Project title:	Modulating the storage temperature for Cox apples for improved quality and control of rotting
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Project leader:	Dr Angela M. Berrie
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Project coordinator:	TBA
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DISCLAIMER:

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 Angela M Berrie
Research Leader
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Report authorised by:

Dr Christopher Atkinson
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GROWER SUMMARY

Headline

- Intermittent cooling of Cox to 1.5-2 ºC during 6 months storage at 3.5-4 ºC gave no benefit in fruit quality.

Background and expected deliverables

Cox remains the most important dessert apple cultivar in the UK despite its susceptibility to a range of physiological disorders and fungal rots. The firmness of the stored fruit at the point of sale is often marginal in relation to specifications laid down by the multiple retailers, despite harvesting at the correct stage of maturity and providing optimum storage conditions. Although the use of 1-MCP (SmartFresh™) has helped significantly in delaying softening during storage and shelf-life, care must be taken when it is used on fruit destined for post-January storage due to a heightened risk of core flush.

This project addresses the need to supply consumers with Cox of consistent quality from September until March and to minimise the wastage incurred by growers due to the development of fungal rots. Current levels of wastage are often unacceptable and there is limited scope for chemical intervention to ameliorate the problem, although use of rot risk assessment can assist in management of rots and minimize losses. Currently there are no fungicides permitted for post-harvest application to apples in the UK. Fungicides applied pre-harvest for rot control usually result in detectable residues in the fruit at harvest.

Reducing the temperature for CA-stored Cox provides an opportunity to improve fruit quality, particularly firmness, and to reduce rot development. However, it is imperative that these benefits are achieved without inducing low temperature breakdown (LTB) symptoms in the fruit. Although climate change means that there is a greater likelihood of warmer growing seasons in the future and consequently a reduced susceptibility to LTB it is unlikely that Cox will tolerate a lower storage temperature for the entire storage period. However, modulating the store temperature to provide shorter periods at lower temperatures may provide the benefits required without inducing LTB in the fruit. This approach has proved successful for other chilling-sensitive cultivars in work done abroad (such as cv. McIntosh in Canada).

There is an opportunity to develop a strategy for modified temperature management of commercial Cox stores in the UK that would include the use of 1-MCP (SmartFresh^{TM}).

Summary of the project and main conclusions

Cox apples were harvested on 2 September 2009 from an 11-year-old Cox orchard planted on M9 rootstock grown at East Malling Research. Maturity measurements (Firmness, Colour, Starch, % Brix and internal ethylene concentration) were made on the day of harvest. Apples were cooled to 3.5°C overnight.

The day following harvest half the fruits were treated with SmartFresh^{TM} (625 ppb) at 3.5°C for 24 hours whilst the untreated fruit were kept in a separate store at 3.5°C.

Subsequently, half of the SmartFresh^{TM} and untreated fruit were inoculated with *Nectria* by dipping two replicate netted samples (50 fruit per net) of Cox in a freshly prepared spore suspension of *Nectria galligena*. This provided a total of four post-harvest treatment combinations: untreated/uninoculated, SmartFresh^{TM}/uninoculated, untreated/*Nectria* and SmartFresh^{TM}/*Nectria.*

Four boxes each containing one of the treatment combinations were loaded into each of eight storage cabinets and flushed with nitrogen to 1.25% O_2. Four cabinets were maintained at 3.5°C and four at 1.5°C. Every two months, the fruit were moved between cabinets at the two temperatures so that eight temperature regimes were tested, as shown in Table 1.

Table 1: Temperature regimes assessed during the Cox storage trials

Treatment	0 – 60 days	60 – 120 days	120 – 180 days
1	3.5-4^{o}C	3.5-4^{o}C	3.5-4^{o}C
2	1.5-2^{o}C	3.5-4^{o}C	3.5-4^{o}C
3	1.5-2^{o}C	1.5-2^{o}C	3.5-4^{o}C
4	1.5-2^{o}C	1.5-2^{o}C	1.5-2^{o}C
5	3.5-4^{o}C	1.5-2^{o}C	3.5-4^{o}C
6	3.5-4^{o}C	1.5-2^{o}C	1.5-2^{o}C
7	1.5-2^{o}C	3.5-4^{o}C	1.5-2^{o}C
8	3.5-4^{o}C	3.5-4^{o}C	1.5-2^{o}C

Fruits were inspected ex-store and after 1 week's shelf-life at 20°C in November, January and March.

Continuous low temperature storage reduced the rate of softening but caused significant amounts (30%) of LTB in long-term stored Cox. The incidence of LTB increased to 60% when continuous low temperature storage was used on SmartFresh^{TM} treated fruit. Shorter periods of low-temperature used at the beginning of the storage period had a small effect on reducing the degree of softening and did not induce LTB in non-SmartFresh^{TM} treated fruit. Where low temperatures were used continuously, LTB was observed on SmartFresh^{TM} treated Cox but was less severe than for the other regimes. .

The incidence of *Nectria* rots was reduced with SmartFresh^{TM} when combined with lower storage temperatures. SmartFresh^{TM} treated Cox that received at least 4 months at 1.5°C had less rots. Interestingly, SmartFresh^{TM} did not affect the incidence of rotting when Cox was stored at 3.5°C for the whole period. Rotting in untreated Cox was more variable and no clear trend in temperature regime was evident; however, fruit stored for the whole storage period at 1.5°C had the lowest incidence of rots.

Main conclusions

- Storing Cox at 1.5-2ºC for 6 months results in significant low temperature breakdown and this is not relieved by intermittent warming for 2 months to 3.5-4 ºC.
- Intermittent cooling to 1.5-2 ºC for months during 6 months storage at 3.5-4 ºC also gives no benefit in terms of fruit quality.
- It has been decided to discontinue these treatments along with continuous low temperature storage. The next year of trials will concentrate on five two-stage temperature storage regimes on fruit picked over three picking dates.

Financial benefits

- No financial benefits identified at this stage of the project.

Action points for growers

- No action points are identified at this stage of the project.

SCIENCE SECTION

Introduction

Cox remains the most important dessert apple cultivar in the UK despite its susceptibility to a range of physiological disorders and fungal rots. The firmness of the stored fruit at the point of sale is often marginal in relation to specifications laid down by the multiple retailers, despite harvesting at the correct stage of maturity and providing optimum storage conditions. Although the use of 1-MCP (SmartFresh^{TM}) has helped significantly in delaying softening during storage and shelf-life, care must be taken when it is used on fruit destined for post-January storage due to a heightened risk of core flush. The project addresses the need to supply consumers with Cox of consistent quality from September until March and to minimise the wastage incurred by growers due to the development of fungal rots. Current levels of wastage are often unacceptable and there is limited scope for chemical intervention to ameliorate the problem, although use of rot risk assessment can assist in management of rots and minimize losses (Cross & Berrie, 2010). Currently there are no fungicides permitted for post-harvest application to apples in the UK. Fungicides applied pre-harvest for rot control usually result in detectable residues in the fruit at harvest.

Reducing the temperature for CA-stored Cox provides an opportunity to improve fruit quality, particularly firmness, and to reduce rot development. However, it is imperative that these benefits are achieved without inducing low temperature breakdown (LTB) symptoms in the fruit. Although climate change means that there is a greater likelihood of warmer growing seasons in the future and consequently a reduced susceptibility to LTB it is unlikely that Cox will tolerate a lower storage temperature for the entire storage period. However modulating the store temperature to provide shorter periods at lower temperatures may provide the benefits required without inducing LTB in the fruit. This approach has proved successful for other chilling-sensitive cultivars such as the cv McIntosh in Canada (Levesque et al., 2006). There is an opportunity to develop a strategy for modified temperature management of commercial Cox stores in the UK that would include the use of SmartFresh^{TM}.

Overall aim of project

To improve the quality and reduce wastage due to fungal rots of Cox apples in long-term CA storage by modulating the storage temperature during CA storage both with and without 1-MCP (SmartFresh^{TM}).

Specific Objectives

1. To investigate the use of modulating store temperature to achieve higher quality and lower rotting in CA-stored Cox
2. To assess the impact of 1-MCP (SmartFresh^{TM}) on sensitivity of Cox apples to chilling and susceptibility to rotting, within the storage strategies tested
3. To develop an improved commercial strategy for modified temperature management of Cox stores

Materials and methods

Cox apples were harvested on 2 September 2009 from plot EH190 at East Malling Research. The orchard was planted in 1998 and trees were grown on M9 rootstock at a spacing of 1632 trees/ha (rows 3.5 m, trees 1.75 m in row). Fruit were randomised and bruised, damaged and misshapen fruits were discarded from the trial.

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), soluble solids (% Brix) were measured using a digital refractometer. Fruits were cut 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).

Apples were cooled overnight to 3.5°C and placed in 360 L cabinets: half the fruit were treated the following day with SmartFresh^{TM} (625 ppb) for 24 hours at 3.5°C, before the atmosphere was exhausted. The remaining non-SmartFresh^{TM} treated fruit were kept at 3.5°C overnight in a separate store.

Six isolates of *N. galligena* previously obtained from wood cankers or fruit rots were grown on Snay medium under UV lights for 1 week at ambient temperature to encourage spore (conidia) production. Fungal cultures were then scraped and rinsed with distilled water into a flask to prepare a spore suspension which was made up to 5 litres. Spore concentration (conidia) was checked on a haemocytometer.

The day following SmartFresh^{TM} treatment sub-samples of 40 fruit of SmartFresh^{TM} treated fruit and untreated fruit were dipped in a fungal spore solution containing 3.7

$x10^{-3}$ Nectria spores per mL for 1 min the sub-samples of 40 fruit were placed in nets in plastic bags and the fruit left overnight to incubate at ambient temperature and high humidity to allow the *Nectria* conidia to germinate and infect fruit. The next day fruit were placed into 8 storage cabinets. Each cabinet represented a single temperature regime and contained both SmartFresh™ and non-SmartFresh™ treated fruit. The storage atmosphere was flushed to 1.2% with nitrogen and external lime-scrubbers were used to remove CO_2.

During the initial 2 month storage period four temperature regimes were maintained at 1.5-2°C while the other four regimes were maintained at 3.5-4°C. The contents of the chambers were moved between temperatures after 60 and 120 days as shown in Table 1. Fruits were assessed every 2 months, for firmness, colours, % Brix and for the presence of external and internal disorders. Respiration measurements were made on two replicate 20 fruit subsamples.

At the end of the storage period on 25 March the netted fruit samples of inoculated fruit were assessed for incidence of rots. Fruit was scored for the presence or absence of *Nectria* rots. Unrotted fruit was left at ambient temperature for 7 days and then reassessed for *Nectria* rots. Uninoculated control fruit was assessed for rots at the same time.

Table 1: Temperature regimes assessed during the Cox storage trials

Treatment	0 – 60 days	60 – 120 days	120 – 180 days
1	3.5-4^{o}C	3.5-4^{o}C	3.5-4^{o}C
2	1.5-2^{o}C	3.5-4^{o}C	3.5-4^{o}C
3	1.5-2^{o}C	1.5-2^{o}C	3.5-4^{o}C
4	1.5-2^{o}C	1.5-2^{o}C	1.5-2^{o}C
5	3.5-4^{o}C	1.5-2^{o}C	3.5-4^{o}C
6	3.5-4^{o}C	1.5-2^{o}C	1.5-2^{o}C
7	1.5-2^{o}C	3.5-4^{o}C	1.5-2^{o}C
8	3.5-4^{o}C	3.5-4^{o}C	1.5-2^{o}C

Results and discussion

In the 2009 season Cox was harvested within the correct harvest window (Table 2), firmness was high at 92 Newtons (9.2 kg), starch scores on the CTFL starch clearance patterns were 3.9, equivalent to just under 70% coverage and sugars were 12.1%. Fruit mineral analysis at harvest showed that calcium content was good and suitable for long-term storage, the ratio of K/Ca was 30 (Table 3).

Table 2: Harvest maturity measurements

Firmness	Sugars (% Brix)	Starch (ctfl score)
92.3 (3.74)	12.10 (0.47)	3.90 (1.5)

Figures in brackets are $LSD_{0.05}$

Table 3: Fruit mineral analysis at harvest

N	P	K	Ca	Mg	Mn	B	Fe
mg/100g fresh weight					mg/kg fresh weight		
45	16	175	5.81	6.7	5.2	3.28	4.40

Storage Trials

Inspection 1 (November 2009)

Ex-store: (Table 4):

Firmness dropped approximately 10 N in the first two months of storage in untreated fruit whilst the drop in firmness in SmartFresh^{TM} treated fruit was approximately 5-7 N. SmartFresh^{TM} treated fruit was generally firmer than untreated fruit by 2-6 N. The lower storage temperature only appeared to reduce significantly the rate of softening in non-treated fruit in treatment 7. The retention of background green colour (Colour a) was improved during the first 3 months of storage at 1.5°C cf. to 3.0-3.5°C.

Shelf-life (Table 5)

SmartFresh^{TM} prevented loss of firmness during shelf-life (Table 5) however, storing SmartFresh^{TM}-treated fruit at 1.5°C did not improve firmness retention. The firmness of untreated fruit dropped by approximately 20 (Newtons) during shelf-life but fruits stored at 1.5°C were 5-6 (Newtons (0.5-0.6 kg)) firmer than those stored at 3.5°C. Background green colour (Colour a) dropped in all treatments during shelf-life but the loss was less pronounced in SmartFresh^{TM} treated fruit. SmartFresh^{TM}-treated fruit were generally less yellow but yellow background (Colour b) was not affected by storage at 1.5°C during the first 2 months of storage and subsequent shelf-life.

Inspection 2 (January 2010)

Ex-store: (Table 6)

SmartFresh^{TM}-treated fruit maintained firmness after 4 months and little or no drop in firmness was observed from those measured after 2 months storage. Storage at lower temperatures for 2 or 4 months gave no improved firmness retention in SmartFresh^{TM}-treated fruit. However, storage at lower temperatures had a benefit on the firmness of untreated fruit. Untreated-apples stored at 1.5°C for the first 4 month period (treatments 5 and 6) were 6-9 Newtons (0.6-0.9 kg) firmer than those that had been at 3.5°C (59.9-64.4 Newtons) for the same period. In general, where untreated fruit had been stored at 1.5°C for only 2 months out of 4 the benefit of firmness retention had been lost, with the exception of treatment 7 (1.5°C-3.5°C).

Ex-shelf: (Table 7)

After shelf-life SmartFresh^{TM} treated apples that had been stored at 1.5°C for either 2 or 4 months remained firm and no significant loss of softening was observed. Untreated fruit softened further during shelf-life, but those that had been stored at 1.5°C for at least part of the storage season were generally less soft than those stored at 3.5°C. Soluble solids (% Brix) were generally lower in non SmartFresh^{TM} treated fruit (with the exception of treatment 2) and those stored at 1.5°C for at least part of the season had slightly higher soluble solid content. SmartFresh^{TM} treated fruit had a greener background colour than untreated fruit but storage temperature had limited effect on green background colour after shelf-life.

Inspection 3 (March 2010)

Ex-store (Table 8)

In general, SmartFresh^{TM} maintained firmness in Cox apples even after 6 months storage. Fruit stored at 3.5°C throughout the season were 4-6 Newtons (0.4-0.6 kg) softer than fruit that had been stored for at 1.5°C for at least part of the season. SmartFresh^{TM}-treated Cox that had spent the either the first 4 months at 1.5°C or the whole 6 months at 1.5°C were slightly firmer than fruit from other treatments.

Untreated fruit were 20-25 Newtons (2-2.5 kg) softer than SmartFresh^{TM} treated fruit. Untreated fruit that had been stored at 1.5°C for the first 2 month period (treatments 5-8) were slightly firmer than those which had received the 1.5°C treatment later in the storage season. The first evidence of low temperature breakdown (LTB) appeared at this inspection: Cox stored at 1.5°C for the whole of the season was worst affected (46.2%), while those that started at 1.5°C and then received a second period at 1.5°C also suffered from LTB. A small amount of core flush was also recorded in SmartFresh^{TM}-treated Cox stored 1.5/3.5/1.5°C (treatment 8). Rotting in SmartFresh^{TM}-treated fruit was highest where Cox had been stored at 3.5°C for the first 4-6 months.

Shelf-life (Table 9)

SmartFresh^{TM}-treated Cox stored at 1.5°C for the whole 6-month period maintained firmness and was 24.8 Newtons (2.5 kg) firmer than fruit stored at 3.0-3.5°C for the entire 6 months. Storage for at least 2 months at 1.5°C was sufficient to improve storage firmness. Untreated fruit were significantly softer than SmartFresh^{TM}-treated fruit and although treatments (5, 6 and 7) improved firmness retention compared to the control, firmness was below the threshold of marketability. Low temperature breakdown was more evident after shelf-life and fruit stored at 1.5°C for the whole period had 60% LTB affected fruit; fruits stored at 3.5°C for the whole period showed signs of senescent breakdown (20%) which was not evident in other treatments. Late season core-flush was most evident in Cox stored for the first 4 months at 3.5°C but also in Cox stored for 3.5°C for the whole period or where two of the storage periods were at 3.5°C.

Respiration (Table 10)

In general, the most obvious effects on respiration were recorded in SmartFresh^{TM} treated fruit. At the November inspection, certain consignments of fruit treated with SmartFresh^{TM} were respiring at a lower rate than untreated fruit but no significant trend between SmartFresh^{TM}-treated and untreated was found. Interestingly, the distribution of respiration rates between consignments of fruit stored at 3.5°C (Treatment 1-4) and those stored at 1.5°C (Treatment 5-8) were not significantly different after the first two months of storage.

However, by January, SmartFresh^{TM}-treated fruit stored at 1.5°C for at least the previous two months (treatments 3, 4, 5 and 6) had lower respiration rates than those that had been stored at 3.5°C for the previous two months.

At the final inspection respiration rates had increased in SmartFresh^{TM} treated apples and were greater than untreated fruit. A significant increase was seen in fruit that had been stored in 3.5°C for the previous 2 months. Although SmartFresh^{TM} -treated fruit had a higher respiration rate and were more likely to suffer from LTB during subsequent shelf-life compared to untreated fruit, there was no strong correlation in terms of the degree of LTB recorded and the elevation in respiration rate

Nectria Rotting (Table 11)

SmartFresh^{TM} generally reduced the incidence of rotting in inoculated fruit compared to untreated. Storage at lower temperature combined with SmartFresh^{TM} treatment reduced the incidence of rotting; those that had been stored at 1.5°C for the whole period had the lowest incidence of rotting. Without SmartFresh^{TM} there was a high degree of variability between treatments, although continuous storage at 1.5°C did lower the incidence of rotting treatments that combined 3.5°C and 1.5°C were less successful.

Conclusions

- Storage at 1.5°C for 6 months reduced the rate of softening and the incidence of *Nectria* rotting; however, by March the high incidence of LTB (30%) in Cox fruits precludes the use of this treatment for long-term storage of Cox
- Use of shorter periods of storage at 1.5°C with the remaining storage at 3.5°C prevented the occurrence of LTB
- Cox receiving periods of low temperature (1.5°C) storage at the beginning of the season were slightly firmer than where low temperature were applied later in the storage period. However, fruits were more predisposed to LTB and Core-flush when subject to low temperatures early on in the storage season
- SmartFresh^{TM} maintained firmness ex-store and throughout the shelf life period whilst reducing the incidence of rotting
- SmartFresh^{TM} was most effective in minimizing softening and disease occurrence when combined with low temperature storage, however, continuous storage at 1.5°C combined with SmartFresh^{TM} treatments led to a high incidence of LTB (60%)
- Restricting low temperature storage to the later half of the season helped to lower the incidence of LTB in fruit assessed in mid-March, but treatment effects were less obvious during the shelf-life period
- No additional benefit of intermittent warming or cooling was observed compared to other treatments, therefore it has been decided to discontinue these treatments along with continuous low temperature storage

- Next year we will concentrate on five temperature storage regimes on fruit picked over three picking dates

Technology transfer

The project was introduced to growers at the Marden Fruit Show Society and EMRA Day in March 2010

References

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Acknowledgements

The assistance of Karen and Clare Lower with the pathology part of the trial is greatly appreciated.

Table 4: **Quality assessment of Cox apples after 2 months storage (1.25% O_2, <1% CO_2) at either 1.5 and 3.5°C (November-ex-store)**

Treatment	**Firmness (N)***		**Brix (%)**		**Colour a**		**Colour b**		**% Water core**	
	SmartFresh™									
	Yes	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**
1 (3.5°C)	**86.7**	80.1	14.0	13.9	-5.0	-5.9	42.7	42.5	5.0	0
2 (3.5°C)	**87.1**	82.4	14.1	14.7	-5.1	-5.7	41.7	42.4	5.0	0
3 (3.5°C)	83.8	83.1	13.6	13.3	-4.9	-5.7	41.7	42.8	0	0
4 (3.5°C)	81.7	76.4	**13.0**	13.4	-5.7	-5.5	42.1	44.0	0	0
5 (1.5°C)	82.7	84.1	13.5	13.8	-5.5	-5.7	43.3	42.7	5.0	0
6 (1.5°C)	**86.7**	77.5	13.5	13.3	**-5.9**	-5.5	42.5	39.6	5.0	0
7 (1.5°C)	**86.3**	**84.8**	13.6	13.4	-5.3	-6.1	**40.3**	40.9	0	5.0
8 (1.5°C)	84.4	81.5	13.9	13.4	**-5.9**	**-6.7**	40.5	42.0	0	0
LSD$_{0.05}$ (16 df)	*4.48*		*0.83*		*0.76*		*2.26*		*8.38*	

To convert Newtons to kg pressure divide by 9.8 (~10)

Table 5: **Shelf-life quality assessment of Cox apples after 2 months storage (1.25% O_2, <1% CO_2) at either 1.5 and 3.5°C followed by 7 days at 20°C (November-shelf life)**

Treatment	**Firmness (N)**		**Brix (%)**		**Colour a**		**Colour b**		**% Water core**	
	SmartFresh™									
	Yes	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**
1 (3.5°C)	85.5	62.0	13.7	14.0	-4.0	-3.1	44.1	49.4	0	0
2 (3.5°C)	86.4	59.1	14.1	14.1	-3.4	-2.6	44.9	50.3	0	0
3 (3.5°C)	85.9	59.5	14.0	14.1	-3.8	-3.7	44.0	50.9	0	0
4 (3.5°C)	84.8	59.2	13.8	13.9	-4.1	-2.6	44.3	49.0	0	0
5 (1.5°C)	84.0	**65.9**	13.7	13.9	**-5.5**	-3.4	43.6	48.7	0	0
6 (1.5°C)	86.0	64.2	13.8	13.9	-4.4	-3.3	44.2	48.0	0	0
7 (1.5°C)	83.7	65.0	13.7	13.7	-4.4	-2.9	41.9	50.1	0	0
8 (1.5°C)	87.1	**66.6**	13.7	14.4	-5.1	-2.7	45.0	48.4	0	5.0
LSD$_{0.05}$ (16 df)	*3.82*		*0.45*		*1.39*		*2.41*		*3.75*	

Table 6: Quality assessment of Cox apples after 4 months storage (1.25% O_2, <1% CO_2) at either 1.5 and 3.5°C (January-ex-store)

Treatment	**Firmness (N)**		**Brix (%)**		**Colour a**		**Colour b**		**% Bitter pit**		**% LTB**		**% Water core**	
	SmartFresh™													
	Yes	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**
1 (3.5/3.5°C)	84.3	64.4	14.2	14.7	-3.8	-4.7	45.2	45.1	0	0	0	0	0	0
2 (3.5/3.5°C)	81.4	59.9	14.0	15.0	-3.7	-4.7	46.6	45.6	0	0	0	0	0	0
3 (3.5/1.5°C)	82.8	64.2	14.4	13.9	-4.5	-5.4	44.4	45.6	0	0	0	0	0	0
4 (3.5/1.5°C)	83.6	61.0	13.8	14.4	-4.5	-4.6	44.8	43.2	0	0	0	0	0	0
5 (1.5/1.5°C)	83.9	**73.0**	14.1	14.5	-4.9	-5.2	44.5	44.7	0	0	0	0	0	0
6 (1.5/1.5°C)	87.6	**70.5**	14.9	14.2	-4.3	-5.7	44.4	45.8	0	0	0	5.0	5.0	0
7 (1.5/3.5°C)	84.4	**70.8**	14.4	14.6	-4.8	-4.7	44.7	44.8	0	0	0	0	0	0
8 (1.5/3.5°C)	83.9	65.7	14.0	13.8	-4.6	-5.4	44.6	44.7	0	5.0	0	0	0	0
$LSD_{0.05}$ (16df)	*3.87*		*1.17*		*1.20*		*2.47*		*3.75*		*3.75*		*3.75*	

Table 7: Shelf-life quality assessment of Cox apples after 4 months storage (1.25% O_2, <1% CO_2) at either 1.5 and 3.5°C followed by 7 days at 20°C (January-shelf life)

Treatment	**Firmness (N)**		**Brix (%)**		**Colour a**		**Colour b**		**% Bitter pit**		**% LTB**		**% Water core**	
	SmartFresh™													
	Yes	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**
1 (3.5/3.5°C)	76.2	48.4	14.1	13.1	-2.5	-1.5	48.8	52.2	0	0	0	0	0	0
2 (3.5/3.5°C)	80.0	50.4	14.4	**14.6**	-1.6	-1.2	48.3	52.3	0	0	0	0	5.0	0
3 (3.5/1.5°C)	**86.1**	50.9	13.9	13.6	-3.2	-1.9	48.2	52.1	0	0	0	0	0	5.0
4 (3.5/1.5°C)	**83.3**	**53.1**	14.5	13.3	-2.3	-1.8	48.7	51.0	0	0	0	0	0	0
5 (1.5/1.5°C)	**82.8**	**57.2**	14.1	**14.2**	-3.4	-2.3	45.7	49.2	0	0	0	0	0	5.0
6 (1.5/1.5°C)	**87.8**	**55.6**	**15.5**	**13.9**	**-4.1**	-2.1	46.9	50.3	0	0	5.0	0	0	0
7 (1.5/3.5°C)	**84.6**	**53.1**	14.5	**14.1**	-2.8	-1.6	47.2	51.2	0	0	0	0	0	0
8 (1.5/3.5°C)	**83.6**	52.9	14.2	**13.9**	-3.0	-2.5	47.7	51.3	0	0	0	0	0	0
$LSD_{0.05}$ (16df)	*4.59*		*0.66*		*1.10*		*1.82*		*0*		*3.75*		*2.60*	

Table 8: Quality assessment of Cox apples after 6 months storage (1.25% O_2, <1% CO_2) at either 1.5 and 3.5°C (March-ex-store)

Treatment	Firmness (N)		Brix (%)		Colour a		Colour b		% Rotting		% Core flush		% LTB	
	SmartFresh™													
	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No
1 (3.5/3.5/3.5°C)	75.9	51.9	13.5	13.4	-0.7	-2.2	45.4	47.2	18.2	0.0	0.0	0.0	0	0
2 (3.5/3.5/1.5°C)	**82.4**	52.8	13.9	13.9	0.2	-3.7	45.7	46.7	10.6	0.0	0.0	0.0	5.0	0
3 (3.5/1.5/1.5°C)	79.9	55.1	14.0	13.8	-2.4	-4.7	45.8	46.0	0.0	4.2	0.0	0.0	5.0	0
4 (3.5/1.5/3.5°C)	79.6	54.3	14.1	14.1	-2.7	-4.1	46.6	47.0	0.0	9.1	0.0	0.0	0	0
5 (1.5/1.5/1.5°C)	**81.7**	**60.6**	13.8	14.0	-3.2	-4.8	43.8	45.6	0.0	4.6	0.0	0.0	**46.2**	14.5
6 (1.5/1.5/3.5°C)	**81.8**	**58.2**	14.6	13.7	-3.5	-4.2	47.0	46.0	0.0	4.2	0.0	0.0	16.6	0
7 (1.5/3.5/3.5°C)	78.7	**56.9**	14.1	14.1	-3.6	-4.5	46.7	46.5	8.3	0.0	0.0	0.0	0	0
8 (1.5/3.5/1.5°C)	79.6	**58.0**	14.1	14.4	-2.3	-3.8	46.6	46.4	0.0	0.0	**4.2**	0.0	**25.0**	**23.2**
$LSD_{0.05}$ (16df)	*4.88*		*0.91*		*1.51*		*2.2*		*5.58*		*3.11*		*18.36*	

Table 9: Shelf-life quality assessment of Cox apples after 6 months storage (1.25% O_2, <1% CO_2) at either 1.5 and 3.5°C followed by 7 days at 20°C (March-shelf life)

Treatment	Firmness (N)		Brix (%)		Colour a		Colour b		% Rotting		% Core flush		% LTB	
	SmartFresh™													
	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No
1 (3.5/3.5/3.5°C)	58.1	46.4	13.7	13.9	3.1	0.7	49.8	49.4	5.0	0	20.0	0	0	0
2 (3.5/3.5/1.5°C)	**68.0**	46.6	13.8	13.7	1.5	1.3	48.1	50.5	15.0	0	47.8	0	15.6	0
3 (3.5/1.5/1.5°C)	**78.6**	46.8	14.1	13.5	-0.6	-0.2	48.9	50.2	5.5	0	0	0	22.2	0
4 (3.5/1.5/3.5°C)	**67.4**	48.4	14.3	13.5	1.9	0.9	49.8	49.2	5.5	0	15.0	0	37.2	0
5 (1.5/1.5/1.5°C)	**82.9**	**51.8**	14.0	13.7	-1.8	0.4	47.5	49.2	0	0	0	0	**60.0**	30.0
6 (1.5/1.5/3.5°C)	**73.8**	**51.8**	14.0	14.3	-0.8	0.1	49.6	48.6	0	0	10.0	0	20.0	0
7 (1.5/3.5/3.5°C)	**65.2**	**52.2**	14.2	14.7	1.6	0.0	49.5	49.0	10.0	0	21.1	0	5.6	0
8 (1.5/3.5/1.5°C)	**75.2**	49.9	13.9	13.9	0.2	0.4	47.9	49.9	0	0	15.0	0	25.0	0
$LSD_{0.05}$ (16df)	*4.71*		*0.83*		*1.98*		*2.24*		*15.21*		*20.0*		*28.25*	

Table 10: The effect of SmartFresh™ on the rate of respiration rates of Cox's apples stored under modulated temperature regimes

Treatment	November		January SmartFresh™		March	
	Yes	**No**	**Yes**	**No**	**Yes**	**No**
1 (3.5/3.5/3.5°C)	1.54	1.64	1.54	1.22	1.20	1.03
2 (3.5/3.5/1.5°C)	**1.39**	**1.28**	1.55	1.37	1.25	0.92
3 (3.5/1.5/1.5°C)	**1.32**	1.57	**0.98**	1.17	1.14	1.16
4 (3.5/1.5/3.5°C)	**1.29**	1.54	**1.07**	1.18	**1.46**	1.12
5 (1.5/1.5/1.5°C)	**1.19**	**1.25**	**1.10**	1.21	1.19	1.14
6 (1.5/1.5/3.5°C)	**1.17**	1.51	**1.37**	1.33	**1.36**	1.07
7 (1.5/3.5/3.5°C)	**1.38**	1.56	1.54	**1.56**	**1.34**	1.11
8 (1.5/3.5/1.5°C)	**1.35**	**1.42**	1.57	**1.56**	**1.34**	1.07
$LSD_{0.05}$ (16df)	*0.2*		*0.16*		*0.16*	

Values in columns highlighted in bold are significantly different (p<0.05) from the untreated control (treatment 1).

Table 11: The incidence of *Nectria* lesions on SmartFresh™ treated Cox's Orange Pippin stored under modulated temperature regimes

Treatment	**SmartFresh™**	
	Yes	**No**
1 (3.5/3.5/3.5°C)	30.0	30.0
2 (3.5/3.5/1.5°C)	17.5	**65.0**
3 (3.5/1.5/1.5°C)	**13.8**	**13.8**
4 (3.5/1.5/3.5°C)	21.2	41.2
5 (1.5/1.5/1.5°C)	**10.0**	**3.8**
6 (1.5/1.5/3.5°C)	**11.2**	33.8
7 (1.5/3.5/3.5°C)	17.5	25.0
8 (1.5/3.5/1.5°C)	**12.5**	**78.8**
$LSD_{0.05}$ (16df)	*14.51*	

Values in columns highlighted in bold are significantly different (p<0.05) from the untreated control (treatment 1).