Interim Report

Use of ethylene on processing varieties

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1. SUMMARY

1.1. Aim

The aim was to identify potato varieties in which sprouting can be well controlled by ethylene without significant deleterious effect on fry colour. A further aim is to investigate the effect on commercial processing varieties of combination treatment of ethylene and CIPC on sprouting and fry colour.

1.2. Methodology

10 varieties were stored in boxes and 6 varieties in bulk, both at 9°C, and treated with a single 9ppm CIPC application, or continuous 10 ppm ethylene, or both. Samples were removed at two monthly intervals for six months and assessed for sprouting and chip or crisp fry colour.

1.3. Key findings

Continuous 10 ppm ethylene suppressed sprout growth in all the varieties tested and to commercially acceptable standards for 6 months' storage for both Markies and Russet Burbank. Ethylene affected fry colour in many, but not all, varieties although it generally did not affect commercial fry colour acceptability overall. In particular, the effect on Markies and Russet Burbank was small and did not compromise commercial acceptable limits.

A combination of a single low dose application of CIPC with continuous 10 ppm ethylene, provided better sprout control, for all varieties at all sampling occasions, than either treatment alone. Sprouting was controlled to within commercially acceptable limits in most varieties to six months' storage. The effects of combination treatment on fry colour were essentially those found with ethylene treatment alone. Maris Piper, for which fry colours were unaffected by ethylene, Markies and Russet Burbank were able to be stored under a combination of CIPC & ethylene for up to six months with good sprout control and acceptable fry colours.

1.4. Practical recommendations

On the basis of this work, Maris Piper, Markies and Russet Burbank can all be stored under CIPC & ethylene for up to six months with good sprout control and acceptable fry colours. However, final recommendation awaits results of the 2015-16 study.

2. INTRODUCTION

There is an urgent need to provide alternatives to the current dominant sprout suppressant CIPC because of the threats to its continued use. AHDB Potatoes is closely involved in developing a range of alternative strategies to CIPC usage to provide growers with a wider range of viable strategies if further restrictions on CIPC use were to be imposed in the future.

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. Previous work in this area has been carried out at Sutton Bridge Crop Storage Research (SBCSR) as part of the Link project LK09217 (Colgan et al. 2013) and which developed methods and partially screened some UK processing varieties for ethylene response.

The aim of the R464 trial is to identify varieties in which sprouting can be well controlled by ethylene without significant deleterious effect on fry colour. A further aim is to build on the results of a previous AHDB Potatoes project (R441) which investigated the effect on commercial processing varieties of combination treatment of ethylene and CIPC on sprouting and fry colour. This study showed the potential control the combination of the two suppressants could effect even on varieties that were not particularly responsive to ethylene.

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 this trial will also investigate whether box stored tubers respond in the same way to ethylene as those in bulk storage.

3. MATERIALS AND METHODS

During this trial experiments were carried out to compare the effects of treatment in both box storage (experiment 1) and bulk storage (experiment 2).

Crops, treatments and experimental design

In 2014 ten processing varieties were supplied for the trial. Arsenal and VR808 [*G.H. Chennells Farms Ltd*]; Chicago and Lady Claire *[United Potato Farmers Ltd];* Fontane [*Lamb Weston Meijer (UK) Ltd*] and Markies, Maris Piper, Ramos, Royal and Russet Burbank [*McCain Foods (GB) Ltd*].

3.1. Experiment 1: Box storage

Netted samples of each variety were buried approximately three tubers down in one-tonne pallet boxes of Russet Burbank divided between four 9.0 °C experimental stores. One was supplied with ethylene maintained at a target concentration of 10 ppm and another left untreated. The crop in the remaining stores was chlorpropham (CIPC) treated *in situ* and then stored with and 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

Three 12-tonne Controlled Environment Rooms were identically configured for positive ventilation. Boxes were stacked in three columns of four, tightly against a four-slotted plenum chamber. Air discharged from the plenum was blocked at ground level and at the bottom of the third box up. Alternate pallet apertures were blocked at the opposite end to force air through the crop. Due to limited trial space each replicate was assigned a height level. Replicate 1 samples were located in the lower level and then in sequence until replicate 4, at the upper level. Net location within a three box level was completely randomised. Air was recirculated through a duct at the bottom of the store for refrigeration or heating as necessary. The untreated control crops were stored in a space ventilated 3 tonne store and stacked in plastic trays on shelving. As above, four levels were assigned, within which replicates were completely randomised. All stores were humidified by conventional compressed air atomiser. No CIPC sprout suppressant had ever been used in the nil CIPC treatment stores.

Pull down and applications

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%). In the appropriate stores, Restrain generators [*ICA75*, *Restrain Company Ltd., 4818 RD Breda, Netherlands*] were used to monitor and record a ramped, daily, manual 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. During the ramp the store was vented to zero every day immediately before reintroducing ethylene at the prescribed concentration. On 1st December 2014, automatic ethylene generation was initiated at 10 ppm. As the generator was designed for a larger scale stores than those used for this trial, 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 a *Swingfog SN50* machine [*Motan*] to pre-loaded 12 tonne box stores at 9 g/tonne a.i. on 13th November 2014. The stores were fogged through ports in a personnel door accessing a corridor beside the stack. An auxiliary fan [*Multifan TB4E50*, *Votermanns Ventilation BV*] was used to immediately draw fogged air into the plenum and force it through the crop at the lowest setting of 0.45 m^3/s for 6 hours. After this period the stores were ventilated by opening the front door for 5 to 10 minutes, resealed and returned to automatic temperature control.

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 Arsenal, Chicago, Lady Claire & VR808 and as chips (French fries) for Fontane, Maris Piper, Markies, Ramos, Royal & 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 Hunter Lab D-9000 colour quality meter fitted with a D25-L optical sensor [*Stothard Group, 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, see §4.1) and reported as a mean.

3.2. Experiment 2: Bulk storage

Crops, treatments and experimental design

Six varieties, Fontane, Maris Piper, Markies, Ramos, Russet Burbank and VR808, were supplied into this trial from the same sources as in Experiment 1. Samples of the crops were netted and buried within two different bulk varieties Markies and 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 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 fan-assisted humidification cell [*Munters Ltd., Huntingdon, UK*]. Netted samples were buried in the bulk material, as the store was filled, at three levels up from the floor, 0.2 m (bottom nets), 1.5 m (middle nets) and circa 3.5 m (top nets) approximately three tubers down from the surface. No 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 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 26th November 2012. After the ramped start was completed the fuel concentration was made up to 20 % and the flow rate initially set to the minimum of 0.1 litres per day.

The store containing Ramos in bulk broke down, due to soft rot, beyond reasonable control and was unloaded early on 17th December 2014.

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 remaining 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 VR808 and chips (French fries) for Fontane, Maris Piper, Markies, Ramos and Russet Burbank, as previously described for Experiment 1.

Statistical analysis experiment 1 and 2.

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

4. RESULTS

4.1. Experiment 1: Box storage

Sprouting

The mean longest sprout length per tuber (mm) for each variety and treatment and resulting ANOVA analysis are shown in Table 4.1.1 (untreated results not shown). In this trial, sprouting to 3mm was considered good for processing crops and between 3 and 10 mm as acceptable. Sprout lengths > 10 mm are considered unacceptable.

For all varieties and sampling occasions, sprouting was always least with the combination ethylene /CIPC treatment.

Of all the varieties examined, untreated Arsenal sprouted the longest from 4 months onwards. All treatments gave acceptable sprout control at 2 months but only the CIPC treatments maintained the control for up to 6 months. The combined CIPC and ethylene treatment gave especially good results with sprout lengths at 3 mm or less throughout although it was not statistically significantly better than CIPC alone on any occasion.

Chicago sprouted moderately with the untreated averaging 35 mm after 6 months. CIPC treatment was more effective than ethylene at all occasions with significant differences at 2 and 6 months. However, only when combined with ethylene was acceptable control achieved at 6 months (7 mm).

No sprout suppressants controlled sprouting in Fontane to less than 3 mm. CIPC treatments gave acceptable control at 2 and 4 months. However, commercially acceptable control at 6 months (8 mm) was achieved only in combination with ethylene.

Sprouting in Lady Claire was acceptably controlled at 2 months by all suppressant treatments and especially well with CIPC + ethylene (2 mm). However, only the latter gave acceptable control by 4 months (9 mm). Ethylene provided better control than CIPC alone, although neither provided commercially acceptable control after 2 months' storage.

Table 4.1.1. Effects of treatment on sprouting of varieties, box storage.

	Storage Period	Mean sprout Length (mm) and treatment				ANOVA			
Variety	**(months)**	**Ethylene**	**CIPC + Ethylene**	**CIPC**		**Suppr-essant**	**E v C**	**E v CE**	**C v CE**
Arsenal	2	6.2	1.0	2.8		**	*	**	NS
	4	13.3	3.0	6.1		*	NS	*	NS
	6	13.3	2.3	6.9		NS			
Chicago	2	6.3	1.3	2.3		***	***	***	NS
	4	19.5	4.3	9.7		*	NS	*	NS
	6	26.6	7.2	14.7		***	**	***	NS
Fontane	2	11.7	3.7	5.5		**	*	**	NS
	4	17.0	5.5	8.1		***	**	***	NS
	6	20.6	8.0	17.0		NS			
Lady Claire	2	5.6	2.0	8.0		**	NS	NS	**
	4	16.4	9.3	43.1		***	***	NS	***
	6	20.9	17.4	43.8		***	***	NS	***
Maris Piper	2	20.5	5.5	6.2		**	**	**	NS
	4	21.2	5.5	15.8		**	NS	**	*
	6	21.1	3.7	38.2		***	***	***	***
Markies	2	4.4	3.4	4.4		NS	-	-	-
	4	4.5	2.4	15.5		**	**	NS	**
	6	5.4	3.1	35.3		***	***	NS	***
Ramos	2	1.4	0.5	0.8		NS			
	4	5.5	1.6	5.4		NS			
	6	11.0	5.1	13.4		NS			
Royal	2	3.2	1.7	9.4		**	*	NS	*
	4	14.3	12.2	45.7		***	**	NS	**
	6	22.4	19.1	65.2		**	*	NS	**
R. Burbank	2	0.2	0.1	0.8		**	*	NS	**
	4	2.5	0.9	3.8		*	NS	NS	*
	6	3.0	2.7	22.3		***	***	NS	***
VR808	2	4.2	1.7	3.0		*	NS	*	NS
	4	9.9	2.5	5.2		**	NS	**	NS
	6	11.5	4.0	8.6		NS			

E, Ethylene., C, CIPC., CE, combined ethylene and CIPC treatment.
ANOVA: NS, Non-significant result (P>0.05), significant results * (P<0.05), ** (P<0.01) and *** (P < 0.001)

After 2 months' storage, Maris Piper was acceptably controlled by the CIPC treatments, and was well controlled by combination treatment for the duration of storage (5.6 mm

mean sprout length). CIPC control of sprouting was as poor, or worse, than that of ethylene at 4 and 6 months.

Sprout control in Markies was acceptable for all suppressant treatments at 2 months and for both ethylene treatments for 6 months. Although the combination treatment provided the shortest mean sprout lengths at all assessment occasions there was no statistically significant difference between the ethylene treatments. At 4 and 6 months, CIPC sprout control was poor and significantly worse than the ethylene treatments.

In Ramos, sprouting was well controlled by all suppressants at 4 months, and for the combination treatment alone up to 6 months. The combination treatment provided the shortest mean sprout lengths at all assessment occasions, with commercially acceptable control for the duration of the trial.

At 2 months, only sprouting in Royal was well controlled for all suppressant treatments. However, subsequent sprout control in this variety was unacceptably poor.

Sprout elongation in untreated Russet Burbank was adequately controlled by both ethylene treatments to 6 months although the combination treatment provided the shortest mean sprout lengths at all assessment occasions. CIPC alone gave adequate control only to 4 months.

In VR808, sprouting was well controlled by all suppressants at 4 months but marginal at 6 months for CIPC or ethylene alone. The combination treatment provided the shortest mean sprout lengths at all assessment occasions, with commercially acceptable control for the duration of the trial.

There was a large variation in the level of sprouting with the single low (9ppm) dose of CIPC applied in this trial. This treatment provided essentially no control for most varieties after 2 or 4 months' storage with the exceptions of Arsenal and VR808. Variation in sprouting was particularly high at the later sampling occasions, possibly due to high sprouting pressure combined with low dose and perhaps imperfect distribution.

Varieties with similar sprout suppressant responses to ethylene treatment can be grouped together. Ethylene control of sprouting was good in Markies and Russet

Burbank with some additional improvement by the addition of CIPC. Maris Piper was particularly notable for the remarkable efficacy of combination treatment and the poor efficacy of individual sprout suppressants. Other varieties in this category might be Arsenal, Chicago, Fontane, Ramos and VR808. Sprout control was generally poor to 6 months' storage in Lady Claire and Royal for all treatments.

Crisps: frying assessments

Crisp fry colour was assessed by Hunter Lab measurement and results are shown in Table 4.1.2. Values greater than L 59 are considered commercially good (shaded green), between L 59 and L 49 crisps may be acceptable but less than L 49 would be rejected. In the assessment method used in the trial a crisp below L 49 would be taken out of the sample as a reject and the remainder assessed. However, when as much as almost half the sample is missing, there is not enough sample left for assessment.

Table 4.1.2. Crisp fry colour, box storage.

		Storage period, Hunter L value					
Variety	**treatment**	**2 months**	sd	**4 months**	sd	**6 months**	sd
Arsenal	Untreated	**58.5**	3.1	**56.3**	2.2	**58.2** (3)	3.2
	Ethylene	**53.0** (2)	0.2	**52.3** (3)	1.9	**58.3** (1)	N/A
	CIPC	**56.2**	2.4	**57.6**	3.0	**56.3**	2.6
	CIPC + Ethylene	**53.2** (1)	N/A	**52.7** (3)	1.6	**61.0** (1)	N/A
Chicago	Untreated	**63.9**	2.4	**64.9**	3.0	**64.0**	1.2
	Ethylene	**61.2**	1.9	**63.1**	2.7	**62.1**	2.0
	CIPC	**62.6**	1.2	**63.1**	1.1	**63.0**	1.4
	CIPC + Ethylene	**59.7**	3.6	**61.5**	2.0	**61.7**	1.6
Lady Claire	Untreated	**66.3**	3.2	**66.6**	1.8	**64.2**	1.5
	Ethylene	**62.9**	1.8	**62.1**	1.6	**63.1**	1.3
	CIPC	**64.3**	1.3	**65.3**	2.3	**60.1**	4.4
	CIPC + Ethylene	**63.8**	2.9	**62.9**	2.6	**60.9**	2.3
VR808	Untreated	**65.5**	1.9	**68.4**	2.1	**65.1**	2.2
	Ethylene	**61.3**	6.3	**63.2**	2.8	**64.4**	1.3
	CIPC	**64.5**	1.4	**64.0**	1.3	**65.6**	2.5
	CIPC + Ethylene	**63.4**	2.3	**64.4**	1.1	**62.1**	3.0

sd, standard deviation. Where fewer than four replicates were available the number remaining is shown in brackets

Generally treatment with ethylene resulted in slightly darker fry colours, with an average Hunter L score of 1.5 less than in its absence. Arsenal had the darkest fry colours of the varieties tested. There were some lost replicates due to too many dark crisps in the sample and, therefore, the fry colour would actually have scored darker.

Although ethylene treatment caused a decrease in Hunter L score with Chicago, Lady Claire and VR808, the fry colours would have been commercially acceptable throughout the experiment.

Crisp defects

Table 4.1.3. shows the percentage weight of crisps with defects. Less than 5% defect would be considered commercially low and acceptable (shaded green) and greater than 15% unacceptable (shaded red).

Table 4.1.3. Mean % weight of crisps with defects, box storage.

		Storage period % weight of crisps with defects					
Variety	**treatment**	**2 months**	sd	**4 months**	sd	**6 months**	sd
Arsenal	Untreated	**10.0**	10.1	**21.6**	13.9	**70.7**	14.3
	Ethylene	**59.4**	31.7	**48.5**	28.7	**84.0**	16.8
	CIPC	**10.6**	5.7	**5.6**	2.9	**52.2**	8.1
	CIPC + Ethylene	**70.3**	21.6	**49.8**	16.7	**70.8**	37.8
Chicago	Untreated	**0.3**	0.6	**0.0**	0.0	**3.6**	3.1
	Ethylene	**3.4**	1.7	**0.5**	0.9	**2.5**	2.2
	CIPC	**0.6**	0.9	**0.7**	1.4	**0.4**	0.7
	CIPC + Ethylene	**3.2**	3.8	**1.7**	2.0	**6.4**	4.0
Lady Claire	Untreated	**1.2**	1.4	**2.6**	2.3	**1.0**	2.0
	Ethylene	**11.8**	5.7	**3.8**	6.3	**5.6**	2.0
	CIPC	**5.0**	5.8	**2.2**	2.5	**26.3**	36.4
	CIPC + Ethylene	**12.3**	5.1	**4.6**	3.4	**6.9**	12.8
VR808	Untreated	**0.3**	0.7	**0.0**	0.0	**0.0**	0.0
	Ethylene	**0.9**	1.7	**1.1**	2.1	**0.9**	1.9
	CIPC	**0.0**	0.0	**0.0**	0.0	**0.6**	1.1
	CIPC + Ethylene	**3.2**	2.7	**1.8**	1.5	**6.2**	5.9

sd, standard deviation

The largest percentage of defects were always found with ethylene treatment, except in Lady Claire at 6 months' storage, due to a single replicate with a dark fry colour. For Arsenal ethylene treatments always greatly exceeded the threshold for rejection and at

6 months no treatments were commercially acceptable. Although ethylene increased defect levels in both Chicago and VR808 the actual levels were below the 5% low target at 4 months' storage and commercially acceptable by 6 months' storage.

At 2 months' storage, Lady Claire had acceptable defect levels in all treatments although the highest levels were found with ethylene treatment. Values with ethylene treatment were low at 4 months and still acceptable at 6 months' storage.

Chips (French fries): frying assessments

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 in Table 4.1.4 and trial chip colour score results are reported as a mean in Table 4.1.5. A score up to 3.9 is considered good (shaded green); 4 to 5.9 borderline, and scores would be rejected. Table 1.3.6 shows the results of ANOVA analysis of the treatments on chip fry colour.

Different varieties provided different ranges of chip colour scores although all were commercially acceptable to 6 months of storage. Generally treatment with ethylene resulted in somewhat darker fry colours, with an average SBCSR score of 0.4 higher than in its absence. There were no statistically significant differences between the treatments for Markies, Maris Piper or Russet Burbank. Ethylene treatment, singly or in combination with CIPC, caused a statistically significant increase in fry colour for Fontane, Ramos and Royal compared to the CIPC treatment alone (Table 4.1.6). Chip fry colours were generally lowest, and with varieties Fontane and Ramos significantly lower with CIPC than with ethylene treatment.

Table 4.1.4. USDA-SBCSR chip colour scale conversion table

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

Table 4.1.5. Chip (French fries) fry colour score, box storage.

		Storage period SBCSR score					
Variety	**treatment**	**2 months**	sd*	**4 months**	sd*	**6 months**	sd*
Fontane	Untreated	**2.1**	0.4	**2.5**	0.6	**3.0**	0.7
	Ethylene	**2.6**	0.7	**2.8**	0.6	**3.1**	0.8
	CIPC	**1.9**	0.5	**2.0**	0.5	**3.2**	0.9
	CIPC + Ethylene	**2.7**	0.7	**3.1**	0.7	**3.9**	0.9
Maris Piper	Untreated	**3.4**	0.6	**3.4**	0.6	**3.9**	0.7
	Ethylene	**3.6**	0.8	**3.4**	0.8	**3.4**	0.9
	CIPC	**3.6**	0.8	**3.3**	0.7	**3.6**	0.8
	CIPC + Ethylene	**3.7**	0.9	**3.4**	0.8	**3.9**	1.0
Markies	Untreated	**2.0**	0.3	**1.6**	0.6	**1.7**	0.6
	Ethylene	**2.1**	0.3	**2.0**	0.5	**2.2**	0.8
	CIPC	**1.9**	0.4	**1.7**	0.5	**1.8**	0.4
	CIPC + Ethylene	**2.1**	0.4	**2.0**	0.5	**2.2**	0.7
Ramos	Untreated	**2.2**	0.5	**2.0**	0.6	**2.8**	0.6
	Ethylene	**2.9**	0.7	**2.9**	0.7	**3.4**	0.8
	CIPC	**2.1**	0.5	**1.8**	0.6	**2.7**	1.0
	CIPC + Ethylene	**2.7**	0.8	**3.0**	0.8	**3.8**	1.1
Royal	Untreated	**3.3**	0.6	**3.3**	0.6	**3.6**	0.8
	Ethylene	**4.0**	0.9	**3.6**	0.8	**3.9**	0.9
	CIPC	**3.3**	0.9	**3.2**	0.7	**3.6**	0.8
	CIPC + Ethylene	**3.8**	0.9	**3.5**	0.7	**3.7**	0.8
Russet Burbank	Untreated	**3.3**	0.5	**3.2**	0.5	**3.8**	0.7
	Ethylene	**3.7**	0.6	**3.2**	0.4	**3.5**	0.6
	CIPC	**3.4**	0.5	**3.2**	0.4	**3.6**	0.7
	CIPC + Ethylene	**3.7**	0.7	**3.3**	0.5	**3.5**	0.6

*sd, standard deviation

Table 4.1.6. Table 3 ANOVA F-test results and post-hoc findings for Chip score, by sampling occasion per variety, box storage.

Variety	Storage period (months)	Suppre-ssant	E v C	E v CE	C v CE
Fontane	2	*	*	NS	*
	4	***	**	NS	***
	6	NS			
Maris Piper	2	NS			
	4	NS			
	6	**	NS	**	NS
Markies	2, 4 & 6	NS			
Ramos	2	**	**	NS	*
	4	*	*	NS	*
	6	*	NS	NS	*
Royal	2	**	**	NS	NS
	4	*	NS	NS	NS
	6	NS			
Russet Burbank	2, 4 & 6	NS			

Suppressants: E, Ethylene. C, CIPC. CE, combined ethylene and CIPC treatment.
ANOVA: NS, Non-significant result (P>0.05), significant results * (P<0.05), ** (P<0.01) and *** (P < 0.001). Post-hoc comparisons between suppressants at the sampling occasion are reported only where the F-test is significant (P<0.05).

4.2. Experiment 2: Bulk storage

Sprouting

The mean longest sprout length per tuber (mm) for each variety under the bulk storage ethylene treatment are shown in Table 4.2.1. As for the Box storage experiment sprouting up to 3mm was considered good for processing crops and between 3 and 10 mm as acceptable. Sprout lengths >10 mm were considered unacceptable.

Table 4.2.1. Effects of treatment on sprouting of varieties, bulk storage.

Variety	Storage period (months)	Store position	Sprout Length (mm)	sd*
Fontane	2	Top	**12.7**	9.4
	4	Top	**15.4**	7.8
	6	Top	**22.2**	5.7
		Middle	**22.2**	8.4
		Bottom	**22.6**	5.3
Maris Piper	2	Top	**16.9**	11.5
	4	Top	**24.4**	12.5
	6	Top	**27.8**	11.2
		Middle	**24.2**	8.9
		Bottom	**22.1**	6.7
Markies	2	Top	**2.6**	5.0
	4	Top	**2.5**	4.5
	6	Top	**5.0**	5.9
		Middle	**4.1**	5.1
		Bottom	**3.3**	4.8
Ramos	2	Top	**1.8**	2.0
	4	Top	**7.8**	3.6
	6	Top	**10.5**	4.3
		Middle	**11.6**	4.6
		Bottom	**9.6**	3.8
Russet Burbank	2	Top	**0.3**	0.6
	4	Top	**4.1**	2.4
	6	Top	**11.0**	7.2
		Middle	**8.2**	6.5
		Bottom	**7.8**	5.8
VR808	2	Top	**5.5**	5.6
	4	Top	**9.8**	2.9
	6	Top	**13.7**	3.9
		Middle	**13.2**	5.6
		Bottom	**13.6**	12.8

*Standard deviation

Fontane and Maris Piper had sprouted excessively after only 2 months under ethylene. Sprouts were short in Ramos at 2 months (1.8 mm) and potentially acceptable at 4 months (7.8 mm). However, by 6 months the samples straddled the unacceptable borderline of 10 mm. VR808 was potentially acceptable only to 4 months' storage.

Russet Burbank sprouted little at 2 months (0.3 mm), moderately at 4 months (4.1 mm). At 6 months' storage sprouting was still potentially acceptable except at the top of the pile where sprouts were somewhat longer (11 mm). Sprout control in Markies was good and commercially acceptable up to 6 months.

An analysis of the effect of bulk pile position on mean sprouting length was possible between top, middle and bottom positions for occasion 6 months. Although the power of the test to detect real differences was somewhat inhibited by the small sample sizes of 3 per position, none of the 6 varieties produced any significant differences (P>0.05) between the means of the 3 positions in store.

Crisps: frying assessments

VR808 was the only crisping variety in this experiment. All frying assessments were commercially acceptable with low defects levels and light fry colour (Table 4.2.2), especially at 2 months where an exceptionally high Hunter L value of 66.9 was recorded.

Table 4.2.2. Effects of ethylene on VR808 crisp colour and defect, bulk storage.

Storage period (months)	Store position	% defects	sd*	Hunter L	sd*
2	Top	**1.3**	2.3	**66.9**	1.1
4	Top	**3.6**	6.2	**63.5**	1.9
6	Top	**1.2**	1.1	**64.0**	1.8
	Middle	**1.2**	2.0	**61.2**	2.4
	Bottom	**1.4**	2.0	**63.5**	0.3

*Standard deviation

An analysis of the effect of bulk pile position on mean crisp colour was possible between top, middle and bottom positions for occasion 6 months. Although the power of the test to detect real differences was somewhat inhibited by the small sample sizes of 3 per position, there were no significant differences (P>0.05) between the means of the 3 positions in store for the 6 varieties.

Chips (French fries): frying assessments

All chip fry colours were commercially acceptable up to 4 months and for Fontane and Markies to 6 months (Table 4.2.3). Markies showed the lightest colours throughout and even its darkest fry colour of 2.9, in the middle of the pile at 6 months, was commercially good. At 6 months for Maris Piper, Ramos and Russet Burbank fry colours were on the border of acceptability.

Table 4.2.3. Effects of ethylene on chip fry colour, bulk storage.

Variety	Storage period (months)	Store position	Score	sd*
Fontane	2	Top	**2.2**	0.7
	4	Top	**2.7**	0.5
	6	Top	**3.7**	0.8
		Middle	**3.7**	0.7
		Bottom	**3.8**	0.7
Maris Piper	2	Top	**3.2**	0.6
	4	Top	**3.0**	0.5
	6	Top	**3.9**	0.9
		Middle	**4.2**	0.9
		Bottom	**4.0**	0.9
Markies	2	Top	**1.8**	0.5
	4	Top	**1.6**	0.5
		Top	**2.8**	0.8
	6	Middle	**2.9**	0.7
		Bottom	**2.5**	0.7
Ramos	2	Top	**2.4**	0.7
	4	Top	**2.6**	0.6
	6	Top	**3.6**	0.9
		Middle	**3.5**	0.8
		Bottom	**4.0**	0.9
Russet Burbank	2	Top	**3.5**	0.5
	4	Top	**3.4**	0.5
	6	Top	**3.4**	0.6
		Middle	**3.7**	0.6
		Bottom	**4.1**	1.0

*Standard deviation

ANOVA of chip fry colour was possible between top, middle and bottom positions for sampling occasion at 6 months only. Although the power of the test to detect real differences was limited by small sample sizes (3 per position), there was a significant difference between the three means for store position only for Russet Burbank (P=0.045). However, a post-hoc Bonferroni test was marginally non-significant (P=0.052) so no safe conclusion can be drawn about any difference between the bottom and top positions within the bulk for this variety.

4.3. Comparison of sprouting and fry colour effects of ethylene treatment in box and bulk storage

The effects of ethylene on sprouting and fry colour were compared for the two methods of commercial storage, box and bulk, used during this and previous years of the trial (2012-13, 2013-14). It should be noted that it was possible to similar but, necessarily, not identical storage conditions for these two systems. A limited range of varieties were used in both types of storage in each year and the comparison was made using the "top" position samples in the bulk trial. Results for ANOVA analysis of sprouting are shown in Table 4.3.1 and for chip fry colour in Table 1.3.11.

Table 4.3.1. Comparison of box and bulk storage, results of ANOVA for sprouting by variety, showing significance of the 2 main factors and interaction.

Variety and trial year	Experiments	Sampling occasions	Experiments x Sampling occasions
Maris Piper			
2014/15	NS	NS	NS
Markies			
2012/13	**	NS	
2013/14	*	***	NS
2014/15	*	NS	NS
Ramos			
2013/14	***	***	***
2014/15	NS	***	NS
Russet Burbank			
2012/13	***	***	*
2014/15	**	***	**

NS : Non-significant result (P>0.05), significant results * (P<0.05), ** (P<0.01) and *** (P < 0.001)

As also suggested by comparison of a sub-set of this data (this report, Tables 4.1.1 and 4.2.1) there was no consistent effect on sprouting with storage in either box or bulk systems.

Chip fry colour scores were statistically significantly higher for Markies and Ramos in bulk compared to box storage during 2013-14. However no such effect was detectable during 2012-2013 or 2014-2015 and there is no consistent effect on chip fry colour from

either box or bulk storage. Chip fry colour between sampling occasions was always significantly different, apart from Russet Burbank 2014/15.

The crisp fry colour of VR808, included in experiments 1 & 2 in the current trial, was significantly different only for 2 month storage, with a very light fry colour in bulk storage compared to box storage. Overall there was no consistent effect on fry colour of the two different methods of potato storage.

Table 4.3.2. Comparison of box and bulk storage, results of ANOVA for chip fry colour by variety, showing significance of the 2 main factors and interaction.

Variety and trial year	Experiments	Sampling occasions	Experiments * Sampling Occasions
Maris Piper			
2012/13			
2013/14			
2014/15	NS	*	**
Markies			
2012/13	NS	***	**
2013/14	**	**	*
2014/15	NS	***	**
Ramos			
2012/13			
2013/14	***	***	**
2014/15	NS	***	NS
Russet Burbank			
2012/13	NS	***	NS
2013/14			
2014/15	NS	NS	NS

NS : Non-significant result (P>0.05), significant results * (P<0.05), ** (P<0.01) and *** (P < 0.001)
Greyed rows, no data available.

5. DISCUSSION

Ethylene treatment and processing varieties

In 1998, Prange *et al.* observed 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 principally confined to fresh market crops. However, although it can effectively control sprouting in some varieties under some storage conditions, not all commercial varieties respond to ethylene sufficiently well for it to be a generically practicable sprout control solution. Furthermore, ethylene tends to stimulate sugar accumulation (Sowokinos, 2001) which adversely affects fry colours making the treatment less well suited to the processing sector.

This trial has further confirmed differential varietal responses to ethylene. Sprouting in Markies and Russet Burbank was well controlled by ethylene with mean sprout lengths of 5.4 and 3.0 mm respectively after six months' storage. Ramos and VR808 were slightly less well controlled with mean sprout lengths of 11.0 and 11.5 mm respectively after six months' storage, both very borderline commercially acceptable. Similar results with these varieties have been observed in previous years of the study

By the fry colour criteria used to assess commercial acceptability here, the effect of ethylene on processing was generally very small. With the exception of crisp production from Arsenal, fry colours from all varieties and treatments and storage durations were generally commercially acceptable. However, crisp fry colour in Arsenal was poor for all treatments. On average, ethylene treatment increased the crisp colour score by 1.5 Hunter L units and the SBCSR chip score by 0.4 units. This average includes a wide varietal response ranging from those that are essentially unaffected by ethylene (including Maris Piper, Markies and Russet Burbank) and those that are more seriously affected, notably during the first 4 months of storage, including Arsenal, Fontane, Lady Claire, Ramos and Royal.

Nevertheless, and as mentioned above, fry colours for all treatments and storage durations were acceptable. For crisping, the largest defect percentages were always found with ethylene treatment but, with the exception of Arsenal, differences were small and defect levels were within commercial limits.

Daniels-Lake (2013) described a combined effect of CO_2 and ethylene sprout inhibitor on the fry colour of stored potatoes. However, CO_2 was not measured or controlled in this trial so its influence in combination with ethylene is unknown.

Ethylene & CIPC combination treatment

Known potato sprout inhibiting compounds have been trialled in combination with CIPC to reduce the dose applied and subsequent potential residues (e.g. CIPC and 2,6-DIPN, Beaver et al 2003). Daniels-Lake et al (2011) studied the potential for reduced use of CIPC by combination treatment with ethylene. They reported on the sprout inhibition in varieties Shepody and NorValley by combination treatment and also on the negative affect on processing colour found in both cultivars with ethylene treatment.

In this trial, a single 9 ppm CIPC application soon after loading with continuous 10 ppm ethylene treatment during storage provided better sprout control, for all varieties and sampling occasions, than either treatment alone. Sprouting was controlled to within commercially acceptable limits in all varieties to six months' storage with the exception of Lady Claire and Royal. This effect was observed in varieties in which ethylene alone did not provide sprout control notably Maris Piper, and others including Chicago and Fontane. In this trial the amount of CIPC applied was low, 9ppm in total, and alone it generally failed to control sprouting after 4 months' storage. Effects on fry colour were essentially those found with ethylene treatment alone, as discussed above. Ethylene had no effect on the fry colour of Maris Piper and combination treatment provided good, commercially acceptable results with this variety to six months' storage.

6. CONCLUSIONS

Continuous 10 ppm ethylene suppressed sprout growth in all the varieties tested and to commercially acceptable standards for 6 months' storage for both Markies and Russet Burbank. Ethylene affected fry colour in some, but not all varieties and generally did not affect commercial fry colour acceptability. Its effect on Markies and Russet Burbank was relatively small and did not compromise commercially acceptable limits.

A combination of a single low dose application of CIPC with continuous ethylene, provided better sprout control, for all varieties and sampling occasions, than either treatment alone. Sprouting was controlled to within commercially acceptable limits in most varieties to six months' storage. The effects of combination treatment on fry colour were essentially those found with ethylene treatment alone. Combination treatment provided commercially acceptable results for sprouting and fry colour for Maris Piper, Markies and Russet Burbank.

No consistent difference between box and bulk storage was observed in relation to the impact of the treatments evaluated on sprouting or fry quality.

Future trials could usefully investigate the effects of different CIPC concentration treatments in combination with 10ppm ethylene to understand the balance between dose and efficacy and further develop options which may have commercial relevance if there is a need to move to lower rates of CIPC use in future.

7. REFERENCES

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8. KNOWLEDGE TRANSFER ACTIVITIES

Project updates to PPA, AHDB/PPA Joint Working Party, 18th March 2015.

Project updates to AHDB Potatoes R & KT Committee, 18th June 2015.

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