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
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Key words:	Apple, Braeburn, CA storage, New Varieties

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

Increasing store oxygen from 1.2% to 1.6% O_2, helps to mitigate symptoms of diffuse core browning during Braeburn storage.

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) that investigated the effect of different rates of CA establishment in Braeburn storage, found that sealing stores immediately after cooling and allowing fruits to establish 2% O_2 by natural respiration and to maintain this for 10 days before allowing O_2 to drop to a holding CA of 1.2% O_2 <1% CO_2 provided fruit with better ex-store quality compared to a storage regime with a delayed establishment of CA conditions for 21 days. Immediate sealing led to a 3 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 does not often 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, the project will examine storage regimes for new varieties. With the support of individual marketing groups a small number of CA regimes will be tested for varieties such as Rubens, Opal, Zari and Envy.

Project aim(s): To extend the storage life, marketing season and quality of Braeburn.

Project objective(s):

1) To investigate the use of modulation of storage temperature to improve the quality and extend the storage life of Braeburn apples.
2) To investigate the use of delayed ethylene scrubbing or delayed SmartFresh™ application to reduce scald development, the incidence of core-flush, Braeburn Browning Disorder (BBD) and carbon dioxide injury in Braeburn apples.
3) To investigate whether controlled atmosphere (CA) regimes of 3% O_2 with a 3 week delayed establishment of 0.7 % CO_2 or 2.5% oxygen and 0.5% CO_2 will reduce the incidence of core-flush while maintaining scald control.
4) To develop CA regimes for extending the storage life of new varieties.

Summary of the project and main conclusions

This project tested a range of strategies to extend the storage life of Braeburn apples through a reduction in the incidence of core-flush, Braeburn Browning Disorder (BBD) and CO_2 injury. Strategies tested included modulated temperature regimes, incorporating a period of lower temperature (0.5-1.0°C) after a period of standard storage temperature (1.5 – 2.0°C) and secondly, delayed ethylene scrubbing and SmartFresh™ application targeted to coincide with the final establishment of CA atmosphere of 1.2% O_2.

Many of the internal core browning problems (diffuse core browning (DCB) that can develop into core-flush) have been previously attributed to a localised depletion of oxygen within the core region. It was anticipated that the incidence of this disorder could be reduced by storing in the higher oxygen regimes used in some parts of Northern Europe including storage in 3% O_2 with a 3 week delayed establishment of 0.7 % CO_2 or a 2.5% O_2 with delayed establishment of 0.5% CO_2. These regimes were tested in this project. An additional CA treatment where an incremental rise in oxygen from 1.2% to 2% after 70 days followed by a further increase of store oxygen to 3% after 210 days was also tested to determine if this strategy would reduce the incidence of BBD and DCB/Core-Flush.

Conclusions

- In the first year of the trial the incidence of BBD was 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 the disorder.
- DCB was influenced strongly by orchard factors. However, storage in low oxygen (1.2% O_2) exacerbated the disorder.
- From the results of the first year of the trial, in orchards with a history of BBD and DCB/ core-flush; storage at 1.6% Oxygen or 1.2% oxygen with modulated storage temperature may help to reduce the incidence of the disorders. These regimes were also preferred for retaining background green colour.
- Combining CA storage in 2% oxygen and delayed ethylene removal or SmartFresh™ did not elevate the rate of BBD.
- Storage at oxygen concentrations above 2% failed to control BBD or DCB.
- 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, where a known orchard history of these conditions (BBD and DCB/Core-Flush) prevail, long-term storage is not recommended.
- Data from storage trials of new varieties was made available to individual marketing groups associated with the variety in question.

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.
- Ensure fruit have good mineral nutrition with calcium and boron at or above the recommendations for Cox calcium (5 mg $100g^{-1}$ FW) and boron (2.5 mg $100g^{-1}$ FW).
- Storage at 1.6% O_2 helps to reduce the overall incidence of browning compared to 1.2 % O_2.

SCIENCE SECTION

Introduction

Braeburn is a variety that maintains good texture and eating quality. However, storage is often terminated prematurely in March due to a risk of fruit developing late-season Diffuse Core Browning/core-flush: the latter condition is associated with a pink/brown discolouring of the flesh surrounding the core cavity. Harvesting over-mature fruit or storing at too low a temperature for prolonged periods can exacerbate the condition. The pre-core-flush condition described as Diffuse Core Browning (DCB) is also a feature of Braeburn. In its pre-browning phase, fruits affected by DCB exhibit a glassy hue around the core cavity. While in some countries this is considered to have 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 of 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. As part fulfillment of Project TF192, the final year's storage trials focused on the use of modulated storage temperature to restrict BBD and core-flush/DCB. Extensive periods of reduced temperature storage led to higher incidence of core-flush. However, introduction of shorter periods of intermittent low-temperature (0.5-1.0°C) or delayed ethylene scrubbing into 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 localized 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

Project objective(s):

- 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 three 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 once this year's storage trials have been completed.
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 15-17th 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 and 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 (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 two 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 ten 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) into 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.

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 immediately ex-store and after seven days shelf-life (18°C) after 150 and 180 days of storage. The same methods of quality analysis were used as described above for harvest.

Results

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 fruits 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. However, 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 Orchards E and NC as 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 4 out of 5 orchards were below 30 classifying fruit capable of long-term storage (April) based on mineral composition. Braeburn from Orchard E with generally larger fruit was lower in calcium and had 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

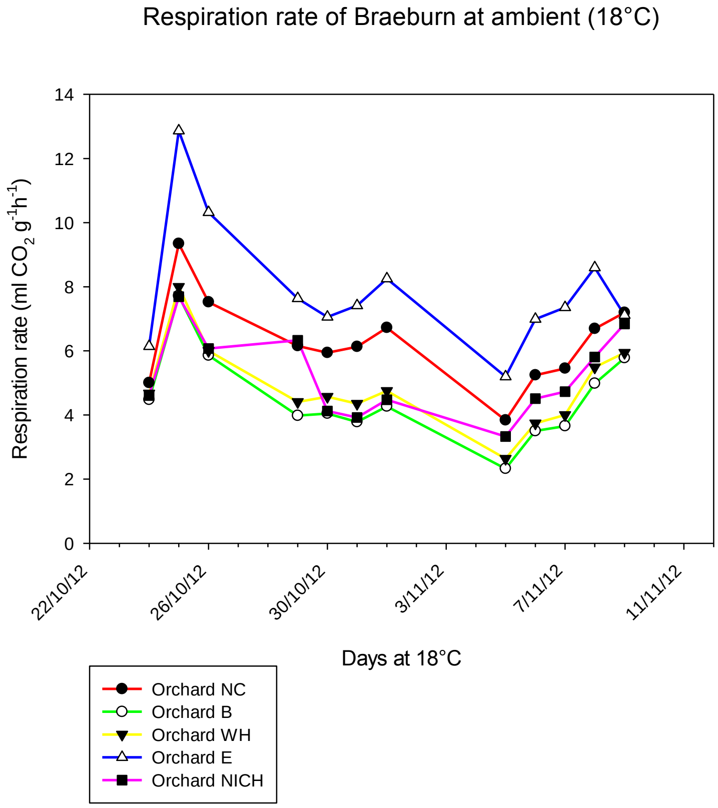

Figure 1. Respiration rate (mL CO_2 $g^{-1}h^{-1}$) of Braeburn apples sampled from five orchards across Kent.

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^{TM} treated fruit (T2) softening the least (Table 3). Storage at lower O_2 concentration of 1.2% O_2 was associated with restricted sugar formation, and lower % Brix of 11.8-12.0 % Brix. 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^{TM} increased fruits propensity to develop both disorders and as such there is no recommendation for using SmartFresh^{TM} 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

Treatment		Firm (N)	% Brix	Colour A	Colour B	% Rots	% CO_2 inj.	% DCB	% BBD	% Core Flush
T1	1.2% O_2 mod T	87.0	11.8	-12.2	41.6	2	0	8	19	30
T2	2% O_2 + 1-MCP	93.6	12.0	-9.8	42.5	1	0	4	34	85
T3	2% O_2 + E Scrub	88.2	12.4	-10.4	42.8	0	2	6	13	57
T4	3% O_2, 0.8% CO_2	81.6	12.5	-12.3	42.9	0	0	0	24	52
T5	2.5% O_2 0.5% CO_2	83.1	11.8	-10.9	43.1	1	1	5	13	54
T6	1.6% O_2	85.3	11.8	-12.1	41.9	1	0	0	24	45
T7	1.2/2/3% O_2	82.3	12.9	-9.1	41.8	2	1	3	24	61
T8	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

Treatment		Firm (N)	% Brix	Colour A	Colour B	% Rots	% CO_2 inj.	% DCB	% BBD	% Core Flush
T1	1.2% O_2 mod T	85.3	12.2	-9.6	42.9	4	0	8	40	70
T2	2% O_2 + 1-MCP	93.8	12.1	-7.5	42.7	4	0	4	40	94
T3	2% O_2 + E Scrub	80.6	12.4	-8.9	44.7	1	3	6	40	73
T4	3% O_2, 0.8% CO_2	78.2	12.0	-8.7	44.5	0	1	0	39	71
T5	2.5% O_2 0.5% CO_2	78.2	12.4	-7.9	44.9	1	0	5	46	77
T6	1.6% O_2	81.4	12.3	-8.8	43.9	2.1	2	0	24	72
T7	1.2/2/3% O_2	74.5	12.4	-7.5	43.3	2.7	0	3	61	78
T8	1.2% O_2	83.7	12.5	-7.5	42.8	3	1	11	26	62
$LSD_{0.05}$	$LSD_{0.05}$ 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 % Brix. 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 5 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

		Firmness	% Brix	Colour L	Colour A	Colour B	% Rotting	% CO_2 injury	% DCB	% BBD	% CF
T1	1.2% O_2 mod T	87.0	11.8	67.1	-12.2	41.6	2.0	0.0	24.0	19.0	30.0
T9	2% O_2 + 1-MCP	93.6	12.0	66.3	-9.8	42.5	1.0	0.0	1.0	33.7	85.0
T3	2% O_2 + E Scrub	88.2	12.4	66.7	-10.4	42.8	0.0	2.0	8.0	13.0	57.0
T4	3% O_2, 0.8% CO_2	81.6	12.5	67.3	-12.3	42.9	0.0	0.0	10.0	24.0	52.0
T5	2.5% O_2 0.5% CO_2	83.1	11.8	66.0	-10.9	43.1	1.0	1.0	7.0	13.0	54.0
T6	1.6% O_2	85.3	11.8	66.5	-12.1	41.9	1.0	0.0	11.0	24.1	45.1
T7	1.2/2/3% O_2	82.3	12.9	66.3	-9.1	41.8	2.0	1.0	2.0	24.0	61.0
T8	1.2% O_2	87.0	12.0	65.3	-9.2	41.1	6.0	4.0	25.0	14.0	27.0
	$LSD_{0.05}$ on 39 df	3.15	0.25	1.41	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 with 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 minimising the incidence of BBD was 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

Treat.		Firm. (N)	% Brix	Colour A	Colour B	% Rots	% CO2 injury	% DCB	% BBD	% Core flush
T1	1.2% O_2 mod T	85.3	12.2	-9.6	42.9	4.0	0.0	8.0	40.0	70.0
T9	2% O_2 + 1-MCP	93.8	12.1	-7.5	42.7	4.0	0.0	4.0	40.1	93.7
T3	2% O_2 + E Scrub	80.6	12.4	-8.9	44.7	1.0	3.0	6.0	40.0	73.0
T4	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
T5	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
T6	1.6% O_2	81.4	12.3	-8.8	43.9	2.1	2.0	0.0	24.3	71.8
T7	1.2/2/3% O_2	74.5	12.4	-7.5	43.3	2.7	0.0	3.0	61.0	78.0
T8	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 averaging 90.4 N while Braeburn from NiC 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 NiC 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
T1	1.2% O_2 mod T	12.7	36.3	45.6	73.8
T2	2% O_2 + 1-MCP	19.4	26.4	74.8	86.1
T3	2% O_2 + E Scrub	14.2	37.3	50.0	76.3
T4	3% O_2, 0.8% CO_2	15.3	37.2	53.8	69.4
T5	2.5% O_2 0.5% CO_2	14.4	32.1	46.9	79.9
T6	1.6% O_2	14.2	39.7	50.1	61.3
T7	1.2/2/3% O_2	15.3	27.1	55.0	88.8
T8	1.2% O_2	8.8	45.3	43.8	62.7

Discussion

Diffuse core browning (DCB) is exemplified 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 was apparent. Recent work by researchers in New Zealand indicated that lower calcium content in the core region may be responsible for this disorder. Interestingly, water-core, a physiological condition typified by the interstitial air spaces filling with sorbitol, and 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. 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.

Fruit density is linked to porosity 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

Storage at 1.6% O_2 provided a better overall control of internal browning conditions than 1.2% O_2. In addition, 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).

Increasing the O_2 concentration within the storage atmosphere to 2% or above did not elevate internal browning of the flesh. Without the application of ethylene control strategies, fruits softened more during shelf-life testing 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.

The final year of the project will continue to investigate storage of Braeburn harvested over two picking dates and stored under either 1.2% or 1.6% O_2 at 1.5-2.0°C or under a modulated storage temperature where some consignments of fruit will be transferred to 0.5-1.0°C after three months storage.

Conclusions

- In the first year of the trial, the incidence of Braeburn Browning Disorder was 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 the disorder.
- Diffuse Core Browning was influenced strongly by orchard factors. However, storage in low oxygen (1.2% O_2) exacerbated the disorder.
- From the results of the first year of the trial, in orchards with a history of Braeburn Browning Disorder and Diffuse Core Browning/ Core-Flush; storage at 1.6% Oxygen or 1.2% oxygen with modulated storage temperature may help to reduce the incidence of the disorder. These regimes were also preferred for retaining background green colour.
- Storage at Combining CA storage in 2% Oxygen and delayed ethylene removal or SmartFresh^{TM} didn't elevate the rate of 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 to reduce the incidence of internal browning. Concentrations $<0.5\%$ CO_2 are beneficial.
- It is important to note that where a known orchard history of these conditions prevail, long-term storage is not recommended.
- 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

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