

## CONTROLLED ATMOSPHERE STORAGE OF APPLES AND PEARS DECEMBER 2001

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### INTRODUCTION

Controlled atmosphere (CA) storage recommendations for apples and pears have been surveyed on a worldwide basis since 1985 and have appeared as part of the proceedings for each International Controlled Atmosphere Research Conference.

This information was obtained by asking recipients of several e-mail mailing lists for input. The mailing lists used were the International Postharvest Mailing List (New Zealand), USDA Regional Project: NE 103 Postharvest Physiology of Fruits (USA and Canadian scientists) and the European Fruit Quality Group. Respondents were asked to submit information via a web site established for this purpose. Unfortunately, even following several requests for information, few scientists submitted information. I appreciate the information supplied by Ann Schenk (Belgium), Duncan Park and Tony Brown (New Zealand), Alex van Schaik (Netherlands), Kobus van der Merwe (South Africa), Paolo Bertolini (Italy), Robert Prange (Canada), Felix Lippert (Germany), Randy Beaudry, Elizabeth Mitcham, Bob Saftner and John Fellman (USA).

For each variety the survey included questions in five major areas:

- Range of atmosphere used
- Optimum levels of oxygen, carbon dioxide and temperature
- Scald susceptibility and control method
- Disorders brought on by low oxygen or high carbon dioxide
- Whether modified or CA shipping containers have been utilized.

### *Fresh Apple Consumption*

There are over 100 varieties of apples grown commercially in the USA, but 15 varieties accounted for over 90% of the production in 1999. The top 5 varieties for the USA and Europe are similar:

USA	Europe
1. Red Delicious	1. Golden Delicious
2. Golden Delicious	2. Red Delicious
3. Fuji	3. Jonagold
4. Granny Smith	4. Granny Smith
5. Gala and Royal Gala	5. Gala

The total fresh USA production for the 2000 crop was 142 million (20-kg) units. In 2000, 33 million units were exported from the U.S. and 9 million units were imported. The top producing states were Washington, New York, Michigan, California, Pennsylvania and Virginia.

In 1999, the average U.S. consumer consumed 8.7 kg of fresh apples and 9.7 kg of processed apples. On a national basis, 56% of the U.S.-produced crop was eaten as fresh fruit. Consumption of fresh apples in the U.S. has been declining since 1989, when consumption was 9.6 kg per person.

Is it possible that our postharvest methods of preservation have not met consumer expectations? Is enough attention paid to edible components of quality as we develop our CA recommendations? Washington state, whose growers have imposed the strictest grade standards in the United States, does not have shipping standards based on soluble solids or acid content, only on firmness and appearance.

***Fresh Pear Consumption***

The top 5 major pear varieties in the USA and Europe are:

USA	Europe
1. Anjou	1. Conference
2. Bartlett (Williams)	2. Williams
3. Bosc	3. Abate Fetel
4. Comice	4. Blanquilla
5. Seckel	5. Comice

**OPTIMUM LEVELS OF CA ATMOSPHERES**

Respondents provided information on the optimum levels for CA storage on the numerous varieties of apples (Table 1) and pears (Table 2). There is a range of optimum levels for each variety listed partly as a result of the intended marketing program in the region, regional climatic differences, different strains of a particular variety and the current level of technology available within a region. So, optimum levels for a particular variety are not necessary the result of research trials established to determine how long a variety can be stored, rather the result of horticultural, technical and marketing constraints.

**ATMOSPHERIC INDUCED DISORDERS**

**Low oxygen injury:** The respondents generally agreed that low oxygen injury to apples appears first as a loss of flavor followed by an alcoholic flavor generated by anaerobic fermentation. In some varieties the red area of the skin will turn purple and green areas will bronze. In some rare cases there will be flesh browning.

Pears manifest low oxygen injury in much the same way as apples—through anaerobic fermentation.

**High carbon dioxide injury:** The skin of the fruit will be rough and stained with a snowflake pattern on some varieties. The flesh of affected fruit will brown (internal browning) and in many cases will develop cavities. The core tissue may brown (coreflush) or develop lens-shaped pits.

Pears subjected to high carbon dioxide develop flesh browning and cavities.

### **COMMERCIAL STORAGE RISKS**

According to the responses from the survey, most varieties of apples have similar storage risks. Storage scald is the most common risk on most apple varieties, especially Cortland, Empire, Granny Smith, Jonagold, Pacific Rose, Pink Lady® brand, Red Delicious, Rome and Stayman.

Internal browning disorders are common to Braeburn, Empire, Fuji, McIntosh and Spartan.

Bitterpit is common to Cox's Orange Pippin, Golden Delicious, Jonagold and Northern Spy.

Short storage life is common to Gala, Elstar, Cox's Orange Pippin and Gravenstein. Firmness loss in storage is common to Elstar, Gala, Jonagold and Stayman, making these varieties also candidates for only short-term storage. Flavor loss in storage should also shorten storage life. Flavor loss is reported in Fuji, Gala, Golden Delicious, and Red Delicious.

In pears storage life is usually shortened by internal browning, skin yellowing or storage scald (Table 3).

In apples, the methods of controlling storage scald are the application of diphenylamine (DPA), storage in low oxygen (0.7%), delaying harvest, or initial low-oxygen shock. In pears, initial low oxygen (0.7%), ethoxyquin drench, or ethoxyquin imbedded in the paper wrapper are utilized to control scald.

### **SHIPMENT IN CA OR MA CONTAINERS**

Several apple and pear varieties have been shipped in CA containers from the Southern Hemisphere. Apples shipped in CA containers include Braeburn, Cox's Orange Pippin, Royal Gala, Golden Delicious, Jonagold and Pacific Rose. Beurre Bosc and Williams pears have been shipped from South Africa in CA containers.

Modified atmosphere containers have been used to ship Cox's Orange Pippin, Royal Gala, Golden Delicious apples and Williams pears.

### **EXPERIENCE WITH APPLES IN WASHINGTON STATE**

It is my observation, based on both research results and industry experience with CA storage that apple varieties can be divided into two types: those that are tolerant of high CO<sub>2</sub> and those that are not. Obviously, this is a broad generalization.

#### ***Carbon Dioxide Tolerant***

Gala and Golden Delicious are varieties in the CO<sub>2</sub> tolerant category. These varieties also benefit from rapid reduction of atmosphere. Rapid CA is valuable in that it helps retain fruit firmness and acidity better than slowly established CA on these varieties. Thus, fruit at moderate temperatures can be placed into a low oxygen environment rapidly without problems.

How rapid is rapid? This question has taken on new meaning as currently available equipment can remove oxygen more rapidly than ever before. Ten years ago, 'rapid CA' was defined as having the first harvested fruit in a room down below 3% oxygen within 7 days. Now several rooms can be filled each day and the oxygen is below 3% within hours of harvest. Fruit should be cooled to below 15 °C prior to lowering the oxygen level.

Non-spur Golden Delicious apples should be harvested at 7.3 kg firmness with a starch rating of 2.7 (1 to 6 scale), soluble solids at 11.5%, and acidity of 0.7% if they are to be held in long-term CA. The rate of change of starch and firmness, as well as the absolute numbers should be considered.

Current conditions do not permit profitable marketing internationally of Golden Delicious with green skin color. Skin color on Golden Delicious is often a reflection of the amount of nitrogen in the tree. Nitrogen levels above 2.15% (leaf analysis) will result in soft Golden Delicious with very green color. If fruit is to be stored in CA, only fruit from trees with moderate nitrogen levels should be selected. There is a temptation to allow Golden Delicious apples to hang longer to promote the change in skin color; these fruit are not suitable for CA.

Gala and Golden Delicious can be stored as low as 1.0% oxygen with CO<sub>2</sub> levels up to 2.5% at 1 °C. As the temperature is lowered below this point, the oxygen should be raised. Regular storage should be at 0 °C.

### ***Carbon Dioxide Intolerant***

Fuji, Braeburn, Granny Smith and Romes are those varieties in the CO<sub>2</sub> intolerant category. The cells appear to be dense and air circulation around the cells within the fruit is difficult.

These apples should have the flesh temperature close to the storage temperature before the oxygen is reduced. These varieties have a tendency for internal browning (e.g., Braeburn browning disorder [BBD]), which is associated with the natural predisposition of the apple (and other preharvest factors) as well as the storage regime. These varieties may develop less internal browning when the fruit has been treated with DPA prior to storage.

Carbon dioxide should remain well below the oxygen level at all times with these varieties. Temperatures should be held slightly elevated during CA storage. For example, fruit stored at 1.5% oxygen should be stored with CO<sub>2</sub> below 0.5% at 1 °C, if the fruit is not overmature at harvest. It is not advisable to store waxed fruit in boxes with polyliners in CA as this can hinder air circulation within the fruit.

Storage in regular atmosphere can be at 0 to 1 °C. The fruit should be subjected to good air circulation and not be in polylined boxes or waxed.

### ***Red Delicious***

Red Delicious, Washington's dominant apple variety, is somewhat CO<sub>2</sub> tolerant and is also tolerant of rapid CA. However, producers have not seen the dramatic positive effects of very rapid CA on Red Delicious that are seen on Golden Delicious or Galas. Storage operators should realize that this fruit softens more rapidly in a bin than on the tree so CA should not be delayed after harvest.

Red Delicious should be harvested at 7.7 kg firmness with the soluble solids at 10.0%, acidity at 0.270%, with a starch rating of 1.6 (1 to 6 scale) for long-term CA storage. Usually these fruits are postclimacteric with ethylene concentrations of 5 to 6 ppm. The rate of change as well as the absolute numbers should be considered.

Storage scald susceptibility decreases with maturity and cold nighttime temperatures. Scientists have determined the risk of scald decreases as temperatures below 10 °C accumulate within 3 to

4 weeks prior to harvest. Once 100 degree-day units below 10 °C have accumulated, scald should not be a problem if Red Delicious are treated with DPA.

Typical storage regimes for CA of non-watercored Red Delicious are 1.5% oxygen and up to 2.0% CO<sub>2</sub> at 0 to 1 °C. I have done trials using early season commercially harvested Red Delicious at 0.7% oxygen with good results. This low level of oxygen should never be used on watercored apples. Regular storage is usually at 0 °C or slightly below.

### ***Pears***

The dominant varieties of pears grown in Washington are Anjou, which is stored up to 9 months in CA, and Bartlett, which is stored up to 3 months in CA. Bartlett pears should be considered mature to harvest starting at firmness of 8.6 kg for CA storage and continuing to 7.7 kg for short-term storage. Anjou pears start at 6.8 kg firmness for CA storage and continue to 5.9 kg for short-term storage. Bosc pears start at 7.3 kg firmness for CA storage and continue to 6.4 kg for short-term storage. In all pears, it is important to monitor the starch level, because in certain seasons firmness will remain high for a time while the starch content changes. This starch change indicates a movement in maturity.

Pears must be at storage temperature before the oxygen is lowered. Anjou pears should be stored with the oxygen at least 1% higher than the carbon dioxide at all times, especially when the fruit is held at -0.5 to 1.0 °C. There has been some research that fruit stored at temperatures higher than 1 °C can tolerate higher CO<sub>2</sub> levels. In Steve Drake's (USDA-ARS) experiments with Anjou pears (1998 and 1999 crops), fruit stored with CO<sub>2</sub> levels 1% above the oxygen level had no internal browning, was greener, and had less skin marking than fruit stored at low CO<sub>2</sub> levels.

### ***CA Storage Summary***

In summary, for Washington state, CA regimes should take into account their effect on edible as well as visual quality. Successful storage in CA depends on the balance between temperature, oxygen and carbon dioxide. For example, at low levels of oxygen, more chilling damage may occur at higher temperatures. Many of the problems associated with fruit storage of certain varieties can be reduced when the fruit is near the storage temperature before the oxygen is reduced.

**Table 1.** Optimum levels for CA storage of apples.

Cultivar—apples	Country*	Optimum O <sub>2</sub> (%)	Optimum CO <sub>2</sub> (%)	Optimum temp (°C)	Storage life (months)
Belle de Boskoop	Netherlands	1.3	0.7	4.5 to 5	5.5
Braeburn	New Zealand	3	<1.0	0.5	6
	New Zealand	3	0.5	0.5	3 to 4
	South Africa	1.5	1.5	-0.5	8
	USA (WA)	1.5	0.5	0 to 1	10
Cortland (all strains)	Canada (NS)	1.5	1.5	3	8 to 10
	Canada (NS)	2.5	4.5	3	8 to 10
Cox's Orange Pippin	Netherlands	1.3	0.7	4	6.5
	New Zealand	2	<2.0	3.0	3
Elstar	Canada (NS)	2.5	4.5	0 to 0.5	no data
	Netherlands	1 to 1.2	2.5	1.8	7
Empire	Canada (NS)	2	0.5	2.0 to 2.5	8
	USA (MI)	1.5	<1.0	3.5	5 to 6
	New Zealand	2	<1.0	0.5	6
Fuji	USA (WA)	2.0	0.5	1	12
Gala	Canada (NS)	1.5	1.5	0 to 0.5	8
Royal Gala	New Zealand	2	2	0.5	4
	New Zealand	2	2	0.5	3 to 4
	South Africa	1.5	1.5	-0.5	7
	USA (WA)	2	1.5	0 to 1	7
Gloster	Canada (NS)	1.5	1.5	0 to 0.5	10
Golden Delicious	Belgium	2.5	1	0.5	9
	Canada (NS)	1.5	1.5	0 to 0.5	10
	Canada (NS)	2.5	4.5	0 to 0.5	10
	Italy	1	2	1 to 2	8 to 9
	Netherlands	1 to 1.2	4	1	8
	South Africa	1.5	2.5	-0.5	9
	USA (MD)	1.0	the lower the better	0	8 to 9
	USA (MI)	1.5	<3	0	6 to 8
	USA (WA)	2	1.5	0 to 1	9
Granny Smith	Italy	1	1	0	7 to 8
	New Zealand	2	2	0.5	6
	South Africa	1.5	1.5	-0.5 to +0.5	11
	USA (WA)	1.5	0.5	0 to 1	10
Gravenstein	Canada (NS)	1.5	1.5	3	4
Idared	Canada (NS)	2	0.5 to 1.5	0 to 3.0	10
	USA (MI)	1.5	<3	0	7 to 8
Jonagold	Canada (NS)	1.5	1.5	0 to 0.5	10
	Netherlands	1 to 1.2	4.5	1	9
Jonathan	USA (MI)	1.5	<3	0	5 to 6

Cultivar—apples	Country*	Optimum O <sub>2</sub> (%)	Optimum CO <sub>2</sub> (%)	Optimum temp (°C)	Storage life (months)
Lobo	Canada (NS)	2.5	4.5	3 to 3.5	no data
Macfree	Canada (NS)	2	2.5	0 to 0.5	~4
McIntosh	USA (MI)	1.5	<3	3.5	4 to 5
	Canada (NS)	1.5	1.5	3	8 to 10
	Canada (NS)	2.5	4.5	3	8 to 10
Marshall McIntosh	Canada (NS)	2.5	2.5	3	8 to 10
Moirra	Canada (NS)	2	2 to 2.5	0 to 0.5	<2
Mutsu	USA (MI)	1.5	<3	0	6 to 8
Northern Spy	USA (MI)	1.5	<3	0	7 to 9
	Canada (NS)	1.5 to 2	1.5	0 to 0.5	10
Nova Easygro	Canada (NS)	1.5	1.5	0 to 0.5	4
Novamac	Canada (NS)	2	2	3 to 3.5	4
Pacific Rose (Sciros)	New Zealand	2 (under review)	2 (under review)	0.5	10
Prima	Canada (NS)	2	2 to 2.5	3	<2
Priscilla	Canada (NS)	2	2 to 2.5	0 to 0.5	<2
Red Delicious	Canada (NS)	1.5	1.5	0 to 0.5	10
	Canada (NS)	2.5	4.5	0 to 0.5	10
	Italy	1	1	0/0.5	8 to 9
	New Zealand	1.5	1.5	0.5	6
	South Africa	1.5	2.5	-0.5	9
	USA (MI)	1.5 (may use 0.25% for 2 weeks)	<3	0	7 to 8
	USA (WA)	1.5	1.5	0 to 1	12
Rome	USA (MI)	1.5	<3	0	7 to 8
	Italy	2	2	1 to 2	7 to 8
Splendour	Canada (NS)	1.5	1.5	0 to 0.5	no data
Spartan	Canada (NS)	2.5	2.5	0 to 0.5	10
Spy (Novaspy)	Canada (NS)	2	2 to 2.5	0 to 0.5	10
Stayman	Italy	2	2	1 to 2	7 to 8

\* WA = Washington state  
 MD = Maryland state  
 MI = Michigan state  
 NS = Nova Scotia

**Table 2.** Optimum levels for CA storage of pears.

Cultivar—pears	Country*	Oxygen (%)	Carbon Dioxide (%)	Temp (°C)	Storage life (months)
Anjou	USA (WA)	1.5	0.3	-0.5 to 0	9
Beurre Bosc	South Africa	1.5	1.5	-0.5	4
Conference	Netherlands	2.5	0.7	-1	7.5
Doyenne du Comice	Netherlands	2.5	0.7	-0.5	5
	South Africa	1.5	1.5	-0.5	6
	New Zealand	2	<1	-0.5	3
Forelle	South Africa	1.5	0.0	-0.5	7
Josephine	South Africa	1.5	1	-0.5	8
Packham's Triumph	New Zealand	2	<1.0	-0.5	5
	South Africa	1.5	2.5	-0.5	9
Rosemarie	South Africa	1.5	1	-0.5	5
Williams Bon Chretien	South Africa	1	0.0	0.0 to -0.5	4
	South Africa	1	0.0	0.0 to -0.5	4
	USA (WA)	1.5	0.5	-0.5 to 1	4

\* WA = Washington state

**Table 3.** Commercial storage risks to pears from storage atmospheres.

Variety	Risk
Anjou	Skin yellowing, inability to ripen, storage scald, internal browning, skin marking
Beurre Bosc	Short storage life
Conference	Internal browning
Doyenne du Comice	Firmness loss, skin yellowing,
Forelle	Skin yellowing
Packham's Triumph	Storage scald, CO <sub>2</sub> injury
Williams (Bartlett)	Skin yellowing, mealy flesh, inability to ripen