Project title:	Improving quality and extending the storage life of Braeburn and selected new apple varieties through improved storage strategies
Project number:	TF 208
Project leader:	Dr Richard Colgan
Report:	Final report July 2014
Previous report:	Annual, 2013
Key staff:	
	Dr Richard Colgan (NRI) - Technical lead on implementation of storage trials and fruit physiology, supported by Debbie Rees (NRI). Natural Resource Institute, University of Greenwich at Medway, Chatham, Kent ME4 4TB Ms Karen Thurston (EMR) - Technical support and management of storage facilities. Ms Lisa Wray-French (NRI)- Technical support
Location of project:	Jim Mount Building (Produce Quality Centre) East Malling Research New Road East Malling, Kent ME19 6BJ
Project coordinator:	Nigel Jenner
Date project commenced:	1 July 2012
Date project completed (or expected completion date):	30 June 2014
Key words:	Apple, Braeburn, CA storage, New Varieties

DISCLAIMER

AHDB, operating through its HDC division seeks to ensure that the information contained within this document is accurate at the time of printing. No warranty is given in respect thereof and, to the maximum extent permitted by law the Agriculture and Horticulture Development Board accepts no liability for loss, damage or injury howsoever caused (including that caused by negligence) or suffered directly or indirectly in relation to information and opinions contained in or omitted from this document.

[The results and conclusions in this report are based on an investigation conducted over a one-year period. The conditions under which the experiments were carried out and the results have been reported in detail and with accuracy. However, because of the biological nature of the work it must be borne in mind that different circumstances and conditions could produce different results. Therefore, care must be taken with interpretation of the results, especially if they are used as the basis for commercial product recommendations.]

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.

Dr Richard Colgan

Research Fellow

Natural Resources Institute, University of Greenwich

Signature ....Richard Colgan....................................Date 25/7/2014 ....

Report authorised by:

Signature .... Date ....

CONTENTS

GROWER SUMMARY

Headline

- During the first four months of Braeburn storage, 1.6% O_2 helps to reduce the overall incidence of diffuse core browning compared to 1.2 % O_2.

Background and expected deliverables

With increasing volumes of Braeburn being stored, strategies to extend the storage life beyond March would facilitate better scheduling of the crop for the UK market. A previous HDC funded project (TF175) investigated the effect of different rates of CA establishment in Braeburn compared to delayed establishment for 21 days. Fruit with better ex-store quality was achieved by sealing stores immediately after cooling and allowing fruits to establish 2% O_2 by natural respiration and by maintaining this for 10 days before allowing O_2 to drop to a holding CA of 1.2% O_2 <1% CO_2. Immediate sealing led to a three-fold reduction in the incidence of core-flush. However, even with more rapid establishment of CA, it has proved difficult to extend the season beyond March due to a high incidence of core-flush and scald.

There is evidence that the incidence of core-flush is associated more strongly with orchard factors than seasonal variation. Reduced seed set in Braeburn has been linked to poor pollination and is reported to lead to a higher incidence of low calcium senescent disorders. Although core-flush is considered a symptom of senescence, and often does not appear until late in the storage season, it is aggravated by poor ventilation, where a build-up of internal CO_2 and depletion of O_2 through respiration, can lead to localised damage. Compared to other varieties Braeburn has a dense flesh with greater resistance to gas diffusion and a heightened risk of developing a localised build-up of CO_2 as well as depletion of O_2. It has recently been reported that physiological damage to the core region of Braeburn is due to the development of localised zones of low-oxygen within the flesh of fruit. Adoption of strategies that attempt to lower respiration rate through storage at lower temperatures or through the use of ethylene control strategies may help to reduce CO_2-injury/core-flush and Braeburn browning disorder (BBD). In addition, storage in higher oxygen concentrations may help to alleviate some of the low oxygen stress type injuries associated with the core region of fruit (diffuse core browning - DCB/Core-flush).

In addition to testing storage regimes for Braeburn it was planned to investigate storage regimes for new varieties. With the support of individual marketing groups a small number of CA regimes will be tested for Rubens, Opal, Zari and Envy.

Overall aim of project

- To extend the storage life, marketing season and quality of Braeburn and selected new varieties.

Specific Objectives

- To investigate the use of a range of storage strategies to improve the quality and extend the storage life of Braeburn and selected new varieties; eg. Rubens, Opal, Zari and Envy.

For Braeburn the storage regimes to be tested would include:

- Modulation of storage temperature.

- Delayed ethylene scrubbing or delayed SmartFresh^{TM} application. (It is anticipated these strategies will reduce fruit respiration rate during long-term storage and lead to a lowering in the incidence of core-flush).

- Controlled atmosphere (CA) regimes of 3% O_2 with a 3 week delayed es$_t$ablishment of 0.7 % CO_2 or 2.5% oxygen and 0.5% CO_2.

- Extending the storage-life of air-stored Braeburn through the delayed application of SmartFresh^{TM} or ethylene scrubbing in 2 % oxygen.

Summary of the project and main conclusions

In year 1 of the project, storage of Braeburn in 1.6% O_2 provided a better overall control of internal browning conditions than 1.2% O_2. Equally the modulated temperature regime of 1.2 % O_2 with storage for five months at 1.5-2.0°C followed by two months at 0.5-1.0°C provided a marginal improvement in quality over the standard storage regime (1.2% O_2 1.5-2.0°C). Storing fruit in less stringent conditions has been successfully used to reduce the incidence of water core symptoms in Cox and Bramley. Raising store oxygen from 1.2 to 1.6% O_2 reduced the severity of DCB in the early stages of storage in year 2 but failed to reduce the number of fruits going onto develop core-flush later in the storage season.

In the first year of the trial increasing oxygen above 2% did not reduce the amount internal browning. In the absence of ethylene control strategies, fruits softened more during shelf-life in late-stored fruit. Although the use of delayed SmartFresh^{TM} application helped to contain late season softening, it exacerbated internal browning. Incremental increase of oxygen from 1.2 to 2% up to 3% by the end of storage also failed to limit internal flesh browning.

Lowering the temperature has in the past been used to reduce internal browning in fruit. However, in this trial, where fruits were stored for longer than two months in 0.5-1.0°C, the incidence of core-flush was increased in long-term stored fruit. Continuous exposure to low temperatures is known to induce core-flush but temperature modulation for shorter periods was considered to be a safer option that may help to reduce internal browning.

In parallel trials funded by the University of Greenwich, dipping fruit in the anti-oxidants helped to reduce core-flush in Braeburn and similar effects have been reported on Bramley (Johnson and Colgan 1996). While the use of antioxidants is no longer permitted, reducing oxidative processes by use of extremely low oxygen storage can help to reduce the incidence of core-flush development.

Main conclusions

- The incidence of Braeburn browning disorder and core-flush were closely related to harvest maturity of fruit entering store. Fruits with an advanced state of maturity and higher fruit respiration had a significantly higher risk of developing disorders.
- Diffuse core browning was influenced strongly by orchard factors. The severity of diffuse core browning was lower when fruits were stored at 1.6% O_2 (1.5-2.0°C) in the early stages of the storage season.
- Fruits stored in 1.6% O_2 had slightly lower background green colour.
- Fruits with higher calcium content (7 mg 100^{-1} g) were less prone to developing core-flush.
- Modulated storage temperature offered little benefit and extending exposure to 0.5-1.0°C beyond two months increased the risk of core-flush.
- Combining CA storage in 2% oxygen with delayed ethylene removal or SmartFresh™ did not control BBD.
- Storage at oxygen concentrations above 2% failed to control BBD or core browning.
- Maximising CO_2 scrubbing from the storage environment in commercial fruit stores will help reduce the incidence of internal browning. Concentrations <0.5% CO_2 are beneficial.
- It is important to note that long-term storage is not recommended in orchards with a history of developing these disorders.

Data from storage trials of new varieties was made available to individual marketing groups associated with the variety in question.

A more detailed account of the regimes investigated and the results achieved can be found in the Science Section of this report.

Financial benefits

Reducing the incidence of internal browning problems in Braeburn may afford the opportunity to extend the marketing window for Braeburn.

Action points for growers

- Late picking of Braeburn can increase the incidence of internal browning.
- Standard harvest maturity parameters are not always sufficient to accurately predict the physiological maturity of Braeburn.
- Ensure fruits have good mineral nutrition with calcium and boron at or above the recommendations for Cox.
- During the first four months of storage, 1.6% O_2 helps to reduce the overall incidence of diffuse core browning compared to 1.2 % O_2.
- Storage at 1.6% O_2 may help to alleviate the glassy water core type symptoms associated with diffuse core browning, allowing more of the solutes trapped in the air spaces between cells to be taken up by adjacent cells.
- Storage at 1.6% O_2 rather than 1.2% O_2 results in slightly higher loss of green background colour.
- Storing Braeburn at 0.5-1.0°C for longer than 2 months increases the risk of core-flush.

SCIENCE SECTION

Introduction

Braeburn is a variety that maintains good texture and eating quality in store. However storage is often terminated prematurely in March due to the risk of fruit developing late-season diffuse core browning/core-flush. The latter condition is associated with a pink/brown discolouration of the flesh surrounding the core cavity. The condition can be exacerbated by harvesting over-mature fruit or storing at too low a temperature for prolonged periods. The pre-core-flush condition described as diffuse core browning (DCB) is also a feature of Braeburn. In its pre-browning phase, fruit affected by DCB exhibit a glassy hue around the core cavity. While in some countries this is considered to be of minimal commercial significance, if left long-enough in store, browning of the core-region leads to classic symptoms of core-flush. Work in New Zealand suggests that DCB is related to lower core calcium concentration compared to that found in the rest of the cortex.

In addition to problems in the core, high density Braeburn is prone to poor diffusion characteristics, leaving zones of tissue predisposed to elevated concentrations of carbon dioxide or depleted oxygen, resulting in browning within the central region of the cortex. This is referred to as braeburn browning disorder (BBD) and is distinct from DCB. In HDC research project TF 192, work in the final year centred on the use of modulated storage temperatures to restrict BBD and core-flush/DCB. Extensive periods of reduced temperature storage led to higher incidence of core-flush. However, the introduction of shorter periods of intermittent low-temperature (0.5-1.0°C) or delayed ethylene scrubbing to a standard CA Braeburn regime (1.2% O_2, <1% CO_2 at 1.5-2.0°C), may help to reduce the overall respiration rate of fruit, preventing a localised depletion of oxygen in the core region which often leads to damage.

Overall aim of project

- To extend the storage life, marketing season and quality of Braeburn and selected new varieties.

Specific Objectives

- To investigate the use of a range of storage strategies to improve the quality and extend the storage life of Braeburn and selected new varieties; eg. Rubens, Opal, Zari and Envy.

For Braeburn the storage regimes to be tested would include:

- Modulation of storage temperature.

- Delayed ethylene scrubbing or delayed SmartFresh^{TM} application. (It is anticipated these strategies will reduce fruit respiration rate during long-term storage and lead to a lowering in the incidence of core-flush).

- Controlled atmosphere (CA) regimes of 3% O_2 with a 3 week delayed es$_t$ablishment of 0.7 % CO_2 or 2.5% oxygen and 0.5% CO_2.

- Extending the storage-life of air-stored Braeburn through the delayed application of SmartFresh^{TM} or ethylene scrubbing in 2 % oxygen.

The choice of storage regimes will be finalised with the industry representative.

For Rubens, Zari, Opal and Envy, storage regimes to be tested will be identified through discussions with commercial advisors.

Materials and Methods

In year 1 of the project, Braeburn apples comprising four Hilwell and one Louchbuie clones were harvested on 15-17 October 2012, from five orchards across Kent. Harvest maturity measurements were made on a subset of fruit (20).

Firmness (N) was measured on opposite sides of the fruit using a Lloyd LRX texture analyser, fitted with a Magness taylor 11 mm probe. Background colour was measured using a Minolta colour meter in lab mode. Soluble solids (sugars) were measured using a refractometer. Starch content was estimated using a 4% [w/v] potassium iodine and 10% [w/v] iodine solution, and scored using starch clearance charts (circular-Ctifl). 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 at FAST Ltd.

Internal ethylene concentration was determined according to Mousdale and Knee (1981): 0.5 mL of core cavity air-space was injected into a GC-FID (ATI-Unicam 610) fitted with a 1 m long, 6 mm OD glass packed column with 100/200 mesh alumina maintained at 130°C. Respiration rates were calculated on replicate ten-fruit samples placed in 5 L glass jars sealed for 2 hours at store temperature. CO_2 production was measured using an infra-red gas analyser (ADC).

Storage samples were cooled for 48 hours to 1.5-2.0°C, before a holding CA of 2% O_2 was established by allowing fruit respiration to lower O_2 concentrations, while CO_2 was scrubbed from the atmosphere using $Ca(OH)_2$ scrubbers and maintained for 10 days. The final storage CA regime of 1.2% O_2 was then established through fruit respiration. Fruit was subject to periods of modulated temperature (Table 1) each lasting 70 days, of either a standard (1.5-2°C) or low temperature regime (0.5-1.0°C). Delayed ethylene scrubbing was applied using 5 kg bags of potassium permanganate coated clay beads (Bion) in selected cabinets after the first 70 days of storage. The delayed application was designed to avoid the early period in the storage-life of fruit where sensitivity to ethylene suppression and CO_2 build up can exacerbate the incidence of internal flesh browning.

In year 2, four Braeburn orchards (EV, WH, BC, NC) were selected from the previous years' trials and harvested on two occasions; the weeks beginning 21 October and 28 October 2013. Fruits were taken to the Produce Quality Centre at East Malling Research where apples were randomised, with damaged and misshapen fruits being discarded. Sub samples of fruit were retained for mineral analysis and harvest maturity measurements.

In year 2, fruits were cooled to store temperature within 48 hours and remained in air for 2 weeks before cabinets were sealed. This was done to avoid a repeat of the high incidence of BBD suffered in year one of the trial. After sealing, oxygen was allowed to drop by 1% O_2 per day until it reached 2% oxygen and this was held for ten days before the final CA of 1.2% or 1.6% O_2 was achieved through fruit respiration. Fruit from each pick was held in separate cabinets.

Long-term exposure to lower temperatures (0.5-1.0°C) appear to exacerbate the incidence of core-flush, but incorporation of shorter periods of low temperature, particularly when applied during the storage season, have been shown in previous years to retain background green colour and reduce internal browning. In this trial fruits remained at standard temperature (1.5-2.0°C) for 70 days until the first quality assessment, thereafter fruit from two cabinets (1.2% O_2) and (1.6% O_2) were transferred to a 0.5-1.0°C store.

Table 1: Controlled atmosphere regimes assessed during the Braeburn storage trials 2012-2013.

Treatment	CA regime	Comments
1	1.2 % O_2 <1% CO_2	5 months @ 1.5-2.0°C, 3 months at 1.0°C
2	2 % O_2 <1% CO_2	Delayed 1-MCP (after 6 weeks)
3	2 % O_2 < 1% CO_2	Delayed scrubbing
4	3.0% O_2, 0.8% CO_2 * Scrub CO_2 for first 3 weeks	
5	2.5% O_2, 0.5% CO_2 * Scrub CO_2 for first 3 weeks	
6	1.6% O_2	
7	1.2 % O_2, increasing to 2% after 2 months, and 3% after 4 months	
8	1.2 % O_2 <1% CO_2 standard 1.5-2.0°C	

All treatments were at 1.5-2.0°C unless indicated otherwise.

Controlled atmospheres were monitored using an ICA oxygen and CO_2 analyser and control was achieved via a computerised ICA 66 system, with automatic injection of compressed air to maintain O_2 concentrations. CO_2 was removed from cabinet atmospheres through the addition of an external CO_2 scrubber filled with lime ($Ca(OH)_2$). Samples were taken for quality analysis on a range of dates; immediately ex-store, after seven days of shelf-life (18°C) and after 90 (year 2), 150 and 180 days of storage. The same methods of quality analysis were used as described above for harvest.

Results

Year 1

Harvest maturity

Picking fruit at optimum maturity for long-term storage is an important factor in reducing the incidence of core-flush and Braeburn browning disorder (BBD). Delaying harvest until fruit reaches 50% red colour can lead to elevated internal ethylene concentrations. Above a threshold of 100 ppb ethylene, many ripening related processes are hard to control under CA storage. A significant proportion of fruit in the trial had already exceeded 100 ppb internal ethylene concentration at harvest. Starch clearing patterns, although generally indicative of harvest maturity were not as sensitive at discriminating fruit maturity when compared to the fruit's internal ethylene status (Table 2). Moreover, % Brix content of fruit at harvest were similar across fruit from all five orchards. However the dry matter content was higher in orchards E, NC and BC. In general, the % Brix content of fruit is correlated to the dry matter content of fruit, although this wasn't observed in this case.

At harvest, fruit from orchard E, despite having relatively low internal ethylene, had a higher respiration rate (6.14 mL CO_2 kg^{-1} h^{-1}) and starch clearance patterns indicated that only 60% starch remained at harvest. Orchard NC had high internal ethylene at harvest (684 ppb) while the respiration rate of 5.0 CO_2 kg^{-1} h^{-1} was the second highest of the samples tested. Subsequent respiration monitoring of fruit in air at 18°C identified Braeburn from orchard E and NC remaining higher during the 14 day period (Fig 1).

The calcium content of fruit was generally above 5 mg 100g FW^{-1} with the exception of Braeburn from orchard E where fruit were larger and calcium content was 3.9 mg 100g FW^{-1} making it unsuitable for long-term storage. Calcium/potassium ratios for four out of five orchards were below 30, designating fruit capable of long-term storage (April) based on mineral composition. Braeburn from orchard E with generally larger fruit, was lower in calcium and a ratio of potassium/calcium of over 30.

The specific gravity of fruit was measured as an indicator of fruit density at 20°C and at an atmosphere of 1013 mbar. Specific gravities did not vary significantly between varieties tested with fruit ranging from 1.03-1.06 g cm^{-3}.

Table 2. The maturity of Braeburn clones at harvest

Orchard (clone)	Fruit size (mm)	Average fruit wt (g)	Int. Ethylene (ppb)	Resp. Rate $mlCO_2$ /kg	Ctifl Starch cover	% Brix	Specific Gravity g cm^{-3}	Firmness N	% Dry matter	Ca mg/ 100g	K/Ca*
WH	67.4	170.2	134.9	4.67	3.7	10.4	1.03	91.4	13.6	5.9	17.79
E	73.1	185	89.1	6.14	5.0	11.0	1.05	96.4	16.0	3.9	34.02
NC	69.6	189.8	684	4.61	4.5	11.0	1.06	89.8	15.6	6.4	19.66
NIC	70.1	172.8	218.2	5.00	6.3	11.1	1.04	96.2	13.3	8.1	14.32
BC	71.7	176.2	300	4.48	4.1	11.6	1.04	104.2	15.5	7.1	12.68

The K/Ca ratio should not exceed 30, while Ca concentrations should be in excess of 5 mg/100g fresh tissue for long-term storage.

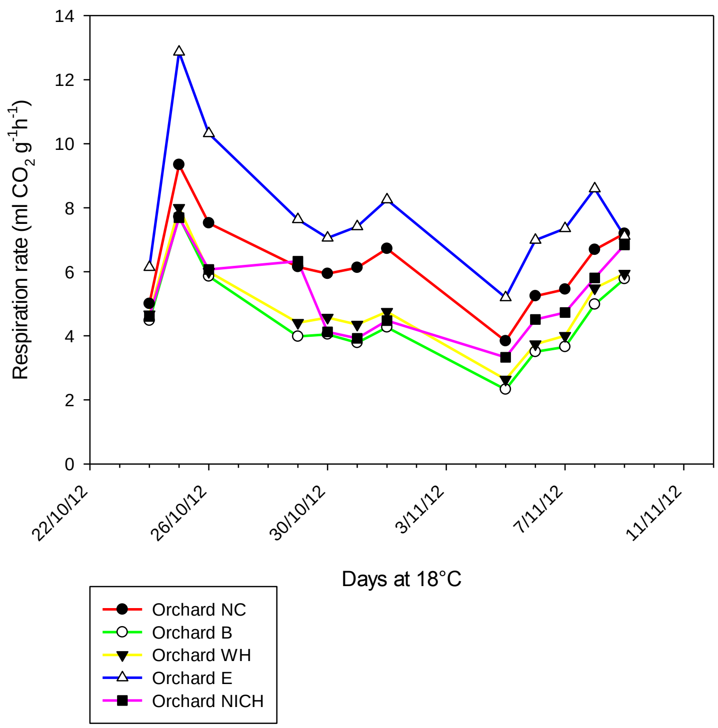

Figure 1. Respiration rate (mL CO_2 $g^{-1}h^{-1}$) of Braeburn apples sampled from five orchards across Kent.

March Inspection (150 days storage)

Fruit firmness coming out of store in March ranged from 8.2-9.4 kg (82-94 N), with SmartFresh™ treated fruit (T2) softening the least (Table 3). Storage at a lower O_2 concentration of 1.2% O_2 was associated with restricted sugar formation, and lower % Brix (11.8-12.0). The retention of background green colour was not well correlated with oxygen concentration. The incidence of rotting was highest (6%) in the standard 1.2% O_2 regime. Internal flesh quality was most affected by the occurrence of BBD and core-flush. Braeburn stored in 1.2% Oxygen at 1.5-2.0°C led to the lowest incidence of BBD in March, while delayed application of SmartFresh™ increased fruits propensity to develop both disorders and as such there is no recommendation for using SmartFresh™ on Braeburn in the UK. Continental type CA conditions where higher O_2 concentrations (2.5-3.0% O_2) were combined with CO_2, maintained between 0.5-0.8%, or where oxygen was sequentially raised from 1.2% to 2% during the first 6 months of storage resulted in an elevated incidence of core-flush, BBD and CO_2 injury.

Table 3. Ex-store quality of Braeburn apples (Mean of five orchards) stored under a range of CA regimes at 1.5-2.0°C or with periods at 0.5-1.0°C March 2012

	Firm (N)	% Brix	Colour A	Colour B	% Rots	% CO_2 inj.	% DCB	% BBD	% Core Flush
1.2% O_2 TM	87.0	11.8	-12.2	41.6	2	0	8	19	30
2% O_2 + 1-MCP	93.6	12.0	-9.8	42.5	1	0	4	34	85
2% O_2 + E Scrub	88.2	12.4	-10.4	42.8	0	2	6	13	57
3% O_2, 0.8% CO_2	81.6	12.5	-12.3	42.9	0	0	0	24	52
2.5% O_2 0.5% CO_2	83.1	11.8	-10.9	43.1	1	1	5	13	54
1.6% O_2	85.3	11.8	-12.1	41.9	1	0	0	24	45
1.2/2/3% O_2	82.3	12.9	-9.1	41.8	2	1	3	24	61
1.2% O_2	87.0	12.0	-9.2	41.1	6	4	11	14	27
$LSD_{0.05}$ on 39 df	3.1	0.2	1.4	0.9	3.7	3.8	7.9	11.4	12.2

After a week's shelf-life at 18°C, fruit firmness remained above the commercial threshold of 60 N in all treatments. In the absence of ethylene removal or 1-MCP treatment, Braeburn stored in O_2 concentrations of 2% or higher softened more than fruit stored at 1.2-1.6% O_2 (1.5-2.0°C) during shelf-life. Storage at 1.2-1.6% lowered the incidence of BBD during shelf-life. The incidence of core-flush increased significantly in apples from all treatments during shelf-life treatment.

Table 4. Ex-Shelf-life quality (March) of Braeburn apples (Mean of five orchards) stored under a range of CA regimes at 1.5-2.0°C or with periods at 0.5-1.0°C

	Firm (N)	% Brix	Colour A	Colour B	% Rots	% CO_2 inj.	% DCB	% BBD	% Core Flush
1.2% O_2 TM	85.3	12.2	-9.6	42.9	4	0	8	40	70
2% O_2 + 1-MCP	93.8	12.1	-7.5	42.7	4	0	4	40	94
2% O_2 + E Scrub	80.6	12.4	-8.9	44.7	1	3	6	40	73
3% O_2, 0.8% CO_2	78.2	12.0	-8.7	44.5	0	1	0	39	71
2.5% O_2 0.5% CO_2	78.2	12.4	-7.9	44.9	1	0	5	46	77
1.6% O_2	81.4	12.3	-8.8	43.9	2.1	2	0	24	72
1.2/2/3% O_2	74.5	12.4	-7.5	43.3	2.7	0	3	61	78
1.2% O_2	83.7	12.5	-7.5	42.8	3	1	11	26	62
$LSD_{0.05}$ on 39 df	2.9	0.2	1.4	0.8	4.8	2.7	7.9	15.3	11.7

May/June Inspection (180 days storage)

The firmness of Braeburn removed from store in late May ranged between 8.2-9.4 kg (82-94 N) across all treatments and was above commercial threshold values of 6 kg (60 N). After 7 months storage, the % Brix values of Braeburn ranged from 11.8-12.9 %. Background green colour values ranged from -9.1 to -12. No clear pattern in % Brix values or background green colour could be attributed to the storage O_2 concentration at this stage in the storage period. Samples of Braeburn inspected in June had a greater incidence of internal disorders than earlier inspections, with a very high incidence of core-flush (27-85%). Storage at lower O_2 (T8:1.2% O_2) at 1.5-2.0°C maintained firmness of fruit (87 N) and was the best treatment for reducing core-flush (27%) and BBD (14%). However, the standard regime incurred the highest incidence of DCB (25%). Lowering the storage temperature to 0.5-1.0°C after five months through the storage season did not reduce the incidence of internal disorders of fruit inspected immediately on removal from store.

Table 5. Ex-store quality of Braeburn after 180 days

	Firm (N)	% Brix	Colour A	Colour B	% Rots	% CO_2 inj.	% DCB	% BBD	% Core Flush
1.2% O_2 TM	87.0	11.8	-12.2	41.6	2	0	24	19	30
2% O_2 + 1-MCP	93.6	12	-9.8	42.5	1	0	1	33.7	85
2% O_2 + E Scrub	88.2	12.4	-10.4	42.8	0	2	8	13	57
3% O_2, 0.8% CO_2	81.6	12.5	-12.3	42.9	0	0	10	24	52
2.5% O_2 0.5% CO_2	83.1	11.8	-10.9	43.1	1	1	7	13	54
1.6% O_2	85.3	11.8	-12.1	41.9	1	0	11	24.1	45.1
1.2/2/3% O_2	82.3	12.9	-9.1	41.8	2	1	2	24	61
1.2% O_2	87	12	-9.2	41.1	6	4	25	14	27
$LSD_{0.05}$ on 39 df	3.15	0.25	1.42	0.93	3.69	1.89	9.05	11.42	12.15

N.B : Diffuse Core Browning (DCB), Braeburn Browning Disorder (BBD), Core Flush (CF)

After a week's shelf-life the fruit stored in higher O_2 (2-3 %O_2) storage regimes started to soften (7.4-7.8 kg - 74-78 N), with the exception of treatments where 2% O_2 storage had been combined with ethylene removal or SmartFresh™ application, leading to firmness readings of 8-9.3 kg (80 – 93 N) respectively. Background green colour dropped significantly during shelf-life. However greater green colour retention was observed where fruit had been stored in lower O_2 (1.6% O_2 or 1.2% O_2) with modulated storage temperatures providing the best colour retention regimes. The incidence of core-flush and BBD increased during shelf-life. The best regimes for minimizing the incidence of BBD appeared to be storage in 1.6% O_2 or the standard 1.2% O_2 regime.

Table 6. Ex-shelf life quality of Braeburn after 180 days storage + 7 days at 18°C

	Firm. (N)	% Brix	Colour A	Colour B	% Rots	% CO2 injury	% DCB	% BBD	% Core flush
1.2% O_2 TM	85.3	12.2	-9.6	42.9	4.0	0.0	8.0	40.0	70.0
2% O_2 + 1-MCP	93.8	12.1	-7.5	42.7	4.0	0.0	4.0	40.1	93.7
2% O_2 + E Scrub	80.6	12.4	-8.9	44.7	1.0	3.0	6.0	40.0	73.0
3% $O_{2,}$ 0.8% CO_2	78.2	12.0	-8.7	44.5	0.0	1.0	0.0	39.0	71.0
2.5% O_2 0.5% CO_2	78.2	12.4	-7.9	44.9	1.0	0.0	5.0	45.8	77.0
1.6% O_2	81.4	12.3	-8.8	43.9	2.1	2.0	0.0	24.3	71.8
1.2/2/3% O_2	74.5	12.4	-7.5	43.3	2.7	0.0	3.0	61.0	78.0
1.2% O_2	83.7	12.5	-7.5	42.8	3.0	1.0	11.0	26.0	62.3
$LSD_{0.05}$ on 40 df	2.88	0.23	1.42	0.85	0.85	2.67	7.89	15.32	11.70

Orchard factors

When averaged across all treatments, the presence of BBD and core-flush was strongly influenced by orchard consignment ($P<0.001$), with fruit from orchard E suffering 46% BBD and 84% core-flush, compared to apples from orchard BC that suffered only 5% BBD and 27% core-flush. Fruits from orchard E were more mature at harvest with a higher respiration rate during the initial period of storage. Firmness of fruit varied by approximately 1 kg, with fruit from orchard WH averaged 90.4 N while Braeburn from NC orchard was only 78 N. Braeburn from orchard E lost the greatest amount of background green colour during storage and shelf-life. Braeburn from Orchard NC was also over-mature at harvest and this led to lower firmness, loss of green background colour and a high incidence of core-flush, although interestingly, this orchard was not particularly prone to BBD.

By the end of the trial in early June, fruit firmness was above commercial levels of acceptability across all orchards. Colour varied significantly with Braeburn from orchard E suffering a loss of green background.

Table 7. Orchard factors contributing to post-harvest quality of Braeburn: Ex-shelf-life quality March :

Orchard	BC	E	NC	NiC	WH
Firmness	84.2	87.6	88.0	79.8	90.4
% Brix	12.3	13.2	11.9	11.8	11.5
Colour A	-13.1	-7.4	-10.0	-10.6	-12.6
Colour B	43.5	43.2	41.0	41.4	42.1
% Rots	0.6	1.3	1.9	0.6	3.8
% CO2 injury	1.9	2.5	0.0	0.6	0.0
% DCB	10.6	6.3	5.0	3.1	30.0
% BBD	5.7	46.7	29.4	3.1	18.1
%CF	27.6	84.4	49.4	63.8	31.9

Table 8. Orchard factors contributing to post-harvest quality of Braeburn. Ex-shelf-life quality May :

Orchard	BC	E	NC	NIC	WH
Firmness	81.2	76.3	85.4	79.1	87.7
% Brix	12.6	13.1	12.0	12.0	11.8
Colour A	-10.0	-4.9	-8.5	-7.0	-11.1
Colour B	45.5	44.0	42.7	42.1	44.1
% rots	0.0	3.1	4.2	2.6	1.3
% CO_2 injury	1.9	0.6	0.6	1.3	0.0
%DCB	6.9	0.6	3.1	0.0	12.5
% BBD	29.4	68.0	47.1	21.9	31.2
% CF	51.1	98.1	73.6	88.3	61.9

Internal Quality

Overall the internal quality of fruit averaged over five orchards, deteriorated with storage time and this was particularly noticeable when fruit was subject to a shelf-life period of seven days at 18°C. Continental style regimes combining higher O_2 (2.5-3% O_2 and 0.5-0.8% CO_2) were slightly worse at controlling BBD and core-flush than the standard 1.2% O_2 regime or a 1.6% O_2 regime used in France. The lower O_2 regimes had the benefit of maintaining background green colour.

Table 9. The overall average of internal disorders- data normalized means of % core-flush, % diffuse core browning, % CO_2-injury and % core flush data taken from four orchards over 4 orchards

CA regime	March Ex Store	March Shelf Life	May Ex-store	May Shelf-Life
1.2% O_2 TM	12.7	36.3	45.6	73.8
2% O_2 + 1-MCP	19.4	26.4	74.8	86.1
2% O_2 + E Scrub	14.2	37.3	50.0	76.3
3% $O_{2,}$ 0.8% CO_2	15.3	37.2	53.8	69.4
2.5% O_2 0.5% CO_2	14.4	32.1	46.9	79.9
1.6% O_2	14.2	39.7	50.1	61.3
1.2/2/3% O_2	15.3	27.1	55.0	88.8
1.2% O_2	8.8	45.3	43.8	62.7

Year 2

Harvest maturity

The firmness of fruit was above the 85N (8.5 kg) required for long-term storage, whilst starch patterns ranged from 4.3-6.2 on the ctfl starch chart (Table 10). While harvest maturity parameters suggested fruit from three out of the four orchards were sufficient for long-term storage, additional measurements of respiration rate and ethylene production showed that there was greater variation in harvest maturity than the standard field based measurements indicated.

Fruit respiration rates at harvest for pick 1 fruit (Figure 2.1) were similar across orchard consignments averaging 1.5 ml CO_2 kg^{-1} h^{-1} over the first 14 days of storage. However, by the second pick, respiration rates of Braeburn from orchard NC and EV were considerably higher (1.6-1.8 ml CO_2 kg^{-1} h^{-1}). These orchards went on to develop significant internal browning during storage. Orchard NC was more mature than other orchards based on internal ethylene production, however the maturity of this orchard was not easily distinguishable from other orchards based on % brix, firmness, background green colour and starch clearance patterns.

Table 10 Harvest maturity of Braeburn pick on two occasions

Orchard	Pick	% SS	Starch	Firmness (N) Max. load	Colour a	b	Internal Ethylene ppb
EV	1	11.0	4.3	117.8	-12.7	41.1	57.7
	2	11.4	5.0	112.1	-11.1	41.2	85.4
WH	1	10.1	5.0	108.2	-14.9	41.6	44.5
	2	10.5	5.1	108.5	-15.1	42.5	74.9
BC	1	11.2	5.7	96.9	-16.0	42.2	37.8
	2	11.4	6.0	100.1	-16.6	43.4	60.4
NC	1	10.5	5.2	104.0	-13.9	40.9	163.4
	2	11.3	6.2	103.9	-14.0	42.8	349.3

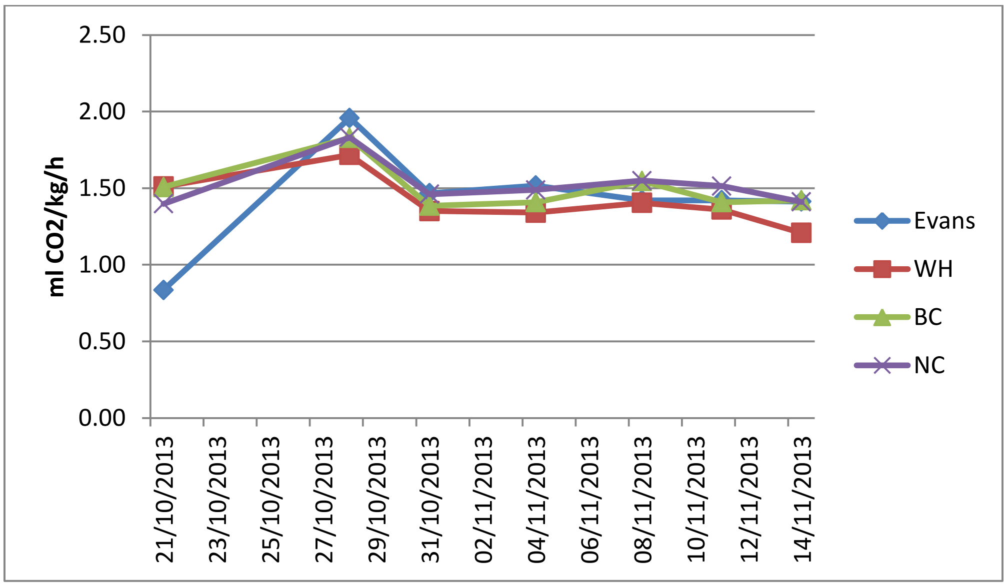

Figure 2.1. Respiration rates of Braeburn (Pick 1) from 4 orchards stored at 1.5-2.0°C

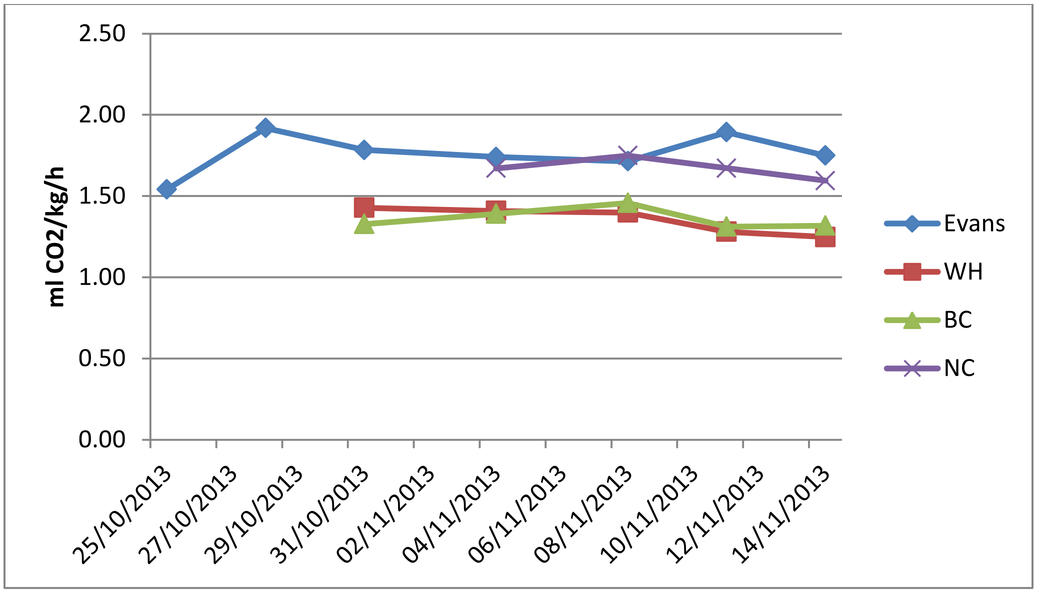

Figure 2.2. Respiration rates of Braeburn (Pick 2) from 4 orchards stored at 1.5-2.0°C

Mineral nutrition values ranged across orchard sites (Table 11) with Braeburn from orchard BC containing the highest calcium (7.4 mg/100g), lowest potassium (91 mg/100g) and a potassium/calcium ratio (12.3), while boron content was 3 mg/kg. Braeburn from the other three orchards contained calcium concentrations ranging from 4.6-5.7 mg/100 g with K:Ca ratio between 20.2-26.7 and boron between 2.2-2.5 mg/kg. Orchard BC had significantly less internal core browning than the other orchards. Low calcium has been implicated in diffuse core browning. The higher calcium content of fruit from orchard BC may have helped protect it from developing core flush.

Table 11 Mineral analysis from Braeburn sampled from each orchard

Orchard	AvgWt	AvgDia	N mg/100g	Ca mg/100g	K:CA Ratio	Cu mg/Kg	Fe mg/Kg
BC	164.8	68.8	52.1	7.4	12.3	0.4	2.7
EV	179.8	71.3	36.4	5.7	20.2	0.4	2.5
NC	178.0	70.4	49.9	4.6	26.7	0.4	2.1
WH	175.8	71.2	36.5	5.2	23.9	0.4	2.3

Orchard	K mg/100g	Mg mg/100g	Mn mg/Kg	P mg/100g	Zn mg/Kg	B mg/Kg
BC	91.3	5.3	0.5	11.1	0.4	3.0
EV	114.3	5.3	0.4	10.7	0.3	2.5
NC	122.1	5.3	0.3	12.8	0.3	2.3
WH	123.2	4.9	0.4	11.0	0.4	2.2

January Inspection: 90 days storage

Firmness of Braeburn coming out of store in January reflected fruit firmness at harvest (Table 12). On average, Braeburn stored at 1.2% O_2 under 1.5-2.0°C lost 10.4 N (1.0 kg) firmness compared to 13.7 N (1.4 kg) where fruit was stored in 1.6% O_2. Fruit from the second pick was on average 3-4 N (0.3-0.4 kg) softer than early picked fruit.

At this first inspection no temperature modulation had been imposed. Diffuse core browning (DCB) symptoms which are typically glassy water core type symptoms, were restricted to the inter-carpel regions of the core in fruit from each orchard (Table 12). In most cases, DCB is not considered of commercial significance until it develops into core-flush symptoms.

After three months storage, the severity of DCB was lower in Braeburn from orchards NC and WH where fruit had been stored at 1.6% O_2, compared to fruit stored at 1.2%. Later picked fruit was more prone to DCB. At this stage in the storage season, no core-flush symptoms were observed in storage samples. Moreover, no signs of Braeburn Browning Disorder (BBD) were seen in the second year of the trial.

The glassy water core-type symptoms are indicative of sorbitol accumulation within the interstitial air spaces between cells and are similar to classic water core symptoms. The latter has been linked to low calcium and is often of a problem in low-ethylene producing/ late maturing apples. Storing fruit at slightly higher temperatures or less stringent CA regimes is often sufficient to allow sorbitol to disperse or become absorbed by adjacent parenchyma cells; allowing fruits to metabolise excess sugars. The slight drawback for storing Braeburn under higher oxygen (1.6 % O_2) was slightly poorer retention of background green colour (Table 12). Background green colour of Braeburn from orchard EV dropped significantly during storage.

Table 12 January: Ex-store quality of Braeburn stored at 1.2% or 1.6% O_2 (<1% CO_2) at 1.5-2.0°C followed by 7 days shelf-life (18°C). Data presented is the overall mean of orchard x storage regime and picking data x storage regime interactions. Data for each replicated cabinet presented.

	Orchard Treatment	BC	EV	NC	WH	Pick 1	 2
Firmness	1.2 % O_2	87.9	106.7	94.3	95.1	98.0	94.0
	1.2 % O_2	88.9	107.3	96.9	96.1	98.9	95.7
	1.6 % O_2	85.9	99.1	93.1	93.0	94.3	91.3
	1.6 % O_2	89.0	98.3	96.8	95.7	96.4	93.5
	$LSD_{0.05}$				***2.31***		***2.31***
% Brix	1.2 % O_2	13.1	14.0	12.9	11.6	13.1	12.8
	1.2 % O_2	13.0	13.5	12.3	11.8	12.6	12.6
	1.6 % O_2	12.9	13.4	12.6	11.8	12.8	12.6
	1.6 % O_2	12.4	13.6	13.2	11.4	12.6	12.7
	$LSD_{0.05}$				***0.24***		***0.24***
Green colour	1.2 % O_2	-10.2	-7.4	-11.1	-13.0	-11.1	-9.8
	1.2 % O_2	-14.2	-8.4	-10.0	-13.9	-12.4	-10.9
	1.6 % O_2	-13.4	-8.6	-10.5	-12.8	-10.9	-11.7
	1.6 % O_2	-13.0	-7.9	-8.3	-11.7	-10.0	-10.5
	$LSD_{0.05}$				***1.20***		***1.20***
DCB index	1.2 % O_2	23.5	21.0	22.5	35.0	20.5	30.5
	1.2 % O_2	18.5	17.0	11.5	17.5	14.8	17.5
	1.6 % O_2	16.5	10.0	11.5	20.5	15.0	14.3
	1.6 % O_2	19.0	21.0	8.5	17	15.5	17.3
	$LSD_{0.05}$				***7.56***		***7.56***

January Inspection: 90 days storage + 7 days shelf-life 18°C

During shelf-life, some of the fruits exhibiting DCB went on to develop core-flush symptoms (Table 13). Core-flush was restricted to fruit (orchards EV and NC) that were more mature entering store at harvest.

Braeburn stored under 1.6% O_2 (<1% CO_2) tended to exhibit less severe DCB symptoms than fruits stored at 1.2% O_2 (<1% CO_2). However, slightly more fruit stored in 1.6% O_2 went on to develop core flush. When evaluating the cumulative total of DCB and core-flush, two out of the four orchards had lower internal browning where fruits were stored in 1.6% O_2.

There was no significant effect on fruit firmness or background green colour during shelf-life where storage oxygen was raised to 1.6% O_2. As expected, later picked fruit were softer than pick 1 fruit coming out of store in January but all fruit were above the commercial threshold of acceptability for firmness (65 N, 6.5 kg). In some cases background green colour was lower in later picked fruit.

Table 13 The quality of Braeburn apples stored at 1.2% or 1.6% O_2 (<1% CO_2) at 1.5-2.0°C followed by 7 days shelf-life (18°C). Data presented is the overall mean of orchard x storage regime and picking data x storage regime interactions. Data for each replicated cabinet presented.

	Orchard Treatment	BC	EV	NC	WH	Pick 1	2
Firmness	1.2 % O_2	88.6	98.0	90.0	95.5	97.1	88.9
	1.2 % O_2	90.7	100.0	91.6	96.6	98.6	90.9
	1.6 % O_2	88.9	98.8	99.8	95.0	95.6	95.6
	1.6 % O_2	86.3	100.8	97.4	96.4	98.2	92.2
	$LSD_{0.05}$				***2.02***		***2.02***
% Brix	1.2 % O_2	12.7	13.9	12.5	11.9	12.9	12.6
	1.2 % O_2	13.0	14.4	12.8	12.1	13.0	13.1
	1.6 % O_2	13.0	13.9	12.9	11.9	12.8	13.1
	1.6 % O_2	13.4	14.3	13.3	12.1	13.0	13.4
	$LSD_{0.05}$				***2.04***		***2.04***
Green colour	1.2 % O_2	-13.6	-8.3	-10.7	-13.5	-11.5	-11.5
	1.2 % O_2	-13.8	-8.3	-12.8	-12.2	-11.9	-11.6
	1.6 % O_2	-13.3	-7.3	-10.2	-12.9	-11.6	-10.2
	1.6 % O_2	-12.8	-7.9	-7.5	-12.1	-10.7	-9.4
	$LSD_{0.05}$				***0.74***		***0.74***
DCB index	1.2 % O_2	16.0	11.5	13.9	17.0	12.8	16.4
	1.2 % O_2	8.5	9.5	8.5	19.0	10.8	12.0
	1.6 % O_2	9.5	7.5	6.7	13.5	7.3	11.3
	1.6 % O_2	6.5	6.5	9.5	16.0	7.3	12.0
	$LSD_{0.05}$				***3.20***		***3.20***
CF index	1.2 % O_2	0.0	8.0	2.1	0.0	2.8	2.3
	1.2 % O_2	0.0	5.0	3.0	0.0	1.3	2.8
	1.6 % O_2	0.0	11.0	7.1	1.5	5.3	4.5
	1.6 % O_2	0.0	7.0	5.5	0.5	3.3	3.3
	$LSD_{0.05}$				***3.63***		***3.63***

March Inspection (150 days storage) Ex-store analysis

There was no significant effect of CA regime or temperature modulation on firmness or background green colour after five months of storage (Table 14). As expected, later picked fruit were softer and less green than pick 1 fruit. At the March inspection, there was no overall effect of CA regime on the incidence of DCB, however temperature modulation for two months had led to a lower incidence of DCB in orchard EV and a similar (albeit not significant at $P<0.05$) trend was observed in orchards BC and WH.

After five months of storage, the first signs of core-flush in ex-store samples were identified in three out of four orchard consignments, with orchard BC remaining free from core-flush. With small numbers of fruit affected no treatment effects were determined.

Table 14. Ex-store quality of Braeburn stored at 1.2% or 1.6% O_2 (<1% CO_2) stored at either 1.5-2.0°C or where temperatures were lowered to 0.5-1.0°C for a period of 2 months post-January (TM). Data presented is the overall mean of orchard x storage regime and picking data x storage regime.

	Orchard					Pick	
	Treatment	BC	EV	NC	WH	1	2
Firmness	1.2 %O_2	87.3	95.3	88.5	90.5	92.0	88.8
	1.2% O_2 TM	85.3	94.8	94.2	95.2	94.1	90.7
	1.6 % O_2	86.2	93.3	84.6	94.5	90.7	88.6
	1.6 % O_2 TM	88.3	84.2	93.8	91.1	92.0	86.7
	$LSD_{0.05}$				***2.3***		***2.3***
% Brix	1.2 %O_2	12.9	14.2	12.4	12.0	12.7	13.1
	1.2% O_2 TM	12.8	13.5	12.8	12.8	12.8	13.2
	1.6 % O_2	13.2	13.4	12.8	12.0	12.6	13.0
	1.6 % O_2 TM	12.7	13.8	12.7	12.0	12.9	12.7
	$LSD_{0.05}$				***0.3***		***0.3***
Colour A	1.2 %O_2	-14.3	-9.5	-15.3	-14.6	-14.2	-12.6
	1.2% O_2 TM	-15.1	-10.2	-11.8	-14.5	-13.1	-12.7
	1.6 % O_2	-14.2	-12.0	-13.6	-15.0	-14.0	-13.4
	1.6 % O_2 TM	-14.5	-10.1	-13.0	-14.1	-13.7	-12.1

	$LSD_{0.05}$				***0.7***			***0.7***
DCB index	1.2 $\%O_2$	9.0	16.0	10.0	15.7		12.6	12.8
	1.2% O_2 TM	6.0	8.0	7.5	12.0		9.8	7.0
	1.6 % O_2	11.5	15.5	2.0	16.5		12.0	10.8
	1.6 % O_2 TM	9.5	9.1	12.0	12.5		11.8	9.8
	$LSD_{0.05}$				***5.3***			***5.3***
CF index	1.2 $\%O_2$	0	10.5	0.5	3		0.5	6.5
	1.2% O_2 TM	0	10	3.5	1		4.25	3
	1.6 % O_2	0	4	5	4		3.5	3
	1.6 % O_2 TM	0	7.78	4.5	6		5.25	3.89
	$LSD_{0.05}$				***7.73***			***7.73***

March/April (150 days storage) + 7 days shelf-life at 18°C

An increase in the severity of diffuse core browning was seen in Braeburn after a week of shelf-life, with more fruit showing signs of discolouration within the core region (Table 15). There was no clear effect of increasing oxygen (1.6 %) or lowering store temperature on reducing the incidence of DCB. The incidence of core-flush didn’t increase during shelf-life and no treatment effects on core-flush development were identified after five months storage. Fruit from orchard BC, containing higher calcium remained virtually free of core-flush. Even though fruit showed symptoms of DCB, none of the fruit went on to develop core-flush.

During shelf-life the background green colour dropped in Braeburn across all orchards with fruit from orchard EV losing the greatest area of green colour. This was observed across all treatments. Dropping the storage temperature to 0.5-1.0°C or storing fruit in 1.6% oxygen did not affect firmness of fruit or background green colour.

Table. 15. Ex-shelf-life quality of Braeburn stored at 1.2% or 1.6% O_2 (<1% CO_2) stored at either 1.5-2.0°C or where temperature was lowered to 0.5-1.0°C for a period of 2 months post-January (TM). Fruits were subject to 7 days at 18°C after removal from store. Data presented is the overall mean of orchard x storage regime and picking data x storage regime interactions.

	Orchard					Pick	
	Treatment	BC	EV	NC	WH	1	2
Firmness	*1.2 % O_2*	*88.4*	*92.7*	*91.8*	*94.9*	*93.9*	*89.9*
	1.2 % O_2 TM	*88.0*	*93.5*	*90.4*	*94.5*	*90.8*	*92.3*
	1.6 % O_2	*85.4*	*88.6*	*84.1*	*91.2*	*86.8*	*87.8*
	1.6 % O_2 TM	*83.3*	*87.3*	*88.5*	*92.7*	*89.9*	*86.0*
	$LSD_{0.05}$				***3.06***		***3.06***
% Brix	*1.2 % O_2*	*12.8*	*14.1*	*12.6*	*12.1*	*12.9*	*12.9*
	1.2 % O_2 TM	*12.7*	*14.4*	*12.9*	*12.0*	*13.1*	*12.9*
	1.6 % O_2	*12.9*	*13.9*	*12.6*	*12.1*	*12.9*	*12.8*
	1.6 % O_2 TM	*13.2*	*13.0*	*12.7*	*12.0*	*12.7*	*12.7*
	$LSD_{0.05}$				***0.33***		***0.33***
Colour A	*1.2 % O_2*	*-12.9*	*-7.8*	*-10.3*	*-12.3*	*-11.1*	*-10.6*
	1.2 % O_2 TM	*-13.0*	*-7.9*	*-12.0*	*-12.6*	*-11.8*	*-10.9*
	1.6 % O_2	*-12.0*	*-7.7*	*-11.2*	*-12.0*	*-11.0*	*-10.5*
	1.6 % O_2 TM	*-12.8*	*-8.8*	*-9.4*	*-11.3*	*-12.1*	*-9.1*
	$LSD_{0.05}$				***0.89***		***0.89***
DCB index	*1.2 % O_2*	*27.5*	*29.5*	*19.28*	*31.5*	*22.9*	*31.0*
	1.2 % O_2 TM	*19*	*25.5*	*29.18*	*28*	*21.3*	*29.5*
	1.6 % O_2	*11.5*	*33*	*20.45*	*30.5*	*23.5*	*24.2*
	1.6 % O_2 TM	*9.22*	*24.5*	*30*	*28.5*	*23.0*	*23.1*
	$LSD_{0.05}$				***7.22***		***7.22***
CF index	*1.2 % O_2*	*1.0*	*7.0*	*6.8*	*2.0*	*5.9*	*2.5*
	1.2 % O_2 TM	*0.0*	*5.5*	*4.7*	*0.5*	*3.6*	*1.8*
	1.6 % O_2	*0.0*	*2.5*	*8.2*	*0.5*	*3.5*	*2.1*
	1.6 % O_2 TM	*0.0*	*8.5*	*4.5*	*1.0*	*5.0*	*2.0*
	$LSD_{0.05}$				***2.98***		***2.98***

May Inspection (210 days storage) – Ex-store quality

After seven months storage, a larger proportion of fruit suffering previously with DCB symptoms went on to develop core-flush as fruits aged physiologically (Table 16). The exception was fruit from orchard BC which remained free from core-flush. Increasing store oxygen from 1.2% to 1.6% appeared to have only short term benefits in reducing internal browning (Table 16). By the May inspection, where fruits had been in CA storage for seven months, there was no significant benefit of storing fruit in 1.6% O_2 compared to the standard 1.2 %O_2. Internal quality of Braeburn coming out of 1.2% was similar to fruit stored in 1.6% O_2 and higher oxygen did not reduce the incidence of DCB or core-flush. Moreover, there was a slightly better retention of background green colour in fruit stored at 1.2% O_2.

While incorporation of short periods of low-temperature have in previous trials helped to lower internal browning, fruit from this years' trial suffered higher losses due to core flush in two orchards (EV and WH) where store temperature had been lowered from 1.5-2.0°C to 0.5-1.0°C from January onwards (4 months). Benefits may only be accrued from low-temperature storage where fruits are subject to shorter periods (two months) of exposure to lower temperatures (0.5-1.0°C).

In terms of other quality attributes, the firmness of ex-store fruit was above commercial specifications and ranged from 78-92 N kg across all treatments. Retention of fruit firmness was not impaired when Braeburn was stored in 1.6% O_2. However, background green colour was slightly lower in two out of the four orchards where fruit was stored in 1.6% oxygen (Table 16).

Table 16. Ex-store quality of Braeburn stored at 1.2% or 1.6% O_2 <1% CO_2 at either 1.5-2.0°C or where temperature was lowered to 0.5-1.0°C for a period of 4 months post-January (TM). Data presented is the overall mean of orchard x storage regime and picking data x storage regime interactions.

	Orchard Treatment	*BC*	*EV*	*NC*	*WH*	*Pick 1*	*2*
Firmness (N)	*1.2*	*77.8*	*92.1*	*81.9*	*86.6*	*86.7*	*82.4*
	1.2TM	*80.9*	*89.8*	*86.9*	*88.0*	*87.9*	*84.9*
	1.6	*78.2*	*86.3*	*85.2*	*86.5*	*84.9*	*83.2*
	1.6TM	*77.8*	*87.3*	*88.3*	*86.8*	*87.5*	*82.5*
$LSD_{0.05}$					***2.48***		***2.48***
% Brix	*1.2*	*12.7*	*13.7*	*12.4*	*12.1*	*12.7*	*12.7*
	1.2TM	*12.8*	*13.4*	*12.6*	*11.9*	*13.0*	*12.4*
	1.6	*12.9*	*13.1*	*12.8*	*12.0*	*12.8*	*12.6*
	1.6TM	*13.2*	*14.1*	*12.6*	*11.9*	*13.1*	*12.8*
$LSD_{0.05}$					***0.31***		***0.31***
Colour A	*1.2*	*-14.9*	*-9.0*	*-11.5*	*-12.8*	*-11.7*	*-12.4*
	1.2TM	*-14.5*	*-9.1*	*-12.8*	*-13.5*	*-12.0*	*-13.0*
	1.6	*-13.9*	*-11.1*	*-9.1*	*-13.3*	*-11.9*	*-11.8*
	1.6TM	*-13.1*	*-7.8*	*-11.7*	*-13.2*	*-12.5*	*-10.4*
$LSD_{0..05}$					***0.76***		***0.76***
DCB	*1.2*	*4.5*	*11.0*	*12.2*	*16.0*	*13.5*	*8.3*

index							
	1.2TM	*8.5*	*11.5*	*13.0*	*16.5*	*10.8*	*14.0*
	1.6	*4.5*	*14.5*	*11.1*	*9.0*	*8.8*	*10.8*
	1.6TM	*4.0*	*10.0*	*17.0*	*8.5*	*11.5*	*8.3*
$LSD_{0.05}$					***2.64***		***2.64***
CF index	*1.2*	*0.0*	*12.5*	*8.7*	*6.0*	*7.0*	*6.6*
	1.2TM	*0.0*	*15.0*	*1.5*	*6.5*	*5.5*	*6.0*
	1.6	*0.5*	*12.0*	*11.8*	*5.0*	*9.1*	*5.5*
	1.6TM	0.0	23.0	5.5	14.5	12.8	8.8
$LSD_{0.05}$					***2.14***		***2.14***

May Inspection: shelf-life (210 days) + 7 days at 18°C

After seven months CA storage followed by a week of shelf-life at 18°C, fruits from the two orchards EV and NC showed signs of senescent breakdown (Table 17). These consignments of fruits were more mature entering storage. Moreover, the incidence of core-flush increased during shelf-life (Table 17) and was present for the first time in small amounts in fruits from orchard BC (2.7-6.7%), while in the other orchards core-flush ranged from (10.1-27.5%).

After seven months of storage, there was no effect of CA regime and temperature modulation on fruit firmness and background green colour (Table 17). Lowering storage temperature reduced the incidence of rotting. Averaged across four orchards, losses attributed to rots totalled 4.3% in Braeburn stored under modulated storage temperatures. This compares favourably to 7.4% rots observed where fruit was stored at the standard 1.5-2.0°C. However, the lowering of store temperature during storage increased the severity of core-flush and DCB in long-term stored fruit.

Table 17. Ex-shelf-life quality of Braeburn stored at 1.2% or 1.6% O_2 (<1% CO_2) stored at either 1.5-2.0°C or where temperature was lowered to 0.5-1.0°C for a period of 4 months post-January (TM). Fruits were subject to 7 days at 18°C after removal from store. Data presented is the overall mean of orchard x storage regime and picking data x storage regime interactions.

		Orchard				Pick	
	Treatment	BC	E	NC	WH	1	2
Firmness	1.2 % O_2	85.7	82.1	78.1	88.6	84.3	83.0
	1.2% O_2 TM	86.0	86.6	82.7	87.2	84.7	86.6
	1.6 % O_2	82.4	80.9	80.9	86.3	81.6	83.6
	1.6 % O_2 TM	81.6	85.0	81.7	89.6	86.3	82.6
	$LSD_{0.05}$				**2.47**		**2.47**
% Brix	1.2 % O_2	12.5	13.8	12.2	11.7	12.3	12.8
	1.2% O_2 TM	12.7	13.9	12.4	12.2	12.9	12.7
	1.6 % O_2	12.7	13.1	12.0	11.7	12.2	12.6
	1.6 % O_2 TM	12.9	14.0	12.4	12.0	13.1	12.5
	$LSD_{0.05}$				**0.26**		**0.26**
Colour A	1.2 % O_2	-12.3	-8.9	-10.8	-13.7	-11.4	-11.5
	1.2% O_2 TM	-13.4	-8.7	-13.1	-13.0	-12.3	-11.7
	1.6 % O_2	-12.3	-8.5	-12.8	-13.6	-12.6	-11.0
	1.6 % O_2 TM	-13.3	-7.6	-10.5	-13.4	-11.3	-11.1
	$LSD_{0.05}$				**0.74**		**0.74**
% Rots	1.2 % O_2	2.5	10.0	12.5	12.5	5.0	13.8
	1.2% O_2 TM	2.5	2.5	2.5	0.0	0.0	3.8
	1.6 % O_2	5.3	5.0	2.5	10.0	3.9	7.5
	1.6 % O_2 TM	7.5	2.5	15.0	2.5	7.5	6.3
	$LSD_{0.05}$				**7.20**		**7.20**
DCB index (Max 60)	1.2 % O_2	14.3	12.7	8.6	19.4	13.4	14.1
	1.2% O_2 TM	15.2	9.5	14.0	11.5	12.0	13.1
	1.6 % O_2	16.7	13.0	16.0	14.7	14.8	15.4
	1.6 % O_2 TM	6.5	6.6	10.9	12.5	11.7	6.5
	$LSD_{0.05}$				**6.41**		**6.41**
Core Flush Index (Max 60)	1.2 % O_2	3.1	21.3	17.4	5.3	13.1	10.5
	1.2 % O_2 TM	6.7	27.5	16.5	23.5	18.3	18.8
	1.6 % O_2	2.6	17.5	10.1	10.1	11.9	8.3
	1.6 % O_2 TM	6.0	25.7	11.0	19.0	12.2	18.6
	$LSD_{0.05}$				**2.05**		**2.05**
Sen breakdown index (Max 60)	1.2 % O_2	0.0	7.2	3.1	0.0	1.0	4.2
	1.2 % O_2 TM	0.0	6.0	4.5	0.0	2.8	2.5
	1.6 % O_2	0.0	3.0	2.5	0.0	1.8	1.0
	1.6 % O_2 TM	0.5	2.0	0.0	2.5	0.8	1.8
	$LSD_{0.05}$				**1.29**		**1.29**

Discussion

Diffuse core browning (DCB) is typically found as a region of translucent tissue surrounding the core that often discolours over time and can subsequently present itself as a classic core-flush symptom during long-term storage. In its early translucent stages, DCB is not considered by many to be commercially significant until symptoms of tissue browning occur. A strong orchard influence is clear and the effect of controlled atmosphere regime can be apparent. Recent work by researchers in New Zealand indicated that lower calcium content in the core region may contribute to the severity of this disorder. Interestingly, water-core, a physiological condition typified by the interstitial air spaces filling with sorbitol, which leads to a translucent appearance, is also related to low calcium content. Braeburn is generally a variety that retains good calcium content (5-8 mg 100 g^{-1} FW). However, variation in the distribution of calcium within the flesh can occur, leaving localized zones of depletion. Moreover, Braeburn apples are generally large fruit (65-80+ mm in diameter) and often the distribution of minerals can be diluted through late season fruit expansion. In year 1, Orchard E produced the largest diameter (73 mm) fruit and retained the lowest calcium (3.9 mg $100g^{-1}$ FW) which may have contributed to the high incidence of internal browning present in the fruit.

There are similarities between the DCB and water core type symptoms. Calcium has been reported to improve the uptake of solutes such as sorbitol and can help to reduce the incidence of water-core damage. Equally, in these trials, fruits with lower calcium content were more likely to develop core-flush from DCB affected tissue. Because Braeburn is denser than many apple varieties, cell numbers are greater, leading to poorer diffusion characteristics. In addition with higher cell densities the requirement for calcium will be greater, with more available calcium binding sites to occupy. And while our current understanding of thresholds for calcium content for long-term storage are based on previous work for Cox's Orange Pippin, where 5 mg 100^{-1}g FW is sufficient for long-term storage, it may be necessary to increase these for Braeburn.

Developing better tools to predict fruit maturity is critical to allow better categorisation of fruit, allowing the best fruit to be allocated for long-term storage. Often the slow development of red colour on the skin of Braeburn can result in fruit being picked later than the optimum for long-term storage. Later picked fruit has an increased risk of developing core-flush and BBD. The slow rate of softening in fruit during storage is not correlated well with the physiological ageing process and while fruit may appear to have a good storage potential based on firmness, the propensity of fruit to develop internal browning is often hard to predict.

Fruit density is linked to porosity, cell number and the number and size of interstitial air spaces within fruit. Earlier work has indicated that much of the internal core browning can be linked to zones of anoxia forming in the core region due to poor gas exchange characteristics of fruit. Measurement of fruit specific gravity found fruit density did not vary between samples.

In year 1 of the project, storage of Braeburn in 1.6% O_2 provided a better overall control of internal browning conditions than 1.2% O_2. Equally the modulated temperature regime of 1.2 % O_2 with storage for five months at 1.5-2.0°C followed by two months at 0.5-1.0°C provided a marginal improvement in quality over the standard storage regime (1.2% O_2 1.5-2.0°C). Storing fruit in less stringent conditions has been successfully used to reduce the incidence of water core symptoms in Cox and Bramley. Raising store oxygen from 1.2 to 1.6% O_2 reduced the severity of DCB in the early stages of storage in year 2 but failed to reduce the number of fruits going onto develop core-flush later in the storage season.

In the first year of the trial increasing oxygen above 2% did not reduce the amount internal browning. In the absence of ethylene control strategies, fruits softened more during shelf-life in late-stored fruit. Although the use of delayed SmartFresh™ application helped to contain late season softening, it exacerbated internal browning. Incremental increase of oxygen from 1.2 to 2% up to 3% by the end of storage also failed to limit internal flesh browning.

Lowering the temperature has in the past been used to reduce internal browning in fruit. However, in this trial, where fruits were stored for longer than two months in 0.5-1.0°C, the incidence of core-flush was increased in long-term stored fruit. Continuous exposure to low temperatures is known to induce core-flush but temperature modulation for shorter periods was considered to be a safer option that may help to reduce internal browning.

In parallel trials funded by the University of Greenwich, dipping fruit in the anti-oxidants helped to reduce core-flush in Braeburn and similar effects have been reported on Bramley (Johnson and Colgan 1996). While the use of antioxidants is no longer permitted, reducing oxidative processes by use of extremely low oxygen storage can help to reduce the incidence of core-flush development. Dynamic Controlled storage where store oxygen is kept below 1% O_2 has been reported (Zanella 2006) to reduce core-flush and Braeburn Browning Disorder symptoms.

Conclusions

- The incidence of Braeburn browning disorder and core-flush were closely related to harvest maturity of fruit entering store. Fruits with an advanced state of maturity and higher fruit respiration had a significantly higher risk of developing disorders.
- Diffuse core browning was influenced strongly by orchard factors. The severity of diffuse core browning was lower when fruits were stored at 1.6% O_2 (1.5-2.0°C) in the early stages of the storage season.
- Fruits stored in 1.6% O_2 had slightly lower background green colour.
- Fruits with higher calcium content (7 mg 100^{-1} g) were less prone to developing core-flush.
- Modulated storage temperature offered little benefit and extending exposure to 0.5-1.0°C beyond two months increased the risk of core-flush.
- Combining CA storage in 2% oxygen with delayed ethylene removal or SmartFresh™ did not control BBD.
- Storage at oxygen concentrations above 2% failed to control BBD or core browning.
- Maximising CO_2 scrubbing from the storage environment in commercial fruit stores will help reduce the incidence of internal browning. Concentrations <0.5% CO_2 are beneficial.
- It is important to note that long-term storage is not recommended in orchards with a history of developing these disorders.
- Data from storage trials of new varieties was made available to individual marketing groups associated with the variety in question.

Technology transfer

Results were presented at the EMRA Member's day in March 2013 and an article was presented in HDC News (July 2014 edition).

Acknowledgements

The authors would like to acknowledge Nigel Jenner (Norman Collett Ltd) and Caroline Ashdown (World Wide Fruits) for their help and guidance with this project.