Project title:	Optimising the rate of establishment of Controlled Atmosphere storage of Bramley's Seedling apples
Project number:	TF 199
Project leader:	Dr Richard Colgan
Report:	Annual report, October 2012
Previous report:	None
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Location of project:	Post Quality Centre East Malling Research New Road East Malling, Kent ME19 6BJ
Project coordinator:	TBA
Date project commenced:	1 July 2011
Date project completed (or expected completion date):	30 June 2013
Key words:	Apple, Bramley's Seedling, Storage, CA storage, Nectria

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AUTHENTICATION

We declare that this work was done under our supervision according to the procedures described herein and that the report represents a true and accurate record of the results obtained.

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GROWER SUMMARY

Headline

- Progress is being made in identifying optimum establishment techniques for controlled atmosphere storage of Bramley.

Background and expected deliverables

Scrubbed low oxygen storage (5% CO_2 + 1% O_2) (5/1 CA) has resulted in major improvements in storage quality of Bramley's Seedling apples particularly in the control of bitter pit and superficial scald. The use of 'SmartFresh^{TM}' (1-MCP) or ethylene scrubbing is widespread and provides further scald control. A disadvantage of 5/1 CA with either SmartFresh^{TM} or ethylene scrubbing is the propensity for carbon dioxide injury to develop. To avoid this, it is recommended that establishment of CA conditions for SmartFresh^{TM}-treated fruit is delayed for three weeks. Concerns regarding the ability of stores to achieve rapid establishment of 5/1 CA after this initial delay has prompted many growers to adopt a procedure whereby stores are sealed immediately and carbon dioxide is scrubbed while oxygen concentrations are allowed to drop to 10% for 21 days before 5/1 conditions are established. An optimum strategy has not however been established.

This project therefore seeks to determine an optimum strategy to control CO_2-injury while maintaining background colour, firmness, bitter pit and scald control in long-term stored Bramley's. Bramley's stored long-term are also susceptible to high numbers of core rots (up to 8-10% losses). More rapid establishment of CA may lead to a reduction in the incidence of core rots.

In addition to low oxygen storage, approximately 40% of the UK's Bramley's Seedling Crop is stored in traditional gas ventilated 9% CO_2, 12% Oxygen (9/12) stores. With the loss of the antioxidant diphenylamine (DPA) to control scald, growers are restricted to treating Bramley's with SmartFresh^{TM} to reduce the development of superficial scald on long-term stored fruit. Currently, a delay of three weeks in the establishment of CA conditions is recommended to avoid the development of CO_2-injury. Such a delay in CA conditions will often result in loss of quality during the storage season. The identification of a strategy to allow stores to be sealed earlier will help to improve the quality of fruit stored in the 9/12 regime.

Summary of the project and main conclusions

5/1 Stores

CA stores of Bramley's sealed immediately after fruit has cooled to store temperature (4-4.5°C) are best established through existing industry protocols; allowing oxygen to drop to 10% O_2 during the first three weeks of storage, and thereafter allowing store oxygen to drop to 1% O_2.

In cases where sealing of stores has been delayed by five days from harvest, an increase in the incidence of internal carbon dioxide injury and core-flush was observed during long-term storage.

Preliminary results from the first year of the project have shown that rapid pull down of oxygen from 21 to 1% over three weeks helped to reduce the incidence of **internal** browning caused by CO_2-injury where store sealing was delayed by five days from harvest. **However, it is important to note that rapid pull down of oxygen from 21% to 1% O_2 on early harvested Bramley's is likely to increase the risk of external CO_2-injury.** This work requires further development before the benefits to industry can be properly evaluated.

9/12 Stores

Delaying sealing of SmartFresh^{TM}-treated Bramleys in 9/12 CA for 3 weeks resulted in an increased incidence of post-harvest rots (8.3%). Immediate sealing of stores and maintaining CO_2 at 1.5% for the first three weeks of storage reduced rotting to 2%. In the first year of this trial, immediate sealing of Bramley stores with a low build up (1.5%) of CO_2 did not result in significant external CO_2-injury.

Storage trials in the 2012-2013 storage season have extended this work to Bramley harvested over several picking dates and fruit selected from a wider range of orchards.

Conclusions

Immediate sealing of Bramley's Seedling stores once fruit has cooled to store temperature (4.0-4.5^{o}C) helps to reduce the incidence of internal CO_2-injury and core-flush in Bramley's stored in 5% CO_2, 1% O_2 (5/1). Delaying sealing of stores after fruit has reached store temperature increased the risk of internal browning.

The existing industry strategy of allowing store oxygen to drop to 10% O_2 during the initial 3 week period after store sealing (<1% CO_2) should be continued by growers at present. While some benefits on the internal quality of Bramley's have been found with more rapid pull down of oxygen over this period, the susceptibility of fruit to external CO_2-injury needs to be assessed more fully.

SmartFresh^{TM}-treated Bramley's kept in traditional ventilated 9% CO_2, 12% oxygen (9/12) storage benefited from sealing stores immediately after cooling fruit to store temperature and maintaining CA at 1.5% CO_2 for the first 3 weeks of storage through venting with air. This regime reduced the incidence of storage rots and internal flesh browning (core-flush and senescent browning).

Financial benefits

Reduced wastage through lowering the incidence of internal browning disorders of Bramley's and lowering the incidence of rotting will have a financial benefit to growers.

Action points for growers

From the results of this project in its first year, growers may consider the following conclusions when managing controlled atmosphere Bramley stores:

- Rapid cooling of fruit and sealing of stores helps to reduce the incidence of internal CO_2-injury, core flush and senescent breakdown in Bramley

- In 5/1 Bramley stores, delaying sealing of stores 5 days from harvest results in fruit with a higher incidence of CO_2-injury and core-flush.

- In 9/12 gas ventilated stores, after cooling, immediate sealing of SmartFresh^{TM}-treated Bramley's stored and maintaining CO_2 at 1.5% for the first three weeks of storage through venting with air, significantly reduced the incidence of post-harvest rots.

SCIENCE SECTION

Introduction

Bramley's Seedling remains one of the most important UK apple varieties. Although 75% production is used for processing, marketing of fresh Bramley apples is very important for the apple industry and a potential area of growth. 80% of fresh sales are through the supermarkets, where strict quality standards are applied, (both visual and taste). The loss of DPA to control scald presented a challenge to certain sectors of the UK industry, particularly those willing to provide high quality fruit throughout the year through long term storage. The introduction of scrubbed low oxygen storage conditions (5% CO_2 + 1% O_2) (5/1) has resulted in major improvements in the storage quality of Bramley apples and has provided a regime which prevents the development of both superficial scald and bitter pit. Many Bramley apples destined for supermarkets are now stored using the 5/1 regime.

In addition, the use of 'SmartFresh^{TM}' (1-MCP) is now a well-established pre-storage treatment for Bramley's, offering the benefit of superficial scald control without the need for post-harvest chemical antioxidant treatment. The scald-free period is largely dependent on CA condition used, although other factors such as picking date will have a bearing on this.

Since the effect of 'SmartFresh^{TM}' is to retard ripening changes such as fruit softening and development of bitter pit by delaying the onset of ethylene production, a beneficial effect on control of rotting may be anticipated through the use of 'SmartFresh^{TM}'. Ethylene scrubbing is also applied in some stores with similar effects. The recently completed HDC project (TF 191) has established the relative impact of these storage conditions on fruit quality and in particular *Nectria* infection.

Although able to provide Bramley storage for up to 12 months without scald, one disadvantage of 5/1 storage with SmartFresh^{TM} or ethylene scrubbing is the propensity for the early development of carbon dioxide injury. Earlier work (1994-1998) funded by APRC (SP31) to reduce the incidence of CO_2-injury in Bramley apple, found that delaying the establishment of 5/1 conditions from immediate sealing of stores to 15 days after loading, avoided the buildup of CO_2 during the critical period in Bramley's storage life where sensitivity to low oxygen combined with high CO_2 is at its greatest (Colgan *et al.* 1999). Since then the Bramley industry has

adopted such procedures when storing Bramley in 5/1 CA. It is clear that treatments that reduce Bramley's capacity to produce/perceive ethylene, increases the risk of developing CO_2-injury. Therefore a recommendation to delay the establishment of 5/1 CA for 21 days has been adopted for Bramley treated with SmartFresh™ or where ethylene scrubbing is being used.

Concerns regarding the ability of stores to achieve rapid establishment of 5/1 CA after this initial delay has prompted many growers to adopt a half-way procedure whereby stores are sealed immediately and carbon dioxide is scrubbed from the store while oxygen concentrations are allowed to drop to 10% during the 21 day period before 5/1 conditions are established thereafter. No comparative trials have yet been undertaken to test the advantages of this approach, or to define an optimum practice.

This project was developed following discussions with key representatives of the apple industry and seeks to define an optimum storage practice for Bramley to be used during the early period of storage. The aim is to achieve a quicker rate of establishment of conditions without compromising control of CO_2-injury whilst having the additional benefit of improved maintenance of background green colour, firmness retention and improved scald control in long-term stored Bramley. In addition, the effect of different establishment of CA conditions on rotting, particularly core-rots, will also be determined. Moreover, this trial will establish the effect on a short delay in the application of SmartFresh™ on the incidence of CO_2-injury in Bramley subject to different rates of establishment as well as other physiological disorders and diseases.

Approximately 40% of the UK's Bramley's Seedling crop is stored in traditional gas ventilated 9% CO_2, 12% Oxygen (9/12) stores. With the loss of the antioxidant diphenylamine (DPA) to control scald, growers using this storage regime are restricted to treating Bramley's with SmartFresh™ to reduce the development of superficial scald on long-term stored fruit.
Currently, a delay of three weeks in the establishment of CA conditions is recommended to avoid the development of CO_2-injury. Such a delay in CA conditions will often result in loss of quality during the storage season. The identification of a strategy to allow stores to be sealed earlier will help to improve the quality of fruit stored in the 9/12 regime.

Overall aim of project

The overall aim of the project is to define strategies for the establishment of controlled atmosphere storage conditions for Bramley apples to improve quality and reduce wastage due to fungal core-rots of long-term stored fruit, so that a higher proportion of fruit is suitable for supermarket sale.

The aim is to achieve a quicker rate of establishment of conditions without compromising control of CO_2-injury, whilst having the additional benefit of improved maintenance of background green colour, firmness retention and improved scald control in long-term stored Bramley.

Specific Objectives

1. To assess selected protocols for the establishment of CA conditions for Bramley apples in terms of their effects on physiological damage including carbon dioxide injury.

1.1 To investigate the use of rapid establishment of oxygen in Bramley 5/1 CA stores to determine the improvements in fruit quality and fungal rots without compromising control of carbon dioxide injury in Bramley.

1.2 To assess the effect of a five day delay in the application of 1-MCP (SmartFresh^{TM}) to early-picked Bramley apples on the sensitivity to carbon dioxide injury and rotting in storage strategies tested.

1.3 To investigate the management of CO_2 accumulation in gas ventilated 9/12 stores to extend the storage season of SmartFresh-treated fruit.

1.4 To develop an improved commercial strategy for oxygen and carbon dioxide establishment in 5/1 and 9/12 Bramley stores.

2. Dissemination of results both through the EMRA fruit storage member's day and training days where appropriate.

Materials and Methods

In year 1 of the project, Bramley apples were harvested on 1 September 2010 from three Bramley's Seedling orchards from West Kent. Orchards A and B were grown on M26 rootstock, planted in 1990 and 1991 respectively, while Orchard C was on M9 rootstock planted in 2004. Harvest maturity measurements were made on a subset of fruit (20). Firmness was measured using a motorised penetrometer (LRX). Colours were determined using a Hunter-lab colourmeter (LAB) and soluble solids (% Brix) were measured using a digital refractometer. Fruits were cut both at the equator and the calyx end to assess for internal disorders. A second sub-set of fruit (20) was sent for mineral analysis (FAST Ltd).

Apples were cooled overnight to 4.0°C and placed in 360 L cabinets: half the fruit were treated the following day with SmartFresh™ (625 ppb) for 24 hours at 4.0-4.5°C, before the atmosphere was exhausted. The remaining non-SmartFresh™ treated fruit was kept at 4.0-4.5°C overnight in a separate store.

The next day fruit was placed into 10 storage cabinets. Each cabinet represented a single temperature regime and contained both SmartFresh™ and a smaller number of non-SmartFresh™ treated fruit.

Bramley's destined for 5/1 storage were either treated with 625 ppb SmartFresh™ immediately for 24 hours or treatment was delayed for five days before chambers were sealed. After sealing, three oxygen pull down rates were imposed: a rapid establishment representing a decline of 1% O_2 per day, achieving 1% oxygen in three weeks, an intermediate establishment rate of 0.75% reduction in O_2 per day reaching 1% oxygen in four weeks, or a gentle decline of 0.5% O_2 reduction where oxygen concentrations reached 1% in six weeks. For the first three weeks after sealing, carbon dioxide was scrubbed from the atmosphere to prevent the incidence of carbon dioxide injury. After this period, scrubbers were set to 5% CO_2 and carbon dioxide was allowed to establish through fruit respiration.

A second part of the trial investigated the management of SmartFresh™-treated Bramley's destined for 8-10% CO_2 storage (9/12 storage). Currently, it is recommended that storage establishment is delayed for 21 days after treatment. A trial was designed with industry input to investigate whether sealing 8-10% CO_2 stores immediately and ventilating the storage environment at different concentrations of CO_2 would help to extend the storage season. Bramley's treated with SmartFresh™ for 24 hours were vented prior to cabinet sealing and:

- maintained at 1.5% CO_2 for three weeks or
- was subject to a gradual increase in CO_2, with ventilation in week two and three set to 3% CO_2 or
- CO_2 allowed to rise to 6% in week three.

After three weeks, ventilation in all treatments was set to 9% CO_2.
Fruits were assessed every two months, for firmness, colours, % brix and for the presence of external and internal disorders. Respiration measurements were made on two replicate 20 fruit subsamples.

Results

March inspection (120 days storage)

5/1 Stores

The rate of CA establishment for 5% CO_2 and 1% O_2 (5/1) Bramley's did not affect the firmness or background green colour of Bramley's Seedling apples (Table 2.1). Rapid cooling of fruit, followed by immediate sealing and a reduction of store oxygen to 10% O_2, following the industry standard protocols, reduced the incidence of internal carbon dioxide injury. Rapid pull down of oxygen from 21% to 1% in three weeks, was equally as effective at reducing internal CO2 injury; however, increasing the length of time to reach 1% O_2 from three to four or six weeks increased the incidence of internal injury. However, rapid pull down of oxygen may increase the risk of external carbon dioxide injury (Table 2.2). Delaying sealing of stores by five days after harvest increased the incidence of internal CO_2-injury. For short-term stored Bramley's the standard protocol for storage establishment provided the best approach for storing fruit limiting the incidence of CO_2-injury. In these experiments carbon dioxide was scrubbed (<1.0 CO_2) from the environment with lime for the first 21 days of storage. The incidence of external CO_2-injury and core-flush and senescent breakdown were low in all treatments.

Table 2.1. Ex-store quality of Bramley's stored under 5% CO_2, 1% O_2 (5/1) with different rates of CA establishment. March (average of 3 orchards)

CA Regime O_2 pull-down per day Store sealing	Firmness N	% Brix	Colour A	Colour B	% Rots
Day 0 -1.0% O_2	90.1	10.7	-20.3	39.7	0.0
Day 0 -0.75% O_2	88.0	10.6	-20.4	40.6	3.3
Day 0 -0.5% O_2	90.4	10.6	-20.1	40.4	3.3
Day 5 -1.0% O_2	89.0	10.5	-20.6	40.7	3.3
Day 5 -0.75% O_2	90.1	10.7	-20.3	41.6	0.0
Day 5 -0.5% O_2	88.6	10.7	-20.3	40.9	0.0
Day 0 Industry 10.0% O_{2*}	91.7	10.6	-20.6	40.9	0.0
Day 5 Industry 10.0% O_2	89.9	10.5	-20.2	40.0	5.0
Day 21 -flushed	90.3	10.8	-20.3	40.7	0.0
P value	0.07	0.646	<0.001	<.001	0.02
$LSD_{0.05}$	2.179	0.3123	0.3453	1.7347	4.768

Table 2.2. Ex-store quality of Bramley's stored under 5% CO_2, 1% O_2 (5/1) with different rates of CA establishment-March

CA Regime O_2 pull down per day Store sealing	% Scald	% Ext. CO_2-injury	% Int. CO_2-injury	% Core flush	%Senescent Breakdown
Day 0 -1.0% O_2	0	0	0	0	0
Day 0 -0.75% O_2	0	1.7	1.7	0	0
Day 0 -0.5% O_2	0	0	3.3	1.7	0
Day 5 -1.0% O_2	0	0	6.7	0	0
Day 5 -0.75% O_2	0	0	10	0	0
Day 5 -0.5% O_2	0	0	15	0	1.7
Day 0 Industry 10.0% O_2	0	0	1.7	0	0
Day 5 Industry 10.0% O_2	0	0	0	0	0
Day 21 -flushed CA	0	0	6.7	3.3	0
P value	0	0.54	<0.001	0.15	0.47
$LSD_{0.05}$	0	3.24	7.60	0.13	1.32

During shelf-life, no change in firmness and ex-store quality was seen between treatments in SmartFresh-treated Bramley's (Table 2.3). Immediate sealing followed by establishment of 1% oxygen within three to four weeks of sealing lowered the incidence (5%) of internal CO_2-injury in Bramleys (Table 2.4). Slower rates of oxygen pull down (-0.5% O_2 d^{-1}) where 1% oxygen was achieved over a six week period from sealing resulted in 8.3% internal CO_2 injury. Delayed sealing by five days and slow oxygen pull down resulted in the highest amount of internal CO_2-injury (11.7%). The incidence of bitter pit, core-flush and senescent breakdown was low across all treatments. Standard industry protocols for 5/1 establishment proved as effective as rapid oxygen pull down in the reduction of internal CO_2-injury damage.

Table 2.3. Ex-shelf-life quality of Bramley's stored under 5% CO_2, 1% O_2 (5/1) with different rates of CA establishment.- March

CA Regime	Firmness N	% Brix	Colour A	Colour B	% Rots
Day 0 -1% O2 d	89.7	10.6	-19.6	41.9	3.3
Day 0 -0.75% O2 d	89.6	10.7	-19.5	42.7	1.7
Day 0 -0.5% O2 d	89.6	10.7	-19.5	42.9	1.7
Day 5 -1% O2 d	90.2	10.7	-19.7	42.1	1.7
Day 5 -0.75% O2 d	88.9	10.8	-19.7	42.3	3.3
Day 5 -0.5% O2 d	86.4	10.6	-19.7	43.5	3.3
Day 0 Industry 10% O2	89.1	10.5	-19.8	42.6	1.7
Day 5 Industry 10% O2	91.0	10.7	-19.7	42.7	0.0
Day 21 -flushed CA	89.0	10.7	-19.5	42.6	1.7
P value	<.001	<.001	<.001	<.001	0.977
$LSD_{0.05}$	2.726	0.2378	0.4174	0.8863	4.924

Table 2.4. Ex-shelf-life quality of Bramley's stored under 5% CO_2, 1% O_2 (5/1) with different rates of CA establishment- March

CA Regime	% Scald	% Ext. CO_2-Injury	% Int. CO_2-injury	% Bitter pit	% Core flush	% Senescent breakdown
Day 0 -1% O2 d	0.0	0.0	5.0	0.0	0.0	0.0
Day 0 -0.75% O2 d	0.0	5.0	5.0	0.0	0.0	3.3
Day 0 -0.5% O2 d	0.0	0.0	8.3	3.3	0.0	0.0
Day 5 -1% O2 d	0.0	0.0	1.7	0.0	0.0	0.0
Day 5 -0.75% O2 d	0.0	0.0	7.0	0.0	0.0	0.0
Day 5 -0.5% O2 d	0.0	0.0	11.7	0.0	0.0	1.7
Day 0 Industry10% O2	0.0	0.0	6.7	0.0	0.0	0.0
Day 5 Industry 10% O2	0.0	0.0	6.7	0.0	1.7	0.0
Day 21 -flushed CA	0.0	0.0	5.0	0.0	1.7	0.0
P value	0.002	0.017	0.085	0.587	0.468	<.001
$LSD_{0.05}$	0.000	3.36	12.85	3.11	3.60	1.27

9/12 Stores

After six months storage of Bramley's under 9% CO_2, 12% O_2 (9/12) storage, the effect of rate of CA establishment on ex-store fruit quality was most evident on the incidence of post-harvest rots. Under current recommendations, delaying the establishment of SmartFresh-treated Bramley's by 21 days averaged over 8% rots in the three orchards under investigation, mainly caused by *Monilinia fructagena* This was reduced to 3.3% when 9/12 CA was established immediately and similar rot reduction was observed where CO_2 was allowed to increase gradually during the first three weeks of storage (Table 2.5). Fruit firmness, sugar and background green and yellow colour were not affected by rate of establishment.

Table 2.5 Ex-store Quality of Bramleys stored under 9% CO_2, 12% O_2 (9/12) with different rates of CA establishment. March

CA Regime	Firmness N	% Brix	Colour A	Colour B	% Rots
1.5/1.5/1.5 % CO2	90.0	10.6	-20.1	41.1	2.2
1.5 /3.0/3.0% CO2	90.2	10.5	-19.4	41.9	1.7
1.5/3.0/6.0% CO2	91.3	10.6	-19.6	42.3	0.0
9% O2, 12% CO2 Day 0	90.8	10.6	-19.7	42.3	3.3
9% O2 12% CO2 Day 21	89.4	10.5	-19.5	42.8	8.3
P value	0.07	0.65	<.001	<.001	0.02
$LSD_{0.05}$	2.18	0.31	1.37	1.73	4.77

After a week's shelf-life Bramley's under all storage regimes lost approximately 10 N (1 kg). Where CA had been increased in a step wise fashion from 1.5 to 3.0% CO_2. the rate of softening was slower than other treatments but little effect on sugars and colours was observed (Table 2.6).

Table 2.6. Ex-shelf quality of Bramley's s stored under 9% CO_2, 12% O_2 (9/12) with different rates of CA establishment followed by seven days at 18°C. March

CA Regime	Firmness N	% Brix	Colour A	Colour B	% Rots
1.5/1.5/1.5 % CO2	79.8	10.4	-19.0	45.9	1.7
1.5 /3.0/3.0% CO2	83.9	10.4	-18.8	44.8	1.7
1.5/3.0/6.0% CO2	79.7	10.3	-18.7	45.1	1.7
9% O2, 12% CO2 Day 0	80.2	10.3	-19.0	44.6	0.0
9% O2 12% CO2 Day 21	79.4	10.4	-18.6	45.7	1.7
P value	<0.001	<0.001	<0.001	<0.001	<0.001
$LSD_{0.05}$	2.73	0.24	0.87	0.42	0.886

The incidence of superficial scald was sporadic and surprisingly, no scald was observed where 9/12 was delayed by three weeks (Table 2.7). However, 6% of Bramley's were affected by superficial scald where the CO_2 was incrementally increased from 1.5/3.0/6.0%.

The presence of CO_2-injury was observed on fruit where 9/12 CA had been established immediately after harvest, through nitrogen flushing resulting in 5% CO_2-injury, while immediate

sealing and maintaining CO_2 at 1.5-3.0% during the first three weeks prevented external CO_2-injury.

Table 2.7. Ex-shelf quality of Bramley's stored under 9% CO_2, 12% O_2 (9/12) with different rates of CA establishment followed by 7 days at 18°C- March continued

CA Regime	% Scald	% Ext. CO_2 Injury	% Int. CO_2 Injury	% Bitter pit	% Core flush
1.5/1.5/1.5 % CO2	0.0	0.0	0.0	1.7	0.0
1.5 /3.0/3.0% CO2	1.7	0.0	0.0	0.0	0.0
1.5/3.0/6.0% CO2	6.7	1.7	3.3	0.0	3.3
9% O2, 12% CO2 Day 0	0.0	5.0	3.3	1.7	0.0
9% O2 12% CO2 Day 21	0.0	0.0	0.0	0.0	3.3
P value	0.002	0.017	0.085	0.587	0.468
$LSD_{0.05}$	2.843	3.363	12.847	3.114	3.596

June inspection (210 days of storage) + 7 days shelf-life

5/1 Stores

The firmness and external quality of Bramleys subjected to 210 days storage followed by seven days shelf-life, was not affected by the rate of CA-establishment (Table 2.8). However, on inspection of internal quality, an increased incidence of core flush was present in Bramley's where cabinets were sealed five days after harvest (Table 2.9) and greater amounts of core flush were observed in SmartFresh™-treated fruit. The incidence of senescent breakdown was higher in untreated control fruit and the severity of the disorder increased with slower rates of oxygen pull down. SmartFresh™ reduced the incidence of the senescent breakdown of fruit. Where there was a five day delay in store sealing, rapid reduction in store oxygen over three weeks lowered the incidence of senescent breakdown (8.3%) compared to 13.3% breakdown where the industry standard protocol was followed.

Table 2.8 Ex-shelf-life quality of Bramley's stored under 5% CO_2, 1% O_2 (5/1) with different rates of CA establishment- June.

CA Regime	Firmness N		Sugars (%Brix)		Colours A		Colours B	
	1-MCP	Control	1-MCP	Control	1-MCP	Control	1-MCP	Control
Day 0 -1% O2 d	64.6	55.4	10.3	10.5	-19.6	-19.1	44.8	45.8
Day 0 -0.75% O2d	63.5	50.5	10.3	10.3	-19.3	-18.7	44.5	46.4
Day 0 -0.5% O2 d	62.9	42.6	10.4	9.9	-19.3	-18.5	45.2	47.0
Day 5 -1% O2 d	74.3	46.3	10.3	10.3	-19.1	-18.5	44.6	46.6
Day 5 -0.75% O2d	73.3	46.8	10.3	10.2	-19.2	-18.1	45.0	46.0
Day 5 -0.5% O2 d	65.7	44.1	10.2	10.1	-18.8	-18.5	44.8	47.4
Day 0 Industry 10% O2	67.2	42.1	10.3	10.1	-18.9	-18.5	44.7	47.2
Day 5 Industry 10% O2	68.5	47.0	10.2	10.0	-19.0	-18.4	44.7	45.4
P value	<0.001		<0.001		0.01		<0.001	
$LSD_{0.05}$	1.42		0.26		0.46		0.98	

Table 2.9. Ex-shelf-life quality of Bramley's stored under 5% CO_2, 1% O_2 (5/1) with different rates of CA establishment- June.

CA Regime	% Scald		% Int. CO_2 Inj.		% Core.Flush		% Senescent Bdn	
	1-MCP	Control	1-MCP	Control	1-MCP	Control	1-MCP	Control
Day 0 -1% O2 d	0.0	0.0	3.3	1.8	5.0	0.0	0.0	0.0
Day 0 -0.75% O2d	0.0	0.0	1.7	1.7	5.0	0.0	6.7	20.3
Day 0 -0.5% O2 d	0.0	0.0	0.0	3.7	6.7	8.5	3.3	51.2
Day 5 -1% O2 d	0.0	1.7	3.3	1.7	15.0	1.7	8.3	13.3
Day 5 -0.75% O2d	0.0	0.0	1.7	1.7	10.0	3.3	6.7	36.2
Day 5 -0.5% O2 d	0.0	3.3	1.7	3.3	6.8	8.5	13.3	33.8
Day 0 Industry 10% O2	0.0	0.0	0.0	1.8	3.3	3.3	0.0	32.8
Day 5 Industry 10% O2	0.0	0.0	6.7	1.7	13.3	5.3	13.3	42.8
P value	0.001		0.822		<0.001		<0.001	
$LSD_{0.05}$	9.9		2.84		4.8		9.5	

9/12 Stores

At the final inspection, a comparison between SmartFresh^{TM}-treated fruit and untreated fruit was possible. After nine months of storage under 9/12 CA conditions and following a further seven days shelf-life at 18°C, fruits stored under 9/12 conditions softened significantly during shelf-life (Table 2.10). Increasing CO_2 incrementally during the initiation of CA provided no benefit over delayed establishment on firmness retention on SF-treated fruit and only provided a marginal improvement in fruit firmness in untreated fruit. Sugars and background colour were not affected by rate of CA establishment.

Table 2.10.Ex-shelf quality of Bramley's stored under 9% CO_2, 12% O_2 (9/12) with different rates of CA establishment followed by 7 days at 18°C-June

CA Regime	Firmness N		Sugars (%Brix)		Colours A		Colours B	
	1-MCP	Control	1-MCP	Control	1-MCP	Control	1-MCP	Control
1.5/1.5/1.5 % CO2	58.7	46.4	10.2	10.1	-17.1	-16.8	48.2	48.1
1.5 /3.0/3.0% CO2	54.7	46.0	10.4	9.8	-17.2	-17.1	48.2	47.7
1.5/3.0/6.0% CO2	55.7	46.6	10.3	10.0	-17.0	-16.9	48.5	46.7
9% O2, 12% CO2 Day 0	57.2	46.7	9.9	9.9	-17.6	-16.9	47.1	47.3
9% O2 12% CO2 Day 21	60.1	43.4	10.2	9.7	-17.0	-17.0	48.0	47.3
P value	<.001		<.001		0.01		<.001	
$LSD_{0.05}$	1.42		0.26		0.4596		0.98	

Immediate establishment of 9/12 CA regime reduced the incidence of scald (71.7%) compared to 81.7% where CA establishment was delayed by three weeks. Moreover, an incremental increase in CO_2 from 1.5 to 6% during the first three weeks of storage reduced scald to 61.7% (Table 2.11). While no internal carbon dioxide injury was recorded, core-flush, a disorder often associated with elevated CO_2 was observed. The incidence of core-flush in SmartFresh-treated Bramley was 8.3% where a delay of 21 days in sealing stores was implemented. Often where CA is delayed, an increase in fruit respiration predisposes fruit to internal damage when CA is finally established. Core flush was reduced to 3.3% where stores were sealed immediately and CO_2 maintained at 1.5% during the first three weeks of storage. Allowing the concentration of CO_2 in the storage atmosphere to rise above 1.5% during the initial three week period, led to an increase in the incidence of core flush.

Table 2.11.Ex-shelf quality of Bramley's stored under 9% CO_2, 12% O_2 (9/12) with different rates of CA establishment followed by 7 days at 18°C-June Continued

CA Regime	% Scald		% Bitter pit		% Core Flush		% Breakdown	
	1-MCP	Control	1-MCP	Control	1-MCP	Control	1-MCP	Control
1.5/1.5/1.5 % CO2	83.3	85.3	0.0	1.7	3.3	11.8	0.0	0.0
1.5 /3.0/3.0% CO2	61.7	90.0	1.7	0.0	6.7	11.7	0.0	0.0
1.5/3.0/6.0% CO2	85.0	96.7	0.0	0.0	8.3	6.7	0.0	3.3
9% O2, 12% CO2 Day 0	71.7	90.0	1.7	0.0	5.0	15.0	0.0	5.0
9% O2 12% CO2 Day 21	81.7	87.3	0.0	5.2	8.3	47.3	0.0	22.8
P value	0.001		0.25		<0.001		<0.001	
$LSD_{0.05}$	9.94		4.95		4.81		9.45	

Conclusions

- Rapid cooling and sealing of stores, while allowing store oxygen to drop to 10% O_2 following standard industry protocols during the first three weeks of CA establishment, lowered the incidence of CO_2-injury and core flush.
- Delayed sealing of stores beyond five days from harvest results in fruit with a higher incidence of CO_2-injury and core-flush in 5/1 Bramley stores.
- Rapid oxygen pull down from 21% to 1% O_2 over three weeks may be appropriate where store sealing has been delayed by five days or more. However, further work is required to establish fruit susceptibility to **external** CO_2-injury. Early harvested Bramley's are particularly susceptible to **external** CO_2-injury.
- Immediate sealing of SmartFresh^{TM}-treated Bramley's stored in 9/12 gas ventilated stores and maintaining CO_2 to 1.5% through venting, significantly reduced the incidence of post-harvest rots.

Technology transfer

The project was introduced to growers at the EMRA Storage Day in March 2012 and to the HDC Tree Fruit panel in March 2012.

Acknowledgements

The assistance of Karen Thurston and Judit Linka is greatly appreciated. The author is grateful for the assistance of Robert Mitchell who provided the fruit and Nigel Jenner of Norman Collett Ltd, and Nigel Bardsley for their assistance in developing the project.

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