



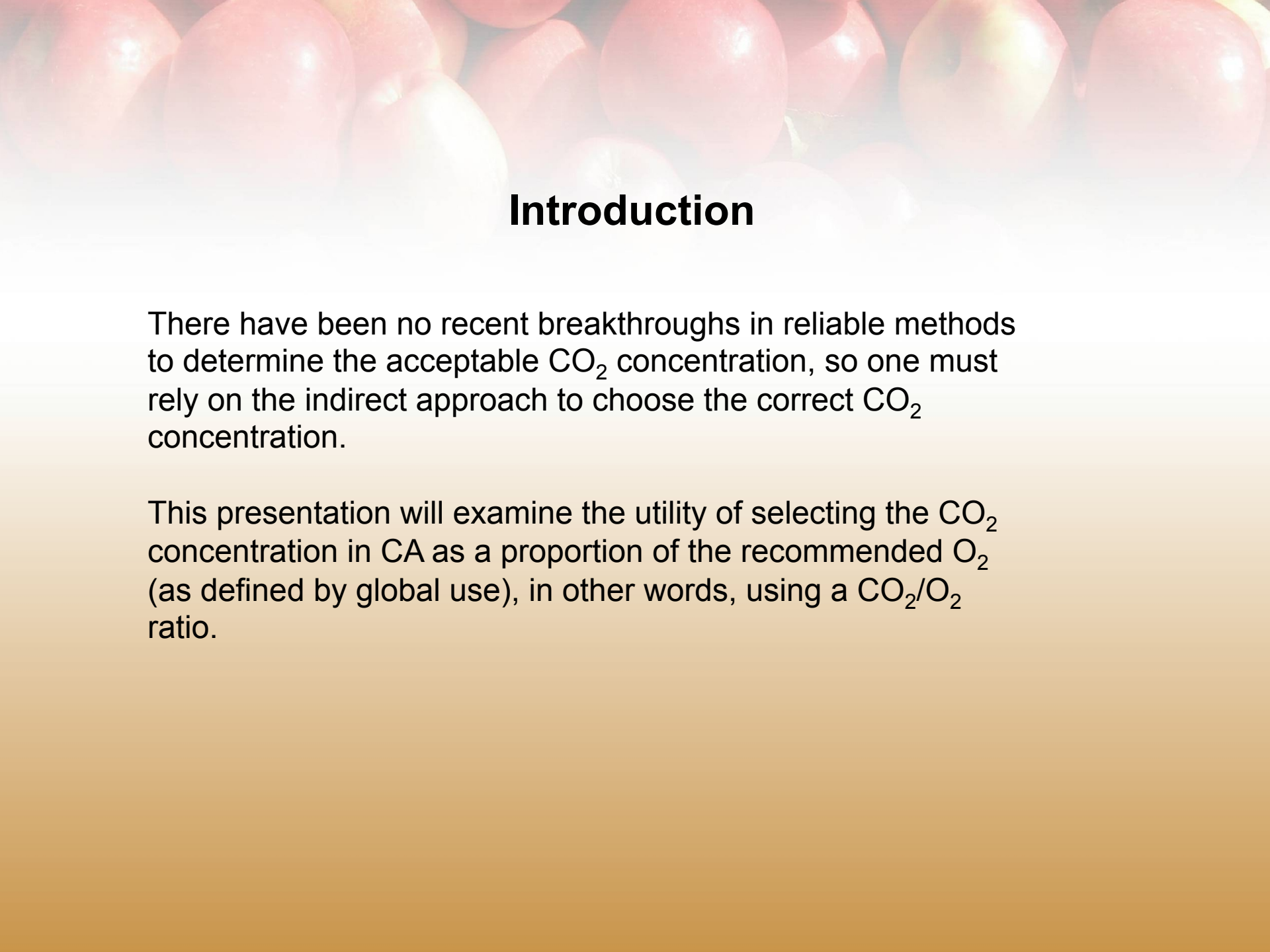
CO₂ in apple and pear storage

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Acknowledgement: I wish to acknowledge the assistance of Dr. Barbara Daniels-Lake for editorial and graphical assistance.

The background of the slide features a close-up, slightly blurred image of several red apples. The apples are clustered together, with some in sharp focus and others in the background being out of focus. The lighting is soft, highlighting the smooth texture and vibrant red color of the fruit. The overall composition is clean and visually appealing, providing a natural and healthy context for the presentation.

Introduction

There have been no recent breakthroughs in reliable methods to determine the acceptable CO₂ concentration, so one must rely on the indirect approach to choose the correct CO₂ concentration.

This presentation will examine the utility of selecting the CO₂ concentration in CA as a proportion of the recommended O₂ (as defined by global use), in other words, using a CO₂/O₂ ratio.

Why discuss CO₂/O₂ ratio?

Very fast cooling to
<1°C + big increase
in CO₂/O₂ ratio.



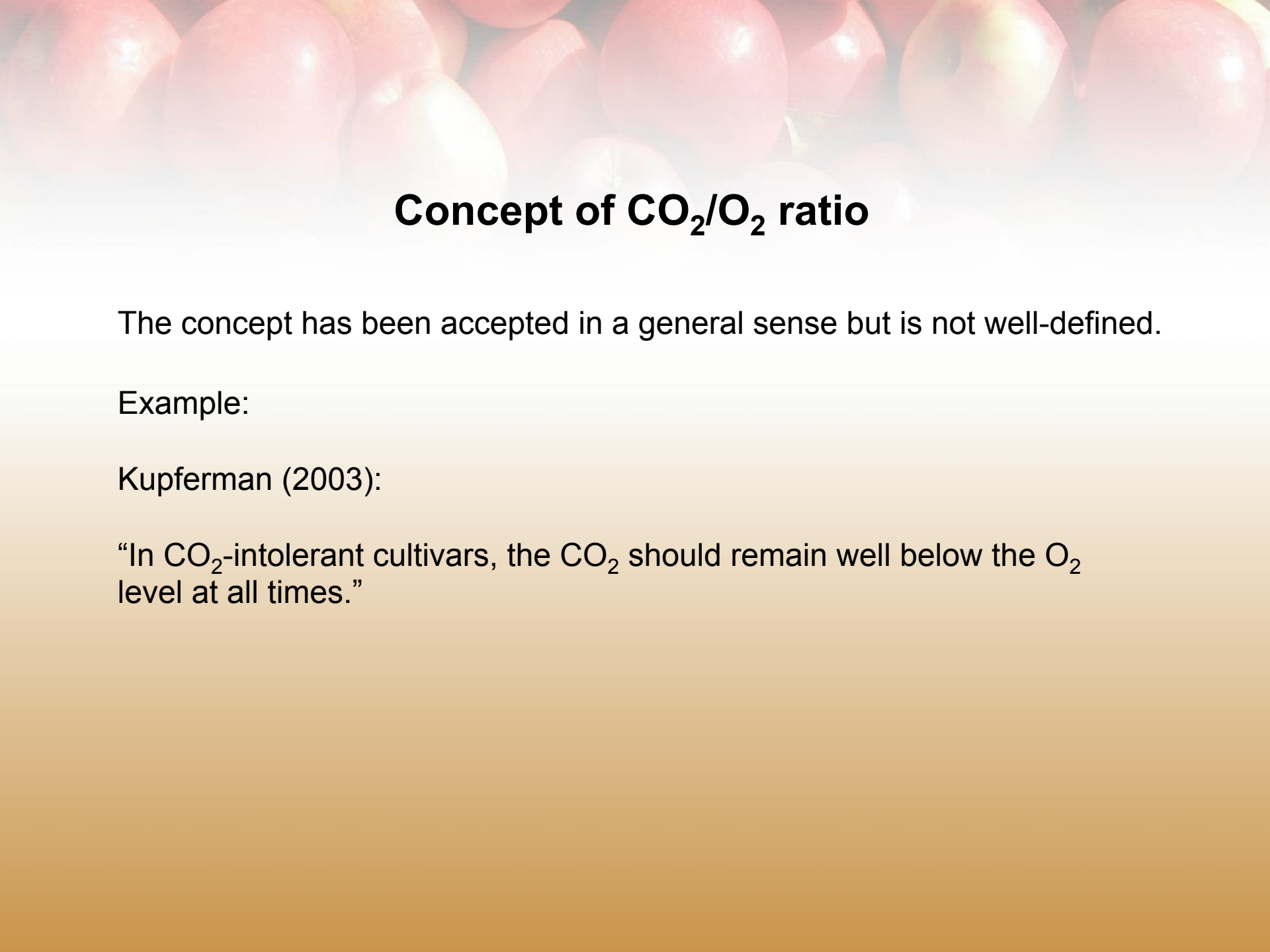
CO₂ damage on
Golden Delicious

Store Room with disorder		Store Room with no disorder	
Temp (°C)	Ratio: CO ₂ /O ₂	Temp (°C)	Ratio: CO ₂ /O ₂
1.3	.01		
1.4	.01		
3.7	.01		
4.4	.02		
4.8	.02		
2.0	.03		
1.0	.10		
1.0	.20		
0.8	0.67		
0.8	1.57	2.6	0.2
0.8	4.50	0.5	0.8
0.8	1.33	-.9	.16
0.7	1.33	-.8	.19
0.9	1.33	-.8	.26
0.7	1.17	-.8	.36
0.8	1.17	-.9	.56
0.9	1.17	-.8	.87
0.9	1.17	-.7	.79
0.8	1.33	-.8	.65
0.8	1.33	-.8	.68
0.8	1.17	-.8	.67



Last Summary of CA storage recommendations for apples and pears was at the 8th International CA Conference in 2001:

Kupferman, E. 2003. Controlled Atmosphere storage of apples and pears. *Acta Horticulturae* 600: 729-735



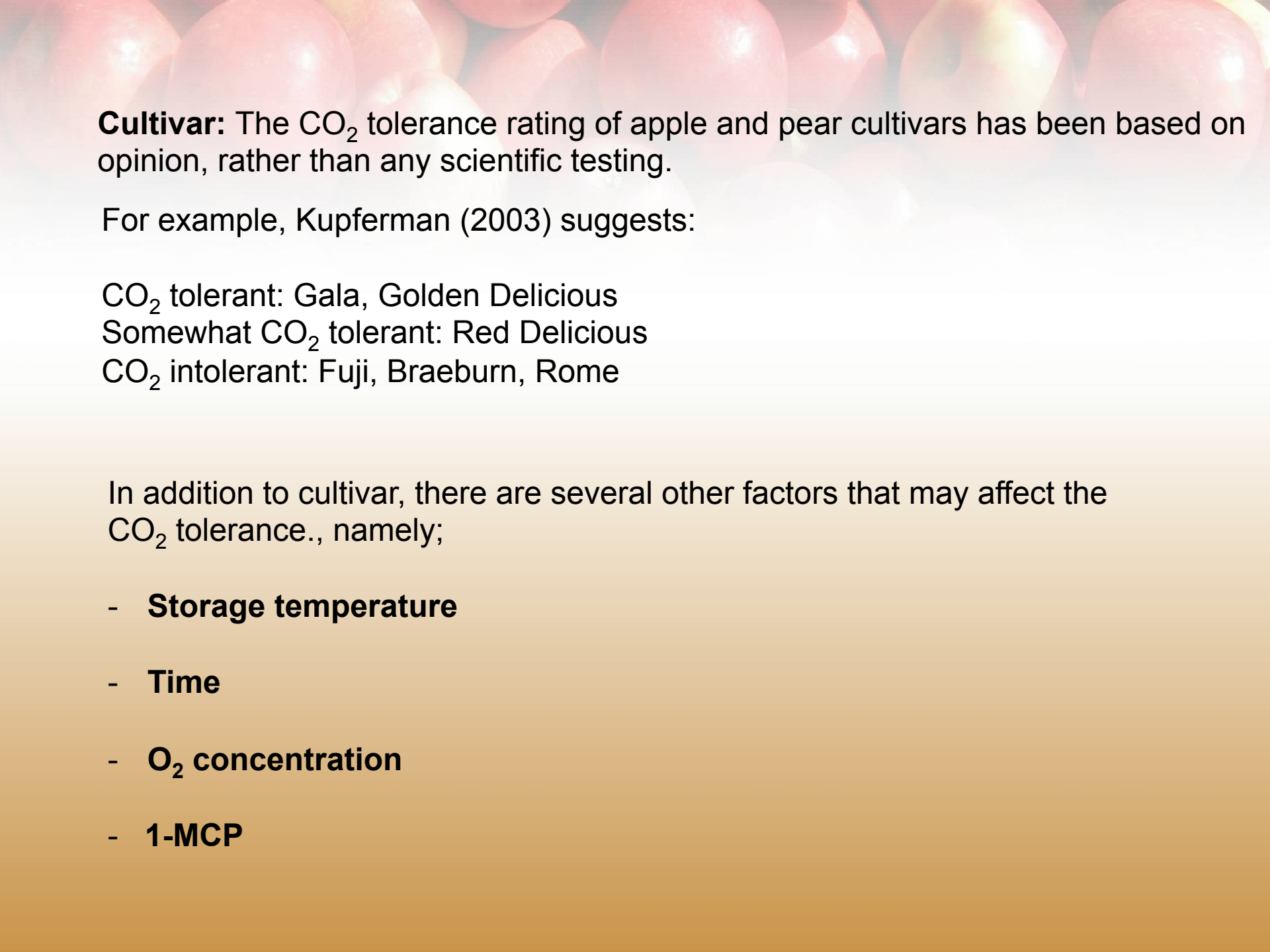
Concept of CO₂/O₂ ratio

The concept has been accepted in a general sense but is not well-defined.

Example:

Kupferman (2003):

“In CO₂-intolerant cultivars, the CO₂ should remain well below the O₂ level at all times.”



Cultivar: The CO₂ tolerance rating of apple and pear cultivars has been based on opinion, rather than any scientific testing.

For example, Kupferman (2003) suggests:

CO₂ tolerant: Gala, Golden Delicious

Somewhat CO₂ tolerant: Red Delicious

CO₂ intolerant: Fuji, Braeburn, Rome

In addition to cultivar, there are several other factors that may affect the CO₂ tolerance., namely;

- **Storage temperature**
- **Time**
- **O₂ concentration**
- **1-MCP**

Temperature: Temperatures that can cause chilling injury (e.g. $< 1^{\circ}\text{C}$) seem to cause more CO_2 – associated disorders.

Time: There is more low-temperature-induced CO_2 (high CO_2/O_2) damage at the beginning of storage (see example in the Introduction).

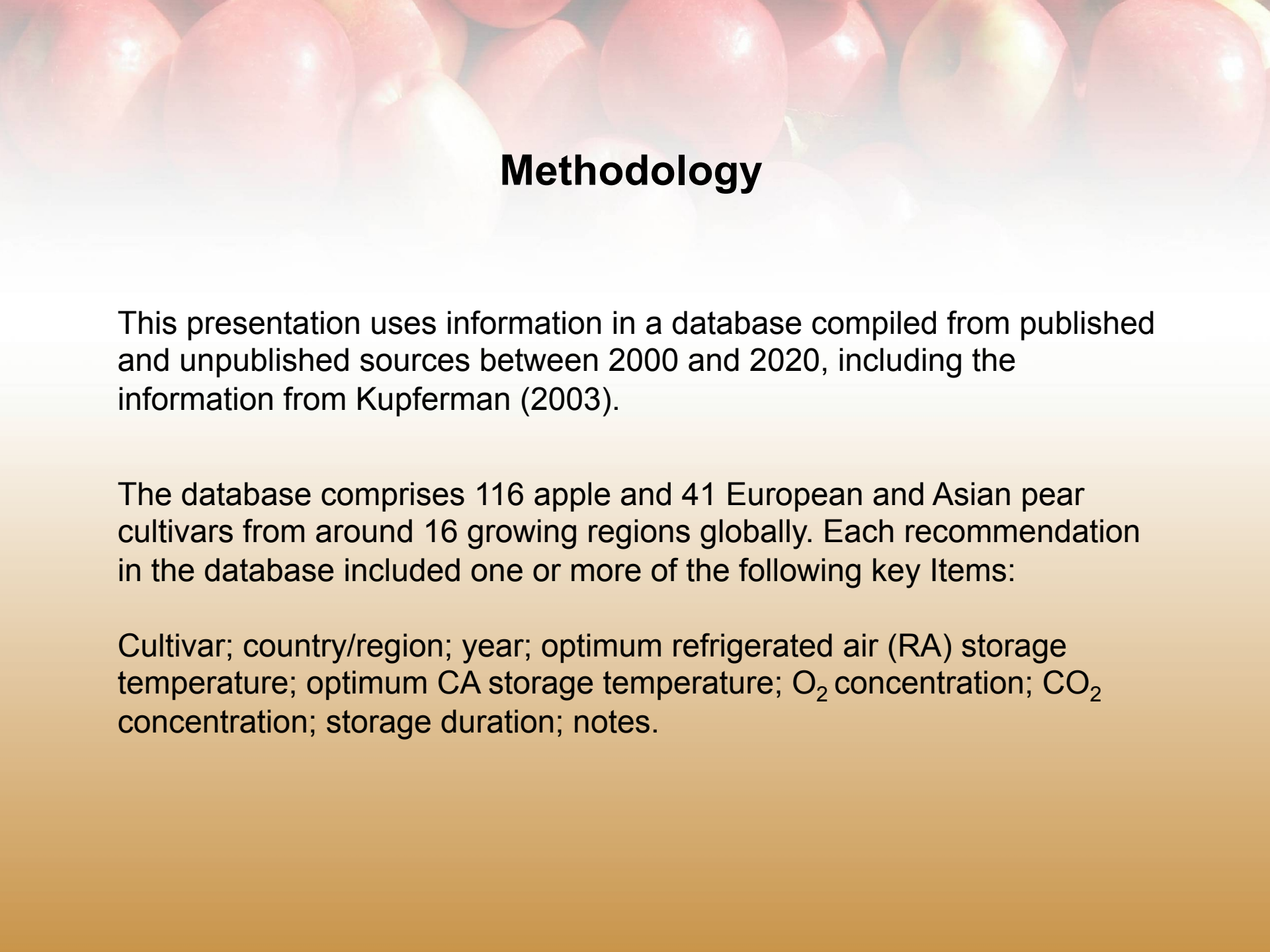
O_2 concentration: There is a general consensus that reducing the O_2 concentration increases the propensity for CO_2 damage, and therefore one must drop the CO_2 when the O_2 is lowered, implying the need to maintain a specific CO_2/O_2 ratio.

Example of a drop in recommended CO_2 with a drop in O_2 (Bramley's Seedling, UK):

<u>O_2 (%)</u>	<u>CO_2 (%)</u>
11-12	9-10
2	6
1	5

DCA (typically $<1\%$ O_2): Researchers and industry have assumed in DCA a further proportional lowering of CO_2 concentrations is necessary but this has never been extensively studied.

1-MCP: 1-MCP can increase CO_2 -induced disorders in CA.

The background of the slide features a close-up, slightly blurred image of several bright red apples. The apples are clustered together, with some in sharp focus and others in the background, creating a sense of depth. The lighting is soft, highlighting the smooth texture and vibrant color of the fruit.

Methodology

This presentation uses information in a database compiled from published and unpublished sources between 2000 and 2020, including the information from Kupferman (2003).

The database comprises 116 apple and 41 European and Asian pear cultivars from around 16 growing regions globally. Each recommendation in the database included one or more of the following key items:

Cultivar; country/region; year; optimum refrigerated air (RA) storage temperature; optimum CA storage temperature; O₂ concentration; CO₂ concentration; storage duration; notes.

Results and Discussion

For each cultivar:

Determined the mean O_2 and CO_2 recommendations

CO_2/O_2 ratio calculated using the mean CO_2 /mean O_2 for apples and pears and presented in separate tables.

Within each group, the cultivars are arranged in order from highest to lowest CO_2/O_2 ratio, and then divided into 7 categories based on this ratio:

Group 1) 1.5 or more (Very high CO_2 tolerance)

Group 2) 1.25 to 1.49 (Moderately high CO_2 tolerance)

Group 3) 1.00 to 1.24 (Slightly high CO_2 tolerance)

Group 4) 0.75 to 0.99 (Medium CO_2 tolerance)

Group 5) 0.50 to 0.74 (Moderately low CO_2 tolerance)

Group 6) 0.25 to 0.49 (Very low CO_2 tolerance)

Group 7) 0 to 0.24 (Extremely low CO_2 tolerance)

CO₂/O₂ ratios for the major apple cultivars in South Africa

1) CO₂/O₂ ratio = 1.5 or more (Very high CO₂ tolerance)

Cultivar	CO ₂ /O ₂ ratio	No. of Records
Golden Delicious	1.6	39

*

2) CO₂/O₂ ratio = 1.25 to 1.49 (Moderately high CO₂ tolerance)

Cultivar	CO ₂ /O ₂ ratio	No. of Records
Gala	1.3	48
Red Delicious	1.3	29

* These are global records

4) CO₂/O₂ ratio = 0.75 to 0.99 (Medium CO₂ tolerance)

Cultivar	CO₂/O₂ ratio	No. of Records
Granny Smith	1.0	24
Cripps Pink (Pink Lady)	0.9	18
Nicoter (Kanzi)	0.8	12
Cripps Red (Sundowner)	0.8	5

5) CO₂/O₂ ratio = 0.50 to 0.74 (Slightly low CO₂ tolerance)

Cultivar	CO₂/O₂ ratio	No. of Records
Fuji	0.6	19
Braeburn	0.5	25

CO₂/O₂ ratios for the major pear cultivars in South Africa

Group 3) CO₂/O₂ ratio = 1.00 to 1.24 (Slightly high CO₂ tolerance)

Cultivar	CO₂/O₂ ratio	No. of Records
Packham's Triumph	1.2	6

Group 4) CO₂/O₂ ratio = 0.75 to 0.99 (Medium CO₂ tolerance)

Forelle	0.8	9
Beurré Bosc	0.8	6

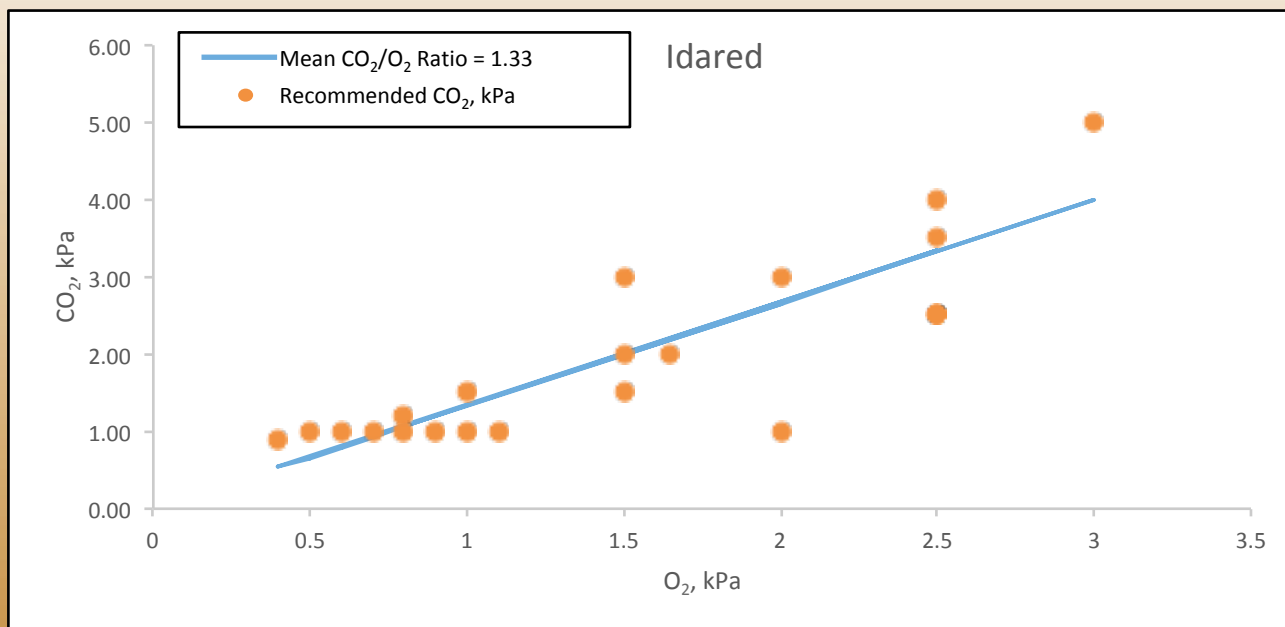
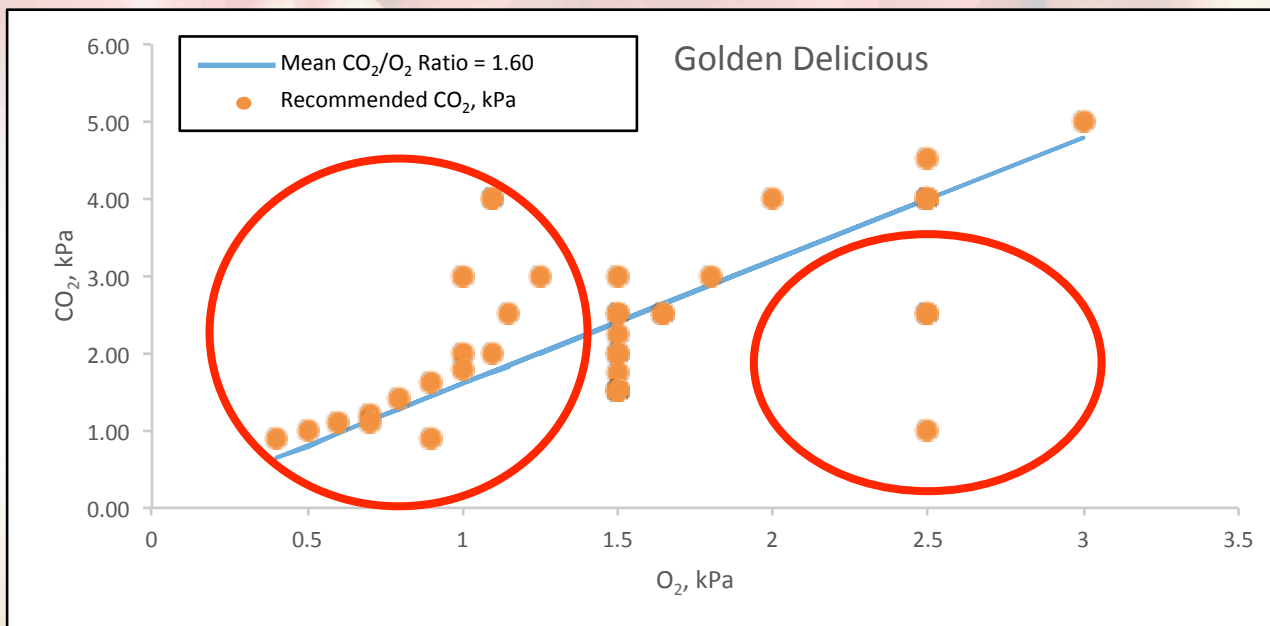
Group 5) CO₂/O₂ ratio = 0.50 to 0.74 (Slightly low CO₂ tolerance)

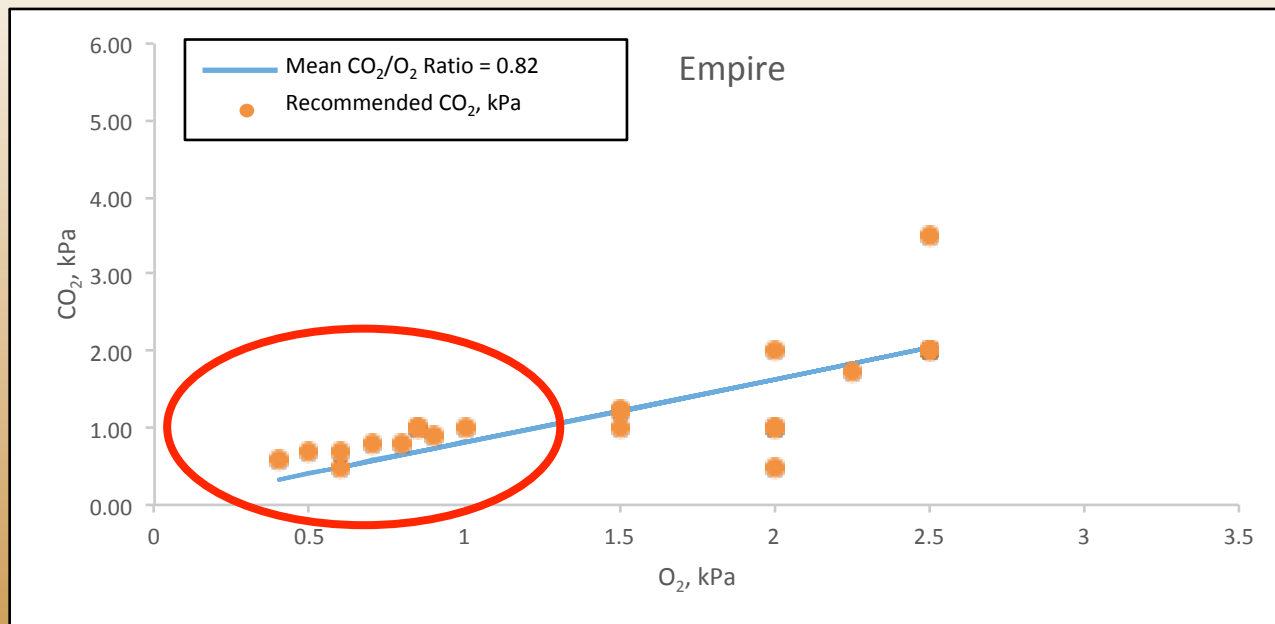
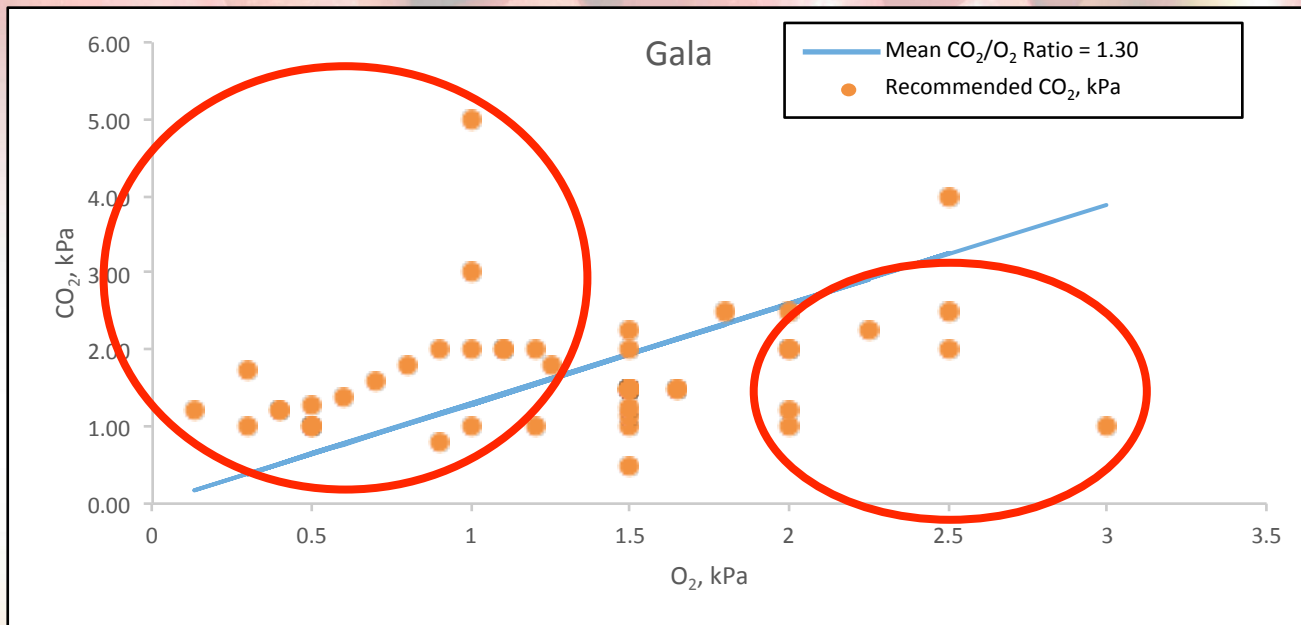
(Rosemarie	0.7	2)
Williams (Bartlett)	0.7	12

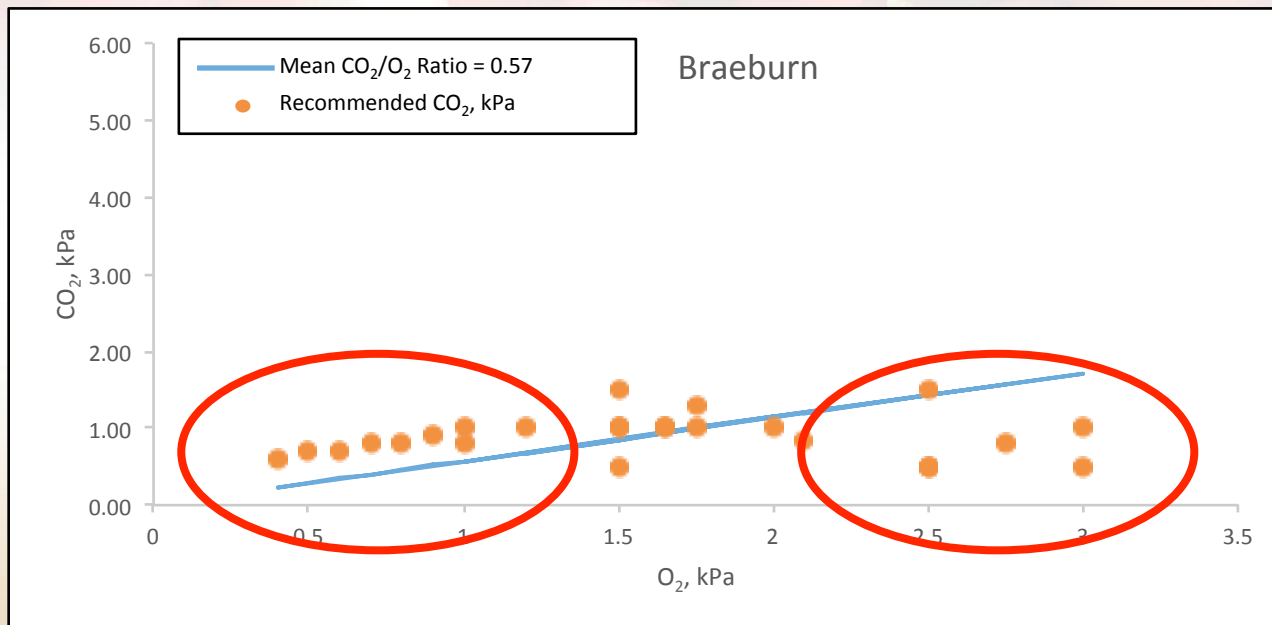
Group 6) CO₂/O₂ ratio = 0.25 to 0.49 (Moderately low CO₂ tolerance)

Abaté Fetel	0.5	5
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Effect of O₂ on recommended CO₂



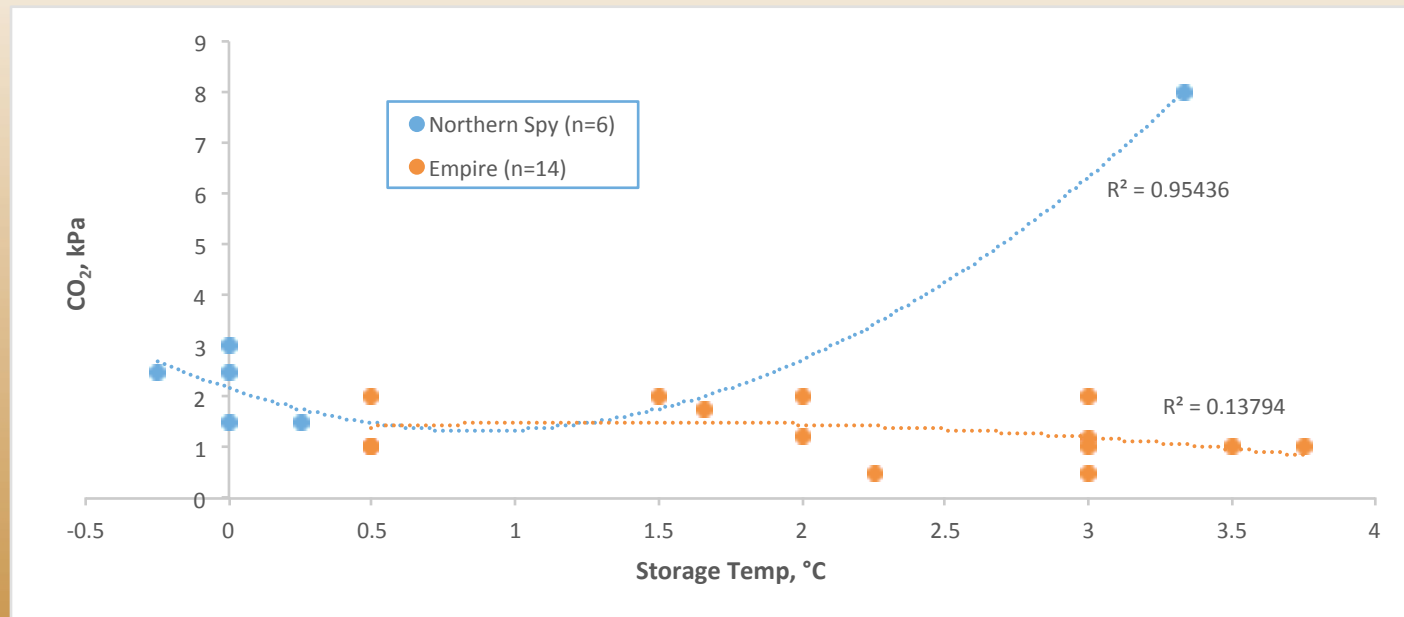
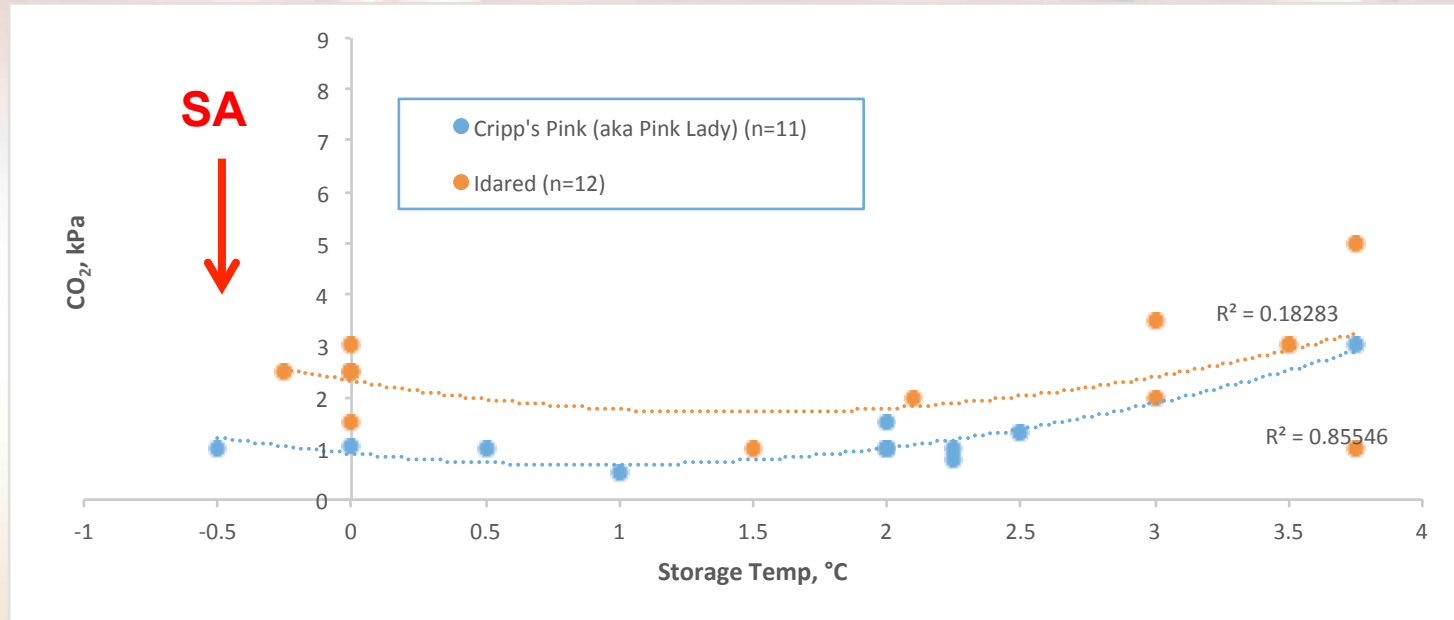


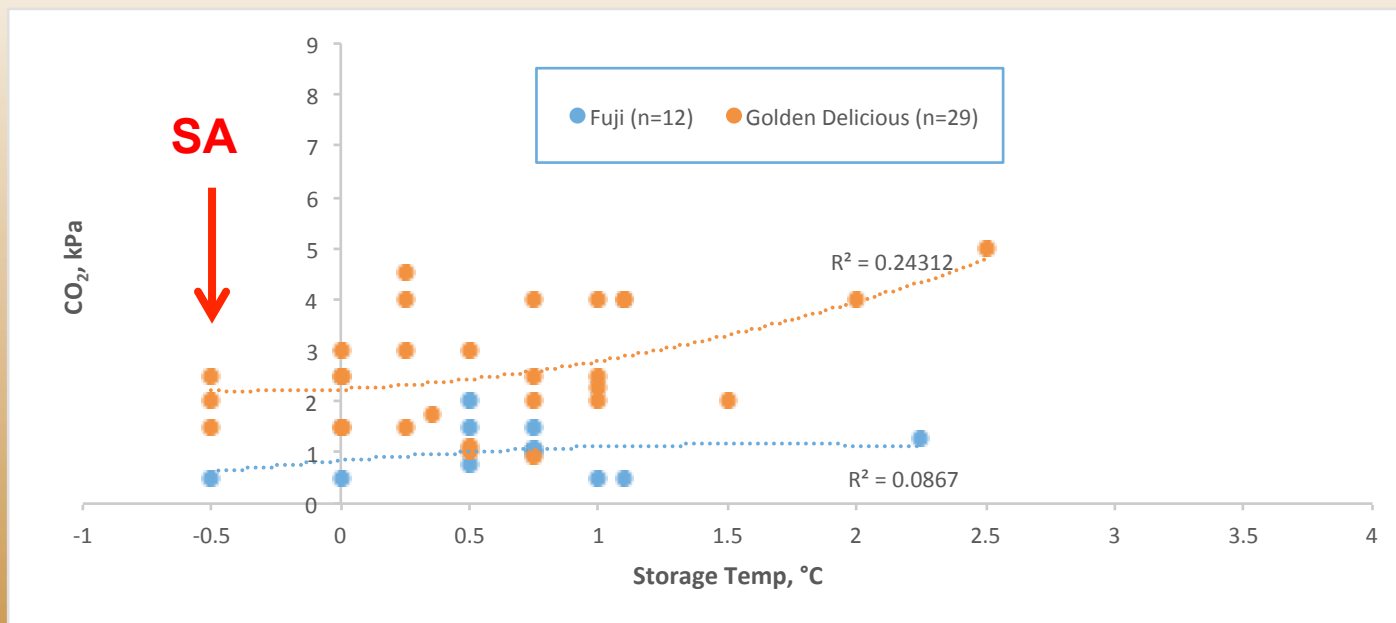
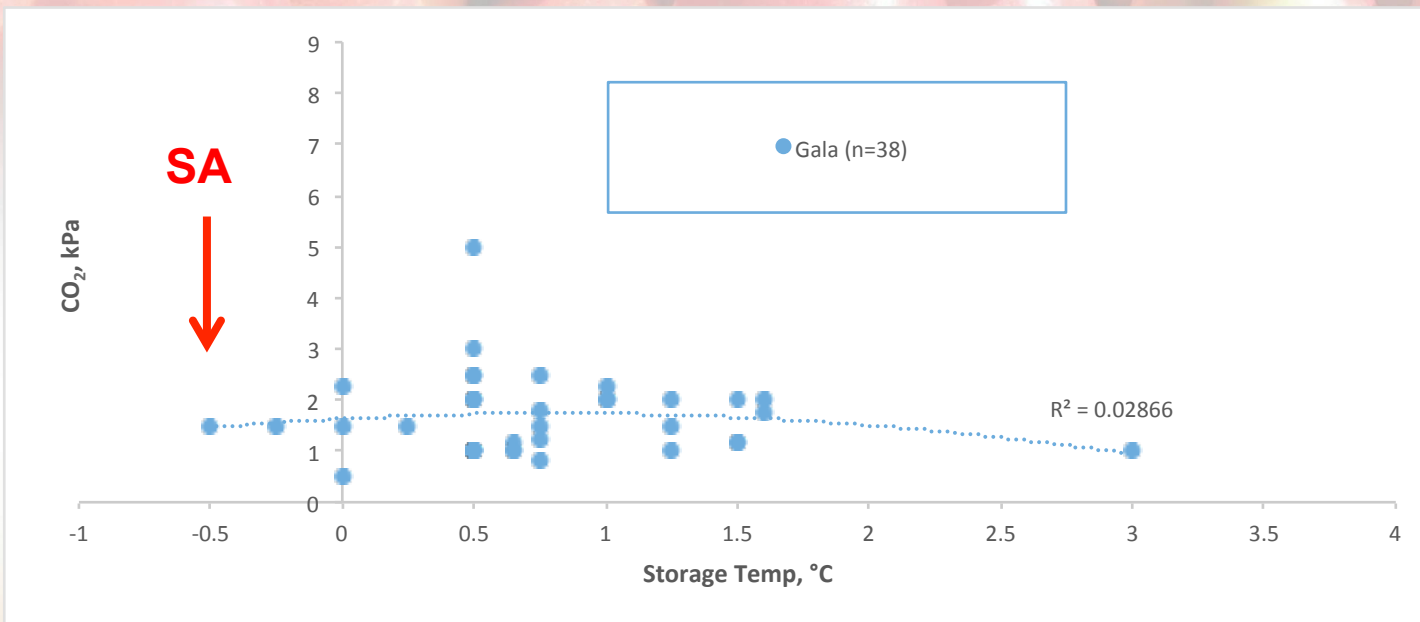


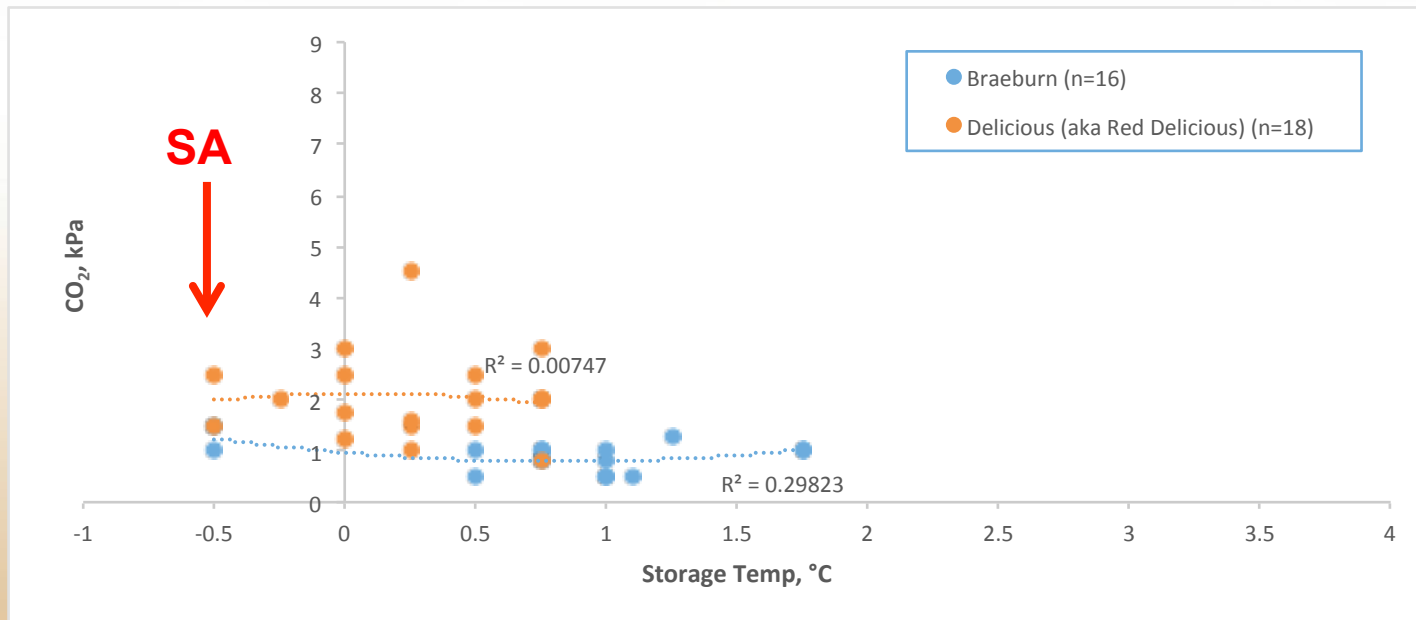
For more information on Storage Oxygen:

<https://harvestwatch.net/download/ca-storage-of-apples-and-pears-part-2-storage-oxygen-recommendations/>

Effect of storage temperature on recommended CO₂







For more information on Storage Temperature:

<https://harvestwatch.net/download/ca-storage-of-apples-and-pears-part-1-storage-temperature-recommendations/>

Effect of 1-MCP on the CO₂/O₂ ratio in CA.

This table is a first approximation based on a small number of recommendations that include both a CA recommendation without 1-MCP (CA only) and a CA recommendation if 1-MCP is applied before CA starts (CA + 1-MCP).

Cultivar	CO ₂ /O ₂ ratio		% CA plus 1-MCP of CA only
	CA Only	CA plus 1-MCP	
Bramley's Seedling	1.6	0.1	6%
Delicious	1.3	0.4	31%
Empire	0.8	0.2	25%
Gala	1.3	1.1	85%
Golden Delicious	1.6	0.4	25%
Honeycrisp	0.7	0.4	57%
Idared	1.3	0.4	31%
Jonagold	1.8	1.0	56%
McIntosh	1.6	0.2	13%
Nicogreen	2.7	2.2	81%
Northern Spy	1.4	0.8	57%
Mean			42%

Final Thoughts

If no history of CO₂ damage – do not consider any changes.

If there is a history of CO₂ damage, consider one or more of the following:

- Scrub CO₂ during loading and cooling, e.g. activated carbon and/or lime
- Scrub CO₂ during O₂ pull-down.
- In CA, control CO₂ levels according to the CO₂/O₂ ratio for a specific cultivar.
- In DCA (<1% O₂), there is evidence that the CO₂/O₂ ratio can be higher than in standard CA (>1 % O₂).
- If 1-MCP is applied before CA, delay CA and/or reduce the CO₂/O₂ ratio in CA to <50% of the ratio in CA alone.