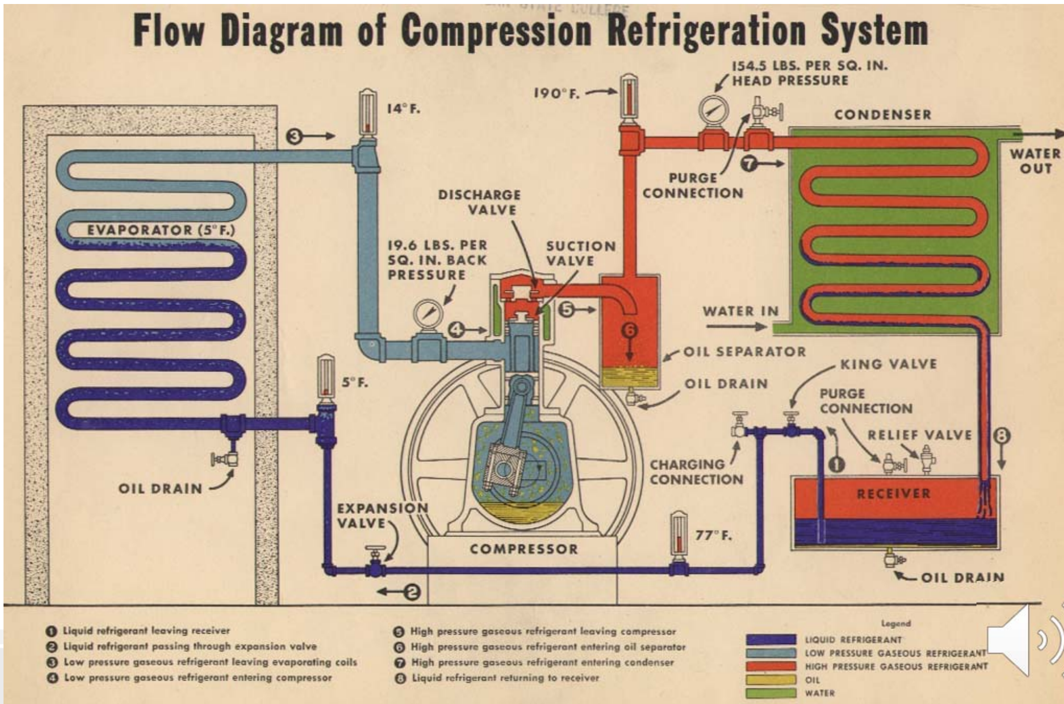

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4. Refrigerated Storage: Mechanical refrigeration

- Refrigerants are chosen based on:
  - Ozone and environment friendly
  - Low boiling point
  - High heat of vaporization
  - Vaporization pressure lower than atmospheric pressure
- Main Refrigerants:
  - Ammonia (R-707): most common for large refrigeration systems
  - Freon (CFC) – concern over ozone depletion
  - Replacements for CFC-12, R-502, and HCFC-22

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4. Refrigerated Storage: Mechanical refrigeration

$$Sugars + O_2 \xrightarrow{k} CO_2 + H_2O + Chemical\ Energy + Heat$$

- Respiration – Heat Generation
  - Maximum Heat Generation (W/kg):

	0°C	5°C	10°C
Apples	0.010	0.019	0.030
Raspberries	0.063	0.094	0.177
Cabbage	0.009	0.021	0.024
Peas	0.217	0.290	0.460
Potato	0.030	0.045	0.060

Dinçer, I. (2003)

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4. Refrigerated Storage: Mechanical refrigeration

- Transpiration – Moisture Loss

$$M = k_{ta} \times A \times (P_s - P_\infty) \quad (1)$$

$$\frac{1}{k_{ta}} = \frac{1}{k_s} + \frac{1}{k_a} \quad (2)$$

- M = Rate of moisture loss
- k_{ta} = *Overall mass transfer coefficient*
- k_s = *Skin mass transfer coefficient*
- k_a = *Air mass transfer coefficient*
- A = *Surface area of product*
- P_s = *Water pressure at surface of the product*
- P_∞ = *Ambient water pressure*

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4. Refrigerated Storage: Mechanical refrigeration

- Transpiration Coefficient (mg/kg-s-MPa)

	Transpiration Coefficient
Apples	16 -100
Brussels sprouts	3250 - 9770
Cabbage	16 - 667
Orange	25 - 227
Potato	20 - 171

Dinçer, I. (2003)

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Part III. Storage design

- Temperature uniformity
  - Refrigeration system capacity - adequate to maintain temperature under peak load conditions
  - ±1°C (2 °F) is desirable
  - Large coil size reduces temperature fluctuation
  - Fans able to circulate 7.5 air changes per hour (15-25 meters/min)
  - Adequate stacking for air circulation

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Storage design

- Humidity management
  - 90-95% RH is desirable
  - Large coil size reduces water condensation (*i.e.*, air does not have to be cooled below the dew point)
    - 5-10°C ΔT maintains 70-80% RH
    - 0.5 °C ΔT maintains 95% RH
  - In practice, supplementary humidification is used (fog, steam, spinning disk)
  - Dehumidification of air, *e.g.*, onions

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Storage design

- Building design considerations
  - Location
  - Power and water supply, zoning
  - Provision of proper facilities for handling the product (forklift movement, pallets, racks)
  - External vapor barrier in floor, walls and roof
  - Adequate insulation: R20 to R60 (required R-value determined by exposure)

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Part IV. Modified and Controlled Atmosphere Storage

$$Sugars + O_2 \xrightarrow{k} CO_2 + H_2O + Chemical\ Energy + Heat$$

- Modified atmosphere (MA) = commodity-generated atmosphere maintained by restricted diffusion
  - Storage rooms, transport vehicles, and packages (“MAP”)
- Controlled atmosphere (CA) = feedback control and active adjustment of atmosphere
  - Storage rooms and transport vehicles

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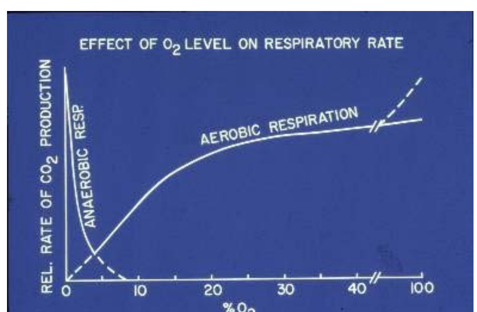
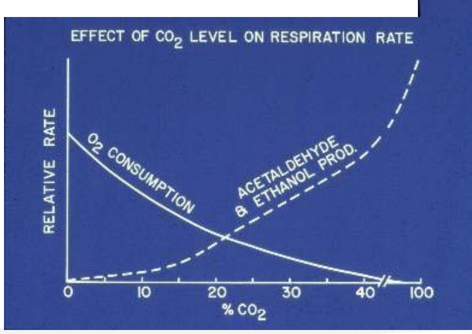
Relationship Between O_2 and CO_2 Concentrations and Respiratory Metabolism





Source: A.A. Kader, UC Davis

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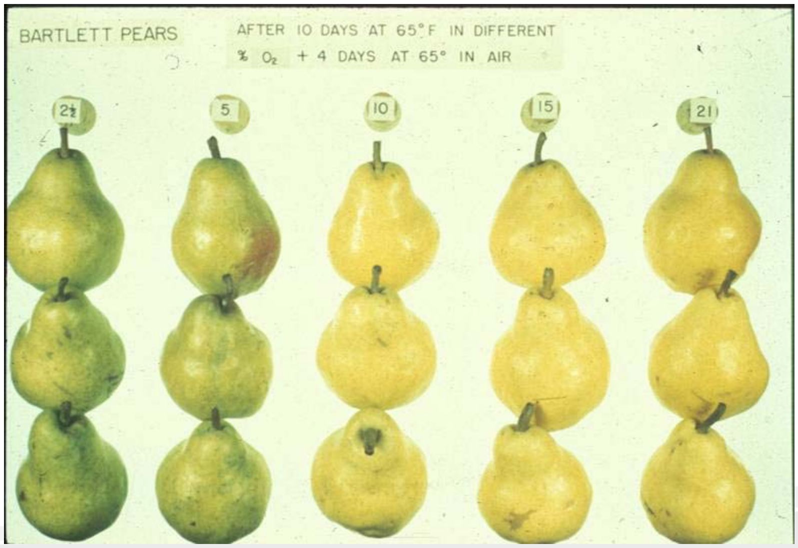
Reduced O_2 Effect on Pears



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Modified Atmosphere Effect on Bananas

Air Control Modified Atmosphere

2 weeks at 15°C

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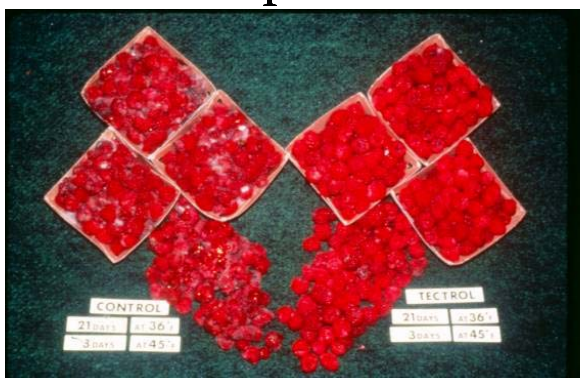
Controlled Atmosphere Effect on Raspberries



Air Control   Controlled Atmosphere

21 days at 2°C plus 3 days in air at 7°C

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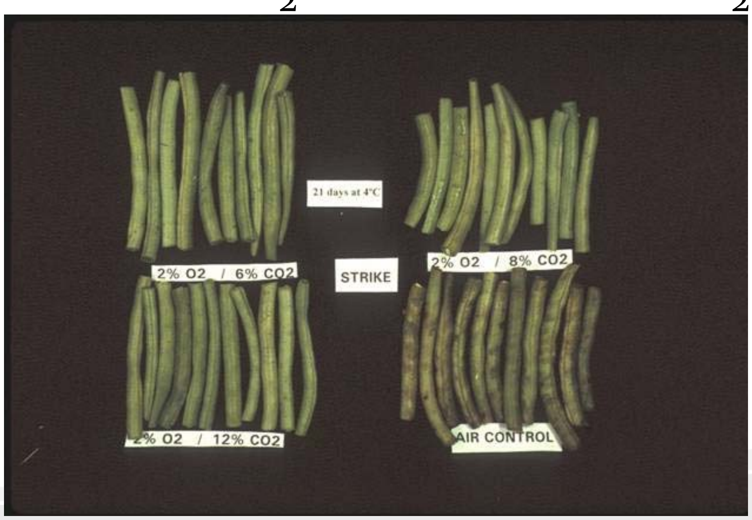
Response of Green Beans to Reduced O_2 and Elevated CO_2



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Modified and Controlled Atmosphere Storage

- Diffusion gradients for respiratory gases depend on:
  - Surface-to-volume ratio
  - Resistance to diffusion (cuticle structure, stomata, lenticels)
  - Metabolic rate (i.e., rate of O_2 consumption and CO_2 production)

➢ This is an important reason why different commodities have different CA optima

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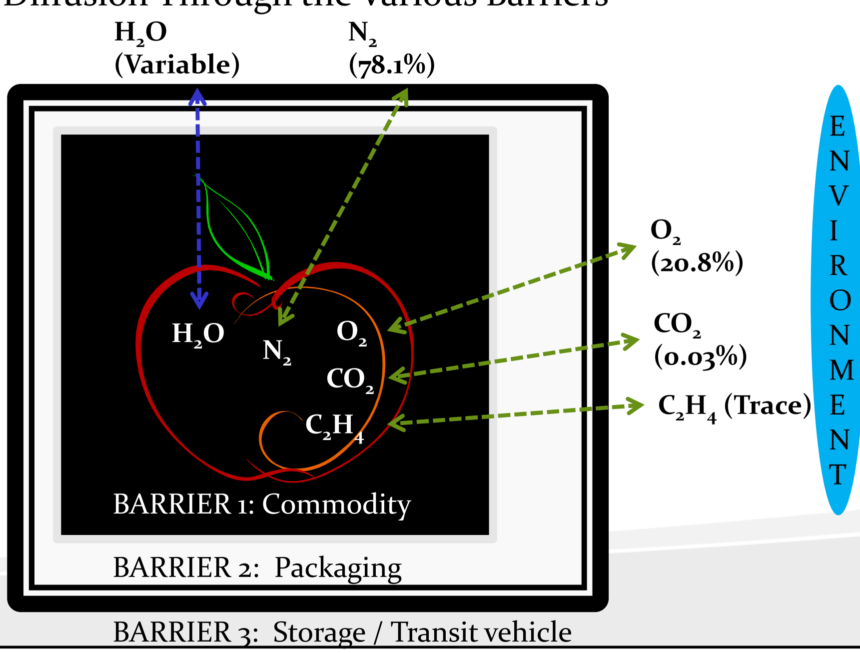
Relationship Between Biological Gas Concentrations Within a Fruit and Diffusion Through the Various Barriers



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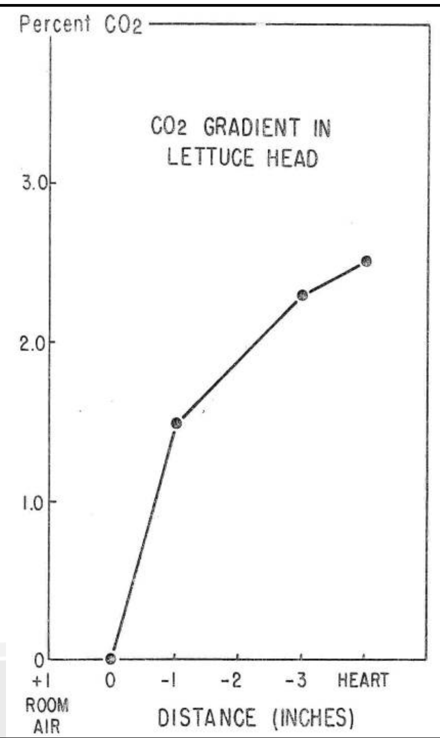
Gradient of CO_2 Concentration Within a Head of Iceberg Lettuce



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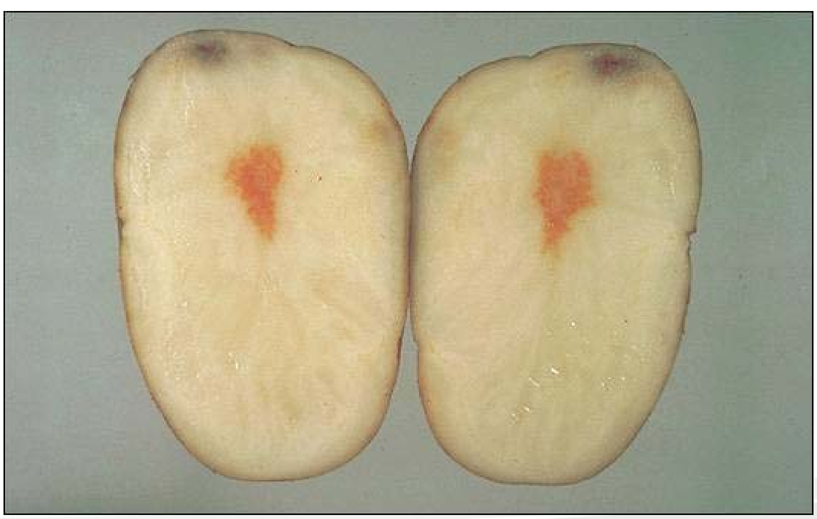
Potato Low O_2 Injury ("Blackheart")



http://ipcm.wisc.edu/scout/vegcrop.htm

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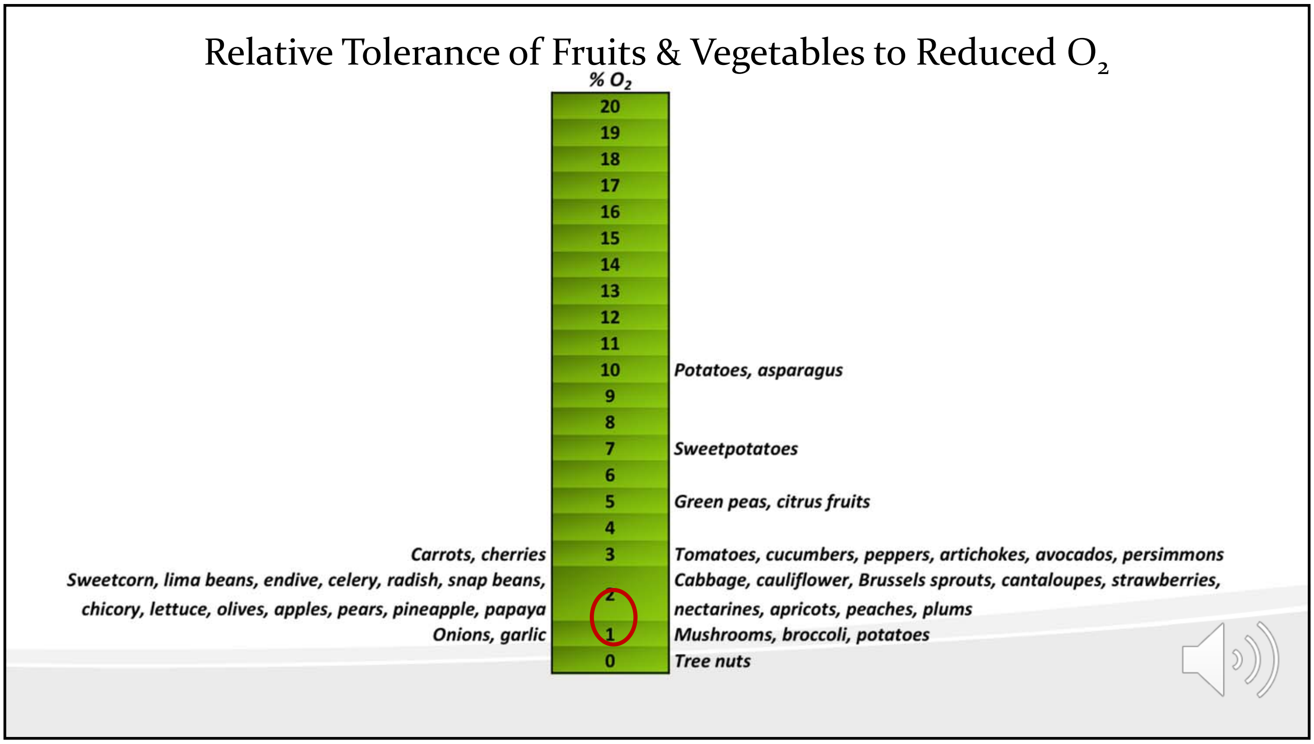
Relative Tolerance of Fruits & Vegetables to Reduced O_2
% O_2
20
19
18
17
16
15
14
13
12
11
10 Potatoes, asparagus
9
8
7 Sweetpotatoes
6
5 Green peas, citrus fruits
4
Carrots, cherries 3 Tomatoes, cucumbers, peppers, artichokes, avocados, persimmons
Sweetcorn, lima beans, endive, celery, radish, snap beans, chicory, lettuce, olives, apples, pears, pineapple, papaya 2 Cabbage, cauliflower, Brussels sprouts, cantaloupes, strawberries, nectarines, apricots, peaches, plums
Onions, garlic 1 Mushrooms, broccoli, potatoes
0 Tree nuts

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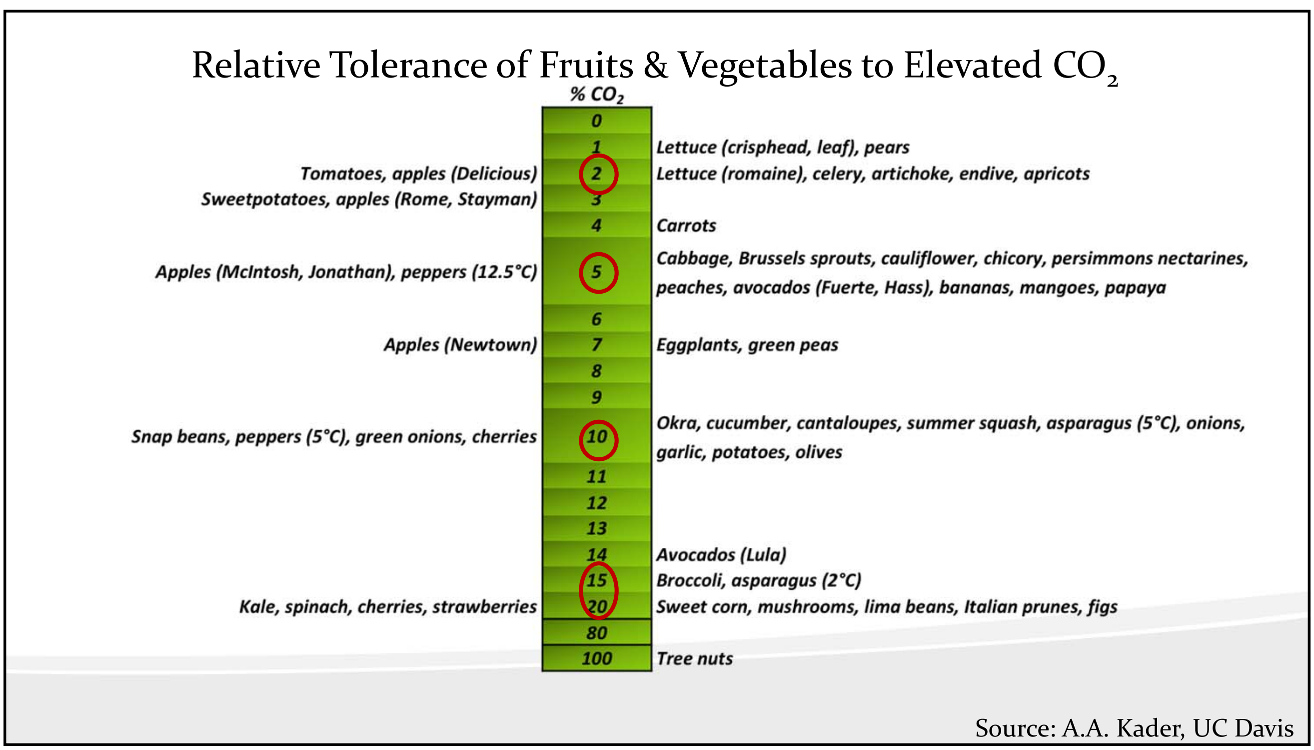
Relative Tolerance of Fruits & Vegetables to Elevated CO_2
% CO_2
0
1 Lettuce (crisphead, leaf), pears
Tomatoes, apples (Delicious) 2 Lettuce (romaine), celery, artichoke, endive, apricots
Sweetpotatoes, apples (Rome, Stayman) 3
4 Carrots
Apples (McIntosh, Jonathan), peppers (12.5°C) 5 Cabbage, Brussels sprouts, cauliflower, chicory, persimmons nectarines, peaches, avocados (Fuerte, Hass), bananas, mangoes, papaya
6
Apples (Newtown) 7 Eggplants, green peas
8
9
Snap beans, peppers (5°C), green onions, cherries 10 Okra, cucumber, cantaloupes, summer squash, asparagus (5°C), onions, garlic, potatoes, olives
11
12
13
14 Avocados (Lula)
15 Broccoli, asparagus (2°C)
Kale, spinach, cherries, strawberries 20 Sweet corn, mushrooms, lima beans, Italian prunes, figs
80
100 Tree nuts
Source: A.A. Kader, UC Davis

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Modified and Controlled Atmosphere Storage

- CA & MA effects on commodities
  - Beneficial (optimum atmospheres)
    - Retards senescence (slows respiration, softening, compositional changes, *etc.*)
    - Inhibits ethylene biosynthesis
    - Reduces sensitivity to ethylene action
    - Alleviates some physiological disorders
    - Slows decay development (especially CO_2)

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Modified and Controlled Atmosphere Storage

- CA & MA effects on commodities
  - Detrimental (incorrect atmospheres)
    - Aggravates some physiological disorders
    - Causes irregular ripening
    - Results in off-flavor and off-odor (related to anaerobiosis/fermentation)
    - Increases susceptibility to decay
    - Stimulates sprouting and inhibits periderm formation in underground storage organs

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Modified and Controlled Atmosphere Storage

- Supplemental treatments
  - Prestorage high CO_2 to inhibit ripening and chilling injury
  - Ethylene removal ("scrubbing") to enhance CA effects
  - Use of carbon monoxide to inhibit discoloration and microbial growth
    - Very limited use in transport MA/CA of lettuce

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Modified and Controlled Atmosphere Storage

- Commercial CA storage
  - O_2 levels controlled by flame burners, catalytic burners or converters, membranes, or flushing with N_2
  - CO_2 added from pressurized gas cylinders
  - CO_2 removed by sodium hydroxide, water, activated charcoal, molecular sieve or $Ca(OH)_2$ (hydrated lime) scrubbers

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Modified and Controlled Atmosphere Storage

- Commercial CA storage
  - Remote gas measurements support feedback control of O_2 and CO_2 levels
  - Gas-tight rooms inhibit leakage, but require breather bags to compensate for pressure changes

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Controlled Atmosphere Storage Control System

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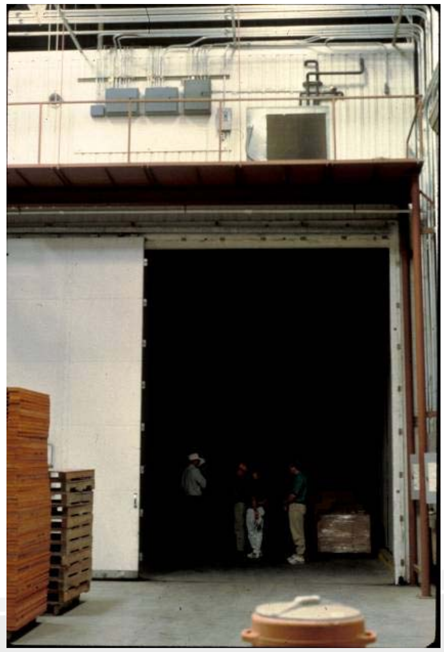
Controlled Atmosphere Storage Room



Breather bags

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Modified and Controlled Atmosphere Storage

- Commercial CA storage
  - Ethylene removed by potassium permanganate, activated/brominated charcoal, and catalytic or ozone scrubbers
  - Low pressure (hypobaric) systems reduce O_2 partial pressure and accelerate gas diffusion
    - Beneficial for ethylene; detrimental for water vapor

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Modified and Controlled Atmosphere Storage

- Transport MA/CA storage
  - MA in shipping cartons or pallets
    - *e.g.*, Banavac and Tectrol, respectively
  - MA or CA in trailers and containers (*i.e.*, truck and marine transport)
    - Membrane systems, N_2 flushing
    - CO_2 addition from cylinders; scrubbing with lime

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Banavac Carton MAP System

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Tectrol pallet MAP

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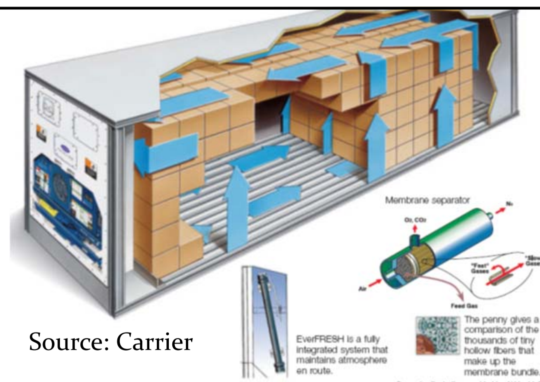
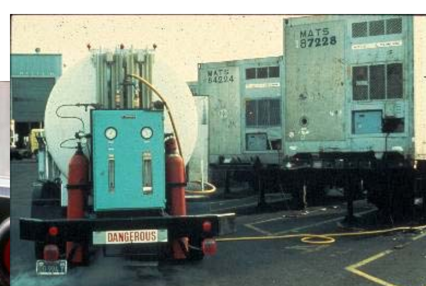
Marine Container CA/MA Systems



Source: Carrier



Source: Transfresh

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Modified Atmosphere Packaging

- Film permeability, film area, produce mass, and produce respiration rate interact to create a modified atmosphere
  - reduced O_2 levels (2-10%)
  - elevated CO_2 levels (1-15%)

$$CO_2^{pkg} - CO_2^{atm} = \frac{(CO_2\ production \times product\ weight \times film\ thickness)}{(film\ permeability\ to\ CO_2 \times film\ area)}$$

- Atmosphere may be actively or passively established

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Modified Atmosphere Packaging

Semipermeable Film

Microperforated Film

Carton Liner

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Fresh-cut Products

Semipermeable Film (MAP) Packages

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