Interim Report Year 1 (2013-14)

Use of CIPC in Commercial Stores

R483

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1. Summary

Modifications were carried out to five commercial box stores with the aim of improving CIPC residue distribution. Stores were in the range 900 tonnes – 1,800 tonnes and included crops of a range of varieties for the fresh market and processing sectors. Modifications consisted of simple, low-cost alterations as well as more fundamental changes in air-delivery.

Assessments were carried out at commercial store out loading. Residue distribution was assessed using three individual tubers, and efficacy using 25 tubers, selected randomly, from netted samples located in boxes at store-loading. Sprout control in low-temperature stores was generally very effective (mean maximum sprout length 0.3mm – 0.9mm) though ethylene was used, in addition to CIPC, in one of these stores. Sprout control was also effective in processing stores (1.4mm and 2.8mm) but, in one store was more variable.

Single applications of CIPC were made to low-temperature stores (12 or 14 g/tonne), while the processing stores each received two applications (total doses of 23 or 26 g/tonne). Mean residue levels at out loading of low-temperature stores were in the range 2.9-3.2 mg/kg and from processing stores were 1.1 and 2.7 mg/kg. On average, more CIPC was retained as residue in low-temperature stores (23%-25%, as a proportion of nominal application rate) compared with processing store (5% and 10%).

Store modifications generally resulted in relatively even residue distributions with coefficients of variation (CV%) in the range 47- 58%. No exceedance of the statutory maximum residue level was detected.

2. Introduction

Chlorpropham (CIPC) is currently the main active substance for the control of sprout growth, and in the United Kingdom is applied to approximately a half of all stored potatoes, with formulations of the chemical making up in excess of 90% of treatments to stored potatoes (FERA, 2013 and FERA, 2009). Alternative sprout suppressants currently include maleic hydrazide, ethylene (which is used under a commodity approval) and spearmint oil.

The use of CIPC in Europe was reviewed successfully under EC directive 91/414, but was then referred to the UK Advisory Committee on Pesticides (ACP) in 2007 because of occasional exceedances of the CIPC Maximum Residue Level (MRL) of 10 mg/kg. In response to this the Potato Industry CIPC Stewardship Group (PICSG) was formed.

Exceedances of the MRL have continued during the lifetime of CIPC stewardship. Of the eight exceedances detected in statutory testing by Pesticide Residues in Food (PRiF) just one was in a bulk store, with the remainder being detected in samples from box stores. The risk of an exceedance is considered higher in box stores because, typically, these are of the 'overhead throw' type and without any design mechanism to deliver fog to the target. Such stores are typically treated with the store switched off. A satisfactory means of applying to such stores is now a very high priority, with future Good Agricultural Practice (the product label) likely to limit use if a satisfactory CIPC residue distribution cannot be predicted.

3. Material and methods

3.1. Box stores

Five commercial box stores were selected for inclusion in the trial. Stores were of a type, or modifications incorporated, that were anticipated to influence CIPC residue distribution. The residue distribution was determined using netted samples located systematically in boxes at store loading, with the position of boxes covering the three store dimensions. Nets were placed centrally in boxes, with the top of the net one or two tubers below the surface. Nets were recovered at commercial unloading of the store. Three tubers, randomly selected were analysed separately, denoted 'A' samples, for CIPC residue concentration (ALS, Chatteris, see Annex 1) and 25 tubers assessed for sprout growth.

The box stacking pattern of stores, location of sample boxes and location at which CIPC was applied are shown in Annex 2. Application details are summarised in Table 1.

Table 1. Store loading and application details. Stores W1, W3 and L2 held crops for the pre-pack market and C6 and H36 were used for potatoes for processing.

store code	loading dates	CIPC 1	rate (g/tonne)	temp.[1] (°C)	CIPC 2	(rate) (g/tonne)	temp.[1] (°C)
Fresh market stores							
W1	21/10 - 31/10/2013	7/11/13	12	7.7	-	-	-
W3	28/9 - 2/10/2013	14/10/13	12	8.2	-	-	-
L2	14/9 - 24/9/2013	3/10/13	14	10.5	-	-	-
Processing stores							
C6	14/10 - 19/10/2013	14/11/13	14	8.2	29/1/14	9	8.1
H36	21/10 - 29/11/2013	29/11/13	14	8.3	29/1/14	12	6.5

[1] Store temperature at the time of application.

Low temperature stores (W1, W3 and L2) storing for the fresh market (that would ultimately be held below 5°C) were treated on only one occasion, according to PICSG recommendations, using application rates of 12 or 14 g/tonne. In addition to CIPC, ethylene was also used in store W3. The low temperature stores were all held at approximately 3°C while store C6 was held at *c.* 8.5°C and H36 at *c.* 7.5°C. The temperature of stores was monitored using Tinytag (Gemini Data Loggers Ltd, Chichester, West Sussex PO19 8UJ, UK) automatic data loggers (see Annex 4).

Stores C6 and H36 were both treated on two occasions using total doses of 23 or 26 g/tonne, respectively. Initial application in store C6 was with the store filled to capacity; however, bacterial soft-rotting required partial unloading of the store and the second application took place with the store only loaded to *c.* 60% of capacity.

Store H36 contained batches of crops for a range of processes and was filled to approximately 50% of capacity at both applications. Store loading was completed on the day of application using crops cured in another store.

Fresh market stores

Store W1

This was a 1,350 tonne capacity store converted in 2013 to a 'suction wall' *(Aspire™)* ventilation system and holding a range of varieties (Safari, Sapphire, Melody and Maris Piper) for the fresh sector (Figure 1). The variety Melody was used for all netted samples in W1. CIPC was applied on a single occasion (12 g/tonne) with application assisted by recirculation using inverter-controlled fans. An inverter (also known as a variable frequency drive (VFD)) modulates the electricity supply to allow the fans to operate at slower speeds. In store W1 the recirculation

fans (Fig. 1a) are separate from the refrigeration system. These were, operated at 25 Hz (giving 50% of full speed). The fans were run until the fog had cleared.

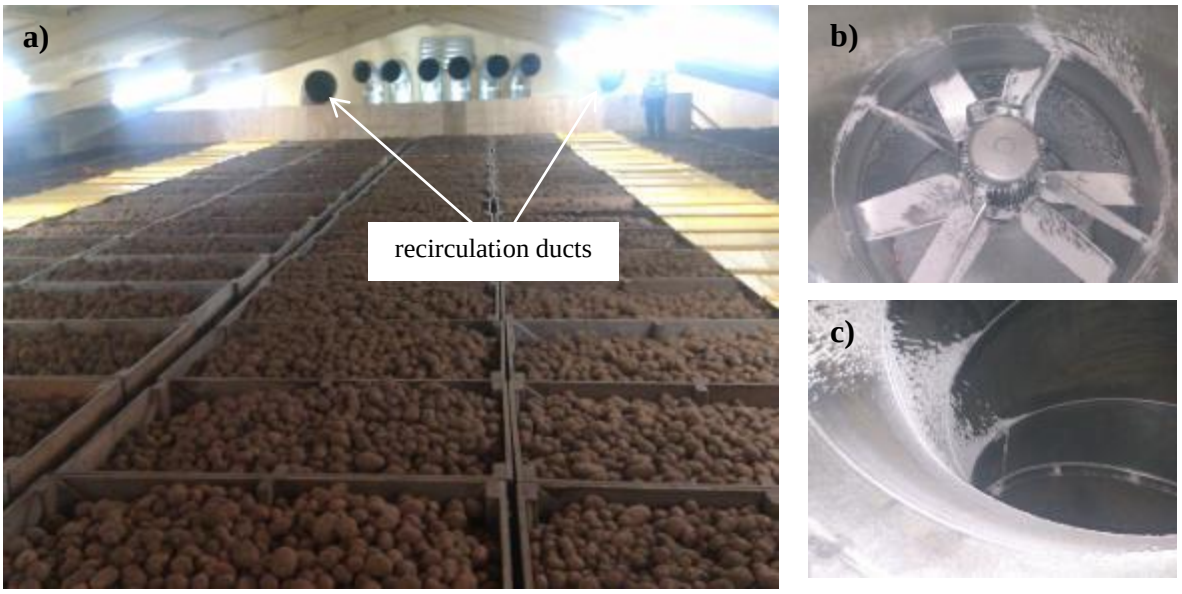


Figure 1. (a) Suction wall *(Aspire ™)* conversion of Store W1 and (b) deposition of CIPC on recirculation fan and (c) ducting, after application.

Store W3

A 1,600 tonne capacity refrigerated store featuring an 'overhead throw' ventilation system fitted with an air separator curtain. The store held a range of varieties (Maris Piper, Melody, Nectar and Sapphire) for the fresh sector. The variety Nectar was used for netted samples. CIPC was applied on a single occasion (12 g/tonne) using two simple plenums (covered walkways) bisecting the main block of boxes (See Annex 2). No fan assistance was used during CIPC application.

Store L2

This was a 1,400 tonne capacity refrigerated store used to hold cv. Jelly for the fresh sector. The ventilation system was an 'overhead throw' system fitted with an air separator curtain (Figure 2a). To promote airflow through the potatoes, alternative pallet apertures were sealed at each end of the main block of boxes, using foam blocks (Fig 2b and Annex 2). CIPC fog was applied with the store fans operating at low speed (20 Hz) through inverter control. Fans within the air handling unit were used for recirculation but the refrigeration coils were by-passed to avoid any risk of clogging with CIPC.

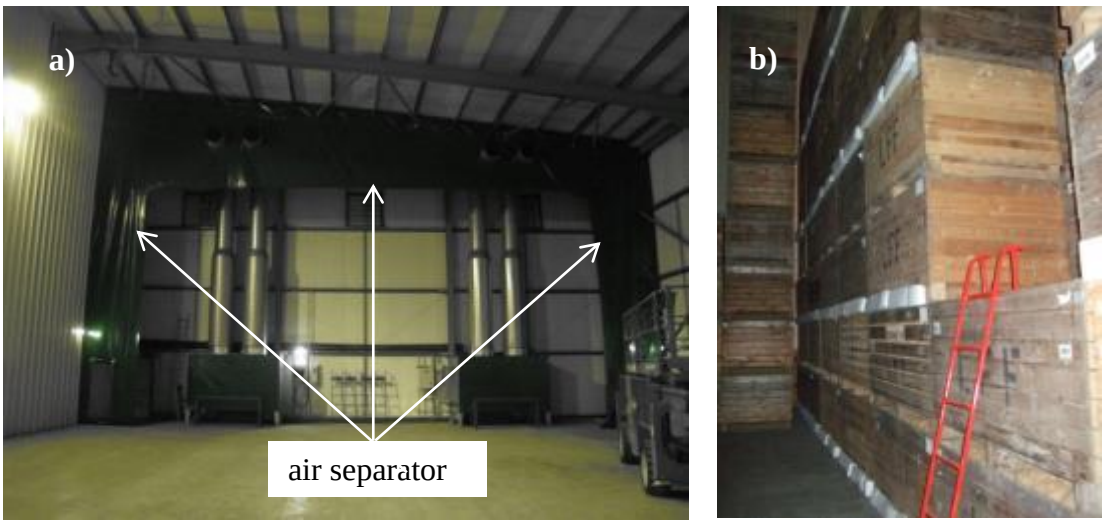


Figure 2. (a) Store L2 showing the air separator and (b) sealing of alternative pallet apertures with foam blocks.

Processing stores

Store C6

This store was a 900 tonne capacity store holding the variety Markies for the crisp processing market. It was an 'overhead throw' type, ambient ventilated store with a fixed (steel frame and wood) air separator (Figure 3). CIPC was applied on two occasions assisted by inverter-controlled fans operated at low speed (10 Hz or 20%).

Figure 3. Fixed, open-fronted 'Strawson wall' against which boxes were stacked to create an 'open suction' circulation system in Store C6.

Store H36

This was a 1,800 tonne capacity store holding primarily cv. Performer for the French fry sector. Maris Piper potatoes were used for the netted samples. CIPC was applied into covered plenums (Fig. 4). Two recirculation fans were located on the top of each plenum, drawing air from the store headspace into the plenums. During application of CIPC, recirculation fans were run at low speed (10 Hz), increasing gradually to full speed approximately 15 minutes after completion of application. Air velocity discharging from the fans was reduced using perforated, tapered wind socks fixed below each fan to balance the vertical distribution of fog.

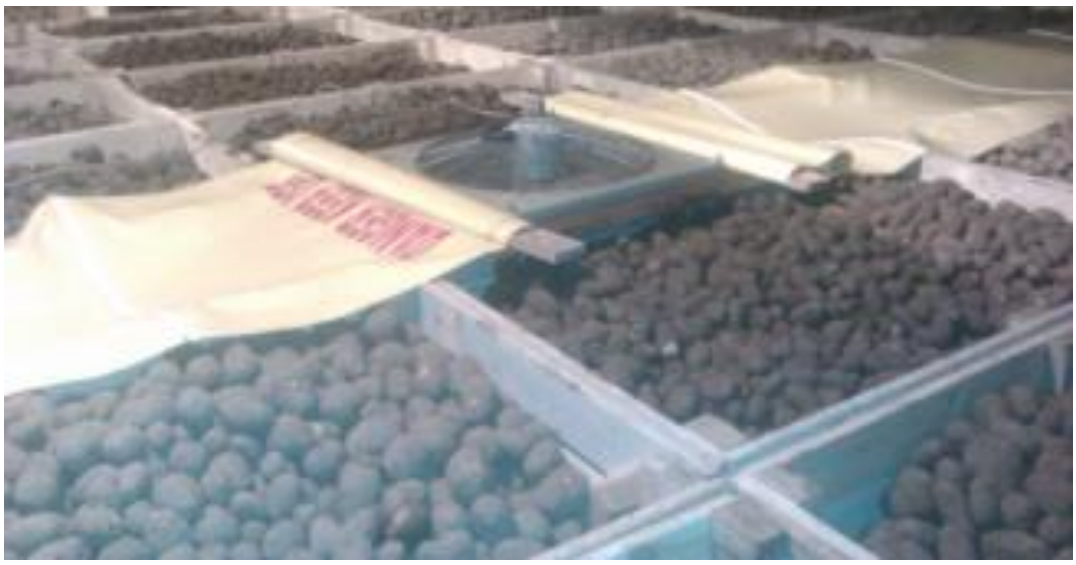


Fig. 4. Covered corridor to create a plenum and fan for recirculation in store H36.

3.2 'Continental' type bulk store

In addition to the five box stores, a newly-constructed 'continental design' bulk store (Omnivent Techniek BV, Zeewolde, The Netherlands) was observed during the 2013-14 storage season. The building (30m x 30m) consisted of two stores sharing a central party-wall. Each store was fitted with five 3 kW fans with a combined displacement of *c.* 0.045 m^3/s/t at 150 Pa pressure (Imperial units: 90 cfm/t at 0.6" WG), serving a design capacity of 1,000 tonnes. Air was supplied to the crop using parallel, tapered, half-round laterals; there were four of these running above ground along the long axis of each store (Figure 5).

The monitored store was used for the crisping cultivar VR808, held at 8-8.5°C. The store was loaded during w/c 16 September 2013 and unloading began w/c 7 July, 2014 (42 weeks).

Four applications of CIPC with a total dose of 39 g/tonne (Table 2) were carried out. CIPC fog was applied using four separate application ports (Fig. 6b), aligned to each lateral duct, with approximately one quarter of the total volume being applied via each port, at each application.

Table 2. CIPC applications.

application	date	rate (g/tonne)	crop temperature[1]
1	17 Oct. 2013	12	12.2°C
2	21 Dec. 2013	9	8.5°C
3	27 Feb. 2014	9	8.5°C
4	24 Apr. 2014	9	8.5°C
total	-	39	-

[1]crop temperature at the time of CIPC applications

Applications were carried out with all store fans running at full speed during and after application. Random samples of tubers were obtained, from the 'face' during store unloading, for CIPC residue analysis (12 tubers) and sprout control efficacy (25 tubers).

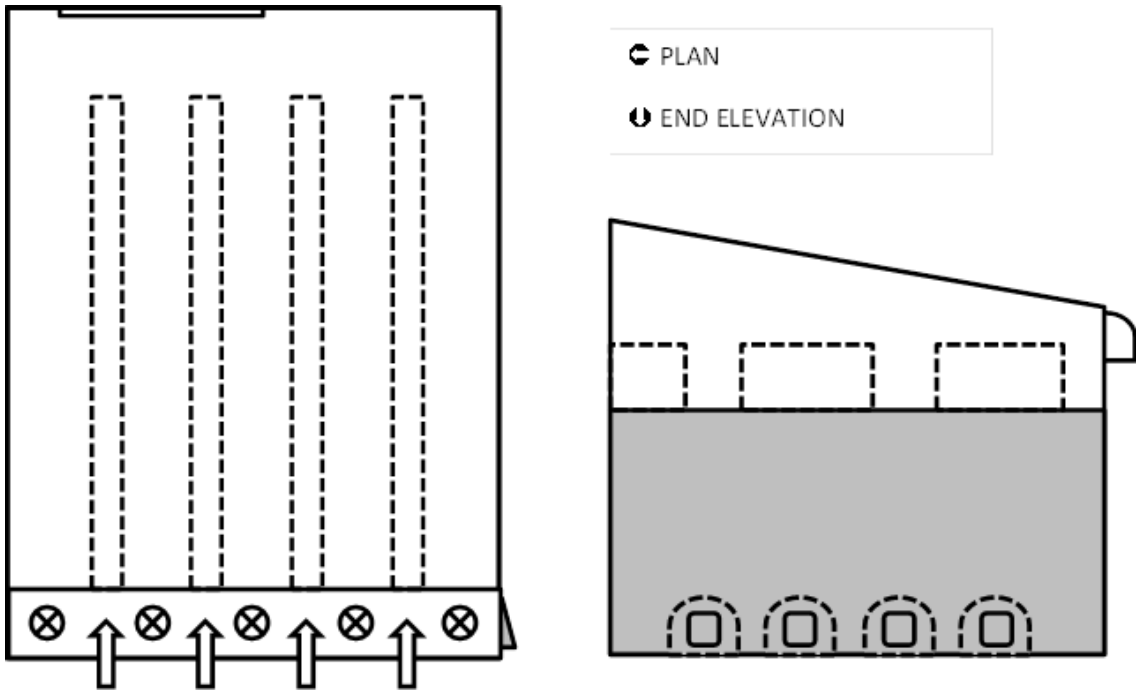


Fig.5. Store layout for one 1000tonne store (second store is a mirror image, not to scale).

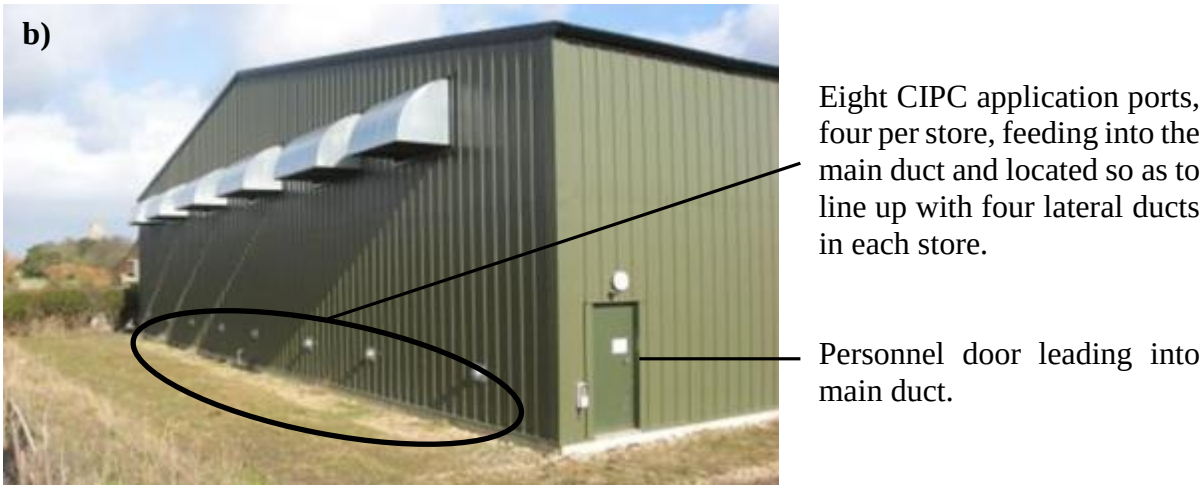


Figure 6. (a) Location of store ventilation and (b) application ports.

4. Results

4.1. Box stores

The netted samples were retrieved as stores were unloaded for commercial marketing; in each case, 25 tubers were assessed for sprout growth and three tubers submitted for individual tuber CIPC residue analysis.

The period of time over which unloading (and sample retrieval) took place varied from store to store (Table 3). Two stores, L2 and H36, took about two weeks to unload. Store C6 was partially unloaded after *c.* 17 weeks' storage but the remainder was not unloaded until *c.* 25 weeks. Stores W1 and W3 (shared co-operative stores) were both unloaded over more extended periods (3 and 5 months, respectively).

Results of efficacy assessments are shown in Table 3. Sprout growth was very effectively controlled in all of the low temperature, fresh market stores (W1, W3 and L2) with mean maximum sprout length in the range 0.3 – 0.9 mm.

Sprouting was also effectively controlled in the processing stores, especially W6, with a mean maximum sprout length of 1.4 mm (SD 1.29). Sprout control was more variable in store H36 (mean 2.8 mm, SD 3.47). In a small number of samples from H36, sprout growth was around 5mm, but CIPC residue levels in these samples was not particularly low, suggesting timing of CIPC application, rather than application efficiency, was less than optimal and compromised control.

Table 3. Duration of storage and sprout growth at store unloading

target market	store	storage (weeks)[1]	sprouting (mm)[2]	standard deviation
fresh	W1	29 ± 6	0.3	0.71
	W3	30 ± 11	0.9[3]	0.98
	L2	32 ± 1	0.7	1.12
processing	C6	17 & 25	1.4	1.29
	H36	20 ±1	2.8	3.47

[1]storage duration using median values; [2]mean maximum sprout length; [3]ethylene sprout suppressant used in addition to CIPC

Summary statistics for CIPC residue level of samples after storage are shown in Table 4. Data is shown in Annex 2. Low temperature stores (W1, W3 and L2 [all at c. 3°C]) resulted in similar overall mean CIPC residue concentrations (in the range 2.9-3.2 mg/kg) from single applications of either 12 or 14 g/tonne. A similar residue concentration (mean 2.7, SD 1.30) was found in H36, after two applications, with a total dose of 26 g/tonne applied, but an approximately similar application rate (23 g/tonne) resulted in a relatively low mean residue level at store C6 (mean 1.1, SD 0.53). Measures of variability (CV%) were broadly similar in fresh market (CV% 54-58) and processing stores (CV% 47 and 48).

Table 4. Summary statistics for CIPC residue concentration (mg/kg) of samples at store unloading.

store	W1		W3		L2	
box position	mean	SD	mean	SD	mean	SD
top[1]	3.7	1.85	3.6	1.44	4.7	1.30
middle	2.7	1.53	3.0	2.07	3.0	1.55
bottom	2.7	1.24	2.1	0.92	1.9	1.53
mean	**3.0**	1.63	**2.9**	1.67	**3.2**	1.84
CV%	54		57		58	
max	9.7		9.3		7.7	
min	0.9		0.4		0.5	
range	8.8		9.0		7.2	
samples (n)	162		108		108	

store	C6		H36	
box position	mean	SD	mean	SD
top1	1.2	0.49	3.0	1.43
middle	1.3	0.56	2.7	1.05
bottom	0.8	0.43	2.5	1.40
mean	1.1	0.53	2.7	1.30
CV%	47		48	
max	3.3		5.3	
min	0.1		0.3	
range	3.2		5.0	
samples (n)	69		90	

[1]top boxes were generally the boxes at the top of a stack except at store C6 where top samples were located in the fifth box of a stack throughout the store. Height at this store was very variable, with stacks ranging from four to six boxes high.

4.2. 'Continental type' bulk store

Application of CIPC with fans operating at full speed resulted in some attachment of a white, friable powder (presumed CIPC) on fan guards (Fig 7). This was, however, limited and is considered unlikely to have had a significant impact on fan performance. The magnitude of these deposits was similar to that seen on fans operated at low speed using inverter control.

Figure 7. Deposition of a white powder on fan guard following CIPC application.

Results of random samples obtained from 'the face' as the store was unloaded, were analysed for CIPC residue concentration (12 tubers, as per MRL) and sprout control efficacy (25 tubers). Samples were taken at intervals during unloading (Table 5). Results indicate very even and effective sprout control (mean 1.0 mm, SD 0.07) with acceptable residue levels (mean 5.0, SD 1.90).

Table 5. Results from 'continental' type bulk store.

sample	date	approximate location[1]	CIPC residue (mg/kg)	SD	sprout length (mm)	SD
1	11 Jul. 2014	5m	2.9	-	1.1	-
2	13 Jul. 2014	15m	5.9	-	1.0	-
3	14 Jul 2014	17m	7.2	-	0.9	-
4	15 Jul. 2014	25m	4.1	-	0.9	-
mean	-	-	**5.0**	1.90	**1.0**	0.07

[1]Approximate sample location relative to main store roller/loading door.

5. Discussion

5.1. Box stores

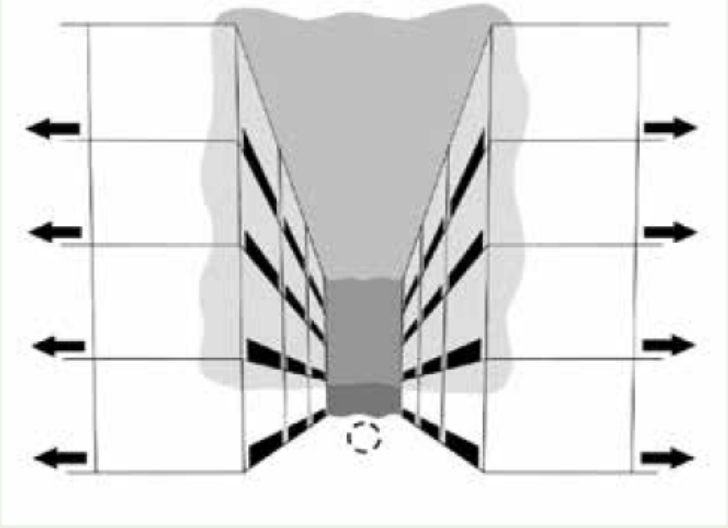
A selection of modified box stores were assessed with the aim of achieving improved CIPC residue distribution. These ranged from simple, low-cost modifications to 'overhead throw' box stores to more fundamental changes, requiring complete refurbishment of the store. A range of varieties were used and stores covered both the fresh and processing potato sectors.

The use of an air separator curtain coupled with low-speed recirculation of fog through open pallet apertures (Store C6) resulted in low CIPC residue variability (mean 1.1 mg/kg, SD 0.53, CV% 47). Although residue variability may have been underestimated by sampling top samples from the fifth box in stacks of six (necessitated by a variable stack height throughout the store) and residue levels were low, sprout control was effective (mean 1.4 mm, SD 1.29). Overall, this approach gave promising results with good control of residue levels and also has the benefit of modest conversion costs, estimated at £2-£4 per tonne.

The use of foam blocks, inserted in alternative pallet apertures in store L2 (in addition to an air separator and low-speed recirculation as used in store C6), resulted in slightly higher but acceptable residue variability (mean 3.2 mg/kg, SD 1.84, CV% 58). Residue values in L2 were generally highest in top boxes, especially at the front of the store, closest to the point where CIPC was introduced. The maximum residue measured in L2 (7.7 mg/kg) was less than in the other low temperature stores (9.7 and 9.3 mg/kg respectively for W1 and W3) where the position of the application port also had a significant effect. Further work is required to assess whether the additional use of the foam bungs is offering any significant benefit over the simple air separator curtain in this type of store.

'Be CIPC Compliant' best practice currently recommends the use of a plenum for application of CIPC in 'overhead throw' type stores (Potato Council, 2014). CIPC fog is applied into a covered

corridor (termed a *plenum*, see Fig. 8) which bisects the main block of boxes, and largely prevents the hot-fog from rising directly into the store headspace, reducing the risk of high residue levels on top boxes. This method was used in store W3 in this trial. Due to the length of the store, two plenums were installed but the store's fans were not used during application.



Modification of 'overhead throw' stores. A fogging port is installed to align with an inspection corridor, through blocks of boxes. The area between blocks is then sheeted over, from ground level, across the top and back down the opposite side, leaving a gap into which CIPC is fogged. Always ensure health and safety regulations are complied with during installation and where access to top boxes is required.

Always ensure fog can disperse and is not directed on to boxes or crop.

Figure 8. Excerpt from Potato Council Technical Note TN05.

Application to store W3 resulted in a mean residue concentration of 2.9 mg/kg (SD 1.67) from a single application at 12 g/tonne. The highest concentrations of CIPC were detected in samples from middle boxes, closest to the plenum and the lowest residues (a number of boxes had residue values below 1 mg/kg), generally occurred in boxes furthest from the plenum. This suggests that the addition of ventilation, as in store H36, may help to even out any gradient.

In store H36, the use of a plenum with additional fans for recirculation, resulted in CIPC residue values which were relatively even (mean 2.7 mg/kg, SD 1.30, CV% 48). However, after two

applications with a total dose of 26 g/tonne, there were still boxes in a number of positions which had low residue values (<1 mg/kg).

Store W1 was converted to suction wall ventilation (using the Pirie *Aspire* ™ system) in 2013. Previous Potato Council research (Project R414) has shown this type of store results in effective application of CIPC fog, with low residue variability, using low-speed fans for recirculation (Briddon, 2013). In this work, the suction wall system also performed well with a mean residue of 3.0 mg/kg (SD 1.63). Residue variability was lowest (CV% 54) of the three low temperature stores in the trial. However, there was a marked effect of the location of the CIPC port with particularly high values recorded in samples close to the application point. Further work is needed to address this in Store W1 but this should not detract from the very good and even CIPC distribution achieved using the suction wall system.

The overall mean residue value was similar in four of the five stores, in the range 2.7-3.2 mg/kg and one store was notably lower with a mean residue value of 1.1mg/kg after storage (store C6). Although insufficient to draw conclusions, data suggest that storage temperature had an effect on persistence of CIPC residue. In low temperature stores (c.3C), with total CIPC inputs of 12 or 14 g/tonne, CIPC efficiencies ([mean CIPC residue/total CIPC application rate]* 100) of 25%, 24% and 23% were obtained respectively for stores W1, W3 and L2. In the stores used for processing crops, with storage temperature in the range 6.5-8.5C, CIPC efficiencies were 5% and 10% for stores C6 and H36, respectively. While reduced CIPC efficiencies (less long-lived residues) may be anticipated in processing stores, due to the greater saturation vapour pressure of CIPC at warmer, processing storage temperatures (Park, 2004) giving rise to greater losses, it is not clear why residue values in store C6 were considerably lower than those from store H36. The integrity of store C6 was greater, with approximately 50% of the leakage of store H36 (see Annex 3, Table A3.1), suggesting the volume of ambient air used for cooling may be a more important factor in residue decline/store losses.

5.2. Bulk store

Application of CIPC using recirculation with full speed fans resulted in effective sprout control and even residue levels. Data indicate however, there is scope for a reduction in CIPC inputs.

PICSG recommends CIPC applications in bulk stores to be carried out using fans at reduced speed, using a VFD, to limit build-up of CIPC on fan-guards. Complete blockage of fans has been observed previously (McGowan *et al*. 2009) in UK type bulk stores. In this work, using fans at full speed, CIPC build-up was similar to that observed in UK type stores and this was of

a magnitude insufficient to interfere with airflow. Observations suggest applications in such stores, using full-speed fans, are acceptable. Deposition of CIPC on fans/guards may be limited in this type of store because there are more fans (5 for 1,000 tonnes, compared with one or two for a typical UK type design), CIPC was applied via a port associated with each lateral duct (so total fog volume was sub-divided approximately equally amongst all fans/ducts), and fog was introduced after the fan. Recirculation of CIPC fog should not be carried out at full speed in UK type bulk stores.

6. References

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Annex 1. CIPC residue analysis

CIPC residue analysis was carried out by:

ALS Food and Pharmaceutical
Medcalfe Way, Bridge Street, Chatteris, Cambridgeshire, PE16 6QZ

The procedure is UKAS accredited.

Analytical method

Preparation

Initial preparation of potato tubers involves a light wash under running water to remove any loosely adhering soil from each tuber. Samples are dried and homogenised at ambient temperature in a Robot-Coupe Blixer3. The homogenised sample is subsampled to pot and bag. Pot for analysis stored in a fridge which is monitored to ensure a temperature of 4±3ºC and bag for re-analysis if required stored in a freezer at ≤-18ºC.

Analysis

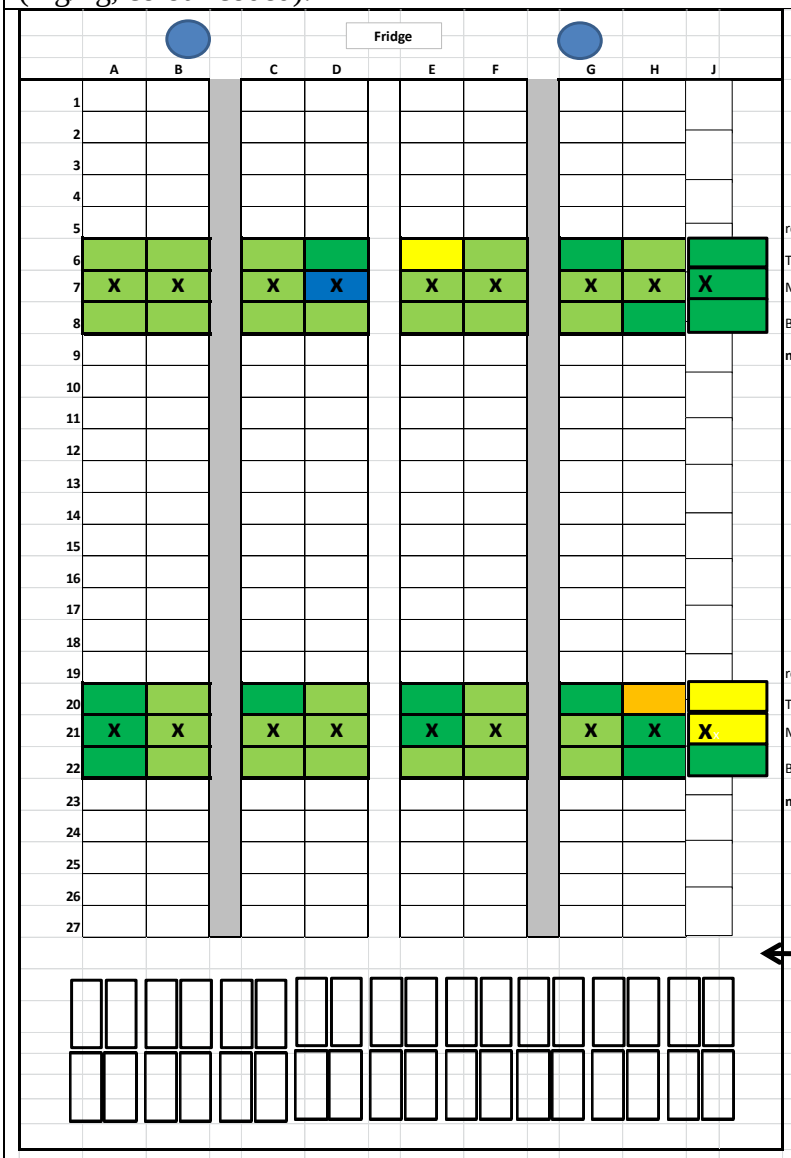
The homogenised sample is extracted with 100ml ethyl acetate. A chlorpropham (CIPC) free potato is spiked with a known amount of CIPC. This recovery sample is extracted alongside every batch of up to 20 samples and a recovery value is calculated (acceptable level for any positive residue is 70 – 120%).

Aliquots of the extract are then analysed by Gas Chromatography with Mass Selective Detection, specifically an Agilent 6890 Series GC System Plus+ with 5973 Mass Selective Detector and ZB-5MSi 30m x 0.25mm x 0.25µm capillary column. These extracts are quantified against CIPC standards ranging from approximately 0.02 to 10µg/ml whose correlation co-efficient for linearity should be at least 0.995.

Results are calculated by the analyst and peer reviewed prior to entry on to the Laboratory Information Management System and then approved before release.

Annex 2. Store schematics

Store W1, showing position of CIPC application port and mean CIPC residue concentrations (mg/kg, colour coded).



row											
	A		B		C		D		E		
Top	3.5	1.13	2.3	0.76	3.4	0.77	3.1	0.57	4.8	1.10	
Mid	2.9	0.78	2.5	0.37	1.8	0.78	1.3	0.42	3.2	1.55	
Bot	3.0	1.09	2.4	0.77	2.2	0.89	1.4	0.21	2.6	0.39	
mean	**3.1**	0.99	**2.4**	0.63	**2.4**	1.03	**1.9**	0.96	**3.5**	1.45	

row											
	F		G		H		J			All data	
Top	2.4	0.74	3.4	0.62	5.3	3.49	5.3	2.51	Top	3.7	1.85
Mid	1.9	0.62	1.9	0.28	2.9	1.35	5.6	1.78	Mid	2.7	1.53
Bot	2.3	0.69	2.0	0.41	4.0	1.25	4.7	1.02	Bot	2.7	1.24
mean	**2.2**	0.68	**2.4**	0.82	**4.1**	2.37	**5.2**	1.80	**mean**	**3.0**	1.63
										maximum	9.7
										minimum	0.9
										range	8.8
										CV%	53.7

row											
	row 7										
Top	3.0	1.22									
Mid	2.0	0.92									
Bot	2.4	1.00									
mean	**2.5**	1.12									
	row 21										
Top	4.5	2.10									
Mid	3.3	1.71									
Bot	3.0	1.40									
mean	**3.6**	1.84									

stack height		
Top	X	5
		4
Mid	X	3
		2
Bot	X	1

Residue results are presented using colour coding. Each set of three coloured cells represents the CIPC residue concentration of top, middle and bottom boxes at coordinates marked with an 'X'.

CIPC Concentration Key (mg/kg)							
<0.1	>0.1-0.5	0.6-1.0	1.1 -3.0	3.1-5.0	5.1-8.0	8.1-10.0	10.0+

Store W3, showing position of CIPC application ports and mean CIPC residue concentrations (mg/kg, colour coded) for top, middle and bottom boxes.

air separator

Fridge

	A	B	C	D	E	F	G	H	J				
1											Top	**2.6**	0.56
2			x				x			row 2	Mid	**1.1**	0.37
3											Bot	**1.2**	0.52
4											**mean**	**1.6**	0.83
5													
6													SD
7											Top	**2.8**	0.72
8			x				x			row 8	Mid	**4.8**	0.94
9											Bot	**3.1**	0.55
CIPC →											**mean**	**3.6**	1.16
10											Top	**3.2**	0.70
11			x				x			row 11	Mid	**2.3**	0.83
12											Bot	**2.9**	0.52
13											**mean**	**2.8**	0.76
14													
15													SD
16											Top	**4.7**	1.08
17			x				x			row 17	Mid	**5.5**	2.29
18											Bot	**2.0**	0.18
CIPC →											**mean**	**4.0**	2.06
19											Top	**3.6**	2.26
20			x				x			row 20	Mid	**3.6**	0.55
21											Bot	**1.7**	0.74
22											**mean**	**2.9**	1.62
23													
24													SD
25											Top	**5.1**	0.91
26			x				x			row 26	Mid	**0.8**	0.41
27											Bot	**1.6**	1.08
			row C	**mean**	**SD**		**row G**	**mean**	**SD**		**mean**	**2.5**	2.08
			T	**3.6**	1.51		T	**3.7**	1.41				
			M	**3.4**	2.32		M	**2.7**	1.78				
			B	**1.9**	0.98		B	**2.2**	0.85				
			mean	**2.9**	1.83		mean	**2.9**	1.51				

				SD
All data	Top	3.6	1.44	
	Mid	3.0	2.07	
	Bot	2.1	0.92	
	mean	**2.9**	1.67	
	max	9.3		
	min	0.4		
	CV%	57.4		
	range	9.0		

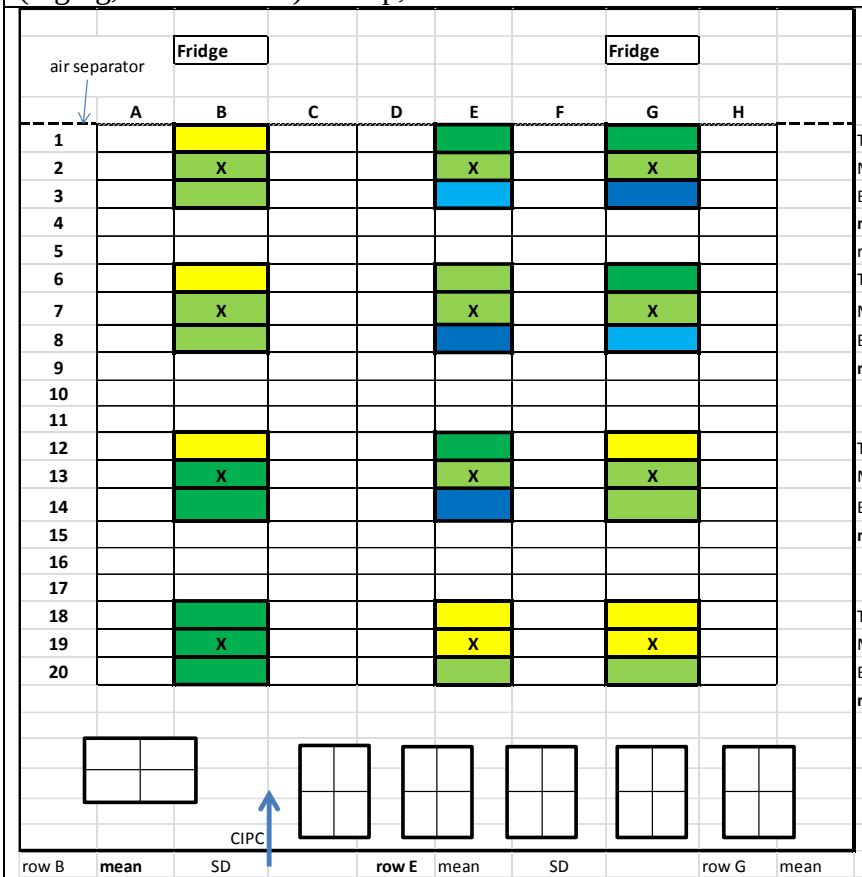
stack height		
Top	**X**	**6**
		5
Mid	**X**	**4**
		3
		2
Bot	**X**	**1**

Residue results are presented using colour coding. Each set of three coloured cells represents the CIPC residue concentration of top, middle and bottom boxes at coordinates marked with an 'X'.

CIPC Concentration Key (mg/kg)

<0.1	>0.1-0.5	0.6-1.0	1.1 -3.0	3.1-5.0	5.1-8.0	8.1-10.0	10.0+

Store L2, showing position of CIPC application port and mean CIPC residue concentrations (mg/kg, colour coded) for top, middle and bottom boxes.



row 2	mean	SD
Top	**3.9**	0.99
Mid	**1.6**	0.20
Bot	**0.8**	0.27
mean	**2.1**	1.46
row 7		
Top	**3.9**	1.16
Mid	**1.8**	0.49
Bot	**1.0**	0.51
mean	**2.2**	1.46
Top	**5.6**	1.41
Mid	**3.5**	1.17
Bot	**2.4**	1.78
mean	**3.8**	1.97
Top	**5.2**	0.69
Mid	**5.0**	0.63
Bot	**3.6**	1.01
mean	**4.6**	1.06

row B	mean	SD	row E	mean	SD	row G	mean	SD
Top	**4.9**	0.58	Top	**4.1**	1.24	Top	**5.0**	1.73
Mid	**3.3**	1.51	Mid	**2.7**	1.58	Mid	**2.9**	1.65
Bot	**3.1**	1.81	Bot	**1.3**	1.01	Bot	**1.4**	1.01
mean	**3.8**	1.60	**mean**	**2.7**	1.71	**mean**	**3.1**	2.06

All data	mean	SD
Top	4.7	1.30
Mid	3.0	1.55
Bot	1.9	1.53
mean	**3.2**	1.84
max	7.7	
min	0.5	
CV%	57.6	
range	7.2	

stack height		
Top	X	8
		7
		6
Mid	X	5
		4
		3
		2
Bot	X	1

Residue results are presented using colour coding. Each set of three coloured cells represents the CIPC residue concentration of top, middle and bottom boxes at coordinates marked with an 'X'.

CIPC Concentration Key (mg/kg)

<0.1	>0.1-0.5	0.6-1.0	1.1 -3.0	3.1-5.0	5.1-8.0	8.1-10.0	10.0+

Store C6, showing position of CIPC application port and mean CIPC residue concentrations (mg/kg, colour coded) for top, middle and bottom boxes.

air separator

	A	B	C	D	E	F	G	H	J	K
1										
2						X			X	
3										
4										
5										
6						X			X	
7										
8										
9										
10										
11						X			X	
12										
13										
14										
15						X*			X	
16										
17					row F			row J		
18					**mean**	**1.1**		**mean**	**1.2**	
19					SD	0.47		SD	0.58	
20										
	CIPC									

			row F	Top	**1.1**	0.22		row J	Top	**1.4**	0.64
				Mid	**1.3**	0.46			Mid	**1.3**	0.65
				Bot	**0.8**	0.57			Bot	**0.8**	0.26
				mean	**1.1**	0.47			**mean**	**1.2**	0.58

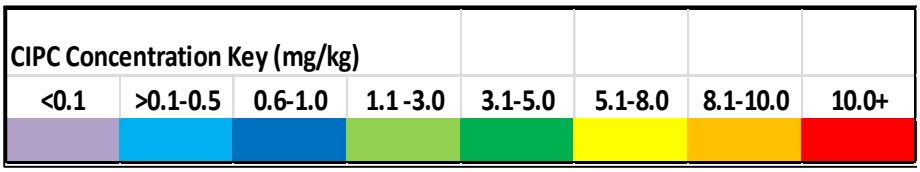
		mean	SD
row 2	Top	**1.2**	0.24
	Mid	**0.9**	0.08
	Bot	**0.7**	0.08
	mean	**0.9**	0.24
row 6	Top	**1.2**	0.15
	Mid	**1.4**	0.23
	Bot	**1.2**	0.54
	mean	**1.3**	0.35
row 11	Top	**1.1**	0.25
	Mid	**1.4**	0.60
	Bot	**0.5**	0.30
	mean	**1.0**	0.55
row 15	Top	**1.5**	0.89
	Mid	**1.9**	0.98
	Bot	**1.0**	0.38
	mean	**1.4**	0.78

	mean	SD
All data		
Top	1.2	0.49
Mid	1.3	0.56
Bot	0.8	0.43
mean	**1.1**	0.53
Max	0.3	
Min	0.2	
CV%	47.5	
Range	0.1	

*No results obtained for middle box at coordinate F15 due to bacterial soft-rotting.

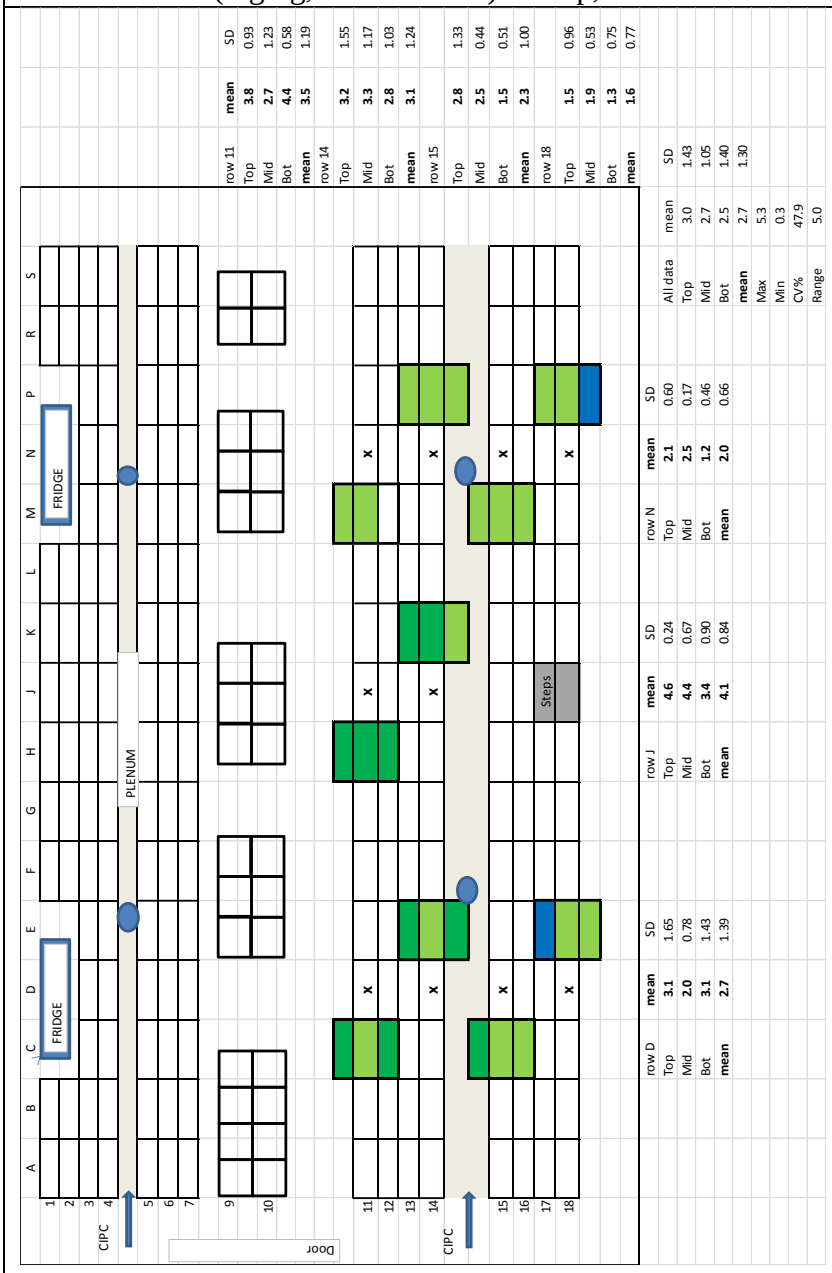
	stack height	
		6
Top	**X**	**5**
		4
Mid	**X**	**3**
		2
Bot	**X**	**1**

Residue results are presented using colour coding. Each set of three coloured cells represents the CIPC residue concentration of top, middle and bottom boxes at coordinates marked with an 'X'. Note 'top' samples in this store came from boxes at height 5, not from actual top boxes.



Note: Samples from rows 11 and 15 were unloaded after c.17 weeks and samples from rows 2 and 6 after c.25 weeks.

Store H36, showing position of CIPC application ports and mean CIPC residue concentrations (mg/kg, colour coded) for top, middle and bottom boxes.



top	x	7
		6
		5
mid	x	4
		3
		2
bot	x	1

Residue results are presented using colour coding. Each set of three coloured cells represents the CIPC residue concentration of top, middle and bottom boxes at coordinates marked with an 'X'.

CIPC Concentration Key (mg/kg)							
<0.1	>0.1-0.5	0.6-1.0	1.1 -3.0	3.1-5.0	5.1-8.0	8.1-10.0	10.0+

Annex 3. Additional information

Sample tuber size grade analysis

Tuber size grade analysis was carried after storage.

Table A3.1. Tuber size grade analysis of netted samples showing the number and proportion (%) of tubers within each size category (mm).

store	tuber	tuber	tuber size (mm)											
	number	weight	30-40	%	40-50	%	50-60	%	60-70	%	70-80	%	80+	%
W1	50	10042g	**0**	-	**10**	21	**17**	34	**16**	32	**6**	12	**0**	-
W3	58	10037g	**0**	-	**10**	16	**23**	40	**23**	39	**2**	4	**0**	-
L2	46	10053g	**0**	-	**3**	7	**20**	44	**21**	44	**2**	5	**0**	-
C6	42	10025g	**1**	3	**8**	18	**12**	29	**12**	29	**6**	15	**2**	5
H36	72	10026g	**1**	1	**28**	38	**28**	38	**16**	22	**0**	-	**0**	-

Store leakage

Each store was assessed using a technique first evaluated in Potato Council project R439 (Swain & Cunnington, 2013) and now used as part of the Potato Council's *StoreCheck* store auditing service (see www.potato.org.uk/storecheck)

Table A3.2. Store leakage.

store	equivalent leakage area (m^2)[1]	air changes/hr at 50Pa[2]	air changes/hr standardised[3]
W1	0.24	0.91	0.05
W3	0.12	0.46	0.02
L2	1.18	4.24	0.21
C6	0.29	2.22	0.11
H36	1.39	4.31	0.22

[1]Size of hole in store if all leaks added together.
[2]Actual air volume change at 50Pa differential pressure.
[3]Standard calculation - air changes at 50Pa/20 for 'normal' conditions.

These data show a relatively high level of leakage at stores L2 and H36 compared with the other stores used in the trial.

Store details

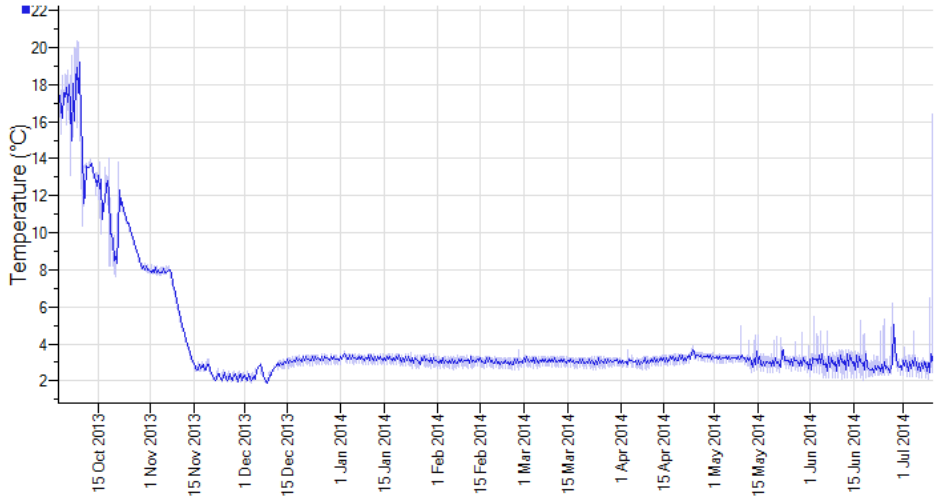
Store	W1	W3	L2	C6	H36
Dimensions					
length (m)	42.2	42.2	31.5	24.0	25.6
width (m)	19.0	19.4	17.8	19.0	27.0
height eaves (m)	5.3	5.3	9.0	5.5	7.7
height ridge (m)	7.9	7.9	10.8	7.7	11.3
Box type					
open boarding	✓	✓			
close boarding					
mixed			✓	✓	✓
Cooling					
refrigeration	✓	✓	✓	✓	✓
ambient	✓	✓	✓	✓	✓
Fan capacity[1]					
main	n/a	n/a	12 cfm/tonne	10 cfm/tonne	n/a
recirculation	18 cfm/tonne	n/a	n/a	n/a	20 cfm/tonne

[1]Fan capacity for CIPC application.

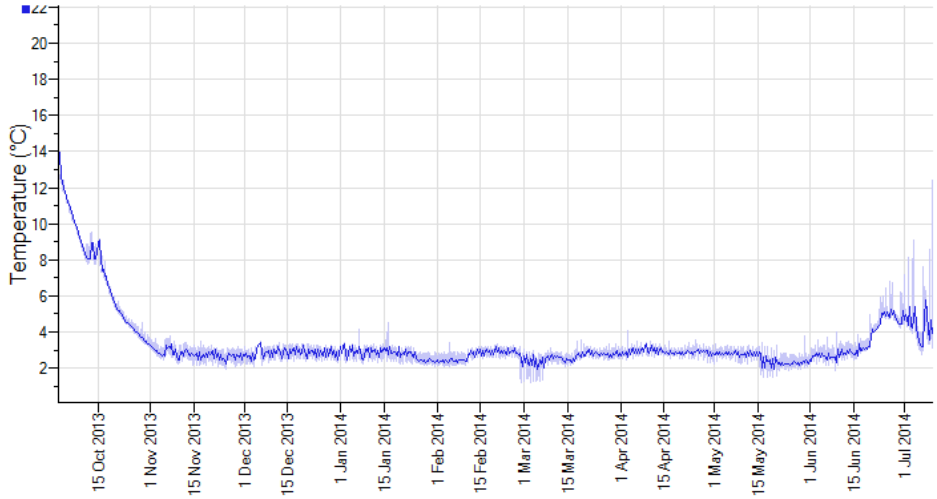
Annex 4. Store temperature data

Fresh market stores

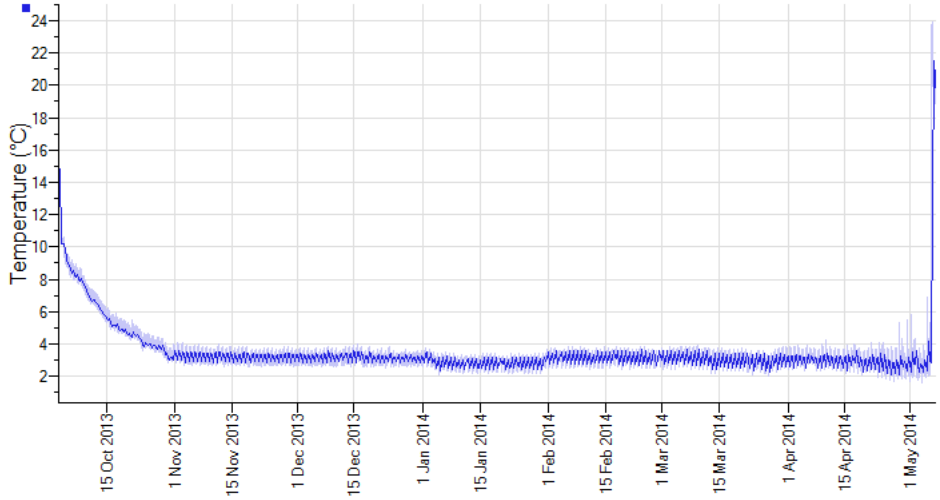
Store W1



Store W3



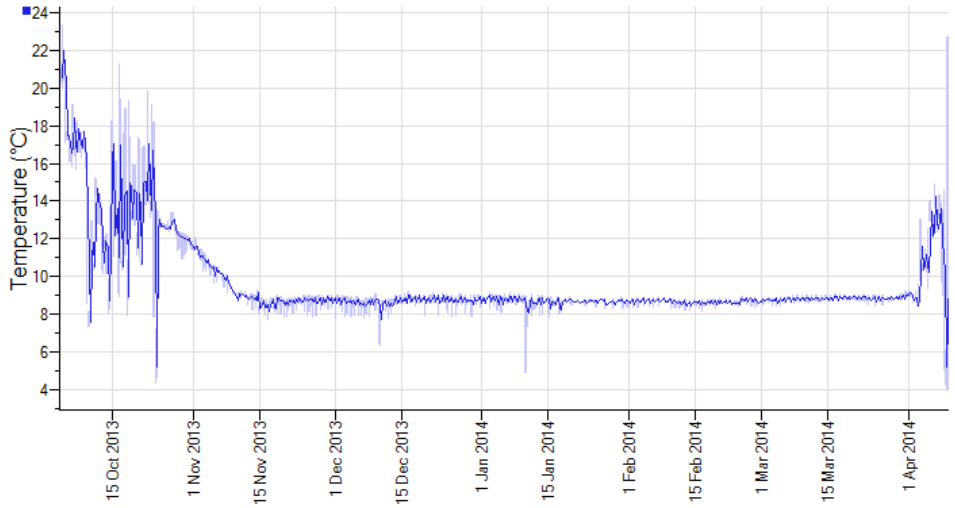
Store L2



Annex 4. Store temperature data

Processing stores

Store C6



Store H36