Interim report

R464 Use of ethylene on processing cultivars:

AHDB - Potato Council
Sutton Bridge Crop Storage Research
East Bank, Sutton Bridge
Spalding, Lincs. PE12 9YD
Tel: 01406 351444 Fax: 01406 351125
E-mail: sbcsr@potato.org.uk

Report Authors: Glyn Harper and Graeme Stroud

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1. Summary

There is an urgent need to provide alternatives to the current dominant sprout suppressant CIPC because of the threats to its continued use. Ethylene has been successfully used with some GB varieties for sprout suppression by the fresh potato sector. However, not all varieties are sufficiently responsive to ethylene and its suitability as a sprout suppressant on any variety must be determined empirically.

The majority of the processing industry uses bulk storage. However, most research trials with ethylene have used small scale containers and most commercial storage under ethylene is within boxes. There are significant differences in the air circulation and air exchange volumes between bulk and box storage and additional work is required to understand whether results from containers can be effectively translated to bulk storage.

During this trial ethylene provided good sprout control for the varieties Fontane, Markies, Ramos and Russet Burbank to 6 months all with acceptable processing colour quality. Ethylene gave satisfactory sprout control to 4 months storage for Desiree, Maris Piper and VR808 although fry colour was somewhat dark in Desiree. Ethylene was ineffective for sprout control in Lady Claire, Innovator and Saturna other than for short term (2 months) storage and had no significant effect on fry colour on these varieties.

In bulk storage trials, ethylene provided good sprout control to 6 months, with acceptable processing colour quality, for Ramos, Markies and Russet Burbank. Ethylene gave satisfactory sprout control to 4 months storage for VR808. Ethylene was ineffective for sprout control in Lady Claire and Innovator other than for short term (2 months) storage and had no significant effect on fry colour on these varieties. Sprouting in Saturna was adequately controlled to 4 months storage with acceptable fry colour.

Some effects of 1-MCP treatment on the sprouting of varieties used in this trial were observed although the effects were both inconsistent and small. 1-MCP did not mitigate any effect on fry colour caused by ethylene in Markies or Saturna. Although there was a small decrease in the fry colour of Desiree at 4 months by 625 ppm 1-MCP treatment no effect was observed using 1-MCP concentrations either lower or higher than this.

2. Experimental Section

2. General Introduction

Chlorpropham (CIPC) is currently the predominant storage sprout suppressant available for the GB processing industry but there are threats to its continued use. Ethylene has been available as an alternative and successfully used with some GB varieties for sprout suppression by the fresh sector. However, its adoption has been constrained by the continued availability of CIPC (a cheaper alternative) and differences in varietal sensitivity it is not equally effective on all varieties. At present there is no clear understanding for this differential response and the suitability of ethylene as a sprout suppressant must be determined empirically.

In the processing sector, it has not been possible to use ethylene to date because of either actual or perceived negative impact on fry colour. However, research by Daniels-Lake *et al*. (2007) and others (cited in Daniels-Lake 2013) suggest that there are varieties whose response to ethylene does not include marked impacts of fry colour. This trial is being undertaken to further assess the potential for ethylene use on processing varieties in Great Britain.

The undesired effect on fry colour can be mitigated, at least partially, by pre-treatment with 1-methylcyclopropene (1-MCP) (Daniels-Lake et al. 2009). The compound competitively inhibits ethylene receptors and prevents signal transduction of an ethylene response. Currently, there is no data defining an optimal concentration of 1-MCP treatment on potato as trials have used 1-MCP at a concentration used in other crop systems. Recent work supported by PCL, including Defra Link project LK09127 and studies R412 and R441, has examined the efficacy of 1-MCP treatment including examination of timing and number of applications. The results have indicated that the compound merits further study.

A further constraint is that the majority of the processing industry uses bulk storage. However, most research trials with ethylene to date have used small scale containers and commercial storage under ethylene has been in boxes. There are significant differences in the air circulation system between bulk and box storage and

additional work is required to understand whether ethylene can be used in bulk storage.

Given the factors mentioned above, there is a need for further research to:

- Understand if and how current and emerging processing cultivars respond to ethylene treatment in terms of sprout suppression and effects on processing quality.
- understand how current and emerging processing cultivars in bulk storage could respond to ethylene treatment
- determine the relationship between 1-MCP concentration and its effect in mitigating ethylene induced fry colour changes in processing varieties

The first year trials to investigate these three research aims are described separately in the following sections as A, B and C respectively.

2.1A Response of processing cultivars to ethylene treatment

The objective of this experiment was to help understand how current and emerging processing cultivars respond to ethylene treatment in order to provide information on potential sprout suppression strategies for these varieties in future.

2.2A Material and methods

Treatments and experimental design

Crops

In 2013 ten processing varieties were supplied for the trials. Desiree [*Branston Holdings Ltd*]; Fontane [*Lamb Weston Meijer (UK) Ltd*]; Innovator, Maris Piper Markies, Ramos and Russet Burbank [*McCain Foods*]; Lady Claire [*Mercian Ltd*]; Saturna [*G.H. Chennells Farms Ltd*]; and VR808 [*R. S. Cockerill (York)*].

Samples of each were divided into four 9.0 °C experimental stores. One was supplied with ethylene maintained at a target concentration of 10 ppm and another with no added ethylene. The crop in the remaining stores was chlorpropham (CIPC) treated and then stored with or without ethylene as above. The experimental design was an un-replicated comparison of treatments with variation measured by four in-store replicates.

Store set up and control

Four 12-tonne Controlled Environment Rooms were identically configured with air discharged by overhead throw from a conditioning duct and recirculated through a duct at the bottom of the store for refrigeration or heating as necessary. Humidification was by conventional compressed air atomiser. The crop was stacked in 10kg capacity polypropylene trays on trolley-racks and completely randomised. No CIPC sprout suppressant had ever been used in the nil CIPC treatment stores.

Pull down and treatment

At the beginning of storage, crop temperatures were pulled-down at a rate of 0.5 °C per day until the holding temperature of 9.0 C (± 0.5 °C). Humidification was then enabled at 95% RH (± 5%) on 12th November 2013. In the appropriate stores, ICA75

Restrain Generators [*Restrain Company Ltd*] were used to monitor and record a manually ramped daily introduction of ethylene at progressively increasing concentrations: from 0 to 1 ppm in increments of 0.1; 2 to 4 ppm in increments of 1; and 6 to 10 ppm in increments of 2. Each day the store was vented to zero immediately before reintroducing ethylene at the prescribed concentration. On 26th November 2013 automatic ethylene generation was initiated. As the generator was designed for a large store, fuel was diluted to 20 % with deionised water and the flow rate initially set to the minimum of 0.1 litres per day.

CIPC [*Pro-long*, MAPP 14389] was applied as a hot fog by *Swingfog* to the pre-trayed crop in a 12 tonne store at 42 ml/tonne on 7th November 2013.

Assessments

Assessments were conducted at intake and after 2, 4 and 6 months of storage. For each sample the longest sprout length was measured on all tubers of a 25 potato sub-sample. Fry colour was measured for potatoes processed as crisps for Lady Claire, Saturna & VR808 and chips (French fries) for Desiree, Fontane, Innovator, Maris Piper, Markies, Ramos & Russet Burbank.

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 HunterLab D-9000 colour quality meter fitted with a D25-L optical sensor [*Mountsorrel, Leics., UK*].

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 1 to 7 (SBCSR scale) and

reported as a mean. Scores of 1 to 3 are good; scores of 4 and 5 acceptable and higher scores rejected.

All statistical analyses were compiled on SPSS software, version 21.0. Graphs are also compiled in MS Excel from resulting Descriptive Statistics. The statistical significance threshold will be set at 5% or less. Parametric Analysis of Variance (ANOVA) was used. Where a significant F-test occured in the ANOVA table, post-hoc two-tailed tests using the Bonferroni correction were used.

2.3A Results

Store temperature and humidity records, and ethylene atmosphere readings are archived at SBCSR.

Sprouting

In order to discriminate between levels of sprouting, sprouting of less than 10mm was taken as an acceptable level of sprouting for processing use. The results of sprout length assessment with or without the presence of 10 ppm ethylene are shown in Table 2.3A.1. No sprouting of any variety was observed at intake. There were large varietal differences in the extent of sprouting at any particular sampling occasion.

The presence of ethylene reduced sprout length in all varieties. Sprout elongation was well controlled by ethylene in Fontane, Markies and Ramos, for the 6 months duration of the trial. Sprouting was controlled for 4 months in Desiree, Maris Piper and VR808. Sprouting was controlled for 2 months in Innovator, Lady Claire and Saturna but not for longer durations.

Sprouting in all varieties was very well controlled by a single CIPC application for the duration of the trial. The combination of CIPC/ethylene was also effective and both overall and for each variety the combination of CIPC/ethylene reduced the sprout length compared to CIPC or ethylene alone.

Table 2.3A.1: Mean length of longest sprout (mm)

Cultivar	Sprout suppressant	2 months		4 months		6 months	
		Length	sd	Length	sd	Length	sd
Desiree	Untreated	**1.6**	2.0	**45.4**	14.2	**53.9**	15.3
	Ethylene	**0.1**	0.3	**3.5**	1.9	**10.9**	4.4
	CIPC	**0.1**	0.2	**0.8**	0.7	**1.0**	0.5
	CIPC-ethylene	**0**	0.1	**0.5**	0.6	**0.7**	0.6
Fontane	Untreated	**5.6**	7.7	**6.6**	9.2	**5.9**	8.0
	Ethylene	**1.5**	1.0	**3.8**	2.5	**4.8**	4.9
	CIPC	**0.9**	0.5	**1.1**	0.7	**1.3**	0.5
	CIPC-ethylene	**0.3**	0.6	**0.9**	0.6	**1.2**	0.5
Innovator	Untreated	**11.2**	9.9	**42.3**	12.6	**57.3**	16.2
	Ethylene	**3.1**	2.6	**16.0**	4.8	**22.9**	4.6
	CIPC	**1.0**	1.0	**2.1**	1.5	**3.2**	5.1
	CIPC-ethylene	**0.5**	0.9	**1.3**	0.7	**2.0**	1.4
Lady Claire	Untreated	**12.9**	10.3	**32.9**	24.1	**29.5**	8.0
	Ethylene	**4.5**	5.5	**15.3**	4.6	**21.8**	4.9
	CIPC	**0.7**	0.9	**1.0**	0.6	**0.9**	1.0
	CIPC-ethylene	**0.8**	1.9	**0.6**	0.7	**0.7**	0.8
Maris Piper	Untreated	**11.4**	9.5	**36.9**	13.8	**44.0**	13.9
	Ethylene	**2.4**	1.8	**9.1**	4.4	**15.8**	5.9
	CIPC	**1.2**	0.8	**1.7**	4.4	**1.5**	2.1
	CIPC-ethylene	**0.5**	0.7	**0.8**	0.7	**1.0**	0.8
Markies	Untreated	**6.7**	6.5	**26.9**	13.5	**41.6**	16.7
	Ethylene	**0.4**	0.8	**1.5**	1.2	**2.7**	1.4
	CIPC	**1.2**	1.0	**1.4**	0.7	**1.4**	0.8
	CIPC-ethylene	**0.2**	0.5	**0.6**	0.7	**0.6**	0.7
Ramos	Untreated	**2.5**	4.4	**32.3**	10.9	**35.5**	12.1
	Ethylene	**0.3**	0.6	**3.5**	2.0	**9.1**	3.2
	CIPC	**0.6**	0.5	**1.0**	0.5	**0.9**	0.6
	CIPC-ethylene	**0.1**	0.4	**0.9**	0.6	**1.2**	1.2
Saturna	Untreated	**7.8**	6.2	**36.5**	20.9	**47.7**	11.4
	Ethylene	**2.3**	2.3	**12.0**	4.2	**20.1**	4.4
	CIPC	**1.3**	1.2	**1.5**	0.8	**2.1**	2.7
	CIPC-ethylene	**0.7**	0.9	**1.5**	1.4	**2.5**	3.2
VR808	Untreated	**6.8**	6.0	**41.2**	11.8	**37.9**	9.8
	Ethylene	**0.6**	1.2	**7.7**	1.8	**12.0**	2.3
	CIPC	**0.7**	0.6	**1.4**	0.9	**1.5**	0.6
	CIPC-ethylene	**0.1**	0.3	**0.8**	0.5	**1.2**	0.6

standard deviation (sd)

Fry colour

Chips (French fry) colour assessment

The USDA assessment scale used for assessing chips (light to dark - 000, 00, 0, 1, 2, 3 & 4) was linearised to a 1 to 7 scale (SBCSR score) as shown below, and reported as a mean shown in Table 2.3A.2. A score of 3 or below is considered good; 4 and 5 borderline and higher scores would be rejected.

SBCSR-USDA conversion table

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

Except for Desiree treated with ethylene or CIPC/ethylene the fry colours of all varieties, under all treatments and storage durations were good. Ethylene increased the fry colour in some but not all varieties. Desiree, Fontane, Markies were affected whereas Innovator and Maris Piper were unaffected.

Table 2.3A.2: Mean SBCSR chip (French fry) score

Cultivar	Sprout suppressant	Intake		2 months		4 months		6 months	
		Score	sd	Score	sd	Score	sd	Score	sd
Desiree	Untreated	**2.4**	0.5	**3.1**	0.7	**3.1**	0.6	**3.6**	0.6
	Ethylene			**4.4**	0.5	**3.3**	0.5	**3.5**	0.5
	CIPC			**4.3**	0.5	**3.1**	0.7	**2.9**	0.6
	CIPC-ethylene			**3.8**	0.6	**3.4**	0.5	**3.6**	0.6
Fontane	Untreated	**2.4**	0.5	**2.6**	0.5	**2.3**	0.5	**2.8**	0.6
	Ethylene			**3.1**	0.3	**2.4**	0.5	**3.0**	0.7
	CIPC			**2.7**	0.5	**2.3**	0.5	**2.8**	0.7
	CIPC-ethylene			**2.9**	0.5	**2.6**	0.5	**3.0**	0.7
Innovator	Untreated	**2.4**	0.6	**2.5**	0.5	**2.6**	0.6	**3.0**	0.5
	Ethylene			**2.6**	0.7	**2.6**	0.6	**2.9**	0.6
	CIPC			**2.5**	0.6	**2.4**	0.7	**2.5**	0.7
	CIPC-ethylene			**2.5**	0.6	**2.5**	0.7	**2.9**	0.7
Maris Piper	Untreated	**2.2**	0.4	**2.5**	0.6	**2.2**	0.4	**2.2**	0.7
	Ethylene			**2.6**	0.6	**2.3**	0.5	**2.2**	0.7
	CIPC			**2.7**	0.7	**2.3**	0.7	**2.3**	0.8
	CIPC-ethylene			**2.3**	0.5	**2.2**	0.7	**2.0**	0.6
Markies	Untreated	**2.0**	0.0	**1.8**	0.3	**1.7**	0.4	**1.4**	0.6
	Ethylene			**2.4**	0.5	**2.0**	0.2	**2.0**	0.6
	CIPC			**2.0**	0.2	**1.8**	0.5	**1.4**	0.5
	CIPC-ethylene			**2.2**	0.4	**2.1**	0.3	**2.2**	0.5
Ramos	Untreated	***2.2***	0.5	**2.7**	0.7	**2.6**	0.6	**2.9**	0.7
	Ethylene			**3.0**	0.5	**2.2**	0.5	**2.7**	0.7
	CIPC			**3.0**	0.4	**2.1**	0.4	**2.8**	0.7
	CIPC-ethylene			**3.3**	0.5	**2.7**	0.7	**3.1**	0.7

standard deviation (sd)

Crisp colour assessment

Where crisp fry colour is assessed by Hunter Lab, values greater than L 60 are considered commercially good, between L 59 and L 49 may be acceptable but less than L 49 would be rejected. For crisps, a weight of defects of <5 % would be considered low and greater than 15 % unacceptable.

Table 2.3A.3. Hunter L crisp colour and mean % defects by weight

Cultivar	Occasion	Sprout suppressant	% defects	sd	Hunter L	sd
Lady Claire	Intake	Untreated	0.0	0.0	64.6	1.2
	2 months	Untreated	0.5	0.9	65.1	0.8
		Ethylene	3.1	2.6	63.5	1.5
		CIPC	0.0	0.0	65.5	1.4
		CIPC-ethylene	0.6	1.2	62.2	1.2
	4 months	Untreated	2.5	2.7	65.6	1.8
		Ethylene	1.9	2.3	65.6	1.9
		CIPC	1.9	2.2	66.8	2.2
		CIPC-ethylene	3.5	5.1	66.4	0.7
	6 months	Untreated	8.2	7.5	63.3	1.5
		Ethylene	2.2	2.7	61.7	1.5
		CIPC	0.6	1.2	64.1	1.9
		CIPC-ethylene	0.0	0.0	63.7	0.9
Saturna	Intake	Untreated	0.0	0.0	63.3	0.5
	2 months	Untreated	3.8	4.1	62.7	0.9
		Ethylene	1.9	2.7	62.3	1.2
		CIPC	0.9	1.8	61.2	1.9
		CIPC-ethylene	2.0	2.3	62.9	1.0
	4 months	Untreated	1.4	1.6	65.3	2.0
		Ethylene	7.7	5.3	64.1	1.5
		CIPC	0.0	0.0	64.2	2.1
		CIPC-ethylene	1.8	2.9	65.0	1.4
	6 months	Untreated	1.6	3.3	60.0	1.9
		Ethylene	2.4	2.8	61.1	1.3
		CIPC	2.2	2.7	62.3	2.4
		CIPC-ethylene	5.1	2.8	61.3	1.6
VR808	Intake	Untreated	0.0	0.0	65.9	0.6
	2 months	Untreated	2.1	1.5	65.9	1.2
		Ethylene	3.1	1.5	62.8	3.2
		CIPC	0.6	1.3	64.2	1.8
		CIPC-ethylene	3.8	1.6	64.3	1.9
	4 months	Untreated	0.3	0.6	68.3	1.0
		Ethylene	1.3	2.6	67.3	1.4
		CIPC	0.0	0.0	67.1	2.0
		CIPC-ethylene	3.2	3.8	67.2	1.1
	6 months	Untreated	0.0	0.0	64.1	1.6
		Ethylene	2.8	3.6	64.9	1.2
		CIPC	1.5	2.0	65.8	0.9
		CIPC-ethylene	1.4	2.9	63.8	0.7

standard deviation (sd)

Crisp fry colours, shown in table 2.3A.3 for Lady Claire, Saturna and VR808 were light and acceptable throughout the duration of the trial. Although the addition of ethylene or CIPC/ethylene reduced the fry colour of Lady Claire at 2 months and ethylene alone for VR808 at 2 months, fry colour was still acceptable.

2.4A Summary

- Ethylene provided good sprout control for Fontane, Markies and Ramos, to 6 months, all with acceptable processing colour quality.
- Ethylene was partially effective for sprout control for Desiree, Maris Piper and VR808, providing satisfactory control to 4 months storage. It resulted in an increase in fry colour in both Desiree and VR808 although fry clour was still acceptable for VR808.
- Ethylene was ineffective for sprout control in Innovator, Lady Claire and Saturna other than for short term (2 months) storage. Ethylene had no deleterious effect on fry colour of Innovator or Saturna. There was an effect on fry colour of Lady Claire although the colours were still acceptable.
- A single application of CIPC at intake controlled sprouting in all varieties for the duration of the trial.
- Combination treatment of CIPC/ethylene also controlled sprouting in all varieties for the duration of the trial.

2.1B Response of processing cultivars ethylene treatment in bulk storage

The objective of this experiment was to help understand how current and emerging processing cultivars in bulk storage respond to ethylene treatment.

2.2B Material and methods

Crops, treatments and experimental design

Six varieties Innovator, Lady Claire, Markies, Ramos, Russet Burbank and VR808 were supplied into this trial as described in section 2.2A Crops. Samples of the crops were netted and buried within two different bulk varieties Markies and Ramos (due to timing constraints there were no Markies nets in bulk Ramos). The experiment was an unreplicated comparison of treatments with variation measured by three in-store replicates. Both stores were maintained at 9.0 °C and 10 ppm ethylene.

Store set up and control

Two 24-tonne Controlled Environment Rooms were fitted with metal bulk bins configured to ventilate the crop through under floor lateral ducts. Recirculated air was refrigerated or heated as necessary. Ambient control was enabled to allow external air to be used when appropriate. Any build-up of carbon dioxide over 0.5 % triggered ambient ventilation. Humidification was by a fan assisted humidification cell [*Munters Ltd*]. Netted samples were weighed and buried in the bulk material at three levels, circa 3.5m (top nets), 1.5m (middle nets) and 0.2m (bottom nets) above the floor, as the store was filled. No chlorpropham (CIPC) sprout suppressant had ever been used in the store.

At the beginning of storage, crop temperature was pulled-down at a rate of 0.5 °C per day until the holding temperature of 9.0 C was achieved (tolerance ± 0.5 °C). Humidification was enabled at 95% RH (tolerance ± 5%) for both stores on 8th November 2013. On the same day two ICA75 Restrain Generators [*Restrain Company Ltd*] were installed to control and record in store ethylene. The machine's integral automatic "*Soft start*" programme for a ramped introduction of ethylene was

selected. As the generators are designed for large stores, fuel was initially diluted to 2 % with deionised water to ensure the ramp was not exceeded. A store air concentration of 10 ppm was achieved by 2nd December 2012. For long term storage fuel concentration was made up to 20 % and the flow rate initially set to the minimum of 0.1 litres per day.

Assessments

Assessments were conducted at intake and after 2, 4 and 6 months of storage. Two and four month samples were taken from the top nets. After 6 months of storage the store was unloaded and sampled from all three levels. For each sample the longest sprout length was measured on all individuals of a 25 tuber sub-sample.

Fry colour was measured for potatoes processed as crisps for Lady Claire & VR808 and chips (French fries) for Innovator, Markies, Ramos and Russet Burbank, as previously described in section 2.2A assessments.

2.3B Results

Sprouting

In order to discriminate between levels of sprouting, a longest sprout less than 10mm might be considered an acceptable level of sprouting for processing use and for this trial is taken as a target maximum length. The results of sprout length assessment in the presence of 10 ppm ethylene are shown in Table 3B.1.

There was no sprouting at intake. Sprout elongation was well controlled in Markies, Ramos and Russet Burbank, for the duration of the trial. Sprout elongation was less well controlled in VR808, just exceeding 10 mm at 6 months and not well controlled in Innovator and Lady Claire, exceeding 10 mm at 4 months.

Table 2.3B.1: Mean length of longest sprout

Cultivar	Occasion	Store position	Bulk Markies		Bulk Ramos	
			Length (mm)	sd*	Length (mm)	sd*
Innovator	2 months	Top	**3.3**	0.9	**3.8**	1.2
	4 months	Top	**16.6**	0.8	**14.5**	1.0
	6 months	Top	**14.6**	0.6	**13.2**	3.8
		Middle	**18.0**	1.9	**16.6**	2.4
		Bottom	**17.8**	4.2	**13.6**	1.6
Lady Claire	2 months	Top	**2.9**	1.0	**3.3**	0.9
	4 months	Top	**16.0**	0.3	**12.2**	4.9
	6 months	Top	**11.5**	5.5	**9.2**	1.5
		Middle	**14.2**	10.0	**15.6**	2.2
		Bottom	**20.0**	4.8	**14.2**	5.9
Markies	2 months	Top	**0.5**	0.0	**n/r**	n/r
	4 months	Top	**2.2**	0.7	**n/r**	n/r
	6 months	Top	**3.0**	0.3	**n/r**	n/r
		Middle	**4.5**	0.7	**n/r**	n/r
		Bottom	**3.5**	0.4	**n/r**	n/r
Ramos	2 months	Top	**0.6**	0.4	**0.8**	0.2
	4 months	Top	**5.0**	1.2	**3.4**	0.8
	6 months	Top	**4.4**	1.1	**3.5**	0.9
		Middle	**4.3**	0.4	**3.7**	1.5
		Bottom	**6.7**	0.7	**5.7**	0.7
Russet Burbank	2 months	Top	**0.0**	0.0	**0.1**	0.1
	4 months	Top	**1.6**	0.3	**1.7**	0.4
	6 months	Top	**2.8**	0.4	**3.2**	0.7
		Middle	**2.8**	0.2	**3.3**	0.5
		Bottom	**4.0**	0.3	**2.6**	0.1
VR808	2 months	Top	**1.5**	0.3	**1.1**	0.0
	4 months	Top	**9.1**	0.6	**6.1**	1.9
	6 months	Top	**6.2**	0.7	**6.0**	0.3
		Middle	**10.2**	0.2	**10.9**	1.7
		Bottom	**10.1**	1.3	**10.2**	1.1

*Standard deviation

Fry colour

Chips (French fry) colour assessment

The assessment criteria for processing colour described in section 2.3 Results fry colour were also used in this section.

All chip fry colours were generally acceptable through the duration of the trial (Table 2.3B.2). Fry colours of Ramos and Russet Burbank were somewhat darker than expected, and darker than those found in section A.

Table 2.3B.2: Mean SBCSR chip (French fry) score

Cultivar	Occasion	Store position	Bulk Markies		Bulk Ramos	
			Score	sd*	Score	sd*
Innovator	2 months	Top	**3.0**	0.6	**3.4**	0.7
	4 months	Top	**2.7**	0.5	**2.9**	0.6
	6 months	Top	**3.3**	0.6	**3.6**	0.6
		Middle	**3.1**	0.4	**3.2**	0.4
		Bottom	**3.3**	0.5	**3.3**	0.5
Markies	2 months	Top	**2.7**	0.6	**n/r**	n/r
	4 months	Top	**2.0**	0.5	**n/r**	n/r
	6 months	Top	**2.9**	0.6	**n/r**	n/r
		Middle	**2.9**	0.5	**n/r**	n/r
		Bottom	**3.0**	0.5	**n/r**	n/r
Ramos	2 months	Top	**3.2**	0.5	**3.1**	0.6
	4 months	Top	**2.8**	0.5	**3.1**	0.4
	6 months	Top	**3.9**	0.5	**3.8**	0.8
		Middle	**3.9**	0.6	**3.9**	0.6
		Bottom	**3.5**	0.6	**3.5**	0.6
Russet Burbank	2 months	Top	**4.2**	0.5	**4.2**	0.4
	4 months	Top	**3.2**	0.5	**3.5**	0.6
	6 months	Top	**3.4**	0.7	**3.5**	0.6
		Middle	**3.8**	0.9	**3.6**	0.5
		Bottom	**3.8**	0.7	**3.7**	0.8

*Standard deviation

SBCSR-USDA conversion table

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

Crisp colour assessment

For crisps a weight of defects of 5 % would be considered low and greater than 15 % unacceptable. Hunter L fry values greater than L 60 are considered good, between L 59 and L 49 are acceptable and any less than L 49 would be rejected.

All fry colour were acceptable with both varieties, for the duration of the trial and when varieties were stores within both bulk Markies and Ramos (Table 2.3B.3).

Table 2.3B.3 Crisping colour and defect assessment

Cultivar	Occasion	Store position	Bulk Markies				Bulk Ramos			
			% defects	sd*	Hunter L	sd*	% defects	sd*	Hunter L	sd*
Lady Claire	2 months	Top	**4.2**	7.2	**59.9**	0.7	**0.0**	0.0	**60.7**	1.4
	4 months	Top	**0.7**	1.2	**62.9**	1.7	**6.5**	6.5	**61.6**	1.0
	6 months	Top	**8.3**	8.4	**61.6**	0.4	**10.5**	13.1	**58.4**	2.0
		Middle	**47.7**	29.7	**60.4**	1.6	**30.8**	16.0	**59.2**	2.3
		Bottom	**58.4**	23.5	**58.4**	1.2	**51.3**	5.1	**60.3**	3.1
VR808	2 months	Top	**7.9**	3.2	**61.0**	1.3	**10.1**	4.3	**60.4**	0.7
	4 months	Top	**5.2**	6.6	**63.1**	0.4	**8.5**	7.7	**63.9**	1.7
	6 months	Top	**11.2**	5.1	**59.4**	0.8	**20.2**	1.6	**60.8**	0.6
		Middle	**14.5**	3.9	**62.1**	1.5	**8.6**	3.3	**63.5**	1.1
		Bottom	**17.3**	14.7	**60.0**	0.6	**6.1**	5.6	**62.7**	0.8

*Standard deviation

2.4B Summary

- Ethylene provided good sprout control during bulk storage for Markies, Ramos and Russet Burbank to 6 months, all with acceptable processing colour quality.

- Ethylene was partially effective in controlling sprouting in Innovator, Lady Claire or VR808 (just exceeding 10 mm at 6 months). Fry colour was acceptable with these varieties throughout storage.

2.1C Introduction; Effect on sprouting, fry colour and sugar content of different 1-MCP concentrations on ethylene treated potato

The objective of this study was to determine the relationship between 1-MCP concentration and its effect in mitigating ethylene induced fry colour changes.

2.2 Material and methods

Treatments and experimental design

Three crops were treated with 4 concentrations of 1-methyl cyclopropene (1-MCP) at intake and stored at 9.0 °C in ethylene maintained at a target of 10 ppm. The experimental design was an unreplicated comparison of treatments with variation measured by four in-store replicates.

Crops

Three varieties Desiree, Markies and Saturna were sourced as described in section 2.2A.

1-MCP and control treatment

1-MCP [*Rohm & Haas*] was applied as *SmartFresh*^{TM} as soon after intake as possible. On 1st November 2013 crops were sealed in chambers (0.5 m^3 capacity) for a 24 hour period at 9.0 C. Air was recirculated inside the chambers for the duration of the treatment period. The 1-MCP concentrations were nil, 390, 625 and 1000 ppb. The 1-MCP untreated material was moved to a 9.0 C holding store and the remaining chambers opened and ventilated in descending order of treatment concentration before moving to the holding store on the 4th November 2013.

Store set up, control, pull down and ethylene treatment were as described in Section 2.2A.

Tuber assessments

Assessments were conducted at intake and after 2 and 4 months of storage. For each sample the longest sprout length was measured on all tubers of a 25 potato sub-sample. Fry colour was measured for potatoes processed as crisps for Saturna

and chips (French fries) for Desiree and Markies as described in section 2.2A assessments.

Sugar analysis samples

After sprout assessment 5 tubers were taken from each sample and opposite eighths peeled. A 10 mm deep, 9 mm diameter core was taken from both peeled surfaces to give 10 cores per sample. All samples were immediately placed in labelled, resealable plastic bags and temporarily sandwiched between ice blocks before deep freezing (c. 20 °C) under solid ice. Frozen samples were sent to Dr R. Colgan, Natural Resources Institute (University of Greenwich) for sugar analysis.

2.3C Results

Sprouting

In order to discriminate between levels of sprouting, a longest sprout less than 10mm might be considered an acceptable level of sprouting for processing use and for this trial is taken as a target maximum length. The results of sprout length assessments after 2 and 4 months storage in the presence of 10 ppm ethylene following treatment at different 1-MCP concentration are shown in Table 2.3C.1.

Table 2.3C.1 Mean length of longest sprout (mm)

Cultivar	Occasion	Sprout suppressant	length	sd
Desiree	2 months	0 ppm 1-MCP + ethylene	**0.0**	0.2
		390 ppm 1-MCP + ethylene	**0.0**	0.2
		625 ppm 1-MCP + ethylene	**0.0**	0.2
		1000 ppm 1-MCP + ethylene	**0.0**	0.1
	4 months	0 ppm 1-MCP + ethylene	**3.7**	2.5
		390 ppm 1-MCP + ethylene	**1.6**	1.7
		625 ppm 1-MCP + ethylene	**1.4**	1.6
		1000 ppm 1-MCP + ethylene	**1.5**	1.6
Markies	2 months	0 ppm 1-MCP + ethylene	**0.4**	0.6
		390 ppm 1-MCP + ethylene	**0.6**	0.8
		625 ppm 1-MCP + ethylene	**0.8**	1.0
		1000 ppm 1-MCP + ethylene	**1.0**	1.1
	4 months	0 ppm 1-MCP + ethylene	**0.9**	1.0
		390 ppm 1-MCP + ethylene	**1.3**	1.7
		625 ppm 1-MCP + ethylene	**1.8**	1.9
		1000 ppm 1-MCP + ethylene	**1.7**	1.9
Saturna	2 months	0 ppm 1-MCP + ethylene	**2.3**	1.8
		390 ppm 1-MCP + ethylene	**2.1**	2.5
		625 ppm 1-MCP + ethylene	**1.5**	1.8
		1000 ppm 1-MCP + ethylene	**1.5**	1.8
	4 months	0 ppm 1-MCP + ethylene	**12.1**	3.6
		390 ppm 1-MCP + ethylene	**10.3**	4.2
		625 ppm 1-MCP + ethylene	**9.5**	4.1
		1000 ppm 1-MCP + ethylene	**9.4**	4.5

standard deviation (sd)

Sprouting was acceptable in all varieties, treatments and storage durations apart from in Saturna after 4 months storage. Some effects of 1-MCP on sprouting were observed. In Desiree and Saturna there were no significant differences (P=0.923, P=0.421 respectively) between the 4 treatments at 2 months storage. For Markies there was no significant difference in mean sprouting length between ethylene alone and 390 ppm 1-MCP + ethylene, but there was a highly significant difference

between ethylene alone and both 625 and 1000 ppm 1-MCP + ethylene (P=0.042) at 2 months.

For both Desiree and Saturna at sampling occasion 4 months the mean sprouting length with ethylene alone were highly significantly different (P<0.001 and P≤0.008 respectively) from the mean sprout lengths for 390, 625, and 1000 ppm 1-MCP + ethylene treatments. However, there were no significant differences between the three concentrations of 1-MCP treatment with any of the varieties at 4 months.

Fry colour

The results of chip fry colour assessments for Desiree and Markies are shown in Table 2.3C.2 and the distribution of sample chip scores for the varieties in Table 2.3C.3 and 4 respectively.

The poor chip colour (>4) of Desiree at 2 month was greatly improved by 1-MCP treatment of any concentration. At 2 months sampling of Desiree the chip colour score for ethylene alone was very significantly different from all 1- MCP treatments (P≤0.013) but there were no significant differences between the 3 MCP concentration treatments. At 4 months the chips score value with ethylene treatment alone had reduced and was just acceptable (3.5). At this time the colour score was significantly different only from 625 ppm MCP + Ethylene treatment (P=0.028). There were no further significant differences between the treatments.

Markies had good, light fry colours in all treatments on both sampling occasions. The distribution of chip fry colour scores (Table 2.3C.3) shows fry colours were virtually all in the range 2-4 at both sampling occasions. There was no effect 1-MCP on fry colour with no significant differences between the chip score colour means for the 4 treatments at either 2 or 4 month sampling (P=0.074, P=0.884 respectively).

Table 2.3C.2 Mean SBCSR chip (French fry) score

Cultivar	Occasion	Sprout suppressant	Chip score	sd
Desiree	Intake	-		
	2 months	0 ppm 1-MCP + ethylene	**4.3**	0.5
		390ppm 1-MCP + ethylene	**3.3**	0.5
		625 ppm 1-MCP + ethylene	**3.1**	0.7
		1000 ppm 1-MCP + ethylene	**3.3**	0.6
	4 months	0 ppm 1-MCP + ethylene	**3.5**	0.6
		390 ppm 1-MCP + ethylene	**3.3**	0.5
		625 ppm 1-MCP + ethylene	**3.1**	0.5
		1000 ppm 1-MCP + ethylene	**3.3**	0.5
Markies	Intake	-		
	2 months	0 ppm 1-MCP + ethylene	**2.3**	0.7
		390 ppm 1-MCP + ethylene	**1.8**	0.4
		625 ppm 1-MCP + ethylene	**2.0**	0.5
		1000 ppm 1-MCP + ethylene	**1.6**	0.5
	4 months	0 ppm 1-MCP + ethylene	**2.1**	0.4
		390 ppm 1-MCP + ethylene	**2.0**	0.4
		625 ppm 1-MCP + ethylene	**2.1**	0.5
		1000 ppm 1-MCP + ethylene	**2.0**	0.3

standard deviation (sd)

SBCSR-USDA conversion table

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

Table 2.3C.3 Distribution % of Desiree chip samples within score category

Treatment	Storage Period (months)	Chip score category						
		1	2	3	4	5	6	7
0 ppm 1-MCP/Eth	2	8	61	28	4	0	0	0
390 ppm 1-MCP/Eth		24	75	1	0	0	0	0
625 ppm 1-MCP/Eth		9	84	6	1	0	0	0
1000 ppm 1-MCP/Eth		41	56	3	0	0	0	0
0 ppm 1-MCP/Eth	4	6	80	14	0	0	0	0
390 ppm 1-MCP/Eth		5	88	6	1	0	0	0
625 ppm 1-MCP/Eth		9	78	14	0	0	0	0
1000 ppm 1-MCP/Eth		3	93	5	0	0	0	0

Table 2.3C.4 Distribution % of Markies chip samples within score category

Treatment	Storage Period (months)	% score per category						
		1	2	3	4	5	6	7
0 ppm 1-MCP/Eth	2	0	0	3	65	31	1	0
390 ppm 1-MCP/Eth		0	1	70	28	1	0	0
625 ppm 1-MCP/Eth		0	19	56	23	3	0	0

1000 ppm 1-MCP/Eth		0	3	66	29	3	0	0
0 ppm 1-MCP/Eth	4	0	0	51	45	3	1	0
390 ppm 1-MCP/Eth		0	0	76	23	1	0	0
625 ppm 1-MCP/Eth		0	0	91	5	3	1	0
1000 ppm 1-MCP/Eth		0	0	70	26	3	0	0

Crisp colour assessment

The result of the crisp fry colour assessments for Saturna are shown in Table 2.3C.5. Fry colours were acceptable throughout the trial for all the treatments. There was no significant difference between the Hunter L Crisp Score of the 4 treatments at either sampling occasion 2 or 4 months (P=0.137, P=0.124 respectively).

Table 2.3C.5 Saturna mean crisp Hunter L colour and % defects

Occasion	Sprout suppressant	% defects	sd	Hunter L	sd
Intake	-				
2 months	0 ppm 1-MCP + ethylene	**1.3**	1.0	**59.6**	2.2
	390 ppm 1-MCP+ ethylene	**0.6**	0.3	**61.5**	0.6
	625 ppm 1-MCP + ethylene	**1.9**	0.8	**62.3**	2.1
	1000 ppm 1-MCP + ethylene	**1.8**	0.9	**62.5**	1.0
4 months	0 ppm 1-MCP + ethylene	**3.5**	1.1	**61.5**	2.1
	390 ppm 1-MCP + ethylene	**3.3**	1.4	**64.2**	2.3
	625 ppm 1-MCP + ethylene	**0.3**	0.3	**61.8**	1.7
	1000 ppm 1-MCP + ethylene	**3.1**	1.3	**64.5**	1.3

standard deviation (sd).

Sugar content, results are not yet available.

2.4C Summary

Effects of 1-MCP treatment on the sprouting of varieties used in this trial were observed. The effects were not consistent and were generally small. An effect was seen with both Desiree and Saturna at 4 months storage when the three 1-MCP treatments reduced sprout length compared to ethylene alone whereas in Markies there was a difference with both ethylene alone and the lowest 1-MCP treatment having shorter sprouts than the 625, and 1000 ppm 1-MCP + ethylene treatments.

1-MCP did not mitigate any effect on fry colour caused by ethylene in Markies or Saturna, there was no effect on the chip fry colour of Markies or the crisp fry colours

of Saturna with any 1-MCP concentration treatment at either sampling occasion. There was a statistically significant although small decrease in the fry colour of Desiree at 4 months sampling by 625 ppm 1-MCP treatment but no effect was observed using 1-MCP concentrations lower or higher than this.

It is possible that earlier application of the treatment, in field or at harvest, would show greater effect.

2.4 Overall Discussion

In 1998 Prange *et al.* made the observation that continuous application of 4 ppm ethylene to potatoes during storage reduced the length of sprouts and ethylene has since been a potential alternative to CIPC. Thus far ethylene use has been confined to fresh market crops and it is effective with some cultivars under some storage conditions, not all commercial cultivars respond to ethylene sufficiently well for it to be a generically practicable solution to control sprouting. Furthermore, ethylene tends to stimulate sugar accumulation (Sowokinos, 2001) which adversely affects fry colours making the treatment unsuited to the processing sector.

Varietal differential response and sprout control

It is known that ethylene is not effective for sprout control in all cultivars and this trial has confirmed differential varietal responses to ethylene. The varieties Fontane, Markies, Ramos and Russet Burbank all responded well to ethylene overs a six month storage period with good sprout control and acceptable fry colours. Ethylene provided adequate sprout control in Desiree, Maris piper, Saturna and VR808 to 4 months storage and, with the possible exception of Desiree, with good fry colour. Ethylene was ineffective for sprout control in Lady Claire and Innovator other than for short term (2 months) storage but no deleterious effect of ethylene on fry colour on these varieties was noted.

Fry colour

By the fry colour criteria used to assess commercial acceptability used here, the effect of ethylene on processing was generally very small and fry colours from all varieties and treatments and storage durations were generally commercially acceptable.

Generally results exploring the effects of treatment under different methods of storage, bulk or box/trays, are similar (2.2A and 2.2B) and storage methods appear to have little effect on the results obtained.

1-MCP

Treatment with 1-methylcyclopropene (1-MCP), a competitive inhibitor of ethylene receptors can ameliorate the effects of ethylene induced darkening of fry colour while

having little or no effect on sprout control. The combination of ethylene and 1-MCP treatments could lead to a practical tuber storage strategy for some cultivars. However, there is variability between varieties in response to 1-MCP (Daniels-Lake, 2008; Coleman, P., Greenvale AP, pers. comm.). Daniels-Lake *et al*., have suggested some variability among varieties in the strength and duration of the protective effect of 1-MCP (unpublished data) which was also observed in this current trial.

CIPC alone provided good sprout control for the duration of the storage trial. Overall and for each variety the combination of CIPC/ethylene reduced the sprout length compared to CIPC or ethylene alone and consideration will be given to reducing the CIPC application rate.

Summary

Ethylene decreases sprout elongation in all varieties and with commercial acceptable results for some varieties. By commercial criteria, fry colour of ethylene treated tubers was general y commercially acceptable.

1-MCP did not mitigate any ethylene induced fry colour deterioration. Because of the relatively small observed effects of ethylene on fry colour and the current costs of treatment, further work is required to understand the cost/benefit of 1-MCP treatment.

Proposed future work (2014-15)

- Conduct ethylene treatment on a wide range of processing varieties to build up a knowledge base of varietal responses to ethylene. PPA to be consulted
- Include Fontane, Russet Burbank, Markies, and Ramos in the trials.
- Reduce the CIPC treatment to half the current maximum allowed application rate
- Carry out ethylene/CIPC treatment on existing as well as new and emerging varieties.

2.5 References

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