CONTROLLED ATMOSPHERE STORAGE CONDITIONS FOR SOME OF THE MORE COMMONLY GROWN APPLE CULTIVARS

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This paper will attempt to outline controlled atmosphere (CA) conditions suitable for some of the predominant apple cultivars. Storage personnel were contacted at apple research centers throughout the world and asked about CA storage conditions employed in their area or country. The information received from these individuals as well as that from the literature was used in establishing storage conditions suitable for specific apple cultivars. Also included on the information sheets are the benefits and disadvantages in altering the concentrations of CO₂ and O₂, the problems encountered when injurious levels of either gas are used, and the commercial use of reduced O_2 or increased CO₂ in the storage atmosphere.

Somewhat different from that found in other areas was the use of unscrubbed atmospheres and higher storage temperatures in European storage facilities. An unscrubbed atmosphere is one in which the CO₂ content is controlled (5-10%) but not the O₂ level. Higher CO₂ levels are known to have an inhibitory effect on softening. The higher storage temperatures may reflect higher energy costs in European countries but it has also been suggested that they permit higher CO₂ levels in the storage atmosphere. Perhaps another reason for higher storage temperatures is a lower incidence of internal disorders prevalent in many of the European grown apples.

A trend towards lower oxygen 0_2 levels has taken place in the past few years. Many countries now recommend 2% 0_2 to improve firmness retention and reduce development of physiological disorders. The 'rapid CA' procedure introduced by Lau (23, 26) has gained wide acceptance particularily in the Pacific Northwest area.

Excellent results are achieved when prompt loading and fast pull-down times are utilized. Oxygen burners or nitrogen gas flushing are used to reduce the 0_2 to 2% or 3% within a short time. Very low levels of 0_2 (<2%) are either in commercial use or under intense investigation in many apple growing areas. Elimination of some disorders and almost total inhibition of softening are significant benefits derived from these ultra low levels of oxygen. It may be appropriate to designate atmospheres as ULO (ultra low oxygen, <2%) or HLO (hyper low oxygen, <1%), both terms suggested by Mr. C. Little of Australia. Responses to the questionnaire revealed the following commercial use of or research activities into low oxygen storage.

Australia: Commercial recommendations of 1-1.5% 02 for Jonathan, Granny Smith, Red Delicious and Golden Delicious are in effect. CO2 levels vary from <1-2% and are dependent upon the sensitivity of the cultivar to CO2 injury.

Canada: Red Delicious, Golden Delicious and Spartan apples are being stored in 1.5% and limited trials are underway with 1% 02. Research currently focuses on the effect of CO₂ with low levels of oxygen and on defining the lower limits of 02 for each cultivar. The unpredictable susceptibility of grower lots to low 02 injury currently precludes the use of 1-1.5% 02 for British Columbia-grown McIntosh apples. However, good results have been achieved in Nova Scotia and Ontario with 1-1.5% 02 storage of McIntosh, provided that proper maturity and nutritional aspects were met. Low oxygen storage of Idared, Spartan and Empire are being investigated in Ontario.

England: Cox's Orange Pippin are commercially stored in 1.25-1.5% 02.

France: Low 0_2 may be useful in storage of Granny Smith and red colored apples particularily where disorders such as scald in Granny Smith and internal browning in Delicious develop in a 3% $C0_2$ + 3% 0_2 atmosphere.

<u>Germany</u>: 0_2 levels of 1-1.5% 0_2 may be suitable for Cox's Orange Pippin, Boskoop and Gloster. However, problems of inadequate instrumentation and $C0_2$ scrubbing prevent its commercial application.

Holland: Research results with 1-2% 0₂ show good results with Gloster but higher flesh browning in Boskoop.

Israel: Preliminary work indicates potential use with Red and Golden Delicious.

Japan: Experimental work with Starking Delicious in 0.5-1% resulted in fermentation problems although good control of scald was achieved.

Poland: McIntosh, Idared and Spartan apples have responded favorably to 1-1.5% 0₂. No commercial recommendations are in effect.

South Africa: Commercial storage of Granny Smith, Red Delicious and Golden Delicious apples in 1.5% O₂ is being practised.

<u>U.S.A.</u>: Some commercial trials of 1-1.5% 0_2 with McIntosh have been attempted in Michigan and results have been mixed. Low 0_2 trials with McIntosh in New York and Massachusetts have usually led to unacceptable levels of internal injury. Encouraging results have been obtained in Vermont with 1% 0_2 storage of McIntosh apples. Excellent results have been achieved with Red and Golden Delicious apples in Washington State. Levels of 1.5% 0_2 are recommended and slightly higher storage temperatures are advocated with these low levels of 0_2 .

Several factors currently prevent the use of ultra-low 0_2 storage; poor room tightness, inability of commercial scrubbers to reduce $C0_2$ levels to 1% or lower, inadequate air circulation in rooms, and the susceptibility of some cultivars to $10w-0_2$ injury. Better constructed CA rooms, more sophisticated instrumentation and more efficient $C0_2$ scrubbers will resolve the mechanical problems but research will be needed to overcome the physiological problems. Of concern is the inability of $10w-0_2$ fruit to develop a strong varietal flavor, an important marketing tool with some cultivars. Nevertheless, $10w-0_2$ storage has enabled the industry to market their apples over a significantly longer period and also provide the consumer with a crisp and juicy product. An excellent review of low oxygen storage has been prepared by Blanpied (7).

An outline of CA storage conditions recommended for the more commonly grown apple cultivars is presented in Table 1. Sensitivity of these cultivars to 0_2 , $C0_2$ and temperature is shown in Table 2.

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Cultivar	Temperature (°C)	0 ₂ (%)	CO ₂ (%)
Belle de Boskoop	3 (3-4.5)*	2 (2-4)*	1 (0.5-3)*
Cox's Orange Pippin Delicious	3.5 (0.5-5)	2 (1.5-5)	1 (0-5)
(Red & Starking)	-0.5 (-0.5-5)	2(1.5-3)	1 (0-5)
Elstar	3 (0.5-3)	3 (2-4)	<1(1-4.5)
Empire	0 (-0.5-2)	2.5 (2-3)	3 (1-5)
Gala	0.5 (0.5-4)	2	2((1-2))
Gloster	0.5 (0-3)	3 (2-4)	3 (1-3)
Golden Delicious	-0.5 (-0.5-3.5)	<3 (1-4)	5 (<1-5)
Granny Smith	0 (0-3)	2 (1-3)	1 (0-3)
Idared	0 (-0.5-4)	3 (2-3)	5 (0.5-5)
Jonago1d	0 (-1-2)	3 (2-4)	5 (<1-5)
Jonathan	0 (-1-4)	2(1-4)	2(1-5)
Laxtons	2 (1.5-4.5)	3 (3-3.5)	3 (3-8)
McIntosh	3 (1-4)	3 (1-3)	5 (<1-5)
Mutsu	0.5 (-1-4)	3 (2-4)	2(1.5-5)
Rome Beauty	0 (-0.5-5)	2 (2-3)	2.5((1-3))
Spartan	0 (0-3)	2(1-3)	2.5((1-6))
Stayman	3 (0-5)	2 (2-3)	2 (<1-5)

Table 1. Controlled atmosphere (CA) storage conditions for the more commonly grown apple cultivars.

* Stated value and range (in brackets) derived from information received from the apple growing areas throughout the world.

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Temperature sensitive		CO ₂ sensitive	02 sensitive
Boskoop		Boskoop	Cox's
Cox's		Cox's	McIntosh
Elstar		Empire	
Granny Smith	n	Gloster	
Idared	(?)	Granny Smith	
Jonathan	•••	Jonathan	
McIntosh		McIntosh	
Mutsu	(?)		
Rome	(?)		
Stayman	(?)		

Table 2. Sensitivity of several apple cultivars to 0_2 , $C0_2$ and temperature.

CO ₂ tolerant	0 ₂ tolerant	
Delicious (Red & Starking)	Delicious (Red & Starking)	
Golden Delicious	Jonathan	
Jonagold	Golden Delicious	
Spartan	Spartan	

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(?) implies sensitivity in some but not all countries

, expected range:	3-4.5
REDUCED O2	
_	INCREASED CO2
	1% (0.5–3%)
firmness retention, higher acid levels, better taste; less scald, coreflush, and flesh browning	
moderate	slight
no data (probably 1%)	1% with 1-1.5% O2
flesh browning	coreflush 10% prestorage treatment caused CO ₂ injury
	moderate
1.25% under investi- gation in Holland	
	2% (2-4%) firmness retention, higher acid levels, better taste; less scald, coreflush, and flesh browning moderate no data (probably 1%) flesh browning 1.25% under investi- gation in Holland

- cultivar is susceptible to low temperature breakdown
- considered as CO₂ sensitive (CO₂ should be less than O₂)
- large fruit not suitable for CA storage HUUD :

- storage duration of 5-7 months

SELECTED REFERENCES:

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3, 38, 51, 52, 54, 59

COMMODITY: Apple	VARIETY: (if necessary) _C	ox's Orange Pippin
OPTIMUM TEMPERATURE: 3.5	, expected range:	0.5-5
	REDUCED O2	INCREASED CO2
Beneficial level:	2% (1.5-5%)	1% (0–5%)
Benefits:	retention of firmness, acidity, skin color, and flavor; reduction of core- flush, bitter pit and breakdown	increased flesh browning and core- flush with 3% CO ₂ and reduction in taste
Potential for benefit:	moderate	slight
Injurious level:	<1.25%	>1% with O2 at 1-1.5%, >5% with O2 at >2%
Injury symptoms:	corky flesh browning breakdown from alcohol accumulation; adverse flavor	
Potential for injury	high	moderate-high
Commercial use or potential:	stored commercially in 1.25% O ₂ in England	

REMARKS:	- susceptible to low temperature breakdown
	- considered CO ₂ sensitive
	- may be prone to coreflush in cool growing years
	- storage duration of 4-7 months

3, 12, 17, 38, 44, 49, 50, 52, 53, 56, 61

OPTIMUM TEMPERATURE:	-0.5 , expected range:	-0.5-5
	REDUCED O2	INCREASED CO2
Beneficial level:	2% (1.5-3%)	1% (0-5%)
Benefits:	retention of firmness and acidity; reduction of scald, flesh browning and core browning	retention of firmness
Potential for benefit	slight-moderate	slight to moderate
Injurious level:	<1%	>1% with low 0_2 >5% with higher 0_2
Injury symptoms:	flesh browning alcoholic taint	flesh browning; off flavors; 9% CO ₂ reduced firmness
Potential for injury:	slight to moderate	slight to moderate
Commercial use or potential:	commercial storage in 1.5% O ₂ in Australia, Washington State and Canada	
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COMMODITY: Apple VARIETY: (if necessary) Delicious (Red & Starking)

REMARKS: - considered CO₂ tolerant - will develop off flavors in Australia if O₂ falls below 1.5% for 10 days or more after 100 days of storage - storage duration of 7-11 months

SELECTED REFERENCES:

1, 9, 14, 16, 19, 24, 26, 29, 38, 39, 40, 41, 42, 43, 44

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COMMODITY: Apple	VARIETY: (if necessary)	Elstar
OPTIMUM TEMPERATURE: 3	, expected range:	0.5-3
	REDUCED O2	INCREASED CO2
Beneficial level:	3% (2-4%)	0-1% (1-4.5%)
Benefits:	overall quality, firmness retention	firmness retention
Potential for benefit:	moderate	
Injurious level:	<3%	>1%
Injury symptoms:	coreflush	CO2 injury, coreflush
Potential for injury:	moderate	
Commercial use or potential:		
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REMARKS: - susceptible to low temperature breakdown - considered CO_2 sensitive (CO_2 levels are lower than O_2 levels)

SELECTED REFERENCES:

12, 46, 44, 48

COMMODITY: Apple	VARIETY: (if necessary) <u>Empire</u>		
OPTIMUM TEMPERATURE:	, expected range:	-0.5 to 2	
	REDUCED O2	INCREASED CO2	
Beneficial level:	2.5% (2-3%)	3% (1-5%)	
Benefits:	firmness and acid retention		
Potential for benefit:	moderate		
Injurious level:		>5%	
Injury symptoms:		excessive CO2 injury	
Potential for injury:	low 02 injury encountered with 1.5% 02 if rapid CA not used	moderate	
Commercial use or potential:	1.5% O ₂ and rapid CA gave good results in trials at Cornell Univ. in N.Y. U.S.A.		
REMARKS: - may be temperatu - considered CO ₂ s - storage duration	re sensitive with low 02 ensitive of 5-7 months		

15, 36

COMMODITY: Apple	VARIETY: (if necessary)	VARIETY: (if necessary) Gala	
OPTIMUM TEMPERATURE: 0	.5, expected range	:	
	REDUCED O2	INCREASED CO2	
Beneficial level:	2%	2% (<1-2%)	
Benefits:	firmness retention		
Potential for benefit			
Injurious level:			
Potential for injury			
Commercial use or potential:	stored well at 1.5% O ₂ for 7.5 months in research trials at Maryland, U.S.A.		

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REMARKS: - storage duration of 8 months

SELECTED REFERENCES:

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INCREASED CO2 3% (<1-3%) oreflush; firmness kin color, ity, and higher CO2 levels
3% (<1-3%) oreflush; firmness kin color, ity, and higher CO ₂ levels
oreflush; firmness kin color, ity, and higher CO ₂ levels
higher CO ₂ levels
higher CO ₂ levels
higher CO ₂ levels
promote breakdown in fruit with watercore; coreflush in late stored fruit
tial 18-20% CO ₂ treatment helped firmness re- tention in Dutch trials

3, 46, 47, 48, 59

COMMODITY: Apple	VARIETY: (if necessary) Golden Delicious		
OPTIMUM TEMPERATURE:	-0.5 , expected range	: <u>-0.5 - 3.5</u>	
	REDUCED O2	INCREASED CO2	
Beneficial level:	<3% (1-4%)	5% (<1-5%)	
Benefits:	retention of firmness, acidity, and skin color; reduction of coreflush	firmness retention	
Potential for benefit:	high	moderate	
Injurious level:		>15%	
Injury symptoms:		typical external and internal CO ₂ injury	
Potential for injury		moderate	
Commercial use or potential:	commercial storage in 1-1.5% O ₂ in Australia, S. Africa, Washington State and Canada	as a pretreatment to air or CA storage but risk of CO ₂ injury precludes commercial applic- ability in most countries	

REMARKS: - considered as CO₂ tolerant

- is given a 16% CO_2 + 5% O_2 prestorage treatment in Australia

- storage duration of 7-11 months

SELECTED REFERENCES:

3, 12, 14, 15, 23, 24, 26, 27, 28, 29, 38, 39, 41, 42, 44, 54, 59, 60

COMMODITY: <u>Apple</u>	VARIETY: (if necessary) Granny Smith	
OPTIMUM TEMPERATURE:O	, expected range:	0-3
	REDUCED O2	INCREASED CO2
Beneficial level:	2% (1-3%)	1% (0-3%)
Benefits:	firmness retention greener skin color higher acid levels reduction of scald coreflush, core browning and flesh browning	
Potential for benefit:	moderate	
Injurious level:		> 1%
Injury symptoms:		coreflush
Potential for injury	slight-moderate	moderate-high
Commercial use or potential:	1-1.5% O ₂ used commercially in Australia and S. Africa	

- REMARKS: low storage temperatures increase coreflesh
 - considered O_2 sensitive ($O_2 < O_2$)
 - stepwise cooling recommended in Australia and France
 - low O₂ storage in Australia calls for reduction of 30% in DPA to reduce risk of coreflush
 - stress period of 10 days at 0.4% O2 used in Australia to prevent scald
 - storage duration of 5-8 months

8, 10, 14, 33, 34, 38, 45, 53, 57

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COMMODITY: Apple VARIETY: (if necessary) Idared		dared
OPTIMUM TEMPERATURE:), expected range:	-0.5 - 4
	REDUCED O2	INCREASED CO2
Beneficial level:		5% (0.5-5%)
Benefits:	quality; reduction of coreflush and breakdown; retention of skin color, acidity and firmness	firmness retention
Potential for benefit:		
Injurious level:		>5%
Injury symptoms:		internal CO ₂ injury may develop coreflush in 8% CO ₂ with long term storage
Potential for injury:		
Commercial use or potential:		

REMARKS: - is susceptible to low temperature breakdown

- considered somewhat sensitive to CO₂ and storage temperature
 develops poor taste in cool growing areas
 storage duration of 6-8 months

SELECTED REFERENCES:

18, 21

COMMODITY: Apple	VARIETY: (if necessary) Jonagold		·
OPTIMUM TEMPERATURE:), expected range:	-1-2	
	REDUCED O2	INCREASED CO2	
Beneficial level:	3% (2-4%)	5% (<1-5%)	
Benefits:			
Potential for benefit:			
Injurious level:			
Injury symptoms:			
Potential for injury:			
Commercial use or potential:			

- REMARKS: develops more internal disorders at lower storage temperatures in Holland

 - considered CO₂ tolerant late picks highly susceptible to flesh browning and have lower overall quality
 - has a short shelf life
 - storage duration of 5-8 months

4, 12, 46, 44, 48

COMMODITY: Apple	VARIETY: (if necessary)	Jonathan
OPTIMUM TEMPERATURE:	, expected range: <u>-1-4</u>	
	REDUCED O2	INCREASED CO2
Beneficial level:		2% (1-5%)
Benefits:	firmness retention, higher acid values; prevention of Jonathan spot and soft scald	reduction in Jona- than spot; firmness retention and skin color
Potential for benefit:	moderate	
Injurious level:	<1%	>3% with higher O ₂ levels >1% with lower O ₂ levels
Injury symptoms:	Jonathan spot	flesh browning, coreflush
Potential for injury:	slight-moderate	high
Commercial use or potential:	1-1.5% O2 is recommended in Australia	10 days of 20% CO ₂ was beneficial in Polish research trials

- stepwise cooling recommended in Australia

- stress period of 10 days at 0.4% O2 used in Australia prior to CA storage

- storage duration of 5-8 months

SELECTED REFERENCES:

5, 12, 22, 35, 38, 39, 41, 54, 57

OPTIMUM TEMPERATURE:	2, expected ran	ge: <u>1.5-4.5</u>
	REDUCED O2	INCREASED CO2
Beneficial level:	3% (3-3.5%)	3% (3-8%)
Benefits:		
Potential for benefit:		
Injurious level:		
Injury symptoms:		
Potential for injury:		
Commercial use or potential;	no low 02 studies conducted	

3, 12, 56

COMMODITY: Apple	VARIETY: (if necessary) McIntosh	
OPTIMUM TEMPERATURE: 3	, expected range:	<u>1-4</u>
	REDUCED O2	INCREASED CO2
Beneficial level:	3% (1-3%)	5% (<1-5%)
Benefits:	firmness retention, higher acid levels; reduction in coreflush and flesh browning	firmness retention with higher O ₂ and reduction of flesh browning
Potential for benefit:	moderate-high	moderate
Injurious level:	<2%	>5%
Injury symptoms:	corky flesh browning, breakdown; friction discoloration of skin	coreflush
Potential for injury:	moderate-high	moderate
Commercial use or potential:	limited commercial storage in 1-1.5% O2 in Nova Scotia, Ontario and Michigan	

SELECTED REFERENCES:

5, 6, 7, 11, 13, 20, 24, 30, 31, 32, 36, 37, 38, 41, 42, 43, 44, 59

COMMODITY: Apple	VARIETY: (if necess	ary) <u>Mutsu</u>
OPTIMUM TEMPERATURE:).5, expected	range: <u>-1 to 4</u>
	REDUCED 02	INCREASED CO2
Beneficial level:		2% (1.5-5%)
Benefits:		
Potential for benefit:		
Injurious level:		
Injury symptoms:		may develop core- flush in 8% CO ₂ with long-term storage
Potential for injury:		
Commercial use or potential:	-	no low 02 studies conducted
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REMARKS: - is somewhat sensitive to storage temperature in England - low temperatures may cause coreflush and breakdown - late picked fruit susceptible to senescent scald, alcoholic taint and short shelf life - storage duration of 6-9 months

SELECTED REFERENCES:

56, 58

COMMODITY: Apple	VARIETY: (if necessary) Rome Beauty	
OPTIMUM TEMPERATURE: 0), expected range	-0.5 to 5
<u></u>	REDUCED O2	INCREASED CO2
Beneficial level:	2% (2-3%)	2.5% (<1-3%)
Benefits:	firmess retention	
Potential for benefit:	low-moderate	low
Injurious level:		
Injury symptoms:		
Potential for injury:		
Commercial use or potential:	cultivar	no low 0 ₂ trials conducted with this

REMARKS: - susceptible to low temperature breakdown in some countries SELECTED REFERENCES:

38, 39, 41, 42

COMMODITY: Apple	VARIETY: (if necessary) Spartan	
OPTIMUM TEMPERATURE:	0, expected range	e: <u>0-3</u>
	REDUCED O2	INCREASED CO2
Beneficial level:	2% (1-3%)	2.5% (<1-6%)
Benefits:	firmness retention, higher acid values; reduction in breakdown and core browning	firmness retention
Potential for benefit:	moderate	slight
Injurious level:	<1%	>7% at higher O ₂ levels
Injury symptoms:	internal browning	flesh browning and breakdown
Potential for injury:	slight-moderate	slight-moderate
Commercial use or potential:	1.5% is being used in British Columbia and under investigation in Nova Scotia	

REMARKS: - large fruit susceptible to internal breakdown - storage duration of 6-10 months

SELECTED REFERENCES:

12, 21, 24, 25, 38, 39, 41, 42, 43, 44, 56

COMMODITY: Apple	VARIETY: (if necessary) Stayman	
OPTIMUM TEMPERATURE:3	, expected range: 0-5	
	REDUCED O2	INCREASED CO2
Beneficial level:	2% (2-3%)	<1 to 5%
Benefits:		
Potential for benefit:		low-moderate
Injurious level:		
Injury symptoms:		
Potential for injury:		
Commercial use or potential:	no low 0 ₂ studies conducted with the cultivar	

REMARKS: - considered susceptible to low temperature breakdown in Italy

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SELECTED REFERENCES:

2, 5, 38, 41