

A SUMMARY OF CA REQUIREMENTS AND RECOMMENDATIONS FOR VEGETABLES

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Conditions for the optimal storage of horticultural commodities are influenced by factors which include crop specie, cultivar, growing conditions, maturity, quality, temperature, relative humidity, packaging, and storage duration. Storage under controlled and modified atmospheres is influenced by the concentration of oxygen, carbon dioxide, ethylene and other gases. The response of pathogens to different storage conditions and altered levels of gases may differ from that of the commodity. Optimal CA conditions for retention of firmness or color may actually increase the virulence of some pathogens.

CA is only beneficial if one or more of the major storage factors is outside the recommended range. If the commodity retains high quality for one week at 0°C, CA storage would not increase quality, but only increase the cost of storing the product at 0°C for one week. However, if the commodity would be in transit for 4 weeks, or the temperature would be 5°C, CA could maintain higher quality and provide additional market life for the crop. Finding the optimal CA storage condition for a commodity is difficult because most factors are independent variables which interact with and influence the response of the commodity to the other storage factors. For a given crop, the influence of cultivar and growing conditions may alter its response to CA. Therefore, no one CA atmosphere comes close to being optimal under all conditions.

Since the last National CA Research Conference in 1982, there have been a large number of papers published on CA storage of horticultural crops. In a recently published index of references on MA for horticultural crops (Kader, 1985) a total of 362 references were listed that dealt with vegetables, fruits and nuts, and ornamentals. Of these references, 70% were on fruits and nuts, 25% on vegetables, and only 5% on ornamentals. While there were more vegetable commodities listed than fruit and nuts (27 vs. 20), there were more fruit and nut references because the latter had more references per commodity (12.75 vs. 3.37). This resulted from a few fruits and nuts contributing large numbers of references (Apples - 125, Pears - 28, Citrus - 24, berries - 14 and Kiwifruit - 12). These 5 groups contributed 203 references; over 80% of the fruit and nut references and over half (56%) of the total number of references. In comparison, only tomatoes - 21 and cabbage - 12 had more than 10 references.

From the preceding discussion, it is obvious that more research should be focused on determining optimal CA storage conditions for vegetables stored for extended times under traditional and exotic atmospheres using various packaging techniques. However, the diversity of anatomy, development, morphology, and physiology in vegetables makes this type of research time-consuming and difficult because under current practices optimal storage conditions are empirically determined in large factorial experiments. Even after 40 years of this type of intensive research on apples the optimum CA storage environment is still unknown for any one cultivar. Research in basic physiology, gas diffusion, and mathematical models to predict optimal CA storage conditions from a few commodity measurements should be investigated by researchers in this area. Some specific research topics that should be addressed are:

The influence of CA and MA on chilling sensitivity of horticultural crops.

Effect of pretreatment with high levels of carbon dioxide on chilling sensitivity of some vegetable crops.

The physiological basis for enhanced injury by the combination of low oxygen and high carbon dioxide.

Information of the relation between maturity, temperature, and optimum oxygen and carbon dioxide levels for long term storage.

Differences in resistance of tissue containing and lacking chlorophyll to high carbon dioxide and low oxygen injury.

The following tables contain a summary of CA requirements and recommendations for some selected vegetables. Data for these tables were taken from a number of sources listed in the Literature Cited section. Where there was limited data, or where the papers presented conflicting data, I evaluated the data and either did not include the vegetables in the list, or made an informed estimation of a beneficial CA environment. A survey of the tables will show that there are many gaps that need filling by additional research.

Ca is not recommended for the following vegetables: carrots, garlic, horseradish, and potatoes.

There is insufficient or conflicting data on the benefits of CA storage for the following vegetables: beets, eggplant, Lima beans, squash, sweet potatoes, and yellow snap beans.

A SUMMARY OF CA REQUIREMENTS AND RECOMMENDATIONS FOR VEGETABLES

Vegetable	Temperature ¹ (°C)	Atmosphere ²		Level of application
		% O ₂	% CO ₂	
Artichokes	0 (0 - 5)	2 - 3	2 - 3	Slight
Asparagus	2 (1 - 5)	Air	10 - 14	High
Beans, Green Snap	7 (5 - 10)	2 - 3	4 - 7	Slight
Processing	7 (5 - 10)	8 - 10	20 - 30	Moderate
Brassicas				
Broccoli	0 (0 - 5)	1 - 2	5 - 10	High
Brussels Sprouts	0 (0 - 5)	1 - 2	5 - 7	Slight
Cabbage	0 (0 - 5)	2 - 3	3 - 6	High
Cauliflower	0 (0 - 5)	2 - 3	3 - 4	Slight
Celeriac	0 (0 - 5)	2 - 4	2 - 3	Slight
Celery	0 (0 - 5)	2 - 4	3 - 5	Slight
Chinese cabbage	0 (0 - 5)	1 - 2	0	Slight
Cucumbers, fresh	12 (8 - 12)	1 - 4	0	Slight
Pickling	4 (1 - 4)	3 - 5	3 - 5	Slight
Leeks	0 (0 - 5)	1 - 6	5 - 10	Slight
Lettuce (Crisphead)	0 (0 - 5)	1 - 3	0	Moderate
Cut salad	0 (0 - 5)	1 - 3	0	High
Lettuce (Leaf)	0 (0 - 5)	1 - 3	0	Moderate
Melons				
Cantaloupes	8 (5 - 10)	3 - 5	10 - 20	Slight
Mushrooms	0 (0 - 5)	Air	10 - 15	Moderate
Okra	10 (7 - 12)	Air	4 - 10	Slight
Onions	0 (0 - 5)	0 - 1	0	Slight
Onions (Bunching)	0 (0 - 5)	2 - 3	0 - 5	Slight
Parsley	0 (0 - 5)	8 - 10	8 - 10	Slight
Pepper (Bell)	12 (8 - 12)	2 - 5	0	Slight
Pepper (Chili)	12 (8 - 12)	3 - 5	0 - 5	Slight
Processing	5 (5 - 10)	3 - 5	10 - 20	Moderate
Radish (Topped)	0 (0 - 5)	1 - 2	2 - 3	Slight
Spinach	0 (0 - 5)	7 - 10	5 - 10	Slight
Sweet corn	0 (0 - 5)	2 - 4	5 - 10	Slight
Tomatoes	12 (12 - 20)	3 - 5	2 - 3	Slight
Witloof Chicory	0 (0 - 5)	3 - 4	4 - 5	Slight

1 Optimum and usual and/or recommended range of temperatures. A relative humidity of 90-95% is usually recommended.

2 Specific CA recommendations depends on cultivar, temperature, and duration of storage.

Commodity: Artichokes

Temperature: 0°C, range expected 0 - 5°C

Cultivar:

Modified Atmosphere Considerations

	Decreased Oxygen	Increased Carbon Dioxide
Beneficial level	2 - 3%	2 - 3%
Benefits	Decreased weight loss & sensitivity to chilling	Decreased weight loss & sensitivity to chilling
Potential for benefits	Moderate	Moderate
Injurious level	Below 2%	Above 3%
Symptoms	Blackening of inner bracts and receptacle	Stimulates Papus development
Potential for injury	Moderate	Moderate
Commercial use or potential	CA storage of artichokes is not used in the USA. Most research on CA storage is done in Europe. There is limited data on commercial storage under CA.	

Remarks: A 2.5% oxygen and 2.5% carbon dioxide atmosphere produced injury in the bracts and receptacles of mature artichokes held for 2 weeks at 0°C.

Commodity: Asparagus

Temperature: 2°C, range expected 1 - 5°C

Cultivar:

Modified Atmosphere Considerations

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Decreased Oxygen	Increased Carbon Dioxide
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Beneficial level	Not beneficial 5 - 9% at 3 - 6 C 10 - 14% at 0 - 3 C
Benefits	None Enhanced tenderness, retention of green color & solids; retards soft rot
Potential for benefits	None High
Injurious level	Below 10% Above 15% at 0 - 3 C Above 10% at 3 - 6 C
Symptoms	Discoloration Increased elongation, weight gain, & sensitive to chilling & pitting
Potential for injury	Moderate Slight
Commercial use or potential	Commonly used for long distance transport of fresh asparagus from Western US.

Remarks: CA is only beneficial if spears are held for longer than 2 days at 2°C.

Commodity: Bean, Green Snap Temperature: 7°C, range expected 5 - 10°C

Cultivar:

Modified Atmosphere Considerations

	Decreased Oxygen	Increased Carbon Dioxide
Beneficial level	2 - 3% 8 - 10%	4 - 7% 20 - 30% for 24 hr
Benefits	Reduced color loss & less discoloration from mechanical injury	Reduced color loss & less discoloration from mechanical injury
Potential for benefits	Moderate	Moderate
Injurious level	Below 5%	Above 7% for long term
Symptoms	Off-flavors	Off-flavors
Potential for injury	Moderate	Moderate
Commercial use or potential	Useful for transport and holding of beans for processing.	

Remarks: Sulfur dioxide at 7,000 ppm for 30 sec reduced broken end discoloration (BED) resulting from mechanical injury.

Commodity: Brassicas -
Broccoli

Temperature: 0°C, range expected 0 - 5°C

Cultivar:

Modified Atmosphere Considerations

	Decreased Oxygen	Increased Carbon Dioxide
Beneficial level	1 - 2%	5 - 10%
Benefits	Reduces loss of green color	Reduces loss of green color, tenderizes stalks & retards decay
Potential for benefits	High	Moderate
Injurious level	Below 0.5%	Above 15%
Symptoms	Off-odors, can be lost upon aeration if slight	Persistent off-odors
Potential for injury	Moderate	Moderate
Commercial use or potential	Currently used during prolonged transit, potential for use in absence of ice, water loss minimized by plastic liners.	

Remarks: CA is only beneficial if storage is at 3°C or higher for 1 week or longer. If high carbon dioxide is used, oxygen should not be below 1%. If ice is not used, perforated plastic bags or liners should be used to reduce water loss. From 5 - 7% carbon monoxide has been used to maintain color and reduce decay.

Commodity: Brassicas - Temperature: 0°C, range expected 0 - 5°C
Brussels Sprouts

Cultivar:

Modified Atmosphere Considerations

	Decreased Oxygen	Increased Carbon Dioxide
Beneficial level	1 - 2%	5 - 7%
Benefits	Reduced yellowing	Reduced yellowing
Potential for benefits	Slight	Slight
Injurious level	Below 1%	Above 10%
Symptoms	Internal discoloration, off-odors	
Potential for injury	Moderate	Slight
Commercial use or potential	Limited commercial data on any storage under CA	

Remarks: CA is only beneficial if storage is at 5°C or higher without ice.

Commodity: Brassicas -
Cabbage

Temperature: 0°C, range expected 0 - 5°C

Cultivar:

Modified Atmosphere Considerations

	Decreased Oxygen	Increased Carbon Dioxide
Beneficial level	2 - 3%	3 - 6%
Benefits	Reduced color and trimming loss, inhibits root growth	Reduced rot, decay and sprouting
Potential for benefits	Good	Good
Injurious level	Below 2%	Above 10%
Symptoms	Increased sensitivity to freezing, off-flavors	Discoloration of inner leaves
Potential for injury	Slight	Moderate
Commercial use or potential	Only vegetable currently in large scale commercial CA storage, used prior to processing	

Remarks: Similar conditions are used for Red and Savoy cabbage. Optimal levels of oxygen and carbon dioxide are influenced by cultivar and storage duration. Relative humidity of 97 - 100% must be used.

Commodity: Brassicas -
Cauliflower

Temperature: 0°C, range expected 0 - 5°C

Cultivar:

Modified Atmosphere Considerations

	Decreased Oxygen	Increased Carbon Dioxide
Beneficial level	2 - 3%	3 - 4 %
Benefits	Maintained white curd, & green leaves; reduced weight loss, & curd spotting	Slight to none
Potential for benefits	Slight	Slight
Injurious level	Below 2%	Above 5%
Symptoms	Persistent off-flavor, & odor after cooking	Off-flavors, aeration removes slight damage; curd must be cooked to show symptoms
Potential for injury	High	Moderate
Commercial use or potential	Long term storage and transport, poor potential for CA over good air storage.	

Remarks: Any CA storage of cauliflower is dangerous because some low oxygen and/or high carbon dioxide injury is evident only after cooking.

Commodity: Celery

Temperature: 0°C, range expected 0 - 5°C

Cultivar:

Modified Atmosphere Considerations

	Decreased Oxygen	Increased Carbon Dioxide
Beneficial level	2 - 4%	3 - 5%
Benefits	Reduced respiration, senescence, and discoloration of mech. damaged tissue	Delayed development of decay
Potential for benefits	Slight	Slight
Injurious level	Below 2%	Above 10%
Symptoms	Off-odor, off-flavor	Internal discoloration, off-odor, off-flavor
Potential for injury	Slight to moderate	Moderate to high
Commercial use or potential	Slight, used in mixed loads under MA	None

Remarks: Benefit from reduced oxygen is slight, but so is the risk of injury. CA storage of celery is compatible with mixed loads of lettuce if no carbon dioxide is added. Increased carbon dioxide is of slight benefit, but its use renders loads incompatible with lettuce.

Commodity: Cucumbers (Fresh) Temperature: 12°C, range expected 8 - 12°C
 (Pickling) Temperature: 4°C, range expected 1 - 4°C

Cultivar:

Modified Atmosphere Considerations

	Decreased Oxygen	Increased Carbon Dioxide
Beneficial level	1 - 4% 3 - 5%	0% (Fresh) 3 - 5% (Pickling)
Benefits	Reduces senescence, respiration, & chlorophyll loss	None
Potential for benefits	Slight	None to slight
Injurious level	Below 1%	Above 5% at 8°C, Above 10% at 5°C
Symptoms	Breakdown, off-odors, & increased chilling injury	Increased softening, chilling injury, & surface discoloration & pitting
Potential for injury	Slight to moderate	Slight to moderate
Commercial use or potential	Slight for transit and holding	None

Remarks: Reduced oxygen levels lower the effect of ethylene-induced senescence in mixed loads. An atmosphere of 5% oxygen and 5% carbon dioxide at 1°C has been reported to be useful for holding fruit for pickling.

Commodity: Lettuce
(Crisphead)

Temperature: 0°C, range expected 0 - 5°C

Cultivar:

Modified Atmosphere Considerations

	Decreased Oxygen	Increased Carbon Dioxide
Beneficial level	1 - 3%	0%
Benefits	Reduces senescence, respiration, & physiological disorders	None
Potential for benefits	Slight to moderate	None
Injurious level	Below 1%	Above 2%
Symptoms	Breakdown at center	Brown stain
Potential for injury	Slight to moderate	Moderate to high, increases at low temp.
Commercial use or potential	Extended transit times in cross-country rail, or over-seas containers	Avoid accumulation in containers

Remarks: These CA recommendations are for atmospheres surrounding the tissue. Wrapping heads and packaging may significantly alter the gas composition near the tissue from that in the storage container. The gas-tightness of the container is critical in maintaining the atmosphere. Reducing ethylene accumulation is another important factor in successful CA storage of lettuce.

Supplemental CO is often added to the storage atmosphere. Leaf lettuce can sometimes be stored in atmospheres containing up to 12% carbon dioxide without injury. Modified atmospheres are no substitute for maintaining the recommended temperature.

These CA recommendations do not apply to packaged or shredded lettuce.

Commodity: Melons -
Cantaloupes

Temperature: 8°C, range expected 5 - 10°C

Cultivar:

Modified Atmosphere Considerations

	Decreased Oxygen	Increased Carbon Dioxide
Beneficial level	3 - 5%	10 - 20%
Benefits	Reduces ripening, respiration, & ethylene production	Reduces ripening, sugar loss & surface molds
Potential for benefits	Slight to moderate	Slight to moderate
Injurious level	Below 1%	Above 20%
Symptoms	Off-flavors & odors; impaired ripening	Off-flavors & odors; impaired ripening
Potential for injury	Slight to moderate	Slight
Commercial use or potential	Slight for transit and/or storage	Moderate for transit and/or storage

Remarks: Carbon dioxide above 10% produces a carbonated taste, but it is lost during subsequent air storage.

Commodity: Mushrooms

Temperature: 0°C, range expected 0 - 5°C

Cultivar:

Modified Atmosphere Considerations

	Decreased Oxygen	Increased Carbon Dioxide
Beneficial level	No value	10 - 15%
Benefits	None	Reduces cap opening & stipe elongation
Potential for benefits	None	Slight to moderate
Injurious level	Near 0%	Above 20%
Symptoms	Off-odors & off-flavors; stimulates cap opening & stipe elongation	Surface pitting
Potential for injury	Slight	Slight
Commercial use or potential	Doubtful	Slight for holding & transit

Remarks:

Commodity: Onions (Bulb)

Temperature: 0°C, range expected 0 - 5°C

Cultivar:

Modified Atmosphere Considerations

	Decreased Oxygen	Increased Carbon Dioxide
Beneficial level	0 - 1%	0%
Benefits	Reduces respiration & extends storage life	None
Potential for benefits	Slight	None
Injurious level	Below 0%	Above 10% for short term Above 1% for long term
Symptoms	Breakdown, off-odors	Accelerated softening & rots; putrid odor
Potential for injury	Very slight	Moderate
Commercial use or potential	Very limited for long term storage	None, avoid buildup

Remarks: Onions are very tolerant to low oxygen concentrations. Low relative humidity is essential for onion storage. CA is unlikely to be economical because onions can be easily stored for one year under refrigeration.

Commodity: Peppers (Bell) Temperature: 12°C, range expected 8 - 12°C

Cultivar:

Modified Atmosphere Considerations

	Decreased Oxygen	Increased Carbon Dioxide
Beneficial level	2 - 5%	0%
Benefits	Reduces respiration, ripening & ethylene production	None
Potential for benefits	Slight	None
Injurious level	Below 2%	Above 5%
Symptoms	Breakdown, off-odors	Calyx discoloration, internal browning, & increased softening
Potential for injury	Slight to moderate	Moderate to high, especially at 5 - 10°C
Commercial use or potential	Slight for transit and/or storage	None

Remarks:

Commodity: Peppers (Chili) Temperature: 12°C, range expected 8 - 12°C

Cultivar:

Modified Atmosphere Considerations

	Decreased Oxygen	Increased Carbon Dioxide
Beneficial level	3 - 5%	15 - 20% at 5°C 0 - 5% at 10°C
Benefits	Reduces respiration, ripening & ethylene production	Reduces chilling at 5°C, & retards decay
Potential for benefits	Slight	None at non-chilling temperatures, moderate at 5 C
Injurious level	Below 2%	Above 20% at below 5°C Above 5% at above 10°C
Symptoms	Breakdown, off-odors	Calyx discoloration, internal browning, & increased softening
Potential for injury	Slight to moderate	Slight
Commercial use or potential	Slight for transit and/or storage	None at 10 - 12°C, moderate at 5 - 8°C for up to 3 weeks storage before processing

Remarks:

Commodity: Sweet corn

Temperature: 0°C, range expected 0 - 5°C

Cultivar:

Modified Atmosphere Considerations

	Decreased Oxygen	Increased Carbon Dioxide
Beneficial level	2 - 4%	5 - 10%
Benefits	Reduces respiration, sugar conversion & senescence	Reduces molds on husks, & sugar & chlorophyll loss
Potential for benefits	Moderate	Moderate
Injurious level	Below 2%	Above 10%
Symptoms	Off-flavors & odors	Off-flavors & odors
Potential for injury	Slight to moderate	Slight to moderate
Commercial use or potential	Moderate for transit and distribution	Moderate to good for transit and/or storage

Remarks:

Commodity: Tomatoes

Temperature: Mature-green, 12 - 20°C
Turning, 10 - 15°C

Cultivar:

Modified Atmosphere Considerations

	Decreased Oxygen	Increased Carbon Dioxide
Beneficial level	3 - 5%	2 - 3%
Benefits	Reduces ripening, respiration & ethylene production and action	Retards ripening
Potential for benefits	Moderate	Slight
Injurious level	Below 2%, depends on length of exposure	Above 3% for mature-green Above 5% for turning, depends on length of exposure and temperature
Symptoms	Discoloration, uneven ripening, & off-flavors	Discoloration, softening, & uneven ripening
Potential for injury	Moderate	Moderate to severe
Commercial use or potential	Moderate potential to control ripening in transit, but the risk of injury may offset benefits.	

Remarks: Short term MA storage may have potential at above chilling temperatures. MA could be provided under pallet covers. Addition of 5% carbon monoxide to the optimal mixture of 4% oxygen and 2% carbon dioxide for mature green fruit, reduced decay, but it stimulated ripening and fruit stored longer than 7 days failed to develop full red color when ripened at 20°C.

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