FINAL REPORT

In-store control of sprouting and processing quality using CIPC and ethylene

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Contents

1. Summary

This project is a companion to the Defra Sustainable Arable Programme Link project LK09127 “Reducing energy usage and wastage by improving ethylene control of potato sprouting”. The latter project seeks to reduce energy usage and cut wastage during potato storage by developing strategies for improved sprout control that reduce quality losses while opening the way for storage at higher temperatures for both processing and fresh marketed potatoes. Through development of alternative strategies to CIPC usage it aims to provide growers with a wider range of viable strategies if further restrictions on CIPC use were to be imposed in the future. The work carried out at Sutton Bridge Crop Storage Research (SBCSR) as part of the Link project, and included in the LK09217 final report, was:

2009: Trial to assess the effect of ethylene and ethylene and 1-MCP (1-Methylcyclopropene) treatment on sprout growth and sugar levels in commercial varieties.

2010: Trials to assess the effects of spearmint (R-Carvone), ethylene and 1-MCP on sprout suppression

2011: Trials to assess the effects of ethylene and 1-MCP, including multiple applications, on sprout suppression

This Potato Council-funded project was developed to address specific questions which arose during the Link project and it had two objectives:

1. to investigate the physiological effects caused by ethylene treatment in the absence of sprouting.

   This required that tubers were treated with CIPC prior to exposure to ethylene to prevent sprouting. As a result, the experimental design allowed a second objective to be addressed.

2. to investigate if the combination of a single CIPC application followed by continual exposure to ethylene (10 ppm) can improve sprout control compared with either treatment alone.

Ethylene (10 ppm) treatment of potato at 9°C had some effect on processing fry colour. The increase of chip fry colour was very modest or absent but more marked in crisp processing. The effect of ethylene on processing fry colour had a varietal component for example, nil for Maris Piper and a commercially insignificant increase for Russet Burbank prepared as chips.

Changes in reducing sugar content were found for some varieties under the different treatments. The lowest reducing sugar contents were generally found with CIPC alone treatment and generally ethylene increased the content but were not increased over the untreated controls. Reducing sugars in the combined CIPC and ethylene treatment were generally higher than found with CIPC treatment alone.

The combined treatment of CIPC (21 ppm) immediately prior to a (ramped) ethylene at 10 ppm gave good control of sprouting, to a mean length of approximately 2 mm or less, in six processing varieties and for up to 6 month's storage duration. This was independent of the varietal effect of ethylene on sprouting.

Based on these results, it is concluded that the combination of CIPC and ethylene treatment (as studied in this project) can provide a practically useful sprout control strategy for some processing crops, for up to six months storage for Maris Piper and Russet Burbank and four months for Cabaret and Saturna.

2. Experimental section

2.1 Introduction

This Potato Council supported project was a companion project to the Defra Sustainable Arable Programme Link project LK09127 "Reducing energy usage and wastage by improving ethylene control of potato sprouting". The project was a collaboration between the Natural Resources Institute, James Hutton Institute, Potato Council, Greenvale AP Ltd, Cygnet Potato Breeders Ltd, PepsiCo International Ltd, Landseer Ltd and Greenwich University Enterprise Ltd supported by the Sustainable Arable Link Programme (DEFRA and RERAD).

Control of sprouting is essential for efficient storage of the c.3.5m tonnes of crop stored in the UK, and without this potato tubers rapidly become unsuitable for both processing and fresh marketing. Until recently the most common strategy for

controlling sprouting in both fresh marketed and processing potatoes has been to treat with the sprout inhibitor Chlorpropham (CIPC). Although alternatives have been identified for fresh marketed produce (see below), in the UK most potatoes destined for processing are still treated with CIPC. A new EU maximum residue level (MRL) for CIPC was established in 2005 of 10 mg kg^{-1} for potatoes. Subsequently, as part of the review of EU 91/414, the risk of MRL exceedance was indentified in the UK and the Advisory Committee on Pesticides introduced application restrictions. An industry stewardship scheme has been implemented in the UK to address this, but concerns remain about the continued availability of CIPC as it is on the B-list of chemicals currently being reviewed by EU for hazard assessment.

Continuous application of ethylene (4-10 ppm) to potatoes during storage has been developed as an alternative to CIPC, as it inhibits the growth of sprouts once they have initiated (Prange *et al*., 1998). Ethylene has been developed for use in the potato industry through previous research funded by DEFRA (HH2114STF) and additional industry funded trials. Currently, over 150,000 tonnes of potatoes are treated with ethylene. However, an important constraint to ethylene use for sprout suppression is that varietal variability in ethylene sensitivity means that most varieties need to be held at low temperature for effective sprout control. In addition to this, ethylene can induce increased respiration and sugar accumulation in some varieties. This is not acceptable for processing varieties as sugar accumulation causes fried products to become unacceptably dark. Sugar accumulation also impacts on the increased potential to produce acrylamide, identified as a potential carcinogen, during potato processing (Muttucumaru *et al.,* 2014).

The work described in this report aimed to understand the effect of ethylene on processing quality, over short and long term storage, in the absence of confounding biochemical and physiological changes caused by sprouting. In the trials sprouting was controlled by CIPC treatment. In Year 1, a single CIPC application was followed by either continuous exposure to 10 ppm ethylene, or tubers were left without ethylene treatment. Processing quality was assessed after 2 and 6 months' storage. In year 2, addditional information was obtained for the reducing suagr and sucrose content of tubers under the different treatments.

The experimental design allowed an additional objective to be addressed: to investigate the potential for reducing the use of CIPC by the additional use of ethylene. The tubers were used to study if such combined treatment would allow

minimal use of CIPC to control sprouting. Sprouting assessments were carried out at the same time as the assessments of processing quality.

2.2 Materials and methods

2.2.1 Year one (2010-11)

Potato varieties

Six processing varieties Cabaret, Hermes, Maris Piper, Markies, Russet Burbank, Saturna and Verdi were provided during 2010 by commercial partners from the companion project (LK09127) in sufficient quantity for the trials as detailed below.

Maris Piper and Russet Burbank *[McCain Foods GB Ltd]:* intake 22nd October 2010
Cabaret *[Sacker Farms for Cygnet PB Ltd]:* intake 28th October 2010
Saturna and Hermes, *[R S Cockerill (York) Ltd]:* intake 1st November 2010
Markies *[McCain Foods GB Ltd]:* intake 2nd November 2010

As soon as possible after intake, potatoes were graded to remove soil, rots, damaged, green and undersize tubers (< 45 mm). Intake samples were taken from the graded tubers. Approximately 35 tubers were packed into onion nets. The netted crop was buried within bulk tubers of Russet Burbank in a 1 tonne box.

Untreated control and ethylene treated comparative samples

The companion project provided untreated control and ethylene treated samples for comparative use. These samples were in trays rather than netted in boxes, and the pull down regime was 0.5°C per day but were otherwise exposed to identical storage conditions to those described below.

CIPC treatment

Chlorpropham *[ProLong, UPL, Warrington, WA3 6AE, UK]*, was applied on one occasion at the highest single dose possible, 42ml per tonne (21 ppm). Application was carried out using a Swingfog SN 50 fogging machine *[Swingtec GmbH, Achener Weg 59, 88316 Isny, Germany]* fitted with a 1mm nozzle and the store was ventilated for between 6 and 7 hours after application.

Pull-down and storage

Once in trays, crops underwent a controlled pull-down regime of 0.3°C per day, at ambient relative humidity (RH), to a holding temperature of 9.0°C to minimise temperature stress and allow time for skin healing after handling.

Twelve-tonne controlled environment rooms were set at a target temperature of 9°C with a tolerance ±0.5°C and 95% RH with a tolerance ±5%. Store temperature and humidity records are archived at SBCSR.

Ethylene treatment

Following pull-down to storage temperature and, where necessary, application of other treatments, ethylene was manually added to store to achieve the desired ramping of concentration to 10 ppm over 16 days, starting on the 16th November 2010. An ICA75 Restrain ethylene generator was used to maintain a constant 10 ppm ethylene in the store for the remainder of the trial. An EMU2 TS Ethylene Management Unit [BioFresh Ltd] was used to maintain a constant 10 ppm ethylene for the comparative ethylene treated samples in the companion project.

2.2.2 Year two (2011-12)

Potato varieties

Six commercial processing varieties were provided during 2011 by commercial partners of the project in sufficient quantity for the trials on the dates detailed below:

Sylvana [supplied by *Greenvale AP*]: 30/9/2011

Maris Piper [*Greenvale AP*]: 12/10/2011

Cabaret [*Sacker Farms for Cygnet PB Ltd*]: 14/10/2011

Hermes and Saturna [*R S Cockerill (York) Ltd for PepsiCo*]: 12/10/2011

Russet Burbank [*McCain Foods (GB) Ltd*]: 13/10/2011

As soon as possible after intake, potatoes were graded to remove soil, rots, damaged, green and undersize tubers (< 45 mm). Intake samples were taken from the graded tubers. Approximately 35 tubers were packed into nylon onion nets. The netted crop was then buried within bulk tubers of cv. Markies in a 1 tonne box.

Treatments

The following treatments and treatment combinations were applied to all varieties.

- untreated (unt)
- 10 ppm ethylene (Eth)
- 21 ppm CIPC (CIPC)
- 21 ppm CIPC and 10 ppm ethylene (CIPC & Eth)

Pull-down and storage

Crop samples were stacked in 10kg capacity polypropylene trays on trolley-racks in a completely randomised manner. The crop underwent a controlled pull-down regime of 0.3°C per day, at ambient relative humidity (RH), to a holding temperature of 9.0°C to minimise temperature stress and allow time for skin healing after handling.

Twelve-tonne controlled environment rooms were set at a target temperature of 9°C with a tolerance ±0.5°C and 95% RH with a tolerance ±5%. Store temperature and humidity records are archived at SBCSR.

Ethylene treatment

Following pull-down to storage temperature and application of other treatments, ethylene was manually added to store to achieve the desired ramping of concentration to 10 ppm over 16 days, starting on the 7th November 2011. An EMU2 TS Ethylene Management Unit [BioFresh Ltd] was used to maintain a constant 10 ppm ethylene and was used from 25th November 2010 for the duration of the trial.

2.2.3 Sample assessments: 2010-11 and 2011-12

Sprout number and sprout length were recorded and processing quality was assessed by fry colour with varieties Cabaret, Maris Piper, Markies and Russet Burbank being processed as chips and varieties Hermes, Saturna as crisps. Each sample assessment was of 25 tubers, replicated four times. These assessments were made in Year 1 (2010-11) after 2 and 6 months' storage and in Year 2 (2011-12) after 2, 4 and 6 months of storage.

Chip preparation and assessment

Chips were processed as single 3/8th inch square longitudinal sections from each of 20 sound tubers and fried for 90 seconds in oil heated up to 190 °C at the start of frying. The fry colour of individual strips was assessed subjectively by comparison with a USDA standard colour chart [*Munsell Color, Baltimore, Maryland, USA*] under standard artificial white light. The USDA assessment scale used for assessing chips (light to dark - 000, 00, 0, 1, 2, 3 & 4) was linearized (SBCSR scale, as shown below) and reported as a mean. Scores of 1 to 3 are good; scores of 4 and 5 acceptable and higher scores rejected.

SBCSR score	1	2	3	4	5	6	7
USDA score	000	00	0	1	2	3	4

Crisp preparation and assessment

For crisping 300 g of slices between 1.22 and 1.47 mm thick were taken from 30 mechanically peeled tubers and washed in water for 45 seconds. Each sample was then fried for 3 minutes in oil heated up to 177 °C at the start of frying. After frying the sample was weighed and then crisps with defects (a dark discolouration larger than a 5 mm diameter circle) removed and weighed. The remaining blemish free sample was then assessed objectively three times using a Hunter Lab D-9000 colour quality meter fitted with a D25-L optical sensor [*Mountsorrel, Leics., UK*].

Sugar analysis: 2011-12

Opposite eighth tuber core samples were from taken from 5 tubers per sample, frozen at -20°C, and delivered to Natural Resources Institute (NRI) for sugar analysis in Year 2 only. A detailed description of the method of analysis is provided in the main LINK project report: Colgan *et al* (2013).

Dry matter

Sample dry matters were assessed at the start and completion of the trial by a method (Burton 1989) that estimates dry matter indirectly via specific gravity using the equation below:

Dry matter (%) = 24.182 + (211.04 x SG) – (211.04 x 1.0988)

Where:

$$SG = \frac{\text{weight of sample in air}}{\text{weight of sample in air} - \text{weight of sample in water}}$$

Analysis of data

Analysis of Variance (ANOVA) was compiled in SPSS 21 on CIPC alone and CIPC/ethylene treatment effects on sprouting and processing colour (chip and crisp) on a per variety basis and per sampling occasion basis. The effects of the sampling occasions or varieties are separated out in this type of factorial analysis, permitting efficient hypothesis testing to take place based on F-tests. No transformation of the data took place to achieve normality of data. Significant differences between mean values and interactions are reported at the 5% level ($P<0.05$). 95% confidence intervals are used to assess if mean scores are different from the critical sprout lengths of 2mm or fry colour thresholds of SBCSR 4.0 (chips) and Hunter 'L' 59.0 (crisps).

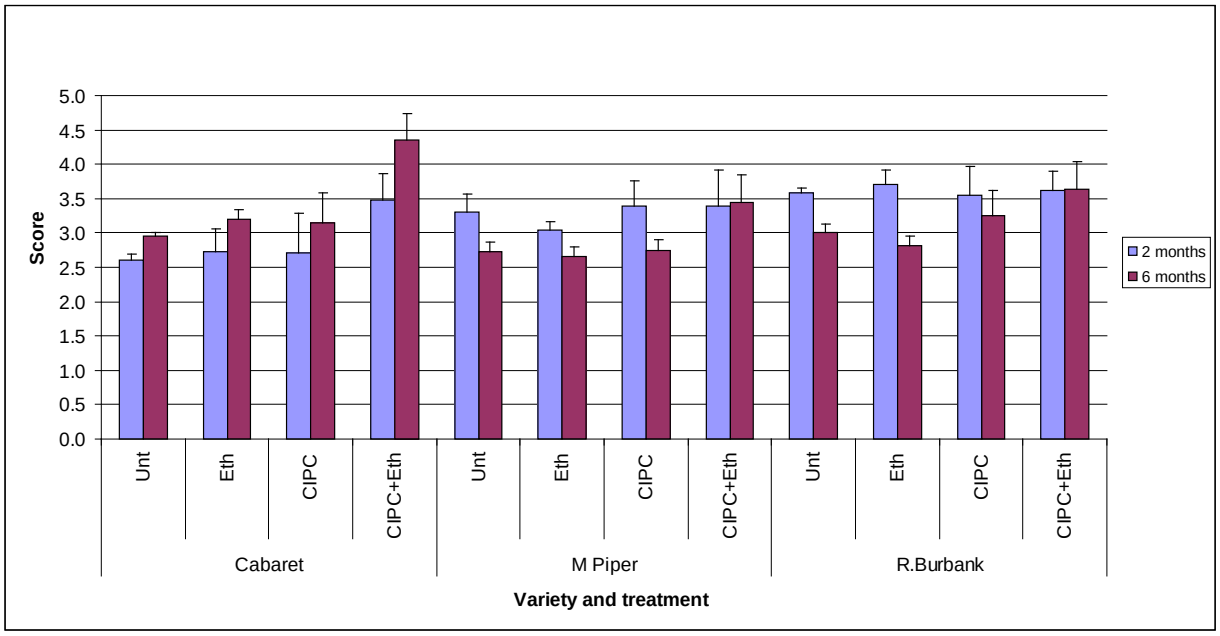
2.3.1 Results

OBJECTIVE 1: What physiological effects are caused by ethylene treatment in the absence of sprouting?

2010-2011

The chip fry colour was acceptable for Cabaret, Maris Piper and Russet Burbank, for all treatments at two months and, excepting Cabaret treated with CIPC/ethylene, also at six months (Figure 1). There was no significant effect of ethylene on processing colour at either 2 or 6 months storage there was very little difference between the treatments for Maris Piper or Russet Burbank.

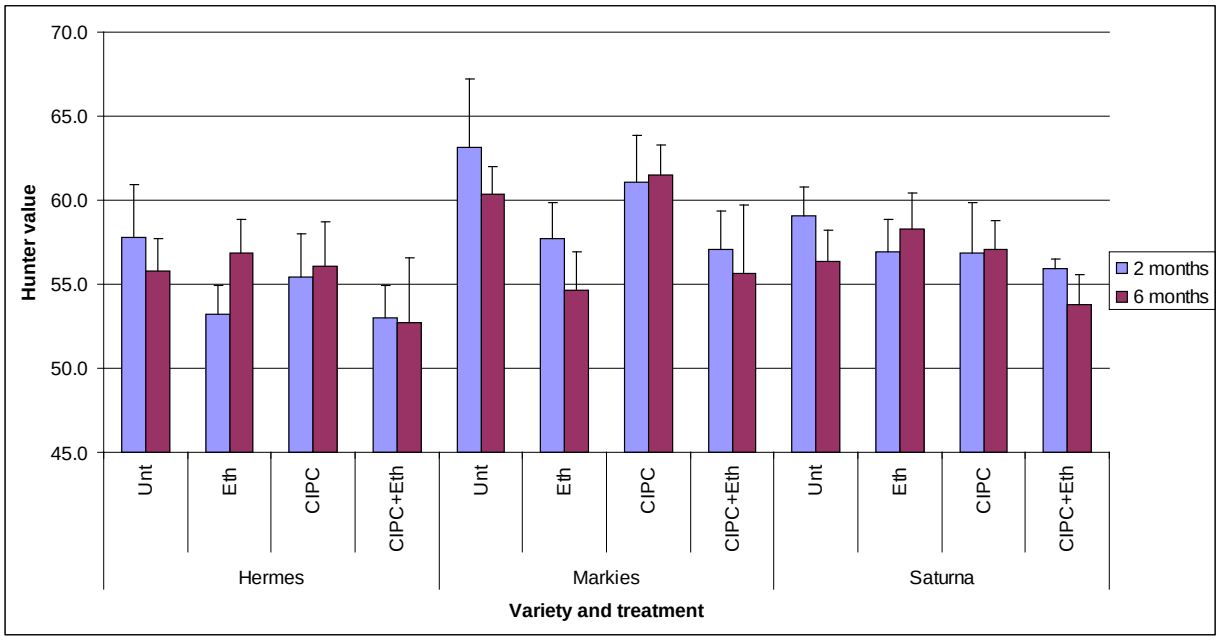
Figure 1. Processing quality, fry colour (SBCSR score*): chipping varieties after 2 or 6 months storage at 9°C



*SBCSR values 1-7 correspond to USDA 000, 00, 0, 1, 2, 3 and 4. **SBCSR values greater than 4 (USDA 1) are considered unacceptable**. +/- s.d.

Overall crisping quality was poor (Figure 2) and with all treatments both Hermes and Saturna would have been commercially unsuitable. Markies would have been commercially suitable only as either untreated or CIPC treated crop.

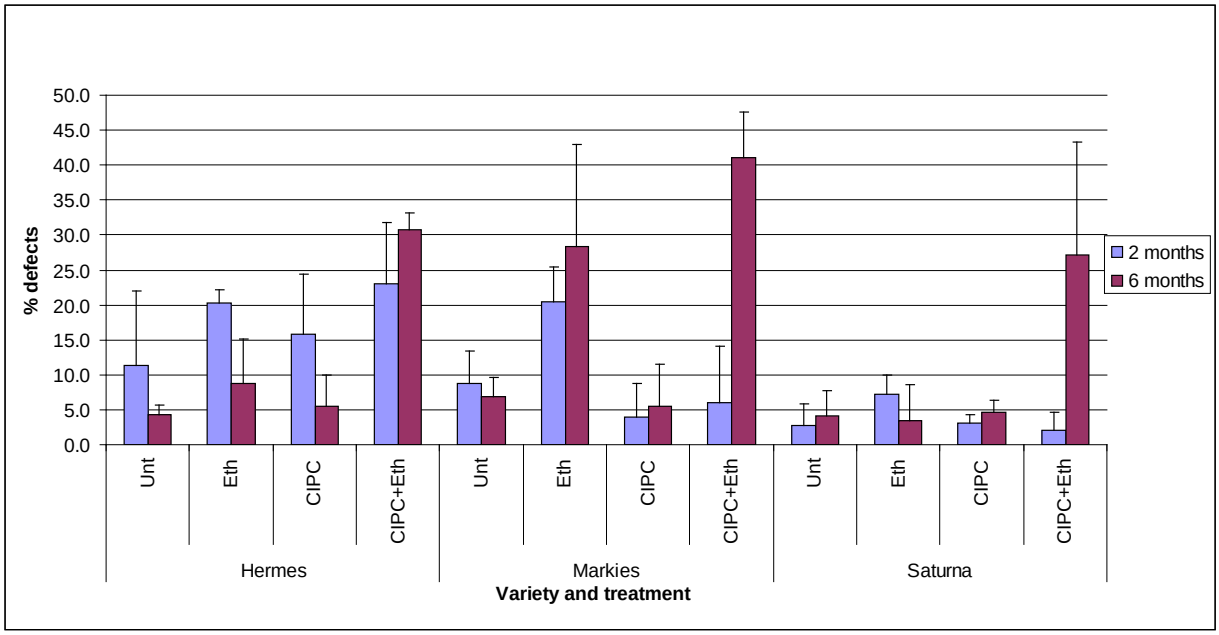
Figure 2. Processing quality; fry colour (Hunter L*): crisping varieties



*Hunter L value is a standard colour scale for crisp fry colour. Lower values indicate increasing darkness and **values of less than 58/59 are considered commercially unsuitable**. +/- s.d.

Fry defect levels were increased by ethylene treatment with or without CIPC (Figure 3) and increased markedly in both Markies and Saturna after six months storage in the presence of ethylene.

Figure 3. Processing quality; crisp fry defects



Defect levels < 10% attract a bonus payment, with increased defect levels increasingly unacceptable for commercial use. +/- s.d.

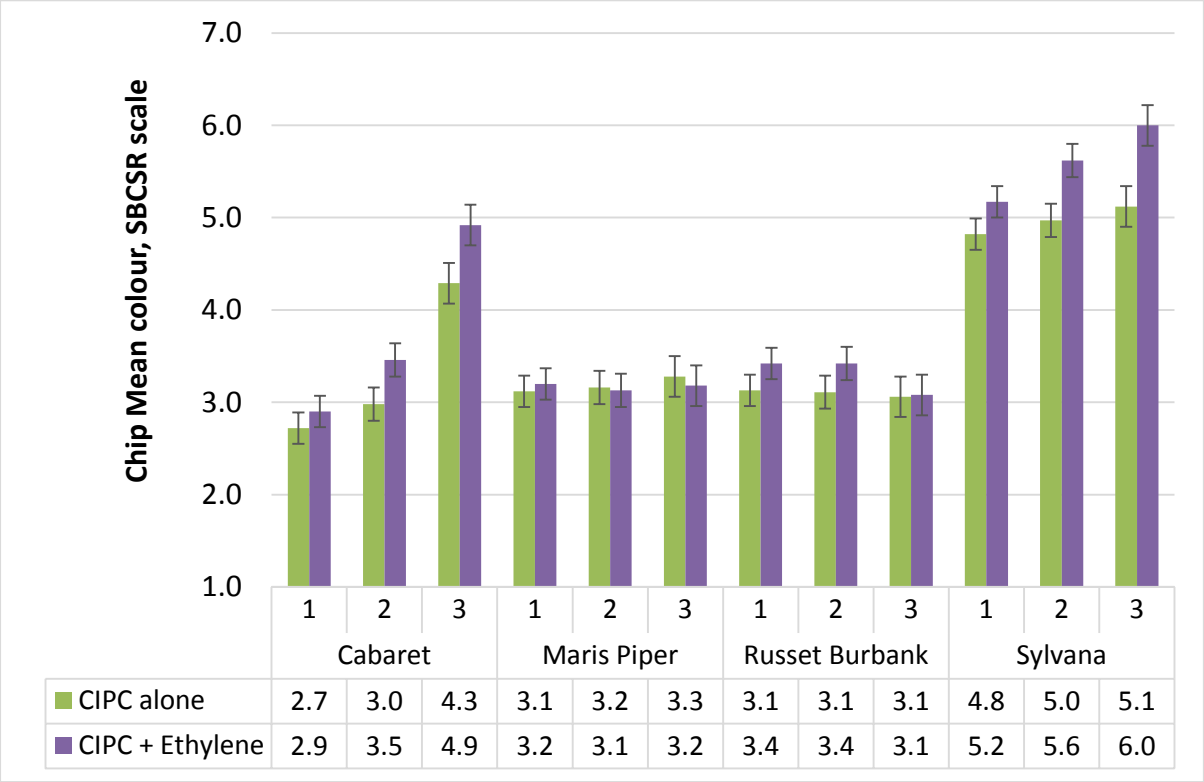
2011-2012

Processing quality: chip fry colour

The chip fry colour was acceptable for Maris Piper and Russet Burbank, for all treatments for the duration of storage. Cabaret fry colour was acceptable for four months storage but had deteriorated with both treatments by six months. Fry colour of Sylvana was unacceptable for both treatments and all sampling occasions (Figure 4).

There was a significantly different effect on chip fry colour between treatment with CIPC alone or CIPC/Ethylene ($P \leq 0.02$) in all varieties apart from Maris Piper ($P=0.693$). However, except for Cabaret at 4 and 6 months and Sylvana on all occasions, this difference was small (Figure 4).

Figure 4. Chip fry colour by variety, sampling occasion and treatment



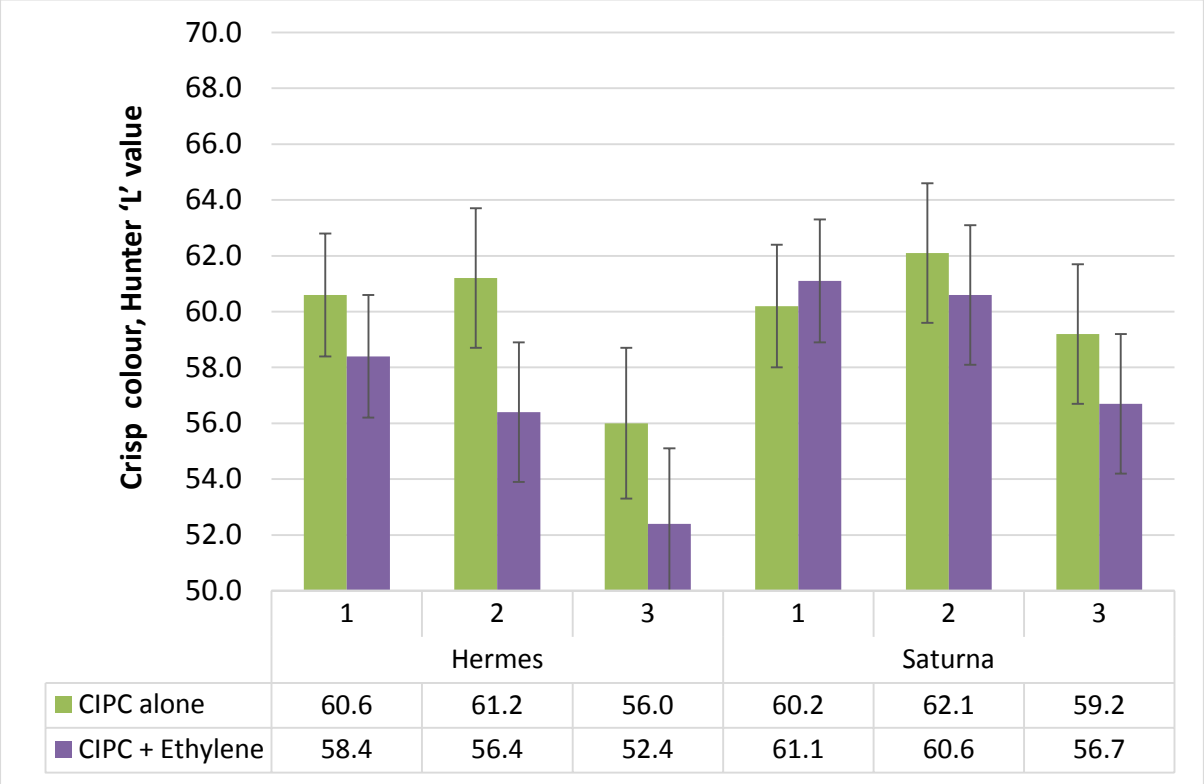
*SBCSR values 1-7 correspond to USDA 000, 00, 0, 1, 2, 3 and 4. SBCSR values greater than 4 (USDA 1) are considered unacceptable. +/- 95% confidence limits.
For each variety, the x axis values are: 1= samples assessed after 2 months storage; 2 = samples assessed after 4 months storage; 3 = samples assessed after 6 months storage.

Processing quality: crisp fry colour

Both treatments provided commercially acceptable crisp colour values for Saturna at 2 and 4 months, and for CIPC treatment alone at six months. Fry colour with CIPC/ethylene treatment deteriorated slightly at six months (mean Hunter 'L' score 56.7).

For Hermes CIPC treatment alone provided commercially acceptable crisp colour values at 2 and 4 months but not at 6 months (Figure 5). The inclusion of ethylene in the treatment reduced fry colour to below commercially acceptable values. CIPC/ethylene treatment significantly decreases the mean crisp score compared with CIPC alone in both varieties. For Hermes the mean Hunter 'L' score for CIPC/ethylene of 55.1 was significantly different (P = 0.001) to the score with CIPC alone (58.8). For Saturna the mean Hunter 'L' score for CIPC/ethylene of 59.0 was significant different (P = 0.015) to Hunter 'L' score with CIPC alone (60.4).

Figure 5. Crisp fry colour Hunter L values by variety, sampling occasion and treatment



	Hermes			Saturna		
	1	2	3	1	2	3
CIPC alone	60.6	61.2	56.0	60.2	62.1	59.2
CIPC + Ethylene	58.4	56.4	52.4	61.1	60.6	56.7

*Hunter L value is a standard colour scale for crisp fry colour. Lower values indicate increasing darkness and values of less than 58/59 are considered commercially unsuitable. +/- 95% confidence limits.

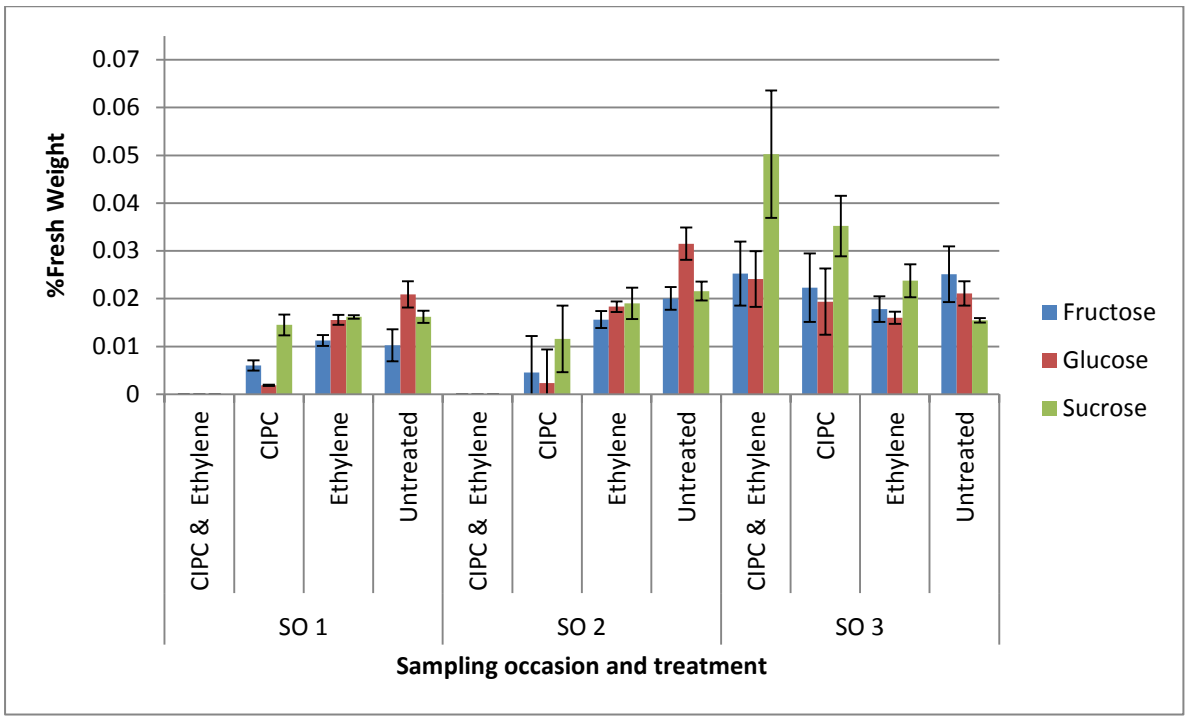
Sugar content 2011-12

Fructose, glucose and sucrose content of the varieties by sampling occasion and treatment are shown in Figures 6-11. Changes in reducing sugar content were found for the varieties under the different treatments. The lowest reducing sugar contents were generally found with the CIPC alone treatment and generally ethylene increased the content. Sugar values in ethylene treatments were similar to those in untreated controls. Reducing sugars in the combined CIPC/ethylene treatment were generally higher than found with CIPC treatment alone. There was no clear pattern of change of reducing sugar content with storage duration and the highest sucrose levels were generally found after six months storage.

Some treatment values were missing for Cabaret however, sugar values were very similar for both untreated and ethylene treatments across all sampling occasions. There was no obvious explanation in terms of reducing sugar content for the increased fry colours at six months. The sugar content of Sylvana was high throughout storage.

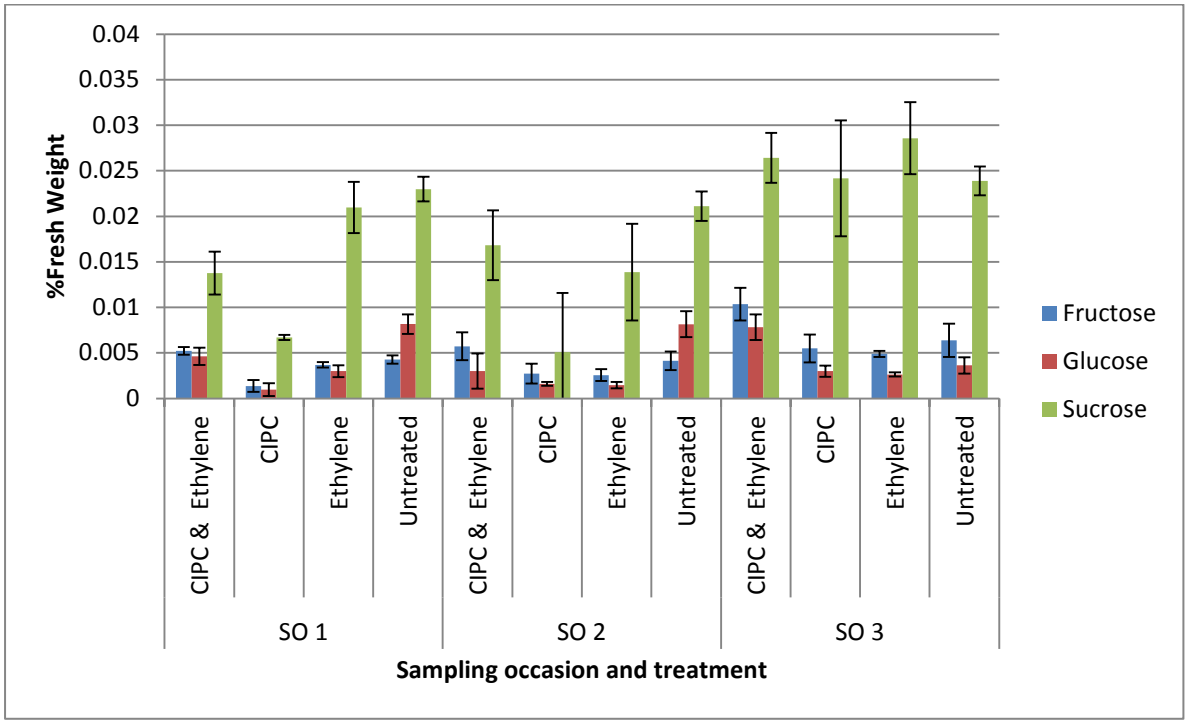
For Hermes and Saturna there was no difference in any sugar values between ethylene and CIPC/ethylene at any of the sampling occasions although there were significant differences in sprout growth between these treatments (Figures 10, 12 and Table 1). Similarly, in Maris Piper and Russet Burbank reducing sugar content was higher at SO1 and SO2 under ethylene treatment than with CIPC/ethylene, again there were differences in sprout length (Figures 8, 9 and Table 1).

Figure 6. Fructose, glucose and sucrose content of Cabaret by sampling occasion and treatment



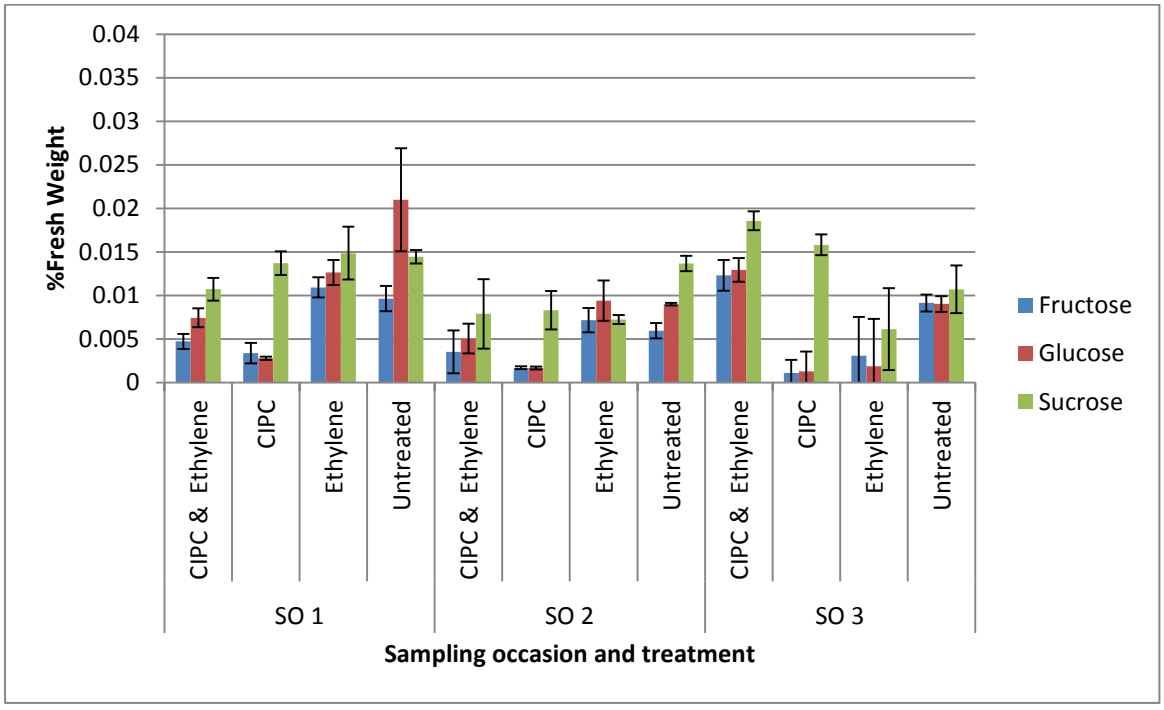
No values available for CIPC/Ethylene at SO1 and SO2. +/- s.d.

Figure 7. Fructose, glucose and sucrose content of Hermes by sampling occasion and treatment



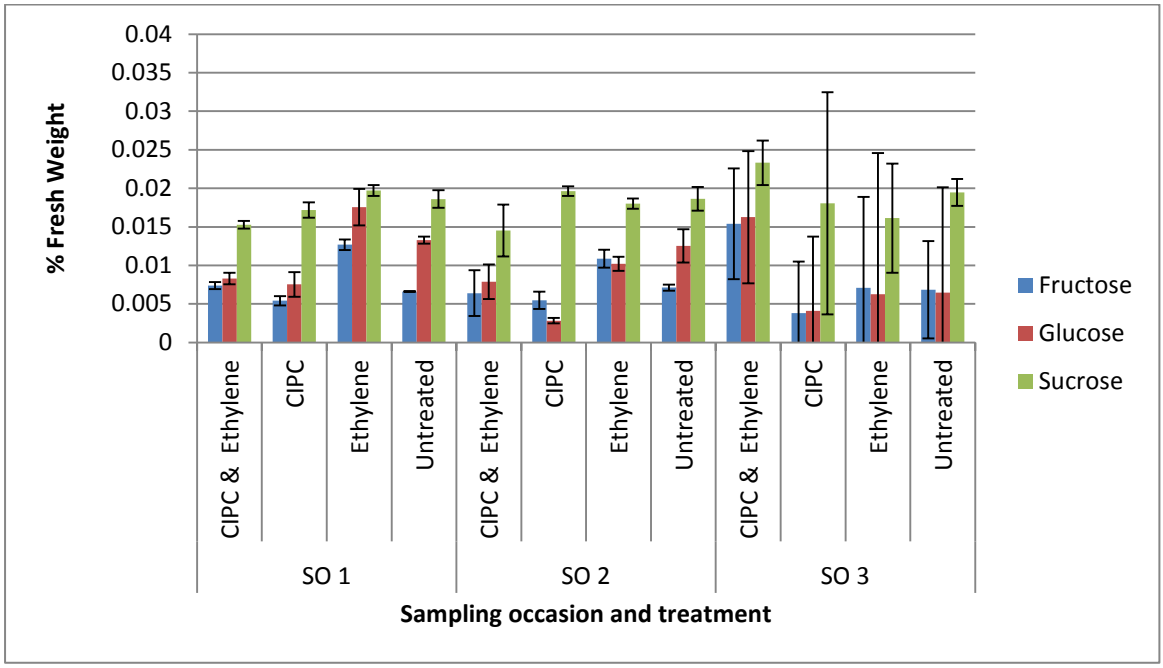
+/- s.d.

Figure 8. Fructose, glucose and sucrose content of Maris Piper by sampling occasion and treatment



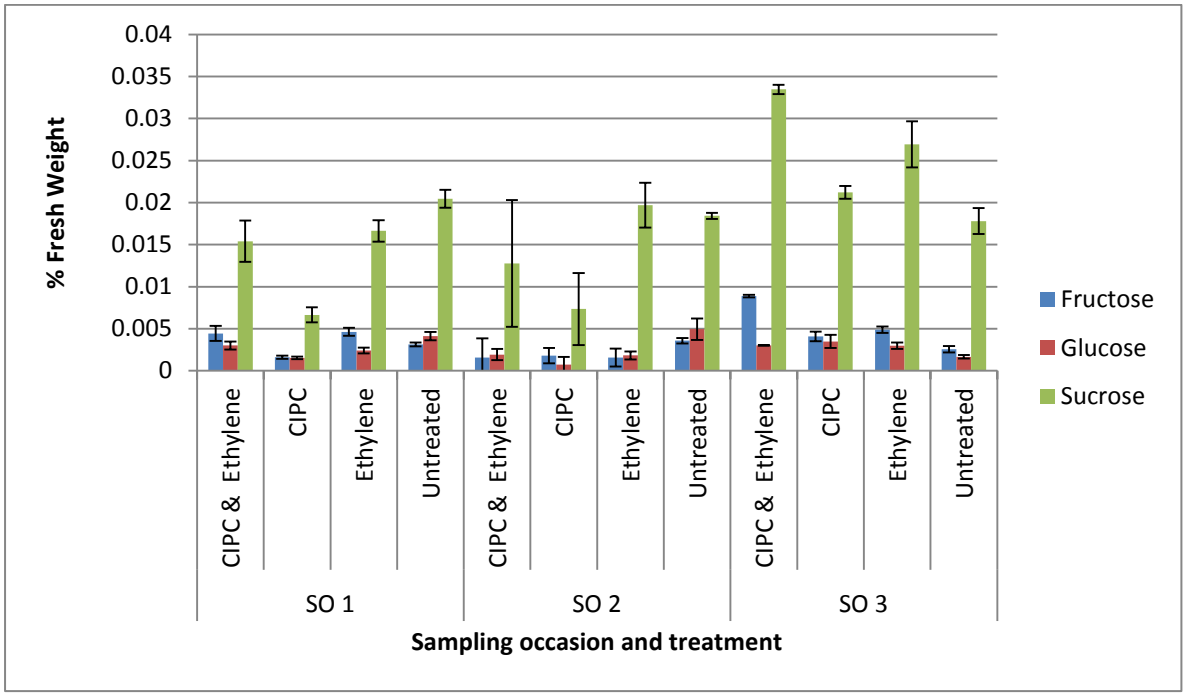
+/- s.d..

Figure 9. Fructose, glucose and sucrose content of Russet Burbank by sampling occasion and treatment



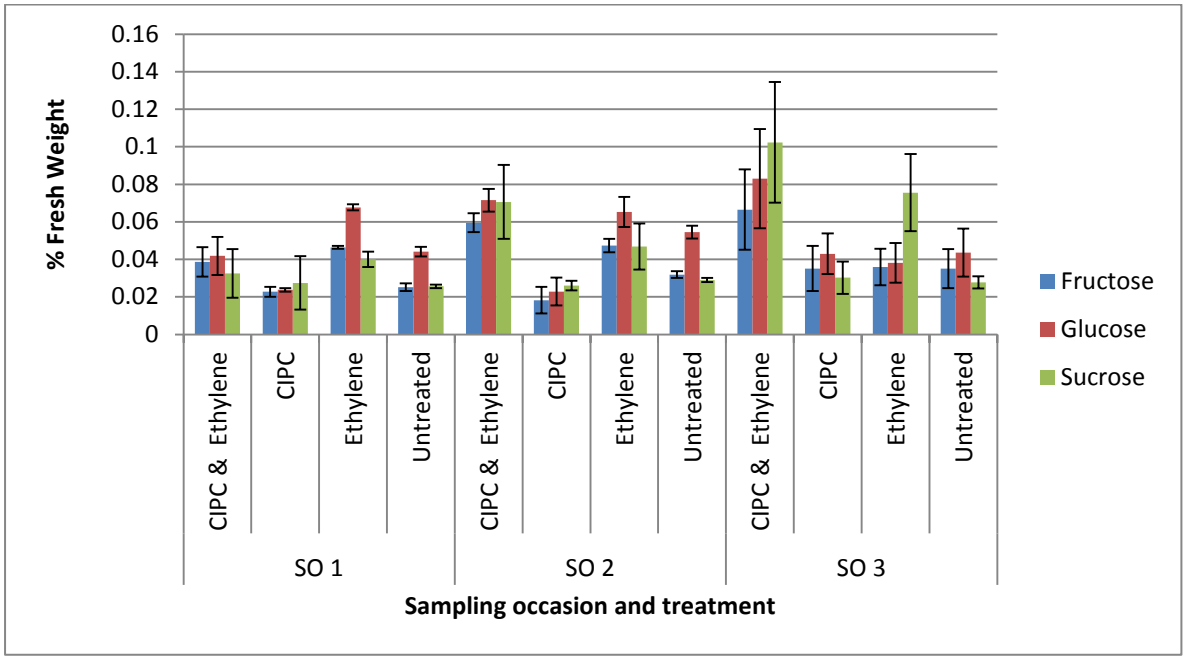
+/- s.d.

Figure 10. Fructose, glucose and sucrose content of Saturna by sampling occasion and treatment



+/- s.d.

Figure 11. Fructose, glucose and sucrose content of Sylvana by sampling occasion and treatment



+/- s.d.

Table 1 Mean scores for variety sprout length and fry colour quality, taken from LK09127 (Colgan *et al* 2013).

		Cabaret		Maris Piper		Russet Burbank		Sylvana		Hermes		Saturna	
		sprout length (mm)	Fry colour (SBCSR units)	sprout length (mm)	Fry colour (SBCSR units)	sprout length (mm)	Fry colour (SBCSR units)	sprout length (mm)	Fry colour (SBCSR units)	sprout length (mm)	Fry colour (Hunter L score)	sprout length (mm)	Fry colour (Hunter L score)
SO 1	Untreated	34.0	3.1	47.1	3.0	2.8	3.1	16.9	5.0	25.9	58.6	20.8	61.3
	1-MCPx1	33.1	2.5	41.1	3.3	1.3	3.2	14.6	4.7	17.2	61.7	13.6	61.6
	Ethylene	7.1	3.0	10.9	3.3	0.5	3.7	1.7	5.5	3.7	53.9	4.6	59.9
	Eth + 1-MCPx1	9.7	2.4	11.2	3.0	0.4	3.2	2.1	5.1	3.6	57.1	4.4	60.4
SO 2	Untreated	44.5	3.6	56.3	3.2	22.0	3.1	24.9	5.4	46.8	60.5	39.9	59.5
	1-MCPx1	48.8	3.3	50.9	3.3	22.3	3.3	26.9	5.5	40.8	60.9	35.5	61.2
	1-MCPx2	45.3	3.2	58.2	3.3	24.0	3.2	26.4	5.0	40.6	60.6	36.3	62.1
	Ethylene	19.8	3.4	15.5	3.2	1.2	3.5	0.7	5.6	16.6	57.1	12.2	59.4
	Eth + 1-MCPx1	19.7	3.2	18.2	3.1	1.5	3.5	0.9	6.0	14.3	59.9	14.2	62.9
	Eth + 1-MCPx2	19.3	3.3	22.6	3.3	2.5	3.2	1.0	5.8	16.6	60.1	16.5	60.4
SO 3	Untreated	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
	1-MCPx1	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
	1-MCPx2	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
	Ethylene	22.3	4.2	18.8	2.9	2.7	3.1	0.3	6.3	20.6	51.6	19.2	57.0
	Eth + 1-MCPx1	19.3	4.4	18.2	2.9	3.4	3.1	0.3	6.2	20.4	53.8	13.3	57.4
	Eth + 1-MCPx2	18.9	4.9	21.0	3.1	4.4	3.4	0.4	6.3	23.8	54.6	14.4	57.0
	Eth + 1-MCPx3	25.4	4.5	23.3	3.0	4.8	3.1	0.2	5.7	25.9	55.2	20.3	56.0

Highlighted values considered commercially unacceptable
nd, not determined

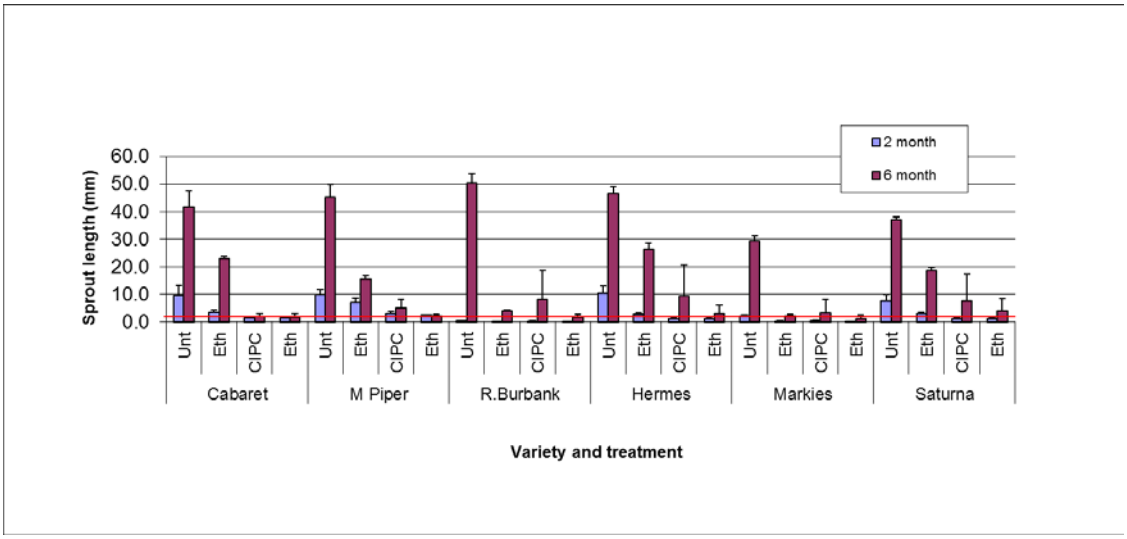
OBJECTIVE 2: Can a single CIPC application followed by continual exposure to 10 ppm ethylene improve sprout control compared with either treatment alone?

2010-11

For all varieties the ethylene, CIPC, and CIPC/ethylene treatments all reduced sprout length compared with an untreated control (Figure 12). However, sprouting was not well controlled by ethylene in varieties Cabaret, Hermes, Maris Piper and Saturna. A single CIPC treatment controlled sprouting well at 2 months for all varieties, an effect that dissipated over the following four months in Russet Burbank, Hermes, Markies and Saturna.

The combined treatment of CIPC/ethylene at six months was the most effective applied treatment generally providing greater control of sprouting than either treatment alone. It controlled sprouting to commercially acceptable levels, a mean of approximately 2 mm or less, in all varieties except Hermes and Saturna which had mean sprout lengths of 3.1 and 4.2 mm, respectively. However, sprouting was not controlled by either ethylene or CIPC alone at six months in either of these two varieties.

Figure 12. Sprouting assessment: length of longest sprout after 2 or 6 months storage at 9°C



cut-off for commercial sprout length acceptability. +/- s.d.

2011-12

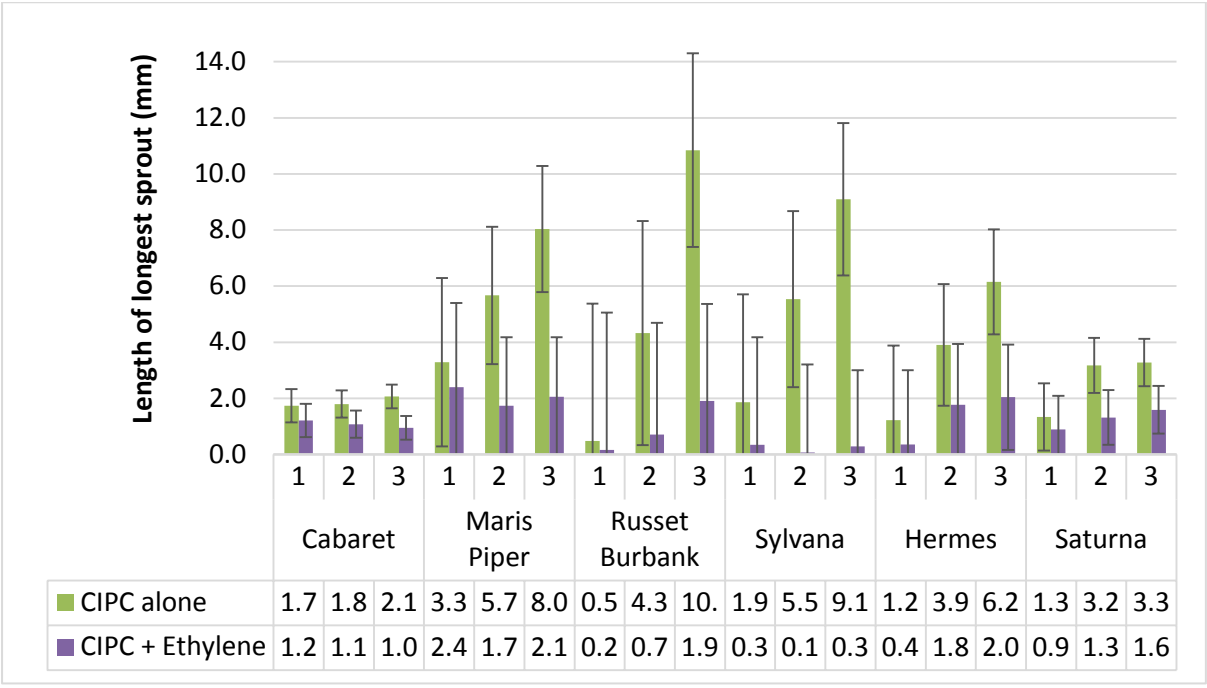
Sprouting

For all varieties the CIPC, and CIPC/ethylene treatments reduced sprout length compared with an untreated control (Figure 13, comparative untreated data not shown).

Sprouting of Cabaret was, surprisingly, exceptionally well controlled through the duration of storage. A single treatment of CIPC controlled sprouting to below 2mm by in all varieties, except for Maris Piper, for 2 months (Figure 7). However, with the exception of Cabaret, longer duration storage resulted in sprout growth substantially greater than 2mm. In contrast, combined CIPC/ethylene treatment controlled sprouting in all six varieties to a mean of ~2 mm for the duration of the storage period.

The mean sprout length for all varieties with CIPC/ethylene treatment was significantly different from the mean for CIPC alone (P-values range from <0.001 to 0.004) and CIPC alone produces higher mean sprout length values than CIPC/ethylene at all sampling occasions (Table 2).

Figure 13. Sprout length by variety, sampling occasion and treatment



CIPC alone	1.7	1.8	2.1	3.3	5.7	8.0	0.5	4.3	10.	1.9	5.5	9.1	1.2	3.9	6.2	1.3	3.2	3.3
CIPC + Ethylene	1.2	1.1	1.0	2.4	1.7	2.1	0.2	0.7	1.9	0.3	0.1	0.3	0.4	1.8	2.0	0.9	1.3	1.6

+/- 95% confidence limits. For each variety, the x axis values are: 1= samples assessed after 2 months storage; 2 = samples assessed after 4 months storage; 3 = samples assessed after 6 months storage**.**

Table 2. Treatment effects on sprout length by sampling occasion (all varieties pooled)

Sampling Occasion 1	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
CIPC	1.657	0.106	1.444	1.869
CIPC/ethylene	0.893	0.106	0.681	1.106
Sampling Occasion 2	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
CIPC	4.069	0.373	3.326	4.812
CIPC/ethylene	1.113	0.373	0.370	1.856
Sampling Occasion 3	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
CIPC	6.579	0.598	5.393	7.766
CIPC/ethylene	1.473	0.591	0.299	2.647

Dry matter

Dry matter increases slightly as an average of all treatments from intake to sampling occasion 3 (6 months' storage) for Cabaret, Hermes, Russet Burbank and Saturna (Table 3).

Table 3. Dry matter (%) measured at intake and at sampling occasion 3 (after 6 months' storage).

	sampling occasion	
	Intake	SO3
Cabaret	19.9	20.5
Hermes	21.4	21.9
Maris Piper	22.9	22.7
Russet Burbank	23.5	23.9
Saturna	22.2	22.8
Sylvana	21.0	20.9

2.4 Discussion

An objective of the project was to understand the effect of ethylene on processing quality, over short and long term storage, in the absence of confounding biochemical and physiological changes caused by sprouting. Chlorpropham (CIPC) was applied to control sprouting.

The inclusion of ethylene in combination treatment with CIPC had an effect on processing fry colour with a significantly different effect on both chip and crisp fry colour between treatment with CIPC alone or CIPC and ethylene ($P \leq 0.02$) in all varieties, apart from Maris Piper. However, in many varieties this effect was small and not commercially significant. This was the case for crisp processing with Saturna at most sampling occasions and throughout for chip processing with Maris Piper, Russet Burbank and Cabaret (although it should be noted that with the latter variety all treatments had poor colour after six months' storage),.

The fry colour and sugar content of Sylvana was affected by ethylene although the significance of the effect was difficult to ascertain as fry colours were poor for both treatments at all sampling occasions. Sylvana had significantly higher reducing sugar content than the other varieties in the trial (Figures 6- 11) likely to be due to pre-trial storage at low temperature.

The effect of ethylene on crisp fry colour could be commercially significant for Hermes as it reduced the mean Hunter 'L' value of crisps prepared from this variety by 2-4 units, depending on storage duration. This reduction could potentially be mitigated by 1-MCP treatment (Colgan *et al* 2013).

Changes in reducing sugar content were found for the varieties under the different treatments. The lowest reducing sugar contents were generally found with CIPC alone treatment and generally ethylene increased the content. However, these levels of the different sugars were similar in ethylene treatments and untreated controls. Sugar levels did not apparently increase with sprouting. Very similar sugar levels were found under both ethylene and CIPC/ethylene treatments for Hermes and Saturna (for all storage durations) or Maris Piper (up to four months storage) despite extensive sprouting occurring during these periods under ethylene alone.

The relationship between sugar content and fry colour is not straightforward, as discussed by Burton (1989) and Colgan *et al*. (2013). The increased reducing

sugars found in ethylene-treated Maris Piper compared with CIPC alone treatments did not result in a discernible effect on fry colour.

A further objective of the trial was to investigate if the combination of a single CIPC application followed by continual exposure to ethylene (10 ppm) can improve sprout control compared with either treatment alone.

In the two years of this trial both CIPC and CIPC/ethylene treatments reduced sprout length compared with untreated control in all varieties (Figures 1 and 5). CIPC alone controlled sprouting to less than 2 mm in all varieties for 2 months but was less effective thereafter in controlling sprouting in any variety other than Cabaret. In contrast, CIPC/ethylene controlled sprouting to around or less than 2 mm in all varieties for the six month duration of storage. It should be noted that sprout control was found in varieties, including Maris Piper, that are poorly controlled by ethylene treatment alone (Table 1).

These results support the findings of Daniels-Lake *et al* (2011) who also studied the potential for reduced use of CIPC by combination treatment of CIPC (Sprout-Nip E 1000 ppm dip) with ethylene (4 ppm). They reported on the sprout inhibition in two varieties by combination treatment, on the negative affect on processing colour in both cultivars when ethylene was included in the treatment and also varietal response differences to treatment.

The trials reported here used the maximum single CIPC dose of 21 ppm allowable at the time. Further treatments to a total of 63.75 ppm would have been possible. The single dose has since been reduced to 18 ppm and the total for processing crop to 58 ppm. It seems likely that a reduction from 21 to 18 ppm would not have adversely affected the observed sprout control observed in the CIPC/ethylene combination treatment.

2.5 Conclusions

- The effect of ethylene on processing fry colour effect had a varietal component.
- Chip fry colour following treatment with either ethylene or CIPC /ethylene was acceptable for both Maris Piper and Russet Burbank after 6 months' storage, and for Cabaret after 4 months' storage.

- Crisp fry colour with either ethylene or CIPC /ethylene was acceptable for Saturna after 4 months of storage.
- Ethylene increased reducing sugar content compared with CIPC treatment alone.
- The combination treatment of CIPC with ethylene gave good control of sprouting in all varieties for 6 months storage.
- Sprout control by the combination treatment was irrespective of varietal response to ethylene alone, in terms of sprouting.

Based on these results a combination CIPC/ethylene treatment can provide a practically useful sprout control strategy, for long term storage of some processing varieties.

2.6 References

Burton W.G. (1989). The Potato, 3rd Edition. Longman Scientific and Technical, Harlow.

Colgan R., Harper G., Taylor M., Bryan G. and Rees D. (2013) Reducing energy usage and wastage by improving ethylene control of potato sprouting. Defra LINK project report ref. LK09127.

Daniels-Lake, B.J., Pruski, K. and Prange, R.K. (2011). Using ethylene gas and chlorpropham potato sprout inhibitors together. Potato Research **54** (3) 223-236.

Muttucumaru, N., Powers, S.J., Elmore, J.S., Briddon, A., Mottram, D.S. and Halford, N.G. (2014). Evidence for the complex relationship between free amino acid and sugar concentrations and acrylamide-forming potential in potato. Annals of Applied Biology **164** (2) 286–300.