

Apples, Controlled Atmosphere Storage

Revised 2018

Controlled atmosphere (CA) storage may be used to extend the storage life of apples. Varieties such as McIntosh are CA stored at 36°F (2°C) to control flesh browning and physiological flesh breakdown caused by chilling injury which develops in storage. Chilling insensitive varieties, such as Delicious and Rome, are CA stored at 30 to 32°F (-1 to 0°C). State Agricultural Experiment Station or cooperative extension specialists, or others depending on different countries, should be consulted for recommended concentrations of carbon dioxide (1 to 5%) and oxygen (1 to 3%) because recommended gas mixtures vary with the variety and the geographic area in which the variety is grown. CA recommendations for apples grown in one area may cause injury to the same variety grown in another area.

Lowering the Oxygen Concentration

An air-tight door is sealed in place after the air-tight CA room has been filled with apples. The oxygen in the room is lowered to the desired concentration generally by flushing the room with nitrogen gas from an external tank or from an air separator (hollow-fiber-membrane or pressure-swing-adsorption), which separates the oxygen from the nitrogen in the air. Generally, the more quickly the cooling and the low oxygen atmosphere are attained after harvest, the longer the duration of storage, and the better will be the condition of the CA apples after storage. Rarely, oxygen is lowered by fruit respiration by a fossil fueled atmosphere generator.

Maintaining the Desired Gas Concentrations

The desired oxygen concentration is maintained by adding either some air or some nitrogen to the CA room when needed. Excess carbon dioxide is removed from the atmosphere by chemical reaction with lime, adsorption onto activated carbon, permeation through silicone elastomer or hollow fiber membranes, or by slow flushing of the CA room with nitrogen gas. Removal of ethylene gas from the storage atmosphere by chemisorption or by catalytic oxidation has found limited commercial application for firmness retention of Empire apples and control of storage scald on Bramley's Seedling apples.

Technology

The technology for establishing and maintaining the desired atmospheres has changed significantly in the last 30 years or so. There has been a rapid increase in the use of air separators for quick establishment of the low oxygen atmosphere. Systems for automatic analysis and computer control of oxygen and carbon dioxide are commonly been used nowadays. Before proceeding with construction of a new CA warehouse facility, the latest advances in CA technology should be appraised by visiting the nearest state-of-the-art CA facility or getting support from experts and CA companies.

Storage Characteristics of Several Apple Varieties in Air and CA

Cultivar	Temperature control		Air storage life (months)	CA				
	(°F/°C)	Cooling rate *		CO ₂ %	O ₂ %	Storage life (months)	Rapid CA availability *	CO ₂ sensitivity
Braeburn	34/1	Stepwise	3-4	0.5	1.5-2	8-10	Slow	Sensitive
Delicious	32/0	Rapid	3	2	0.7-2	12	Rapid to Moderate **	
Empire	36/2	Slow	2-3	2-3	2	5-10	Slow	Sensitive
Fuji	32-34/0-1	Stepwise	4	0.5	1.5-2	12	Slow	
Gala	32-34/0-1	Rapid	2-3	2-3	1-2	5-6	Rapid	
Golden Delicious	32-34/0-1	Rapid	3-4	2-3	1-2	8-10	Rapid	
Granny Smith	34/1	Rapid	3-4	0.5	1.5-2	10-11	Slow	Sensitive
Jonagold	32/0	Rapid	2	2-3	1-1.5	5-7	Rapid	
Pink Lady	34/1	Slow	3-4	1	2	9	Slow	
* Cooling rate and rapid CA availability (O ₂ pulldown rates): Rapid = within 3 days; Slow = 5 to 7 days; Stepwise = 2-3 °C during loading, 2°C at sealing, and 1°C after 2 to 3 weeks of CA establishment.								
** Fruit for long term CA are recommended to use rapid CA, but water-cored fruit should be stored at high oxygen (2-2.5%) to prevent internal breakdown.								

1-methylcyclopropene (1-MCP), an ethylene inhibitor, can delay fruit softening, yellowing, respiration, loss of titratable acidity, and sometimes the reduction in soluble solids, as well as development of some physiological disorders, although volatile aroma compounds can also be inhibited. The U.S. EPA in 2002 approved this compound. The use of 1-MCP in combination with CA can further improve storability of fruits.

Precautions

Only apples of good quality and long storage potential should be cold-stored in controlled atmospheres. Immature or over mature apples should not be held in this manner. Rapid cooling and quick filling of the room are essential. Use storage scald control methods practiced in your area.

The atmospheres used in CA apple storage will not support human life. If inspection or repair is needed, aerate the room and then quickly reestablish the atmosphere after making the inspection and/or repairs.

CA Storage Disorders

CO₂ Injury	<p>Irregular, sunken, dry, pebbly patches of brown on the green skin of apples indicates the carbon dioxide was too high early in the CA season. This skin injury is aggravated by the presence of water on the fruit. There are also three forms of flesh carbon dioxide injury: one often begins as a discrete milk-chocolate browning between the core and the skin, where the brown tissue is firm, but not necessarily moist. Another form of carbon dioxide injury appears as cavities, sometimes surrounded by patches of discolored tissue. Finally, in Delicious apples there is often very premature mealiness without tissue browning.</p> <p>Control: Follow recommendations of the local State Agricultural Experiment Station or other extension authority, because varietal susceptibility to carbon dioxide injury varies with the fruit growing region and the recommended oxygen concentration used in CA.</p>
Low Oxygen Injury	<p>Symptoms of low oxygen injury include: skin lesions which are similar in appearance to soft scald; a purplish or bluish cast to red areas of the skin; clearly defined chocolate brown areas in the flesh; apples become very soft and split open. If the tainted flavor associated with low oxygen injury is not present, it may be difficult to distinguish low oxygen injury from high carbon dioxide injury.</p> <p>Control: Follow recommendations of the local State Agricultural Experiment Station because varietal susceptibility to low oxygen injury varies with the fruit growing region and the recommended CA temperature.</p>

NOTE: CO₂-related disorders have caused severe commercial losses in Braeburn and Empire apples when kept under poor circulation (e.g., in packed cartons) within a few weeks of harvest.

WFLO is indebted to Dr. Chris Watkins, Cornell University, Ithaca, New York, and Dr. Elhadi Yahia, Universidad Autonoma de Queretaro, for the review and revision of this topic.