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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™' (1-MCP) or ethylene scrubbing is widespread and provides further scald control. A disadvantage of 5/1 CA with either SmartFresh™ or ethylene scrubbing is the propensity for carbon dioxide injury to develop (Colgan et al. 1996). To avoid this, it is recommended that establishment of CA conditions for SmartFresh™-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 in 5/1 CA. 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.

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™ 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 in 9/12 stores. 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.

Early harvested fruit are particularly susceptible to external CO_2-injury. Bramley's are harvested in an immature state and the lack of reliable indicators of harvest maturity makes it difficult to predict fruits' susceptibility to damage. Moreover, large orchard to orchard variability compounds the problem of predicting fruits' susceptibility.

In Year 2 of the project, rapid establishment of CA within three weeks of sealing, in very early picked fruit (31/8/2012), led to 15-20% external CO_2 damage. By the following week's harvest (6/9/2012), the incidence ranged from 4-20%. In SmartFresh^{TM}-treated Bramley's, by delaying the rate of oxygen pull down and CO_2 establishment to four to six weeks, the incidence of external and internal browning damage was reduced without any apparent loss in fruit quality during long-term storage.

However, in Year 1, a five day delay in sealing cabinets, increased the incidence of internal carbon dioxide injury and core-flush during long-term storage. In cases where establishment took four or six weeks to achieve, the incidence of damage increased.

9/12 Stores

In the first year of the trial, delaying sealing of SmartFresh^{TM}-treated Bramleys in 9/12 CA for three 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.

In the second year of the trial, immediate sealing of cabinets and allowing a low concentration of CO_2 (1.5-3.0%) to build up during the first three weeks of storage didn't induce CO_2-injury. However there was no benefit in terms of rot control or improvement in fruit quality during storage.

Main conclusions

- The impact that the establishment of CA conditions has on Bramley quality is dependent on fruit maturity at the point of cabinet sealing.
- In the first year of the trial, the incidence of external injury was low and the impact of rapid CA establishment was difficult to determine. However there was a greater incidence of internal damage and a slight trend for increasing internal browning with slower rates of establishment.
- In the second year of the trial, the potential for external and internal CO_2 injury was greater. Early harvested fruit was more susceptible to external CO_2 damage when a rapid pull down to 1% oxygen was achieved within three weeks of sealing. Extending the pull down rate to four to six weeks before establishing CO_2, reduced the incidence of damage.
- A more rapid pull down of oxygen may be possible on later picked fruit where the propensity to develop external CO_2 injury is less.
- The incidence of internal browning was made worse by rapid establishment over a three week period in early harvested fruit. Slowing CA establishment over six weeks helped to reduce internal injury. Internal browning was worse on later picked fruit.
- A more rapid pull down of oxygen may help to reduce internal injuries on later picked fruit where delay in establishment can lead to higher fruit respiration rates.
- In these small scale trials, the rate of CA establishment did not improve retention of firmness or background green colour of fruit.
- 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 three 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 more an earlier pull down of oxygen the susceptibility of fruit to external CO_2-injury in early harvested fruit makes this a risky strategy.

- In the first year of the trial SmartFresh™-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 in the first year of the trial reduced the incidence of storage rots and internal flesh browning (core-flush and senescent browning), but was not observed in the second year. While in the second year no benefit in rot control was achieved, immediate sealing of stores and maintaining CO2 at 1.5-3.0% did not lead to external or internal CO2 injury.

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 over two storage seasons, growers may consider the following conclusions when managing controlled atmosphere Bramley stores:

- Early harvested Bramley's are more susceptible to CO_2 injury
- Susceptibility to external CO_2 injury declines with increasing fruit maturity
- For lowering the incidence of external CO_2 injury, immediate sealing of stores and allowing oxygen to deplete to 1% over a period of six weeks was as effective as current industry practice of maintaining store oxygen at 10% during the first three weeks of storage.
- A more rapid establishment may be possible on later picked fruit.
- A slower decline of oxygen over a six week period reduced the incidence of internal browning.
- The optimum strategy for CA establishment of Bramleys is subject to the relative state of fruit maturity at harvest.
- Delaying store sealing after fruit has cooled to store temperature can increase the risk of internal browning.
- In 9/12 gas ventilated stores, after cooling, immediate sealing of SmartFresh™-treated Bramley's stored and maintaining CO_2 at 1.5% for the first three weeks of storage through venting with air, did not induce external or internal CO_2 damage. In the first year

of the project, this strategy significantly reduced the incidence of post-harvest rots, but this was not observed in the second year of the trial.

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, offering the benefit of superficial scald control without the need for post-harvest chemical antioxidant treatment. The scald-free period is largely dependent on the 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 also 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 in fruit. 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 build-up 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, increase 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 sought 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 sought to 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.

A delay of three weeks in the establishment of 9/12 CA conditions is currently 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 3 Bramley's Seedling orchards in 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 fruits 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. Carbon dioxide was scrubbed from the atmosphere to prevent the incidence of carbon dioxide injury. After fruit had reached 1% oxygen, scrubbers were set to 5% CO_2 and carbon dioxide was allowed to establish through fruit respiration.

In Year 2 Bramley's were harvested over 2 picking dates (31/8/2012 and 6/9/2013) from four orchards, two grown on M26, one on M9 and the fourth on M106 rootstocks. Pick 1 fruit were harvested a week ahead of the commercial harvest for the orchards (6/9/2013) to provide a range of early harvested fruits that are most susceptible to damage by rapid establishment of CA. Fruit was randomised and sorted into replicate 15 kg boxes. Bramley's were cooled for 36 hours to achieve store temperature of 4-4.5°C. After cooling, Bramley's were treated with SmartFresh (625 ppb) for 24 hours and cabinets were vented before sealing. The oxygen

concentration was allowed to decline from 21% to 1 % over three, four or six weeks at a rate of -1%, -0.75% or -0.5% O_2 per day. Carbon dioxide was scrubbed from the environment until oxygen concentrations reached 1% O_2 thereafter; carbon dioxide was allowed to rise to 5% through respiration. Bramley's from each pick were kept in separate chambers.

A second part of the trial investigated the management of SmartFresh^{TM}-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^{TM} 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

Year 1: 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 - allowing store oxygen to drop to 10% O_2 during the initial three week period after store sealing (<1% CO_2) - 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 - allowing store oxygen to drop to 10% O_2 during the initial three week period after store sealing (<1% CO_2) - 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 6 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 fructigena* (brown rot). 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 7 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^{TM}-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^{TM} 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	

Year 2 -2012-2013

Harvest Maturity

Pick 1 fruits were harvested a week before (31/8/2012) the commercial harvest on the 6/9/2012. Internal ethylene concentrations were below the threshold of 100 ppb in both picking dates (Table 2.12), while starch clearance patterns from pick 2 fruit suggested Bramley's were ready to pick for long-term storage.

The respiration rate of Bramley's from pick 2 stored at 4-4.5°C (Figure 1) and 18°C (Figure 2) show a similar pattern of CO_2 production. Bramley's are atypical in that fruits are normally harvested when physiologically immature, at a stage in the developmental cycle where respiration rates are high, declining before rising again during the climacteric. This is observed in the respiration rates of fruit stored at both temperatures (Figures 1 and 2). Early harvested fruit is particularly sensitive to damage when CA is established rapidly due to the inherently high respiration rate of fruit.

Table 2.12 Harvest maturity measurement of Bramley's harvested over two picks

		Harvest Maturity Assessment				
Pick	Orchard	% SS	Ctifl Starch	Firmness (N)	Int Ethylene (ppb)	Respiration rate ml/CO_2/kg/h
1	CP	**8.6**	**2.75**	**90.2**	25.0	*
1	CK	**9.3**	**3.35**	**90.8**	16.5	*
1	HD	**9.8**	**2.1**	**98.8**	8.2	*
1	ML	**9.45**	**3.15**	**98.7**	18.4	*
2	CP	**9.4**	**3.45**	**91.7**	24.6	*
2	CK	**9.45**	**4.5**	**91.2**	22.4	2.38
2	HD	**10.05**	**2.6**	**99.8**	13.9	2.47
2	ML	**9.75**	**4.25**	**91.9**	21.3	2.28

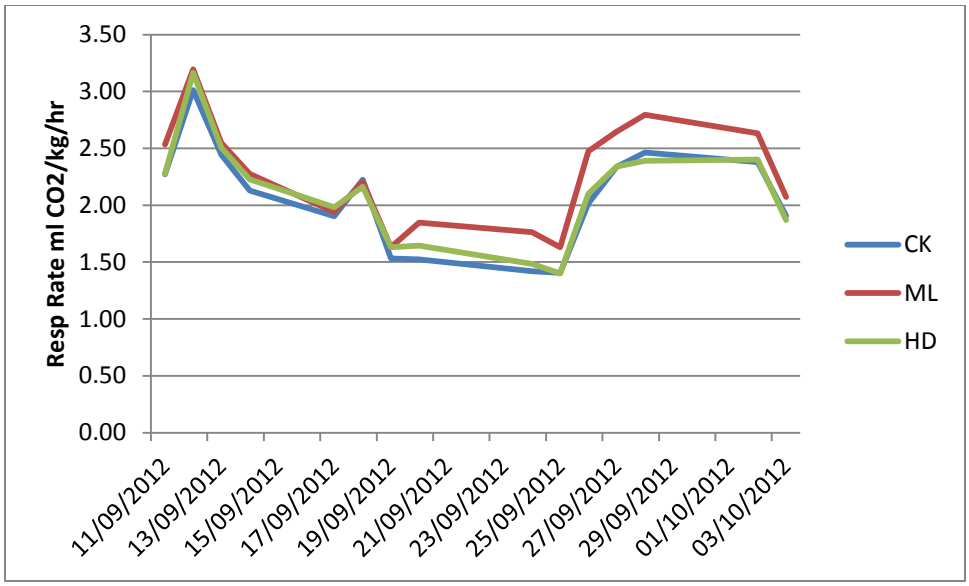

Figure 1 . Respiration rate of Bramley's harvested on the 6/9/2012 and kept in air at 4°C

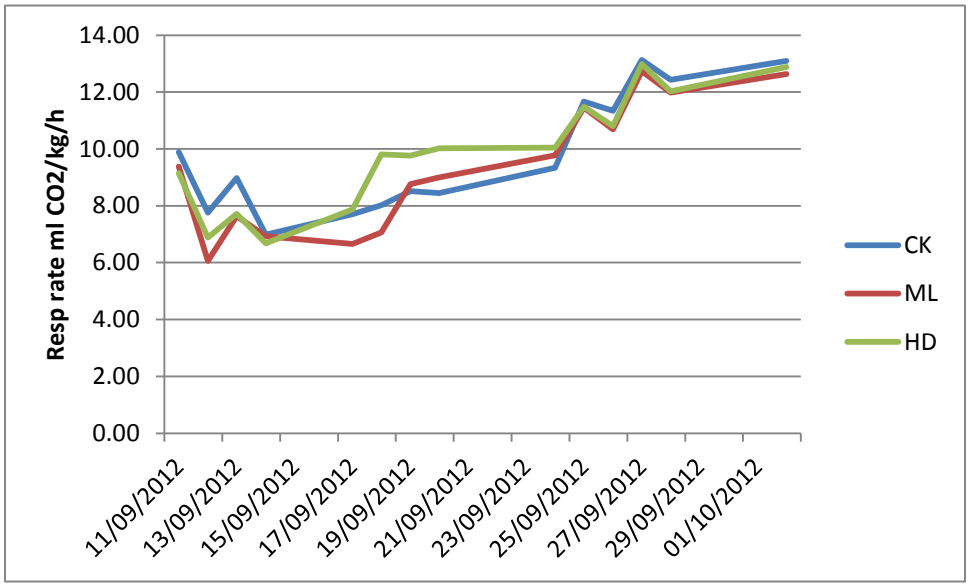

Figure 2. Respiration rate of Bramley's harvested on the 6/9/2012 and kept in air at 18°C

Establishment rates of 5/1 stored Bramley's harvested over two picking dates (Tables 2.13-2.17)

Firmness: The firmness of Bramley's was not affected by the rate of oxygen pull down during the initial phase of storage. Moreover the % Brix was similar in fruit across all treatments.

% Brix. There was no treatment effects on oxygen pull down rates on fruit sugars during the nine months of CA storage

Colour: There was no significant change in background green colour of fruit over the range of oxygen pull down treatments tested and green background colour didn't change with time. The yellow background colour of fruit increased on removal from shelf-life but treatment effects were limited.

External CO2 injury: Sealing Bramley's immediately after cooling and allowing the oxygen to drop over 21 days to 1% led to an average of 17.5 % damage in early picked fruit and 11.9 % injury to fruit picked the following week (Table 2.17). Interestingly, where second pick fruit had been left five days in cold storage prior to SF treatment and subsequent rapid pull down, the incidence of injury was lower (1.4%). In early picked fruit, slowing the rate of oxygen pull down from -1% to -0.75% O_2 per day from immediate sealing after cooling led to an average of 10.8% damage dropping to 1.0% damage where oxygen pull downs where kept at -0.5% O_2 per day. Where fruit had been kept at 10% oxygen during the first three weeks of establishment, the incidence of external damage was 9.7%. The industry standard of allowing oxygen to drop to 10% O_2 before establishing CA was effective at keeping the incidence of external CO_2 damage low, but could lead to a higher incidence of internal browning compared to Bramley's subject to a slow decline in O_2 over a six week period (Table 2.17).

Colour: There was no significant change in background green colour of fruit over the range of oxygen pull down treatments tested and green background colour didn't change with time. The yellow background colour of fruit increased on removal from shelf-life but treatment effects were limited.

In later picked fruit, the incidence of external damage was lower across all rates of oxygen pull down. Decreasing the rate of oxygen depletion to -0.5% per day lowered the incidence of damage to 1.7%. Where fruit had been kept at 10% oxygen for the initial three week period, only 2.3% of the fruit suffered damage.

The incidence of internal browning/staining in fruit was generally similar between picks with the highest incidence recorded where rapid oxygen pull down had been used. Decreasing the rate of oxygen pull down to four to six weeks lowered the incidence of internal injury.

% Rots: In the March inspection there was no significant effect of treatment on rots either immediately ex-store or after a week's shelf-life. After a further three months shelf-life, the incidence of rotting had increased but no clear trend in treatment effects were noted.

Table 2.13: Ex-store quality of Bramley's after 6 months (March) storage in 5% CO_2, 1% O_2 at 4-4.5°C

		-1% O2	-0.75% O2	-0.5% O2	10% O2	day 5 -1% O2	$LSD_{0.05}$
Firmness	Pick 1	92.9	98.3	94.0	93.9		
	Pick 2	90.3	92.1	94.3	91.8	94.6	2.78
% Brix	Pick 1	10.4	10.5	10.2	10.5		
	Pick 2	10.4	10.5	10.3	10.3	10.3	0.25
Colour A	Pick 1	-20.9	-21.1	-21.2	-20.7		
	Pick 2	-20.7	-20.9	-20.5	-20.9	-20.6	0.29
Colour B	Pick 1	40.6	40.8	40.4	41.0		
	Pick 2	39.5	40.7	40.1	41.1	40.4	0.96
% Rots	Pick 1	2.5	3.75	6.25	3.61		
	Pick 2	3.75	5	5.25	6.25	8.38	8.68
% Ext CO2 injury	Pick 1	15	6.25	0	10.69		
	Pick 2	3.75	1.25	0	2.5	2.77	6.27
% Internal injury	Pick 1	25	10	3.8	17.2		
	Pick 2	27.6	11.2	13.3	22.9	13.8	1.10

N.B. Bramley's were subject to 5 rates of CA establishment. Cabinets were sealed after overnight cooling and 24 h of SmartFresh™ application; thereafter 3 rates of oxygen decline of -1% O_2, -0.75% O_2, or -0.5 % per day were established achieving 1% oxygen within 3,4 or 6 weeks of sealing. A repeat treatment of rapid oxygen decline (-1% per day) after 5 days storage in air at 4-4.5°C prior to SmartFresh™ was included in year 2. A fifth treatment allowed oxygen to decline to 10% O_2 during the initial 3 weeks of storage before a decline to 1% O_2 through fruit respiration. CO_2 was allowed to build to 5% when fruit had reached 1% oxygen.

Table 2.14 Ex-store quality of Bramley's after 6 months (March) storage in 5% CO_2, 1% O_2 at 4-4.5°C followed by 7 days at 18°C

		-1% O2	-0.75% O2	-0.5% O2	10% O2	day 5 - 1% O2	$LSD_{0.05}$
Firmness	Pick 1	93.1	92.3	94.0	93.9		
	Pick 2	92.1	93.2	89.8	91.2	92.6	2.39
% Brix	Pick 1	10.7	10.9	10.5	10.6		
	Pick 2	10.8	10.7	10.3	10.2	10.2	0.37
Colour A	Pick 1	-20.6	-20.3	-15.2	-20.3		
	Pick 2	-20.3	-20.3	-20.1	-15.4	-20.9	6.06
Colour B	Pick 1	41.8	42.3	42.3	41.4		
	Pick 2	41.2	42.1	42.2	42.5	42.6	0.79
% Rots	Pick 1	8.8	8.8	10.0	7.5		
	Pick 2	0.0	10.0	10.0	15.0	10.3	6.80
% Scald	Pick 1	1.25	0	0	0		
	Pick 2	1.25	0	0	5	0	2.57
% Ext CO2 injury	Pick 1	15	11.56	1.25	11.56		
	Pick 2	8.75	6.7	1.39	1.25	0	7.54
% Internal injury	Pick 1	24.7	10.3	8.1	5.7		
	Pick 2	21.2	3	11.8	27.5	9.7	11.58

N.B. Bramley's were subject to 5 rates of CA establishment. Cabinets were sealed after overnight cooling and 24 h of SmartFresh™ application; thereafter 3 rates of oxygen decline of -1% O_2, -0.75% O_2, or -0.5 % per day were established achieving 1% oxygen within 3,4 or 6 weeks of sealing. A repeat treatment of rapid oxygen decline (-1% per day) after 5 days storage in air at 4-4.5°C prior to SmartFresh™ was included in year 2. A fifth treatment allowed oxygen to decline to 10% O_2 during the initial 3 weeks of storage before a decline to 1% O_2 through fruit respiration. CO_2 was allowed to build to 5% when fruit had reached 1% oxygen.

Table 2.15: Ex-store quality of Bramley's after 9 months (June) storage in 5% CO_2, 1% O_2 at 4-4.5°C

		-1% O2	-0.75% O2	-0.5% O2	10% O2	day 5 - 1% O2	LSD
Firmness	Pick 1	91.9	91.9	94.0	92.1		
	Pick 2	90.1	91.7	92.2	90.6	90.95	2.21
% Brix	Pick 1	10.2	10.2	10.4	10.2		
	Pick 2	10.2	10.4	10.4	10.4	10.3	0.36
Colour A	Pick 1	-21.23	-21.36	-21.29	-20.95		
	Pick 2	-20.83	-20.83	-20.43	-20.90	-21.03	0.24
Colour B	Pick 1	41.7	43.3	43.5	42.1		
	Pick 2	41.2	41.5	41.1	41.6	41.8	0.88
% Rots	Pick 1	12.5	7.5	1.25	7.5		
	Pick 2	12.5	7.5	6.25	15	10	8.59
% Scald	Pick 1	6.07	0	0	0		
	Pick 2	1.25	0	0	0	0	9.58
% EXT CO2 injury	Pick 1	16.18	14.06	0	5		
	Pick 2	20.24	4.03	0	2.78	0	7.26
% Internal Injury	Pick 1	26.88	25.34	2.5	13.05		
	Pick 2	26.8	19.45	11.25	20.82	23.19	9.83

N.B. Bramley's were subject to 5 rates of CA establishment. Cabinets were sealed after overnight cooling and 24 h of SmartFresh™ application; thereafter 3 rates of oxygen decline of -1% O_2, -0.75% O_2, or -0.5 % per day were established achieving 1% oxygen within 3,4 or 6 weeks of sealing. A repeat treatment of rapid oxygen decline (-1% per day) after 5 days storage in air at 4-4.5°C prior to SmartFresh™ was included in year 2 A fifth treatment allowed oxygen to decline to 10% O_2 during the initial 3 weeks of storage before a decline to 1% O_2 through fruit respiration. CO_2 was allowed to build to 5% when fruit had reached 1% oxygen.

Table 2.16 Ex-store quality of Bramley's after 9 months (June) storage in 5% CO_2, 1% O_2 at 4-4.5°C followed by 7 days at 18°C.

	-1% O2	-0.75% O2	-0.5% O2	10% O2	day 5 -1% O2	LSD
Firmness	88.7	89.4	90.4	91.1		2.63
	88.8	88.9	89.3	87.6	91.9	
% Brix	10.0	10.0	10.0	9.9		0.32
	10.0	10.1	10.2	10.0	10.03	
Colour A	-20.8	-20.5	-20.3	-20.5		0.28
	-20.6	-20.6	-20.4	-21.0	-21.0	
Colour B	44.9	44.9	45.0	44.3		1.00
	44.4	44.3	41.1	45.4	41.8	
% Rots	17.5	10.0	21.3	2.5		8.43
	12.5	12.5	3.8	15.0	12.5	
% Scald	2.77	0	0	0		3.76
	1.39	0	1.25	0	0	
% EXT CO_2 inj.	20.0	11.2	2.8	11.7		4.39
	14.9	4.0	1.3	5.4	0	
% Internal Injury	29	14	5.5	14		10.27
	18.5	22.6	10.3	31.3	29.1	

N.B. Bramley's were subject to 5 rates of CA establishment. Cabinets were sealed after overnight cooling and 24 h of SmartFresh™ application; thereafter 3 rates of oxygen decline of -1% O_2, -0.75% O_2, or -0.5 % per day were established achieving 1% oxygen within 3,4 or 6 weeks of sealing. A repeat treatment of rapid oxygen decline (-1% per day) after 5 days storage in air at 4-4.5°C prior to SmartFresh™ was included in year 2. A fifth treatment allowed oxygen to decline to 10% O_2 during the initial 3 weeks of storage before a decline to 1% O_2 through fruit respiration. CO_2 was allowed to build to 5% through fruit respiration when storage atmospheres had reached 1% oxygen.

Table 2.17 The overall mean of external and internal CO2-injury of fruit inspected after 6 and 9 months storage with additional assessments after 7 days at 18°C

		-1% O2	-0.75% O2	-0.5% O2	10% O2	day 5 - 1% O2
External CO_2-injury	Pick 1	17.5	10.8	1.0	9.7	
External CO_2-injury	Pick 2	11.9	8.0	1.7	2.3	1.4
Internal CO_2-injury	Pick 1	26.9	15.3	10.7	9.9	
Internal CO_2-injury	Pick 2	21.5	15.9	13.7	23.2	18.4

Establishment rates of gas ventilated (9% CO_2, 12% O_2) stored Bramley's harvested over 2 picking dates (Tables 2.18-2.21)

Firmness: SmartFresh™ application was effective at maintaining firmness of fruit throughout the CA storage trial and little change in ex-store firmness was observed in fruit examined from September through to June. Only after the final shelf-life testing of fruit in June were treatment differences observed. Sealing 9/12 stores immediately and allowing CO_2 to build up to 1.5% through venting stores at 19.5% oxygen provided Bramley's that were 8.1 kg in firmness, compared to 7.4 kg firmness where CA storage was delayed by three weeks before 9/12 storage was allowed to develop through respiration. Allowing CO_2 to build up to 6% during the initial three weeks of storage offered no additional benefit in terms of firmness retention.

Colour: There was no significant effect of colour on Bramley's where stores were sealed immediately compared to where conditions were delayed for three weeks.

Rots: The incidence of rotting was variable amongst treatments and within orchards and there was no significant effect of sealing stores immediately and keeping a low build up concentration of CO_2.

CO_2 injury: Generally, there was little evidence of external CO_2 injury in Bramley's subject to the different establishment rates. However, at the initial inspection in March there was a small incidence (6.6%) of CO_2-injury within Bramley's where CO_2 had accumulated to 6% during the initial three week period, but no further damage was recorded at future inspections. There was no internal CO_2 injury identified in the samples.

Table 2.18 Ex-store quality of Bramley's after 6 months (March) storage in 9% CO_2, 12% O_2 at 4-4.5°C

	1.50% CO_2	3% CO_2	6% CO_2	3 week delay	$LSD_{0.05}$
Firmness	95.8	94.1	94.6	93.7	2.78
% Brix	10.5	10.4	10.2	10.4	0.25
Colour A	-20.1	-20.0	-20.1	-20.0	0.29
Colour B	41.0	40.1	39.9	41.4	0.96
% Rots	14.7	8.1	14.7	9.7	8.68
Ext CO_2 inj.	0.0	0.0	6.6	0.0	6.27
Int CO_2 inj.	0.0	0.0	0.0	0.0	1.10

N.B. Bramley's were either sealed immediately after cooling to 4-4.5°C and 24 h SmartFresh™ treatment and CO_2 allowed to accumulate to 1.5% CO_2 for 3 weeks, or 1.5% CO_2 for 1 week followed by 2 weeks at 3% CO_2, or a week each at 1.5%, 3.0% and 6% CO_2

Table 2.19 Ex-store quality of Bramley's after 6 months (March) storage in 9% CO_2, 12% O_2 at 4-4.5°C followed by 7 days at 18°C

	1.5% CO_2	3.0% CO_2	6% CO_2	3 week delay	$LSD_{0.05}$
Firmness	92.8	95.9	93.5	92.5	2.39
% Brix	10.4	10.4	10.1	10.3	0.37
Colour A	-20.2	-20.7	-20.2	-20.0	6.06
Colour B	44.7	43.2	43.1	43.7	0.79
% Rots	6.9	6.9	9.7	10.9	6.80
% Ext CO_2 inj.	0	0	0.38	0	0.01
% Int. CO_2 inj.	0	0	1.9	0	0.50

N.B. Bramley's were either sealed immediately after cooling to 4-4.5°C and 24 h SmartFresh™ treatment and CO_2 allowed to accumulate to 1.5% CO_2 for 3 weeks, or 1.5% CO_2 for 1 week followed by 2 weeks at 3% CO_2, or a week each at 1.5%, 3.0% and 6% CO_2.

Table 2.20 Ex-store quality of Bramley's after 9 months (March) storage in 5% CO_2, 1% O_2 at 4-4.5°C

	1.5% CO_2	3% CO2	6% CO_2	3 week delay	$LSD_{0.05}$
Firmness	93.6	92.97	95.39	92.18	2.21
% Brix	9.754	9.807	11.181	10.396	0.36
Colour A	-19.387	-19.438	-19.609	-19.796	0.28
Colour B	43.14	42.02	42.62	42.70	0.88
% Rots	17.67	10.87	9.17	12.57	8.58
% Scald	57.46	58.97	54.23	32.79	9.58
% EXT CO_2Inj.	0	0	1.76	0	7.26
% Int CO_2 inj.	0	0	0	0	9.83

N.B. Bramley's were either sealed immediately after cooling to 4-4.5°C and 24 h SmartFresh™ treatment and CO_2 allowed to accumulate to 1.5% CO_2 for 3 weeks, or 1.5% CO_2 for 1 week followed by 2 weeks at 3% CO_2, or a week each at 1.5%, 3.0% and 6% CO_2.

Table 2.21 Ex-store quality of Bramley's after 9 months (March) storage in 5% CO_2, 1% O_2 at 4-4.5°C followed by 7 days at 18°C

	1.5% CO_2	3% CO2	6% CO_2	3 week delay	$LSD_{0.05}$
Firmness	81.0	76.2	71.0	74.5	2.63
% Brix	10.0	10.0	9.5	9.8	0.32
ColourA	-18.9	-19.3	-19.5	-19.7	1.00
Colour B	42.2	44.2	43.9	45.0	0.28
% Rots	11.86	6.87	10.2	8.54	8.43
%Scald	96.06	78.79	63.04	69.07	1.00
% EXT CO_2 inj.	0	0	0	0	4.39
% INT CO_2 inj.	0	0	0	0	10.27

N.B. Bramley's were either sealed immediately after cooling to 4-4.5°C and 24 h SmartFresh™ treatment and CO_2 allowed to accumulate to 1.5% CO_2 for 3 weeks, or 1.5% CO_2 for 1 week followed by 2 weeks at 3% CO_2, or a week each at 1.5%, 3.0% and 6% CO_2.

Conclusions

- The impact that the establishment of CA conditions has on Bramley quality is dependent on fruit maturity at the point of cabinet sealing.
- In the first Year of the trial, the incidence of external injury was low and the impact of rapid CA establishment was difficult to determine. However there was a greater incidence of internal damage and a slight trend for increasing internal browning with slower rates of establishment.
- In the second year of the trial, the potential for external and internal CO_2 injury was greater. Early harvested fruit was more susceptible to external CO_2 damage when a rapid pull down to 1% oxygen was achieved within three weeks of sealing. Extending the pull down rate to four to six weeks before establishing CO_2, reduced the incidence of damage.
- A more rapid pull down of oxygen may be possible on later picked fruit where the propensity to develop external CO_2 injury is less.
- The incidence of internal browning was made worse by rapid establishment over a three week period in early harvested fruit. Slowing CA establishment over six weeks, helped to reduce internal injury. Internal browning was worse on later picked fruit.
- A more rapid pull down of oxygen may help to reduce internal injuries on later picked fruit where delay in establishment can lead to higher fruit respiration rates.
- In these small scale trials, the rate of CA establishment did not improve retention of firmness or background green colour of fruit.
- 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 three 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 using an earlier pull down of oxygen, the susceptibility of fruit to external CO_2-injury in early harvested fruit makes this a risky strategy.
- In the first year of the trial, 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 three weeks of storage through venting with air. This regime in the first year of the trial reduced the incidence of storage rots and internal flesh browning (core-flush and

senescent browning), but was not observed in the second year. While in the second year no benefit in rot control was achieved, immediate sealing of stores and maintaining CO_2 at 1.5-3.0% did not lead to external or internal CO_2 injury.

Technology transfer

The project results were presented to growers at the EMRA Storage Day in March 2012 and 2014 and to the HDC Tree Fruit panel in March 2012.

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References

Colgan, R.J., Dover, C.J., Johnson, D.S. and Pearson, K. (1999). Delayed CA and oxygen at 1 kPa or less control superficial scald without CO2 injury on ‘Bramley's Seedling’ apples. Postharvest Biology and Technology 16, 223-31