Apples, Controlled Atmosphere Storage

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Controlled atmosphere (CA) storage may be used to extend the storage life of all varieties of apples. CA storage is a postharvest management practice based on manipulating the oxygen (O_2) and carbon dioxide (CO_2) concentrations in the fruit storage environment, at the optimum temperature and relative humidity, in order to maintain the quality and increase the postharvest life and shelf life of stored apple fruits. It is common that O_2 concentration is reduced, and CO_2 concentration is increased in the storage atmosphere from those commonly found in regular air (20 to 21% O_2 and 0.03% CO_2). Oxygen concentrations lower than the optimum and carbon dioxide concentration higher than the optimum can be very harmful to CA stored apples. Optimum temperatures vary slightly from one apple variety to another, but optimum relative humidity is similar.

In addition to manipulating and controlling O_2 and CO_2, ethylene concentration is maintained at the lowest possible temperature. CA reduces fruits metabolic activity (respiration), ethylene production, ameliorates physiological disorders such as chilling injury, and may reduce disease activity, among other possible advantages. 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 could develop in storage. Chilling insensitive varieties, such as Delicious and Rome, are CA stored at 30 to 32°F (-1 to 0°C). The State Agricultural Experiment Station, Cooperative Extension Specialists, and/or other related specialists depending on different countries, should be consulted for recommended optimum storage temperature, and concentrations of carbon dioxide (1 to 5%) and oxygen (1 to 3%). Recommended gas mixtures vary with the variety and the geographic area in which the apple is grown, as well as the fruit maturity at harvest. CA storage should be done immediately after fruit harvest. 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 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 condition the apples will be in after CA storage.

Maintaining the Desired Gas Concentrations

After lowering the oxygen concentration to optimum level, it is maintained by adding either some air (if the concentration is reduced) or some nitrogen (if the concentration is increased) 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. 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 now being commonly used. 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 to 34/0 to 1	Stepwise	4	0.5	1.5-2	12	Slow	
Gala	32 to 34/0 to 1	Rapid	2-3	2-3	1-2	5-6	Rapid	
Golden Delicious	32 to 34/0 to 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 pull-down rates): Rapid = within 3 days; Slow = 5 to 7 days; Stepwise = 2 to 3 °C during loading, 2°C at sealing, and 1°C after 2 to 3 weeks of CA establishment.								
** Fruit for long term CA is 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 action 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 reduced or 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 stored in controlled atmospheres. Immature or over mature apples should not be held in this manner. Rapid cooling, quick filling of the room, reducing the oxygen concentration as soon as possible and maintaining the lowest optimum temperature and the optimum relative humidity 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

CO_2 Injury	Irregular, sunken, dry, pebbly patches of brown on the green skin of apples indicate the carbon dioxide was too high early in the CA storage duration. 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. 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, the storage temperature and the recommended oxygen concentration used in CA.

Low Oxygen Injury	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. Control: Follow recommendations of the local State Agricultural Experiment Station, or other extension authority that creates reliable recommendations relating to controlling a low oxygen environment. By maintaining the optimum oxygen concentration, varietal susceptibility to low oxygen injury varies with the fruit growing region. The optimum temperature and optimum carbon dioxide levels vary as well.

NOTE: CO_2-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.

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