



## **Project Report**

# **Review and development of the CIPC application process and its impact on potatoes stored for processing**

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## Executive Summary

Thermal fogging of CIPC has been associated with a transient, but not fully reversible, deterioration (darkening) in fry colour. Research (funded by the British Potato Council, *BPC* and guided by the Potato Processors Association, *PPA*) carried out collaboratively by Glasgow University (GU) and Sutton Bridge Experimental Unit (SBEU) since 1999 has been investigating the cause of this effect and developing methods of alleviating it.

Initially (BPC project 807/208, 1999-2002) this involved verifying ethylene as the critical component of fog responsible for darkening, studying the effect of timing and frequency of application and modifying application machinery (including use of alternative fuels). The main outcome of this work was the development of an altered store management regime to reduce the time of exposure of crops to ethylene after CIPC application.

Based on the knowledge gained in this earlier project and prominent issues in the potato industry at the time in relation to CIPC use, the project aims were developed for a further three-year research program (2002-2005). The areas of work identified were application of CIPC and reducing its effect on processing quality, and investigating the potential for an 'at loading' treatment of CIPC using controlled release technology.

### ***Reducing the impact of fogging on processing quality***

#### **Agrochemical treatment**

1-MCP is an ethylene 'blocker' which limits plant responses to ethylene by 'permanently' attaching to ethylene receptor sites. Together with 'spiking' of stores with pure ethylene, 1-MCP was used as a research tool to confirm the importance of ethylene in causing deterioration in processing quality after CIPC application.

MCP became commercially available in GB (for use on stored apples) during the lifetime of this project, and so was also considered in terms of commercial use. In experimental work, MCP has consistently resulted in improvement in processing quality, compared with untreated samples, when fogged with CIPC. However, control was, on occasion, incomplete. Trials in the 2004-5 season assessed 1-MCP dose rate, to determine if efficacy could be improved by use of a higher dose and whether under dosing was the cause of incomplete control. There was no evidence that doses above those normally used (1000ppb compared with around 625ppb) gave rise to more effective control after CIPC application.

It has since been proposed that crops can regain sensitivity to ethylene by producing new ethylene receptors (*Prange et al, 2005*). Although the protective effects of 1-MCP are long term, increased sensitivity after long-term storage (evident in our data) does support this proposal. If confirmed, this would have an impact on how 1-MCP could be used and, importantly, raises the possibility of a need for regular re-treatment. On the basis of this, it is unlikely that the cost of 1-MCP can be justified.

The principle of ethylene 'blocking' however remains as a potential method for control of fry colour, if other similar compounds become available.

### **Modification of existing fogging equipment/regime**

Current practice is for CIPC to be applied repeatedly, as and when required. An attempt is made to mitigate the impact of this, on processing quality, by ventilating stores 'as soon as CIPC has settled'. While this approach is, to an extent, successful, a deleterious affect on processing quality was observed (and is to be expected) when regular re-applications of the chemical are made. In three out of four cultivars tested, processing quality was superior when the number of CIPC applications was minimised. In addition to minimising the *number* of 'ethylene events', the *concentration* of ethylene also has a bearing on processing quality.

Initial trials (1999-2002) of existing equipment showed that alternative fuel sources (methanol and LPG) significantly affected ethylene yield and the consequent effect on processing quality. It was considered, however, that the cost of engineering development work associated with optimising equipment for the combustion of different fuels would have been excessive and, importantly, would have been limited to a particular fogger type. As a consequence, this approach was not pursued and, instead, work concentrated on a system that could be 'retro' fitted to all existing commercial scale foggers using any fuel source. A catalytic conversion system was developed that, in experimental scale treatments using a Unifog, repeatedly resulted in a headspace yield of ethylene below 0.2ppm following CIPC applications. Such applications resulted in an improvement in processing quality compared with standard treatments. It is recommended that this system is now tested under commercial conditions. The system is expected to allow stores to remain sealed for longer periods following CIPC applications, to ensure complete deposition of the fog, without impact on processing quality.

As well as measuring potato tuber responses, any testing should also consider the dynamics of the CAT system. Automotive catalytic converters, as used in this work, can be damaged during operation and reduce efficiency of the system. Common causes of CAT failure are fracturing of the internal structure (forceful impact), flooding with unburned fuel, use of fuel additives and rapid change in temperature. Commercial testing of the system should be accompanied with regular inspection/testing of the CAT prior to CIPC applications.

CAT systems may be a cost-effective way of minimising the concentration of ethylene to which crops are exposed, but they are not expected to remove all trace of ethylene. This can only be accomplished, for the application of CIPC, by the use of equipment using heat-exchange principles. Two prototype heat-exchange applicators were tested. The outputs of these though, were modest, and the cost of development is likely to be prohibitive. A commercial applicator, based on heat-exchange principles, is operated in the USA (Industrial Ventilation Incorporated, Nampa, Idaho, USA).

## **Potential CIPC treatment using controlled release technology**

A range of materials were evaluated for their potential as a controlled release formulation matrix. The more successful of these were further tested in crop storage trials throughout the duration of the project.

CIPC vapour itself has shown potential for use as a potato sprout suppressant, but the effectiveness of the vapour depends heavily on environmental conditions. An even temperature throughout the volume over which CIPC is expected to work would help to encourage an even concentration of vapour. Air movement was found to be critical to the volume over which CIPC vapour inhibited sprouting, with negative pressure (pulling) preferred to positive (pushing air through the potatoes). The effects of air speed are threefold. Initially it will affect the rate of sublimation with a higher flow rate resulting in faster vapourisation of CIPC. Even air movement throughout the tubers helps improve distribution of the CIPC vapour. The results indicated that a very low airflow rate of 6ml/min was not adequate to achieve this even in small 5kg tuber trials, but when the rate was increased to 58ml/min (still relatively low flow) overall control of sprouting was improved. Thirdly the rate of air movement will influence the residual CIPC concentration remaining on the tubers. Experimental results showed that at very high flow rates (c.79ft<sup>3</sup>/hr) residues were below 0.5mg/kg with little variability. Therefore not only did the high airflow rate cause lower residues and more even distribution but also used the CIPC rather efficiently, in that only 1.75mg/kg was applied. It is anticipated that an optimum flow rate would be less than the higher rate used in these experiments. The main goal is to create an even controlled flow through the potatoes at a suitable rate.

The rate of sublimation of CIPC into vapour is dependant not only on air speed, but also on a number of factors including surface area, location of CIPC, existing vapour concentration and temperature. A greater surface area will allow a higher rate of vapourisation. The surface area can be maximised by using a support material that has an inherently high surface area plus a formulation that maintains CIPC as discrete particles. The location of CIPC is important because if it is held within a material as opposed to on the outside of it then less of the CIPC is exposed and hence the rate of vapourisation will be less. The benefit of this is persistence of CIPC over a longer period providing the CIPC held within the matrix become available to vapourise over time. A balance has to be struck between immediately available CIPC and a long term supply to ensure a formulation can provide sprout control over a given time period. This was done in the experimental trials by assessing and combining features of formulations and support material. The existing vapour concentration will effect the ability of the CIPC to sublime for example if no CIPC is present in vapour then the pull to establish an equilibrium is great and CIPC will vapourise and diffuse in the locale until equilibrium between air and solid is reached. The concentration at which equilibrium exists depends on the temperature and humidity. Warmer air can hold more CIPC vapour than colder air.

The alginate material used in the storage trials demonstrated good CIPC loading and release properties at a range of temperatures and high humidity. It was effective in controlling growth both as a remote source and when applied to the surface of tubers. Ideally it would be used as a remote source away from the tubers with controlled air speed and movement employed to minimise residues. However if it were to be



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applied onto the surface of tubers the effect on the skin and respiration rate would have to be examined.

## Experimental section

### **Background**

Sprout suppressant chemicals are applied to crops to maintain commercial acceptability when low temperature storage is not a suitable option. Chlorpropham (CIPC) and Maleic Hydrazide (MH) are the permitted active ingredients for sprout suppressant chemicals in the UK, however CIPC is the only one that can be applied during storage. A survey focusing on the 1998/1999 storage season highlighted that 43% of stored ware potatoes were treated with CIPC. A later publication noted that CIPC accounted for 80% of the chemical applied to stored ware potatoes (*Fox et al, 2000*).

CIPC is mainly applied as a thermal fog. The first treatment is carried out after the crop has cured and subsequent treatments are conducted periodically over the storage season. Ethylene produced by thermal fogging causes a darkening of fry colour for at least a twenty-eight day period after application. The extent of deterioration in processing quality depends on the concentration of ethylene and exposure time of the crop (*Dowd, 2004*). Deterioration was often followed by some recovery in fry colour, though this was usually incomplete.

Ventilating stores earlier than the recommended twenty-four hours post application can help to minimize the damage to the potatoes. Using cleaner fuels than petrol to create the fog can also help to reduce the impact, although of the fuels considered only methanol has been found to have a positive effect (*Dowd et al, 2003*). The benefit of ventilating early and reducing the exposure time to ethylene far outweighed that of using cleaner fuels.

Although venting early is the most effective means of maintaining fry colours it does not prevent adverse ethylene effects completely. Even short exposures (within 8 hours) to ethylene are sufficient to elicit a response in stores tubers in terms of fry colour (BPC 807/208).

The impact of fogging on processing quality was found to be more detrimental towards the end of the storage season. Commonly by this stage there have been a number of CIPC treatments, each causing brief ethylene exposure. Repeated short-term exposure has an amplified effect on fry colours and the decline in quality becomes increasingly more pronounced with each application.

The sprout suppressant activity of the CIPC could be compromised to some extent by the presence of ethylene, as it is a plant hormone associated with dormancy break (*Abeles, 1992, Suttle, 1996 & Saltveit, 1999*). When exposure occurs in short bursts it is likely to stimulate growth (*Rylski et al, 1974, Timm et al 1986 & Coleman 1998*).

Further options for protecting processing quality and sprout control efficacy within a CIPC treatment regime need to be identified.

Despite the announcement of a realistic new European Maximum Residue Level (MRL) of 10mg/kg, growers and store managers still consider using less active

ingredient a priority. Major commercial buyers do not easily accept residues of any pesticide and rigorous testing is performed prior to sale of the crop. These continually increasing demands have intensified the pressure on store managers to provide sprout free, high quality crop throughout the year with only minimal agrochemical inputs.

An 'at loading' CIPC formulation could avoid the use of thermal fogging machines at the start of the storage season and therefore the detrimental effect of ethylene generated by these machines. Application 'at loading' is traditionally associated with better distribution than thermal fog treatment because it is applied per box as opposed to per store. It could influence when repeat applications are necessary and at what dose rate. Potentially it could lead to reduced residues by less CIPC being applied over the course of a season.

## **Introduction**

The first project objective is to show how CIPC can be applied with minimal effect on processing quality. Ideally ethylene would be completely removed from the exhaust stream that creates the fog. This would prevent the negative influence on fry colour and respiration rate.

## **Reducing the impact of fogging on processing quality**

### **Agrochemical treatment**

In the first two years of the project it was concluded that application of 1-Methylcyclopropene (MCP), prior to CIPC treatment, lessened that damage caused by fogging. Although the benefit in protecting crop appears to be temporary and re-application may be necessary during the storage season.

MCP is an ethylene blocker that binds to specific receptors in plants preventing the manifestation of 'normal' ethylene responses (*Sisler & Serek, 1997, Blankenship & Dole 2003*). Its effects will remain until new receptors are produced or it is lost from the receptors by diffusion (*Watkins et al 2000*). It is of note that the higher the number of receptors the less sensitive to ethylene the plant is expected to be, because more ethylene would be required to reduce the output of the receptors (*Kende, 2001*).

In year one the effect of MCP was still evident up to four months after CIPC treatment in a single experiment. Whereas in year two the beneficial effect of MCP was much less pronounced 56 days after CIPC treatment in a series of replicated trials. This suggests that by this time the MCP had started to diffuse from the binding sites or new receptors had developed in the tubers. The maximum protective element of MCP was noted to correspond with the usual occurrence of the darkest fry colours at approximately 21 days after CIPC treatment.

In year two there were disparities in the protection provided by MCP when crop was fogged with different fuel types, which would theoretically produce different atmospheric levels of ethylene. The suggestion being that not all of the ethylene receptors were blocked by the level of MCP now being applied as a standard dose. Implying that this difference in atmospheric ethylene concentration was manifesting itself through differing extents of darkening of fry colour between fuel types.

In the third year of the project the potential additional benefit of using higher doses of MCP was investigated.

### **Modification of existing fogging equipment**

In the 2<sup>nd</sup> year of the project a purpose built heat exchanger machine was tested for effects on fry colour by comparison with a conventional fogger machine. The principle of heat exchange is to provide sufficient energy to heat the air to the required temperature without the introduction of combustion products which would eliminate ethylene. However this equipment did cause a darkening of fry colour. The system was not particularly efficient with an input in excess of 2000°C and an output of approximately 200°C; this resulted in a poor quality fog. A much higher and more stable temperature output would be needed to meet the demands of thermal fog applications of CIPC in the UK. To achieve this large and not easily mobile generators would be required. Although this is not traditionally how thermal fog contractors have operated in the GB, systems like this do exist in North America. It is unlikely that fixed location large-scale heat exchangers will be introduced in GB.

During the 2<sup>nd</sup> year of the project the first tests of an inline exhaust CAT system were conducted in empty experimental stores at SBEU. Although there were problems with excessive backpressure because of the CAT restricting out flow from the fogger, these initial results indicated that the system had potential but would need development.

### **Potential CIPC treatment using controlled release technology**

Controlled release technology would rely on the sprout suppressant activity of CIPC to be effective through the vapour phase. Experiments were conducted in the first year of the project which confirmed that this was possible. This work also indicated that the source of CIPC has to be in a suitable form, with a high surface area and be readily available to vapourise. CIPC must also be present in sufficient quantity to provide CIPC for a relatively long period. The proximity of the source of CIPC vapour to the sight of sprouting was limiting the efficacy of the treatments. This could be overcome to an extent by air movement causing distribution of the vapour.

In the 2<sup>nd</sup> year a number of materials were tested for their ability to be loaded with CIPC and their ease of release of CIPC. A cress seed bioassay was used as a quick response indicator in storage trials to determine which materials had the most potential. Storage conditions were similar to typical potato storage environments at 9°C and 80% RH. In all of these experiments the CIPC source was kept separate from the cress seeds and later when tuber storage trials were conducted again the CIPC source was kept separate from the tubers to ensure activity was only occurring through the vapour phase.

The use of solvents, other than water, in the production of these potential formulations was avoided where possible, but this is not always possible as CIPC has limited solubility in water. The ability of the CIPC to sublime was affected by the use of solvents, including water but not to the same extent. Often the CIPC is still associated with some solvent making it harder for sublimation to occur.

It was confirmed that the rate of vapourisation depends on the surface area and hence if the particles are not small enough there will be a delay before the release of vapour from that surface. Alternatively if they are too small all the CIPC will dissipate over a short time and the prolonged release effect is lost. Additionally the location of CIPC in or on the support media was found to be influential to the rate of vapourisation.

CIPC loaded potato starch was found to be a good carrier of CIPC with equally good release properties and some degree of longevity of release under emulated potato storage conditions. The problem with this type of formulation was the expected non-acceptance from the within the industry of using a dust formulation because of potential health implications. For this reason research into the potato starch formulation ceased after year two of this project.

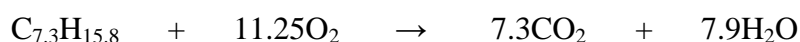
Following discussions with a commercial manufacturer of controlled release household products three controlled release formulations were prepared by the company and supplied for testing. Tuber storage trials were conducted at SBEU. The application rate of CIPC was very low, but was adequate to provide a CIPC vapour in the stores for the duration of storage. Control was relatively good with these type of treatments and the residues were all significantly below the MRL, in most cases <0.2ppm. However the greatest effect noted across treatments was that of the air movement around the store. Where air movement was high efficacy was better. It was concluded that strict control of the air movement around the tubers and application over a larger surface would increase the volume over which controlled release formulations can be effective.

In the 3<sup>rd</sup> year these ideas were tested with use of air movement and support materials themselves that offered additional surface area for tuber storage trials.

### ***Catalytic converter trials***

Catalytic conversion is an established technology, most obviously in the automotive industry, where principles are applied to bring about more complete oxidation of potentially harmful hydrocarbon combustion by-products in vehicle emissions. The aim is to improve air quality by reducing smog, particularly in densely populated areas. Additional environmental benefits include a decrease in nitrous oxides and hence acid rain.

If combustion of petrol was 100 % efficient the only products would be water and carbon dioxide as outlined in the reaction below



**Equation 1 Theoretical combustion reaction for the mean formula of petrol derived from the fractional distillation crude oil.**

Most modern catalytic converters have a free-flowing honeycomb ceramic structure (monolith) that is coated with catalytic metals, platinum, palladium and rhodium. At high temperature the exhaust gases enter the three-way converter where the metals cause oxidation of unburned hydrocarbons into water and carbon dioxide and reduction of nitrous oxides to nitrogen.

The chemical structure of ethylene (double bond) makes the molecule amenable to oxidation by CAT conversion systems used routinely in the automotive industry.

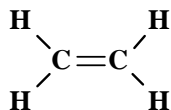


FIGURE 1 CHEMICAL STRUCTURE OF ETHYLENE

The Catalytic converters (CAT's) used in this work were designed for a high throughput, specifically for a Chrysler Grand Cherokee 4.0i 1/93 – 12/98 (60001, from [www.catsdirect.com](http://www.catsdirect.com)).

### **Objective**

The objective of these studies was to produce a working prototype fogger, fitted with an effective in-line catalytic conversion system (resulting in reduced ethylene concentration in-store post CIPC application), to allow the potential of this technology to be determined under commercial conditions.

## Background

In an initial trial with an inline CAT system an effective reduction in ethylene concentration was observed. However, in this initial configuration the CAT caused considerable backpressure on the combustion process and reasonable combustion temperature could only be maintained by using a very high and potentially unreliable fuel pressure. In order to reduce backpressure, a novel system was manufactured which doubled the cross sectional area by configuring two CAT converters in parallel.

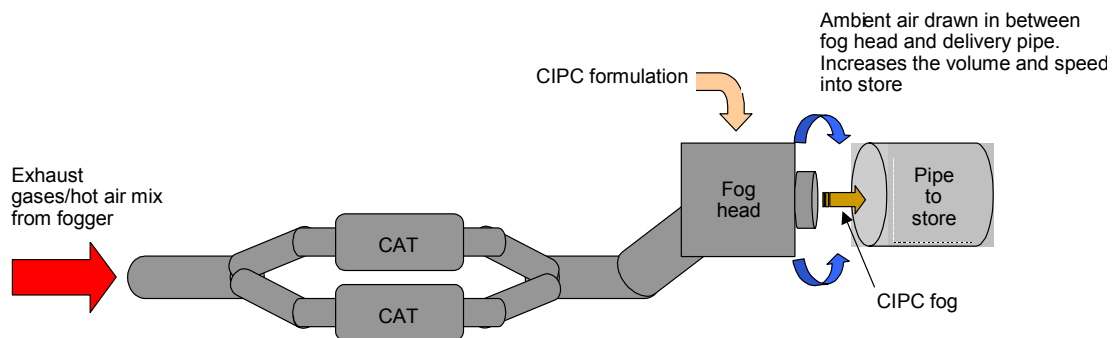


FIGURE 2 SCHEMATIC DIAGRAM OF THE MODIFIED SECTION OF A THERMAL FOGGER MACHINE INCORPORATING A TWIN CATALYTIC CONVERTER SYSTEM (NOT TO SCALE)

The twin system also allowed for more effective contact between the exhaust gases and the monolith structure of the CAT, by reducing the flow rate, and therefore was expected to oxidise contaminant hydrocarbons such as ethylene more efficiently.

## Experimental

This twin system was tested initially for changes in temperature profile. Significant changes in temperature profile of the air/exhaust flow would be expected to have an effect on the fog quality produced. In subsequent testing, efficiency of ethylene reduction and effects on potato quality were assessed.

The system was subsequently trialled in a sequence of factorial experiments at SBEU in May and June 2005. The effect on fry colour of fog applications with and without the twin CAT system was assessed one and seven days after application in crop storage trials. This was done in combination with a standard 8-hour ventilation time and an extended ventilation time of 24 hours. The 24 hours treatment was included to ascertain whether it was possible, with the aid of a CAT, to leave stores closed for longer after CIPC treatment without affecting processing quality

### Temperature gradient

CAT systems of the type used only work efficiently at high temperatures ([www.cats-direct-shop.co.uk/technical-information.php](http://www.cats-direct-shop.co.uk/technical-information.php), [www.xtremeflow.com/about.htm](http://www.xtremeflow.com/about.htm), [www.platinuminfo.net](http://www.platinuminfo.net)). Initially an insulating jacket was used but this was later removed due to physical breakdown as a result of excessive heat accumulation.

The temperature of ‘exhaust gases’ was measured at several points in the system and were compared with measurements from a standard Unifog fogger. Values similar to a standard fogger were desired, as significant changes would be expected to have an effect on fog quality.

| fogger       | flame trap <sup>1</sup> | fog head | delivery duct |
|--------------|-------------------------|----------|---------------|
| conventional | 475°C                   | 398°C    | 224°C         |
| CAT fogger   | 470°C                   | 398°C    | 230°C         |

TABLE 1 TEMPERATURES MEASURED AT CRITICAL POINTS IN A UNIFOG MACHINE WITH AND WITHOUT A CATALYTIC CONVERTER<sup>1</sup>

There was no substantial change in temperature profile, compared with a standard Unifog, as a result of the incorporation of the CAT system. A slight increase in temperature at the end of the delivery duct may be as a result of exothermic reactions occurring within the CAT.

The volume flow rate of ‘exhaust gases’ could not be measured. However, operation of the fogger (i.e. revolutions per minute of the blower) was similar to a standard Unifog, and, together with data showing a similar temperature profile this indicates that fog quality should not be changed as a result of the use of a CAT.

#### Ethylene reduction efficiency

The efficiency of ethylene reduction was assessed by comparison of standard and CAT equipped Unifog foggers. The exhaust output from each fogger-type (operated at normal fogging temperature but without introduction of CIPC formulation) was delivered into empty 12-tonne capacity stores at SBEU for thirty seconds. Treatments were carried out in duplicate with ethylene concentration (Gastec semi-quantitative colorimetric method sensitive to 0.2ppm) measured immediately after ‘application’.

| fogger       | first application | second application |
|--------------|-------------------|--------------------|
| conventional | 10                | 10                 |
| CAT fogger   | 0-0.2             | 0                  |

TABLE 2 ETHYLENE CONCENTRATION (PPM) IN STORE ATMOSPHERES RESULTING FROM CONVENTIONAL AND CAT EQUIPPED FOGGERS.

In both tests the CAT system was effective at reducing ethylene contamination of stores, compared with the conventional fogger. Traces of ethylene were detected after the first run, but not the second. It is considered likely that this is the result of the CAT being closer to its optimum operating temperature at the time of the second run, as a result of retained heat from the previous application.

On the basis of these observations a defined warm-up period was instigated prior to subsequent applications.

<sup>1</sup> The flame trap is the hottest point, immediately after the combustion chamber and preceding the CAT system.



### Crop trials

Factorial studies were conducted (in duplicate, using 6 and 12-tonne capacity stores) at 10°C with the cultivar Saturna. Applications were carried out using a conventional and a CAT equipped Unifog, with ventilation intervals of 8 hours and 24 hours after application. With both machines, applications were carried out with a burner temperature of 475°C and a formulation flow rate of 1l/minute (50% CIPC w/v in methanol)

Application time, on the basis of store volume, was 30 seconds for 12-tonne capacity stores and 21 seconds for 6-tonne capacity stores.

The catalytic converter was conditioned prior to applications by running the CAT fogger, without generating CIPC fog, at 600°C for 5 minutes then for a further 10 minutes at 475°C prior to application of CIPC.

The trial was first conducted in May 2005 and repeated in June 2005.

Headspace gas samples were collected after application and analysed for ethylene (Gastec) and oxygen and carbon dioxide concentration (HiTech Instruments, Gaslog 6000). Ethylene was monitored at intervals until ventilation but oxygen and carbon dioxide levels were only assessed immediately after application.

Fry colour (fry defects and Hunter L value ) was assessed 1 and 7 days after treatment and CIPC deposit concentrations analysed on samples collected 1 day after application

### **Results**

Store headspace ethylene concentrations, following applications in May are shown in Table 3. Ethylene was not detected in stores where applications were made using the CAT equipped fogger. Immediately after application with the conventional fogger, headspace ethylene concentration was in the range 5-10ppm. Carbon dioxide was not detected in stores after application (concentration <0.1%) and changes in oxygen concentration were very slight.

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| fogger       | ventilation         | store                | ethylene (ppm)      |                         |
|--------------|---------------------|----------------------|---------------------|-------------------------|
|              | interval<br>(hours) | capacity<br>(tonnes) | post<br>application | prior to<br>ventilation |
| conventional | 8                   | 6                    | 5-10                | 5-10                    |
| conventional | 8                   | 12                   | 5                   | 1                       |
| CAT fogger   | 8                   | 6                    | 0                   | 0                       |
| CAT fogger   | 8                   | 12                   | 0                   | 0                       |
| conventional | 24                  | 6                    | 5-10                | 5                       |
| conventional | 24                  | 12                   | 5                   | 1                       |
| CAT fogger   | 24                  | 6                    | 0                   | 0                       |
| CAT fogger   | 24                  | 12                   | 0                   | 0                       |

TABLE 3 ETHYLENE CONCENTRATION IN STORE ATMOSPHERES FOLLOWING APPLICATIONS IN MAY 2005

The fry colour of samples (Fig. 3) deteriorated during the 24 hours after CIPC application (compared with samples assessed on the day of application [day 0]). Deterioration was most marked in samples ventilated 24 hours after application using the conventional fogger. Deterioration was slight when application was made using the CAT equipped fogger or when ventilating early (8 hours) using the conventional fogger.

One week after application, when deterioration from fogging is typically greatest, fry colour of samples from CAT treatments was similar to that obtained from a conventional fogger with ventilation taking place 8 hours after application. Mean fry colour at this time was darkest in samples where CIPC was applied conventionally and with store ventilation taking place 24 hours after application.

Fry defects occurred at low levels (<5%) at the start of the trial, and changes, as a result of application/ventilation treatments, were small. Mean defects levels were greatest in samples one week after application was made by conventional fogger with ventilation 24 hours after application.

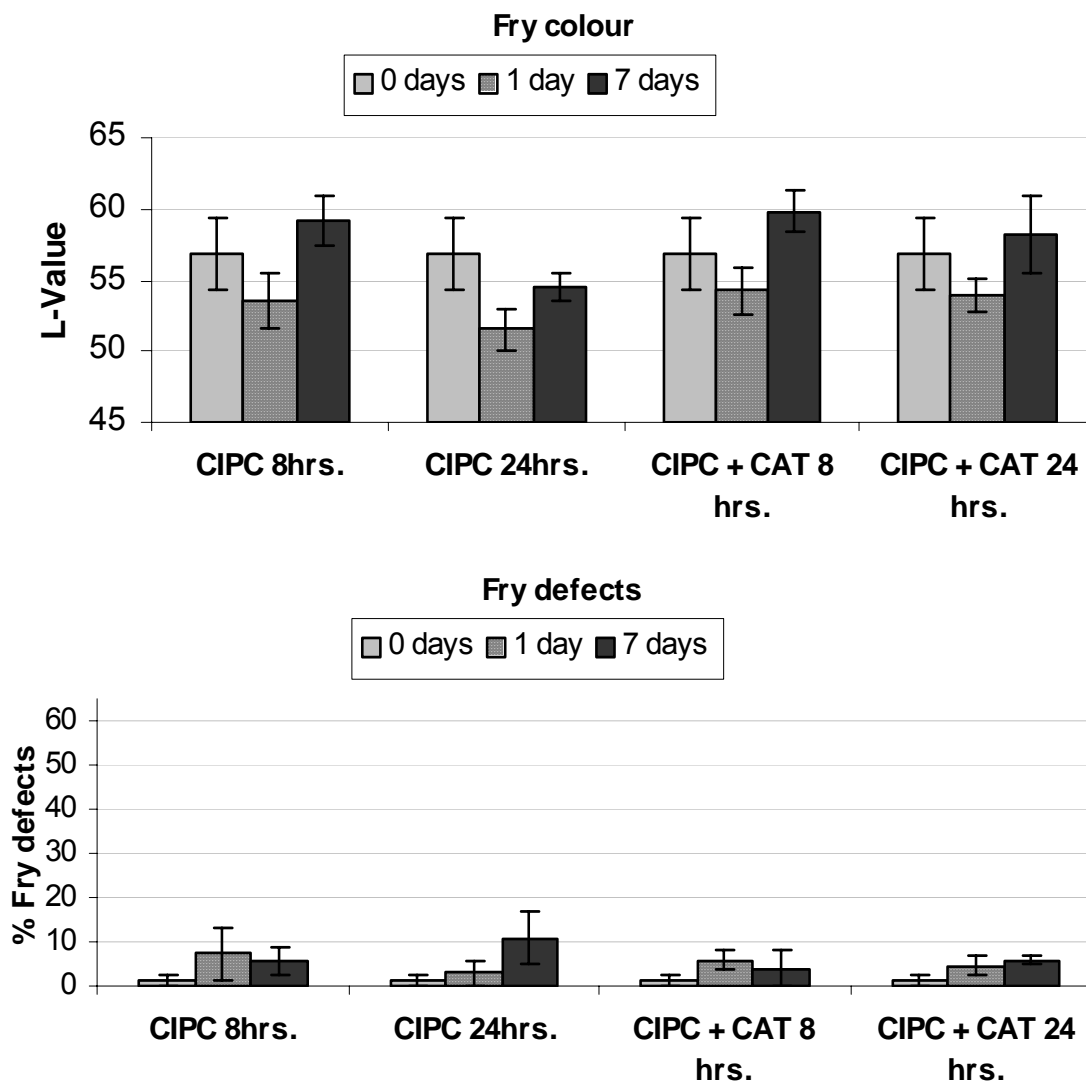


FIGURE 3 FRY COLOUR AND FRY DEFECT RESULTS FROM CAT CIPC APPLICATION TRIALS IN MAY 2005 +/-95% C.I.

Store headspace ethylene concentrations following applications in June 2005 are shown in Table 4. As in applications in May, ethylene was not detected in stores treated using the CAT equipped fogger. Conventional fogging resulted in headspace ethylene concentrations in the range 5-10ppm. Carbon dioxide occurred at a concentration below 0.1%.

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| fogger       | ventilation      | store capacity (tonnes) | ethylene (ppm)           |                          |                           |
|--------------|------------------|-------------------------|--------------------------|--------------------------|---------------------------|
|              | interval (hours) |                         | 3 hours post application | 8 hours post application | 24 hours post application |
| conventional | 8                | 6                       | 10                       | 5-10                     | n/a                       |
| conventional | 8                | 12                      | 5                        | 1-5                      | n/a                       |
| CAT fogger   | 8                | 6                       | 0                        | 0                        | n/a                       |
| CAT fogger   | 8                | 12                      | 0                        | 0                        | n/a                       |
| conventional | 24               | 6                       | 5-10                     | 5-10                     | 1-5                       |
| conventional | 24               | 12                      | 5-10                     | 5-10                     | 5                         |
| CAT fogger   | 24               | 6                       | 0                        | 0                        | 0                         |
| CAT fogger   | 24               | 12                      | 0                        | 0                        | 0                         |

TABLE 4 ETHYLENE CONCENTRATIONS IN STORE ATMOSPHERES FOLLOWING APPLICATIONS IN JUNE 2005

Fry colour of samples following applications in June are shown in Fig. 4. A slight deterioration occurred in all samples assessed 24 hours after application. Deterioration continued in samples where ventilation was delayed for 24 hours and was greatest when application was by conventional fogger. The fry colour of samples ventilated 8 hours after CIPC application by CAT equipped fogger, 7 days after treatment, was similar to that at the start of the trial.

Fry defect levels remained largely unchanged, at around 10%, in samples treated with the CAT fogger and ventilated 8 hours after application. With a similar ventilation interval, but with a conventional fogger, fry defects increased to c. 15% in samples one week after application. In treatments where ventilation was carried out 24 hours after application, fry defects one week after application were increased to c. 25%, using the CAT equipped fogger, and to in excess of 50% using the conventional fogger.

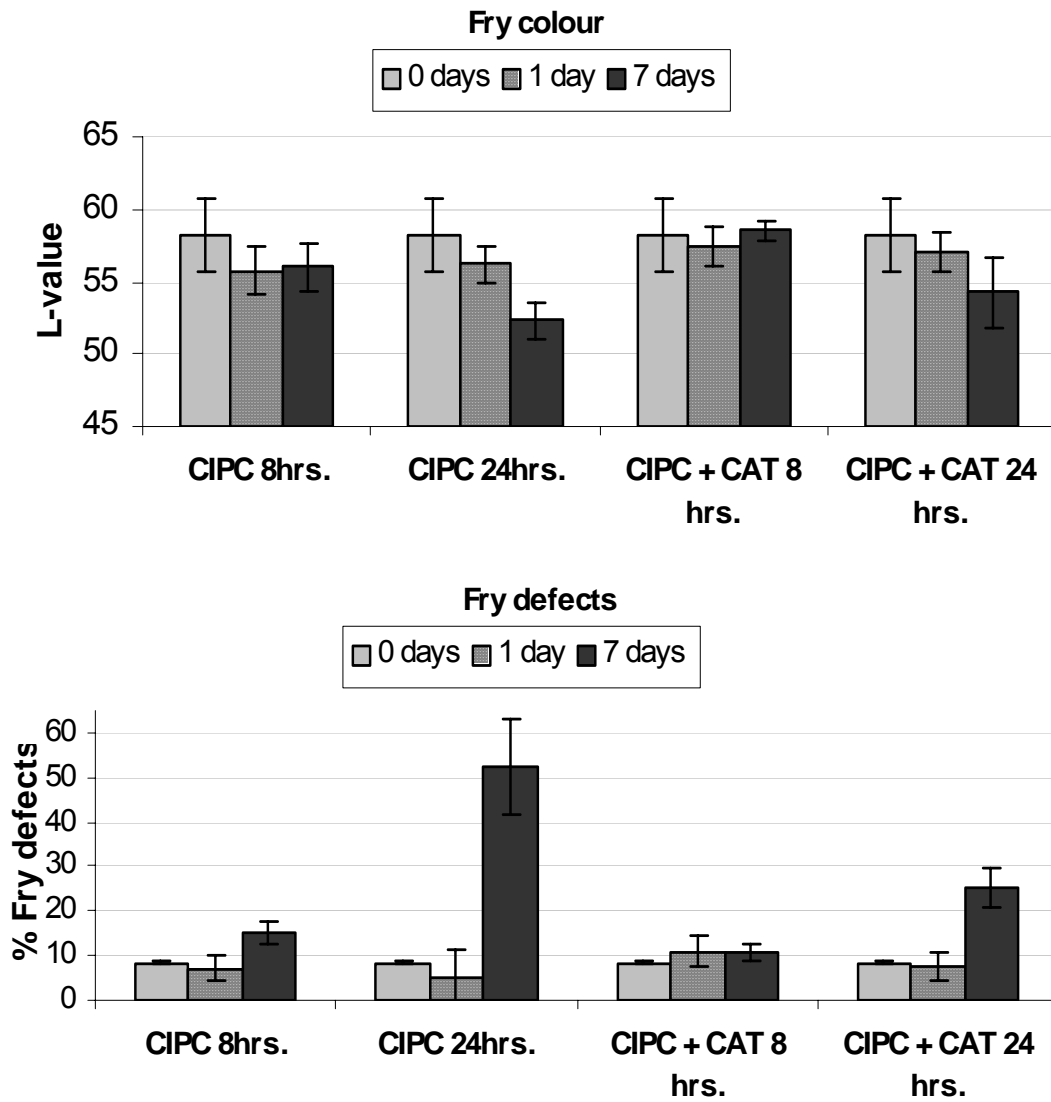


FIGURE 4 FRY COLOUR AND FRY DEFECTS FROM CAT CIPC APPLICATIONS TRIALS IN JUNE 2005 +/-95% C.I.

Results of average CIPC deposit analysis of samples removed 24 hours after application, are shown in Table 5. Deposit values from the conventional fogger and the CAT fogger ventilated at 8 hours were similar. Higher deposit values occurred in samples where CIPC was applied by CAT fogger with ventilation after 24 hours and variability of CIPC deposit levels was greater in samples treated with the CAT fogger. On the basis of a small sample size and short application time (30 seconds) these results are considered to show that fog quality is not likely to have been dramatically affected by the CAT modification.

| fogger       | ventilation interval |       |          |       |
|--------------|----------------------|-------|----------|-------|
|              | 8 hours              |       | 24 hours |       |
|              | Mean                 | SD    | Mean     | SD    |
| conventional | 22.6                 | 6.98  | 23.0     | 5.77  |
| CAT fogger   | 20.6                 | 13.69 | 33.9     | 10.29 |

TABLE 5 AVERAGE CIPC DEPOSIT RESULTS FROM CAT APPLICATION TRIALS .

## Discussion

Two-stage catalytic conversion systems, that oxidise hydrocarbons such as ethylene, are an established technology in the automotive industry, where they are used to bring about a reduction in the concentration of (potentially) harmful emissions from internal combustion engines. The same technology may be of benefit to the potato industry, but application will be subject to a different set of constraints.

While the effect of ethylene on processing quality is established, it is not known what reductions in ethylene concentration are required to reduce impact on fry colour. Headspace ethylene concentrations in (relatively well-sealed) stores at SBEU are typically 5-10ppm immediately after CIPC application (similar values have been recorded in commercial stores). Exposure of potatoes to ethylene at 20ppm is reported to result in a c. 6-fold increase in respiration rate (*Reid & Pratt, 1972*), but, significantly, this increased respiratory activity is not different to that observed from exposure to 2ppm ethylene. Substantially lower respiratory activity was only recorded when ethylene concentration was reduced to 0.15ppm at which time peak respiration rate was approximately double the basal rate. In order to reduce the impact of fogging on fry colour, therefore, it is considered that very large reductions (in the order of 100-fold) in headspace ethylene concentration are required.

The initial CAT system tested, consisting of a single, in-line catalytic converter, reduced ethylene concentration but was considered unreliable because of the fuel pressure required to maintain correct fogging conditions. In the twin-CAT system ethylene concentration in the store headspace after application has not exceeded 0.2ppm, and after incorporating a heating phase to raise CAT temperature prior to application, has consistently occurred at a concentration less than 0.2ppm.

In CIPC application trials, the concentration of ethylene to which crops were exposed was limited to <0.2ppm, by use of the CAT system. In comparison with a conventional fogger (yielding 5-10ppm ethylene in the store head-space) this resulted in a general improvement in quality (lighter fry colour and lower fry defects levels). However, even at low ethylene levels (<0.2ppm) ventilation interval may be a factor in determining processing quality. With the CAT equipped fogger, in the first test, delaying ventilation for 24 hours had little effect on processing quality, but in the second test, there was an increase in the level of fry defects.

It is concluded therefore that reducing ethylene concentration as a result of CIPC applications does benefit processing quality, however, systems need to be particularly efficient to achieve the very low ethylene levels required to reduce impact on processing quality. It is recommended that the system developed should now be tested under commercial conditions.

## ***Ethylene Blocker***

### **Objective**

To evaluate the potential benefit of applying a higher dose rate of 1-methylcyclopropene (MCP). MCP is a compound that binds irreversibly with ethylene receptor sites and is registered for use in apples where it is used to delay (ethylene induced) ripening in storage. In previous work MCP has been demonstrated to reduce the impact of fogging on processing quality.

### **Experimental work**

#### Crop trials

Earlier work with MCP and different fuel types raised the possibility that the common dose rate applied (between 500 and 625ppb) may have been insufficient and that fry colour implications from exposure to ethylene may have occurred as a result of under dosing. This hypothesis was tested in an experiment at SBEU that was run for the duration of the 2004/2005 storage season.

Experimental work was carried out with cv Saturna, held at 10°C and 95% relative humidity. Application rates of 500ppb and 1000ppb were assessed, in comparison with an MCP untreated control. Chemical applications were not replicated.

The MCP applications were carried out after crop was cured, in October 2004.

Seven days after MCP treatment, samples from all treatments were fogged, in a single store, with CIPC (Swingfog applying 500ml/12-tonne store of 50% w/v CIPC in methanol) Further CIPC applications were carried out, using the same methods, in January and April representing short, medium and long storage terms.

Fry quality was assessed, using three replicate samples, after 0, 1, 7, 14, 28 and 35 days after the initial application and 0 and 7 days after subsequent applications.

### **Results**

Mean fry colour (Hunter L) of samples after the initial CIPC application (Fig. 5) were generally lightest in samples treated with MCP. Different dose rates of MCP had little affect on fry colour. Fry defects occurred at low levels and were not affected by MCP or MCP dose rate.



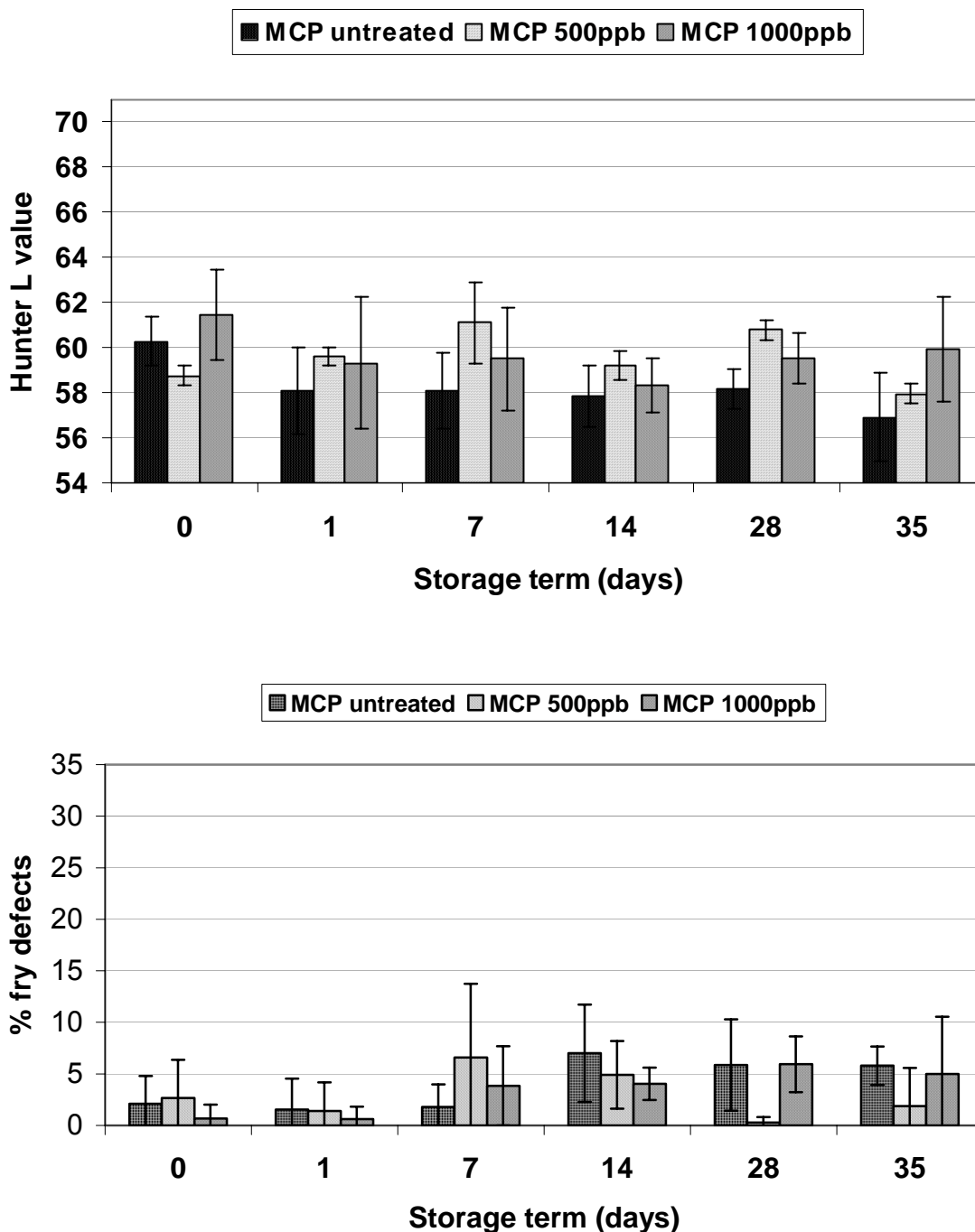


FIGURE 5 FRY COLOUR AND FRY DEFECTS RESULTS FROM MCP/CIPC APPLICATION IN OCTOBER 2004 (+/-95% CONFIDENCE INTERVAL)

The fry colour and fry defects of samples treated after short, medium and long storage terms is shown in Fig. 6. Significant effects occurred after medium and long storage term durations. Although no effect was observed after the initial application, samples treated at the 500ppb MCP rate had a poorer fry colour prior to application.

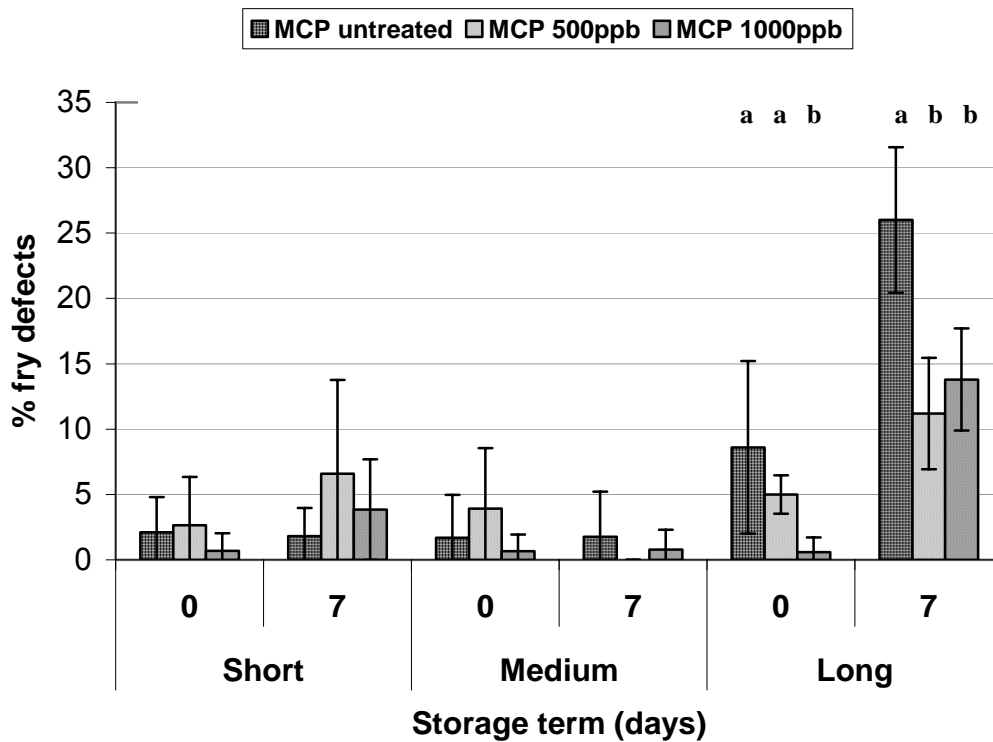
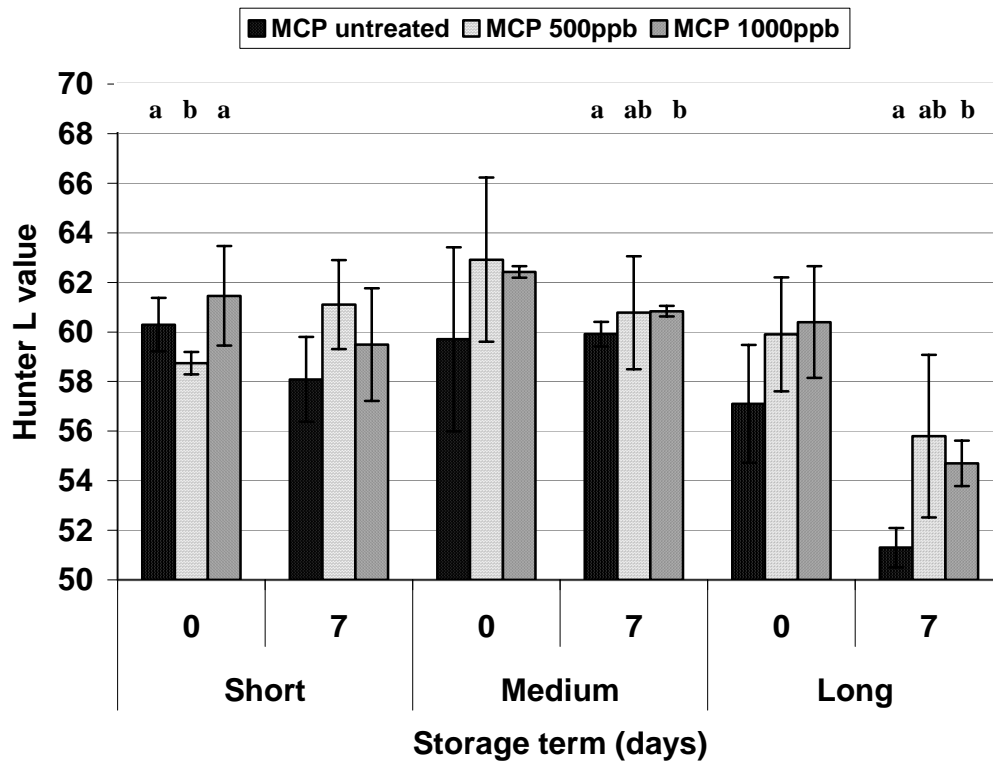


FIGURE 6 FRY COLOUR AND FRY DEFECTS (MEAN +/-95% CONFIDENCE INTERVAL) OF SAMPLES FROM MCP/CIPC APPLICATION TRIALS AFTER SHORT, MEDIUM AND LONG TERM STORAGE DURATIONS. SIGNIFICANT DIFFERENCES ARE DENOTED BY THE LETTERS.

After medium and long storage terms, CIPC applications were least damaging, in terms of processing quality, to samples pre-treated with MCP. While on both occasions the higher MCP rate resulted in significantly lighter fry colour compared with the untreated crop, there was no difference between the two rates of MCP and no difference between untreated samples and those treated with lower MCP rate. Changes in fry defects levels were only significant after long-term storage. Application of MCP, at 500ppb and 1000ppb rates, resulted in significantly lower incidence of fry defects, compared with untreated samples, after the final CIPC application.

As observed in previous work, application of CIPC relatively late in storage was particularly damaging to processing quality.

## Discussion

MCP is registered for use in the UK, on stored apples, where it is used to delay ethylene induced ripening.

The compound also reduces the impact of fogging on processing quality. In detailed sampling, after the initial application of CIPC, both rates of MCP resulted in acceptable fry colour, while quality of MCP untreated crop was poor. The incidence of fry defects, which, at this stage in the season was generally low, was however unaffected by MCP.

The use of MCP also showed improvements in fry colour, and fry defects, over an extended storage period, following repeat applications of CIPC (in January and April). Although MCP pre-treatment significantly reduced the incidence of fry defects (compared with untreated samples) following the final CIPC application, values still increased substantially (from c.1% to c.13%). This increased sensitivity of crops to CIPC applications late in storage (demonstrated in this study and observed previously) can also be accounted for by tubers producing new ethylene receptors as postulated by *Prange et al, 2005*. This observation, if confirmed, indicates that further work would be needed to optimise use of MCP (or other ethylene 'blocker') in commercial situations.

## CIPC dose rate/application frequency

### Objective

Previous work (*Dowd et al, 2003*) demonstrated that regular applications of CIPC resulted in greater deterioration in processing quality of cv Saturna than a single application at a higher dose rate, presumably as a result of repeated exposure to ethylene. This work was repeated using several cultivars, to determine the more general applicability of this affect, and used an 8 hour ventilation period (as opposed to the 24 hours used earlier), as is now commonplace. In addition, the impact of different regimes on CIPC residue and efficacy was assessed.

### Materials & Methods

Experimental work was conducted in 12-tonne capacity stores starting in October 2004 and using two crisping (Lady Rosetta and Saturna) and two chipping (Maris Piper and Pentland Dell) cultivars. All crops were held at 10°C and 95% relative humidity. CIPC (50% w/v in methanol) was applied using a Swingfog using one of three treatment regimes:

1. Half rate. CIPC applied on four occasions, at a rate of 0.25l per 12-tonne capacity store, with a four week application interval (applications at 0, 4, 8 and 12 weeks)
2. Full rate. CIPC applied on two occasions, at a rate of 0.5l per 12-tonne capacity store, with an eight-week application interval (applications at 0 and 8 weeks).
3. Double rate. CIPC applied at a rate of 1l per 12-tonne capacity store at the beginning of the study (application at 0 weeks)

Ventilation following CIPC application in all treatments occurred 8 hours post application. CIPC treatments were carried out in duplicate and samples from all treatments were combined, in a single store, between applications. Additional, untreated samples were assessed for sprout growth.

Fry colour and defects of samples from all treatments was assessed just prior to, and 7 days after applications in the half-rate treatment (treatment 1 above). Fry colour and fry defects assessments of crisps were made using a modified sampling procedure, with 300g raw slice samples obtained at a rate of 1 slice per tuber, as opposed to the usual 3-4 slices per tuber, in an attempt to reduce the variability associated with this assessment. Other details for crisping and methods for preparation of chips were similar to that used in previous work.

Three tuber sub-samples were obtained from all treatments approximately 24 hours after applications in the half-rate treatment. These were used for CIPC residue analysis at GU by the standard method.

Efficacy of sprout control was assessed after an extended period of storage, and when sprouting had become established.

## Results

The duration of application was affected by CIPC dose rate (c.2 minutes for the half-rate treatment, up to c.6 minutes for double-rate treatment). As a consequence, considerable differences in head-space ethylene concentrations were observed (Table 6) with values in the range 5-10ppm, 10-30ppm and 30-50ppm eight hours after application in half, full and double rate treatments respectively at the first application. Carbon dioxide was only detected in the double rate treatment (HiTech Instruments GasLog 6000, with a sensitivity of 0.1%)

| CIPC dose rate | ethylene (ppm) | carbon dioxide (%) |
|----------------|----------------|--------------------|
| double         | >50            | 0.4                |
| double         | 30-50          | 0.2                |
| full           | 10-30          | 0.0                |
| full           | 30             | 0.0                |
| half           | 5-10           | 0.0                |
| half           | 5-10           | 0.0                |

TABLE 6 STORE HEADSPACE ETHYLENE AND CARBON DIOXIDE CONCENTRATIONS EIGHT HOURS AFTER HALF, FULL AND DOUBLE RATE CIPC APPLICATIONS.

Changes in the dose/frequency of CIPC application did not have an overriding influence on fry quality of cv Lady Rosetta (Fig. 7) with all treatments resulting in samples with light fry colour and low defects levels throughout storage.

With cv Saturna small changes in fry colour occurred as a result of the modified CIPC application regimes (Fig.8). At the final assessment occasion (application period 4) fry colour was lightest in those treatments where the number of CIPC applications was reduced (full and double dose treatments). Although there was a tendency for the double dose treatment to result in lower levels of fry defects late in storage, overall levels of defects were low and variability associated with this assessment remained high.

The effect of modified treatment regimes on the fry colour of cvs Maris Piper and Pentland Dell (Figs 9 and 10, respectively) was modest and all treatments easily resulted in commercially acceptable product. With both cultivars though, there was an improvement in fry colour at the end of storage where frequency of CIPC application was limited (Full and double dose treatments). The greatest differences in fry colour occurred prior to completion of treatments (application period 2) and not at the end of storage.

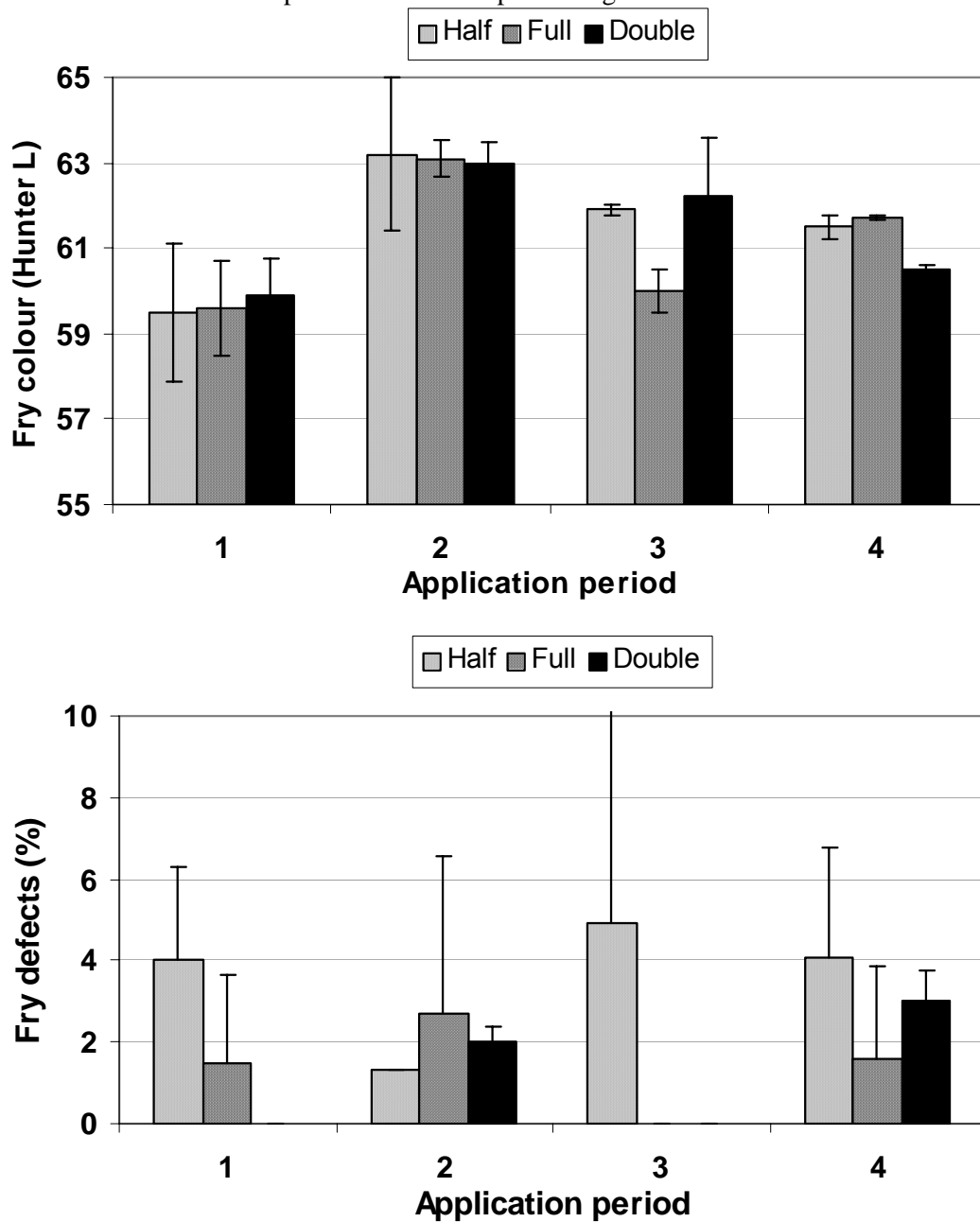


FIGURE 7 FRY QUALITY OF CV LADY ROSETTA IN MODIFIED CIPC APPLICATION REGIMES.

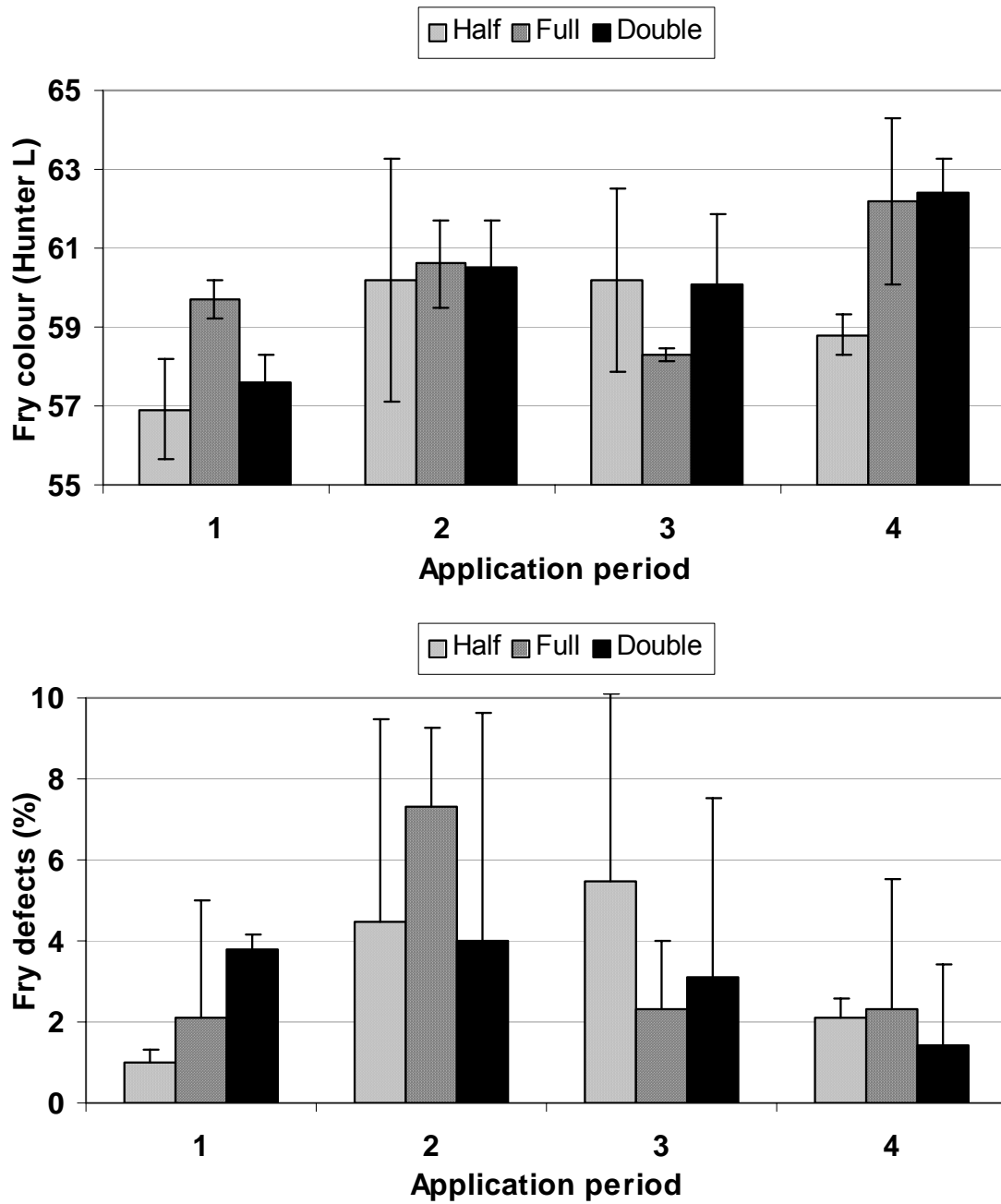


FIGURE 8 FRY QUALITY OF CV SATURNA IN MODIFIED CIPC APPLICATION REGIME

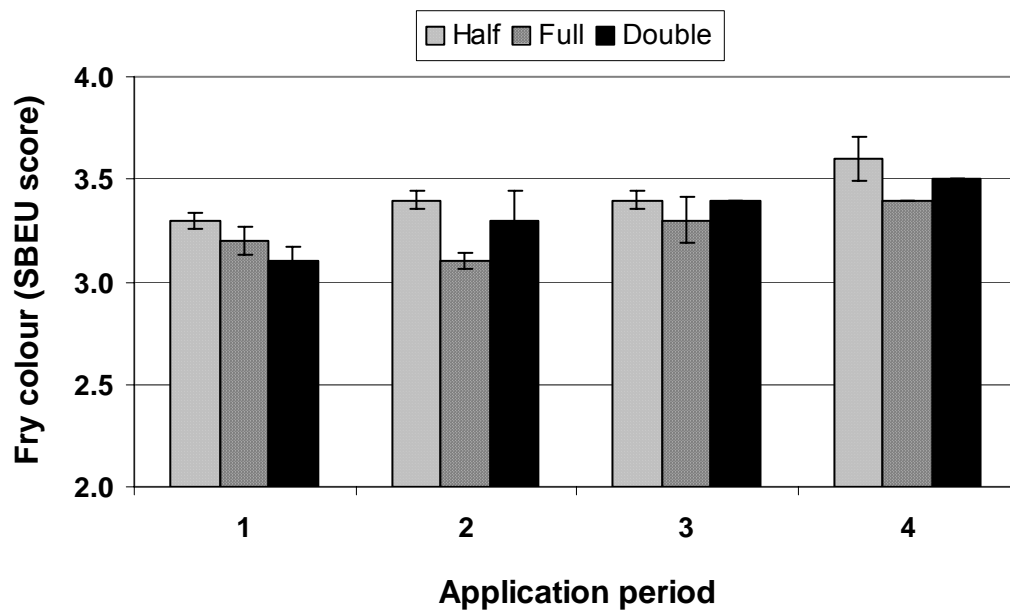


FIGURE 9 FRY QUALITY OF CV MARIS PIPER IN MODIFIED CIPC APPLICATION REGIME

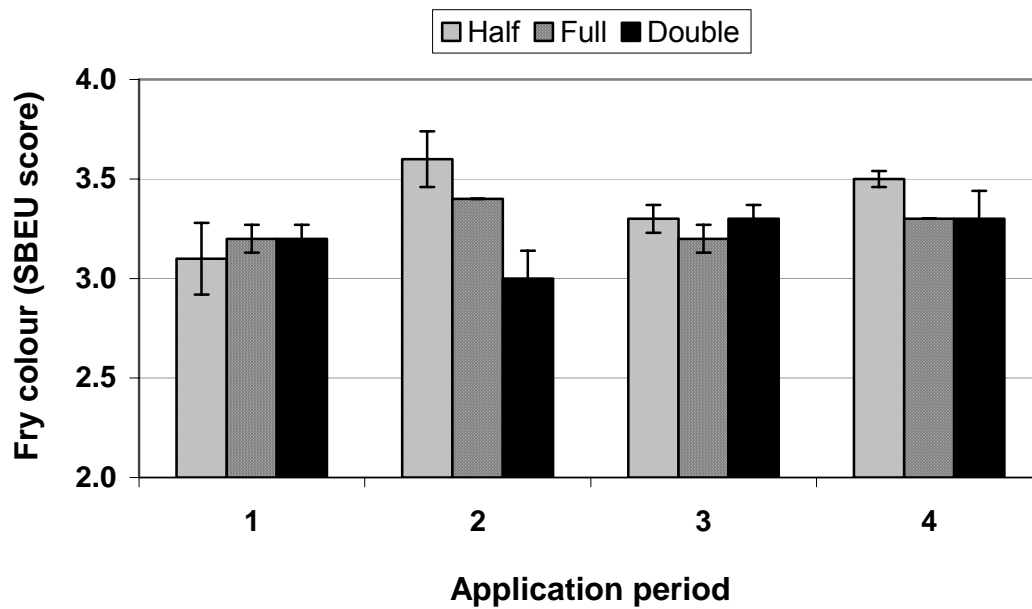


FIGURE 10 FRY QUALITY OF CV PENTLAND DELL IN MODIFIED CIPC APPLICATION REGIMES



Results of CIPC residue analysis of all four cultivars are shown in Fig 11. Samples were collected from all treatments, 24 hours after applications in the half-rate treatment regime. Samples were derived from small scale (20kg) storage trays; hence values are greater than those seen in commercial situations.

Initial applications resulted in relatively high residue levels in the double-dose treatment, and lower values in the half-dose treatment. Regular re-applications of CIPC in the half-rate treatment gradually increased residue levels, while samples in the double-rate treatment were characterised by no change or a gradual decline in residue level during storage. Residue levels, at the end of storage, tended to be lowest in samples from the double-dose treatment.

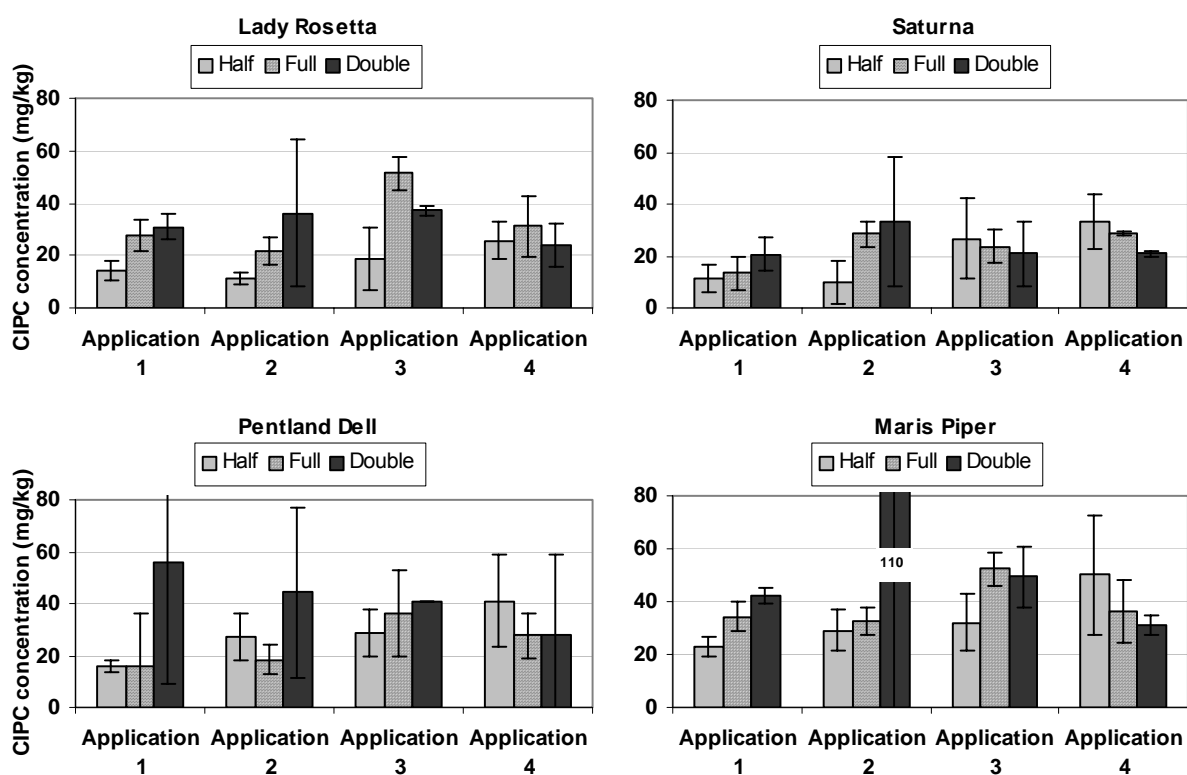


FIGURE 11 MEAN CIPC RESIDUE CONCENTRATION (WITH 95% CONFIDENCE INTERVAL) OF SAMPLES FROM MODIFIED CIPC APPLICATION REGIMES.

Sprout growth of all cultivars (Fig 12) was maintained at very low levels and was unaffected by the modified CIPC application regimes.

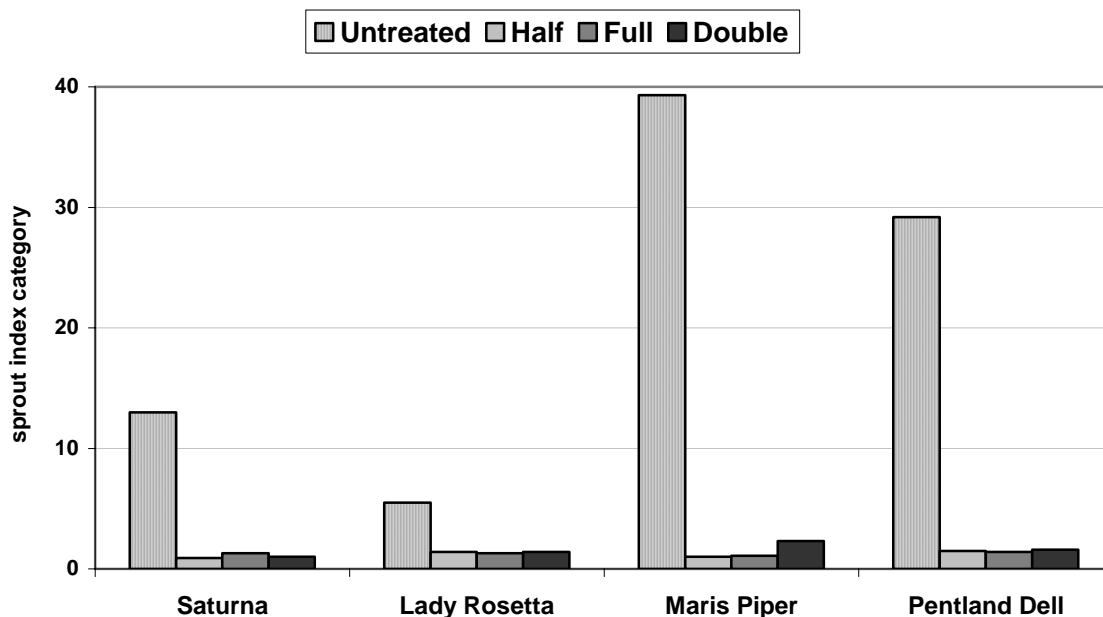


FIGURE 12 MEAN SPROUTING INDEX (BASED ON LONGEST LENGTH)

## Discussion

In previous work with cv Saturna regular re-application of CIPC resulted in a marked deterioration in fry quality at the end of storage (BPC Study 208). In that work, however, as was more common then, ventilation of stores took place 24 hours after applications. In this work, ventilation of stores was carried out 8 hours after application, as is now routine.

Early ventilation (c.8hours) of stores has already been demonstrated to be an effective method for limiting deterioration in fry quality. However, the responses to only a single application of the sprout suppressant have previously been characterised. In many situations, particularly during long-term storage, the chemical is used repeatedly, and there is therefore scope for quality deterioration as a result of repeated exposures to ethylene, albeit for a shorter duration.

With ventilation taking place after 8 hours, CIPC application frequency did not have an overriding impact on processing quality, whether this was applied once, as a large dose, or regularly, in the form of a series of small doses. Differences in quality from imposed treatments in this work were very small compared with previous work using a 24-hour ventilation interval. The data indicates, however, that application frequency does still have an influence. In three of the four cultivars tested, fry colour at the final sampling occasion was significantly lighter in treatments where frequency of application was reduced by the use of larger doses.

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Although early ventilation of stores mitigates the impact of fogging, quality is likely to be improved when the number of fog applications is limited, and, in commercial situations, where efficacy of sprout control permits, this is recommended. In small scale trials efficacy of sprout control was unaffected, and residue levels lower, when the number of CIPC applications was reduced.

## Controlled release of CIPC

Practical work completed in the first two years of this project lead to the conclusion that a vapour source of CIPC could potentially inhibit sprout growth under the right conditions.

Through storage trials with commercially produced experimental CIPC formulations, it was determined that not only surface area but also air movement and temperature differentials were critical in the behaviour of and thus effectiveness of CIPC.

During the third year of this project, studies of controlled release formulations have focused on laboratory-based trials, providing a closely monitored environment. These small-scale experiments make it easier to test individual factors, but the results cannot be directly extrapolated to larger stores without considering the effect that scale has on patterns of air flow, contact with surfaces etc. Linked BPC projects study 258 ('Use of modelling techniques to predict the distribution of vapour and particulate CIPC in potato stores') and study 243 ('CIPC application and environmental issues') address these related issues, while this project has concentrated on the source of CIPC release.

The results from each experiment have been progressively built upon to further develop a suitable formulation and storage environment that allows good sprout control with reduced CIPC residues.

### Formulation requirements

It is essential that any controlled release formulation has a high CIPC loading capacity and a good release profile in relatively cold and moist conditions. To achieve this the CIPC must

have a high surface area

be located appropriately in or on the material, allowing it to sublime and act as a source

A formulation is required to provide CIPC that will persist over a number of weeks or even months yet will leave only a low residual concentration on tubers. Therefore a careful balance needs to be found between CIPC availability and persistence.

Ideally a flow of CIPC would be available constantly to maintain a saturated vapour around the tubers even in dynamic airflow conditions. This involves CIPC continually being taken out of vapour and adsorbed onto available surfaces (building up a residue on tubers) as it passes by. However if a continually available source is present in the right conditions theoretically a saturated or near saturated vapour will be maintained because the equilibrium will tend towards generation of CIPC from the source to replace that which has been lost by adsorption. Therefore the sublimation of CIPC from the source has to be energetically more favourable than sublimation from the adsorbed sites on tubers and other surfaces.

## Experiment 1 Investigation of a vapour formulation of CIPC

### Objective

To assess the suitability of Cotton Scrim material as a support and release media for CIPC in a short-term storage trial.

### Experimental design

Cotton scrim ([www.artex-bluehawk.co.uk](http://www.artex-bluehawk.co.uk)) was used as a support media for CIPC (sprayed on in a methanol solution). It has an inherently high surface area (Fig 13). The CIPC should be readily available as it is on the surface of the material rather than inside of it. The cotton scrim was wrapped around each basket of tubers

Movement of CIPC was only possible through the vapour phase as the scrim was not in direct contact with the tubers at any point.

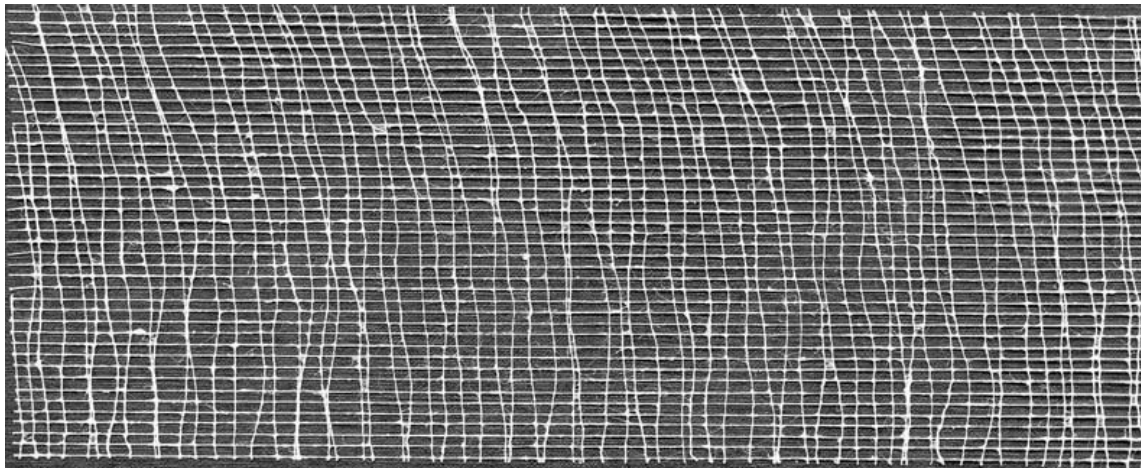


FIGURE 13 COTTON SCRIM MATERIAL USED AS A SUPPORT MEDIA FOR CIPC (TO SCALE)

### Materials and Methods

In October 2004 a storage trial was conducted at GU for 11 weeks (loose skinned Maris Peer c.10°C). 5kg lots of tubers were placed inside open weave plastic baskets (aquatic planting baskets with extra ventilation holes added).

The cotton scrim was measured and treated with CIPC in a high concentration methanol solution. After application the material was allowed to air dry for approximately 20 minutes. Each basket was wrapped with 5.75m of cotton scrim (non CIPC treated baskets were wrapped in untreated scrim material). Airflow through the baskets was not impeded by the presence of the scrim.

After analysis of the material following CIPC treatment it was determined that each CIPC treated basket was wrapped with material equating to a dose rate of 1.25mg/kg on a fresh potato weight basis (see Appendix 1).

The treatments were:

Non CIPC treated static air (no replication)

Non CIPC treated constant 6ml/min air flow (2 replicates)

CIPC treated static air (3 replicates)

CIPC treated constant 6ml/min air flow (no replication)

CIPC treated constant 6ml/min increased to 58ml/min air flow after 4 weeks of storage (2 replicates)

Experiments in the 2<sup>nd</sup> year of the project indicated that CIPC distribution improved with airflow distribution. Replication was restricted due to equipment and space. Originally the CIPC treatments had three replicates each and the restrictions were carried out in the control treatments. After 4 weeks two of the air pumps had broken and were replaced with 58ml/minute pumps, hence there is only one replicate at 6ml/min and two replicates at 58ml/min for the CIPC treatments (6ml/min was the maximum rate of the original pumps and 58ml/min was the minimum flow rate of the replacement pumps).

Each basket was placed inside a larger box thus each basket had its own headspace and was not in any way contaminating or being contaminated by other treatments. Regular manual ventilation was provided to supply fresh air.

After 6 weeks of storage a proportion of tubers from each basket had to be removed due to rot. The weights and tubers numbers were recorded and added to the number of rots counted out from each basket at the end of the trial.

After 11 weeks of storage every tuber from each basket was assessed for efficacy by means of:

Number of eyes open

Maximum sprout length (mm)

Percent of tubers sprouting (per basket)

Depending on the number of tubers remaining 11 or 12 tubers were collected per basket (CIPC treated baskets only) for CIPC concentration. These were solvent extracted using a standard GU soxhlet method and analysed by GC-FID.

## Results

Where error bars are shown on graphs they are +/-95% Confidence Intervals. Different letters above columns denote significant differences (95% confidence level).

CIPC vapour was transported from the scrim material through the vapour phase and accumulated on the surface of the tubers throughout the boxes. The uptake rate of CIPC was quite high considering the application rate of approximately 1.25mg/kg

Residues varied from approximately 0.1ppm up to 6ppm with the mean concentrations for each treatment given.

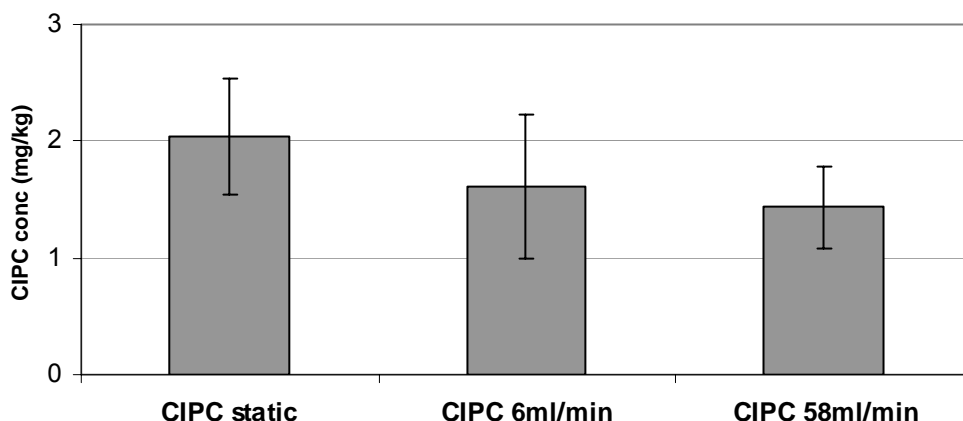


FIGURE 14 MEAN CIPC CONCENTRATION ON TUBERS RESULTING FROM SCRIM VAPOUR TREATMENTS

Although the differences between treatments are not significant there is a general trend of higher residues within the static system. The highest of these values were located near to the edges of the baskets (closer to the scrim material), but there was not sufficient replication to confirm this pattern. There was less variability within the values from the 58ml/min airflow baskets than any other treatment i.e. the spread of CIPC concentration values was smaller with the higher airflow rate.

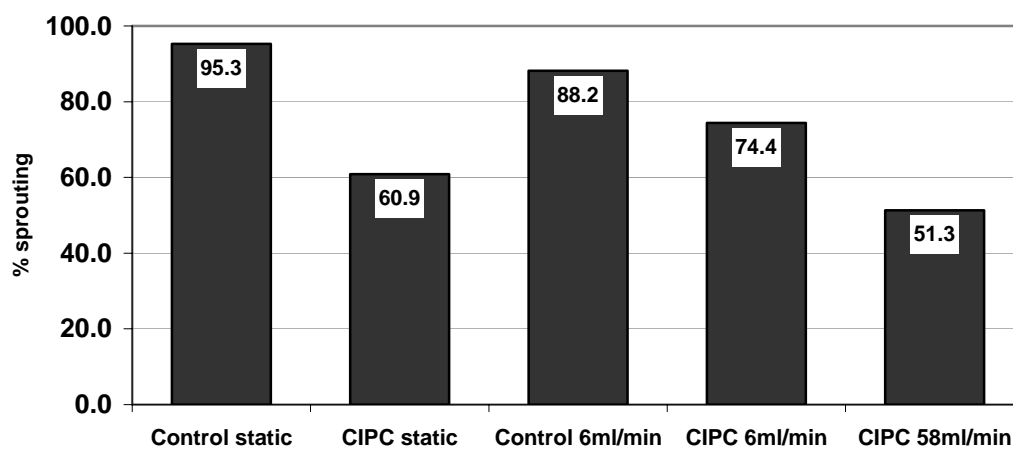


FIGURE 15 EFFECT OF CIPC VAPOUR TREATMENT ON TOTAL PERCENT OF TUBERS SPROUTING

Static vapour application in these conditions reduced sprouting from c.95% to c.60%. When airflow was included the control treatment (6ml/min) had c.88% sprouting. Adding CIPC to this flow rate reduced sprouting to c. 75% but when the flow rate was increased to 58ml/min the CIPC vapour reduced sprouting down to c.51%. Although CIPC control is thought to be aided by air distribution the 6ml/min CIPC treatment did not reduce sprouting to the same extent as the static CIPC treatment. 6ml/min may not be sufficiently high enough to encourage CIPC all around the baskets, but it would reduce the effect of bulk temperature rising through the 5kg basket. The static system would be subject to natural upward movement of warmer air through the

tubers, which could have distributed CIPC better than a low air recirculation pulling downward through the pile. The 58ml/min airflow was the most effective treatment indicating that at this flow rate CIPC was circulated around the baskets more, but still only managed to completely inhibit sprouting in half of the treated crop.

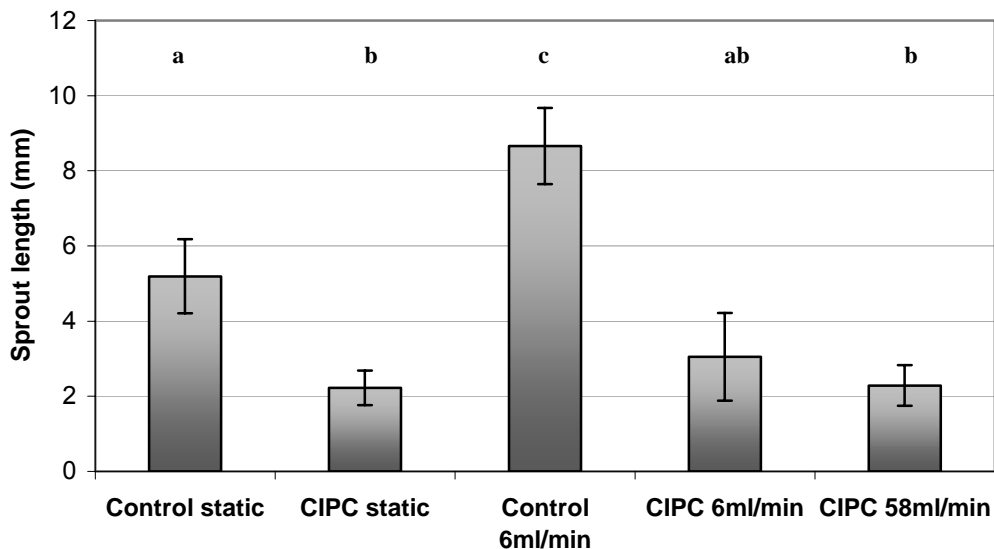


FIGURE 16 EFFECT OF CIPC VAPOUR TREATMENT ON MEAN MAXIMUM SPROUT LENGTH

Of the tubers that were sprouting both control treatments had the longest sprouts indicating again that some control was possible through this vapour phase treatment of CIPC. Although the maximum sprout length was not significantly less for the 58ml/min treatment than for the other CIPC treatments it was the most successful because it had the greatest number of non-sprouting potatoes.

Comparing the maximum length and the number of eyes open demonstrates the pattern of inversion between them.

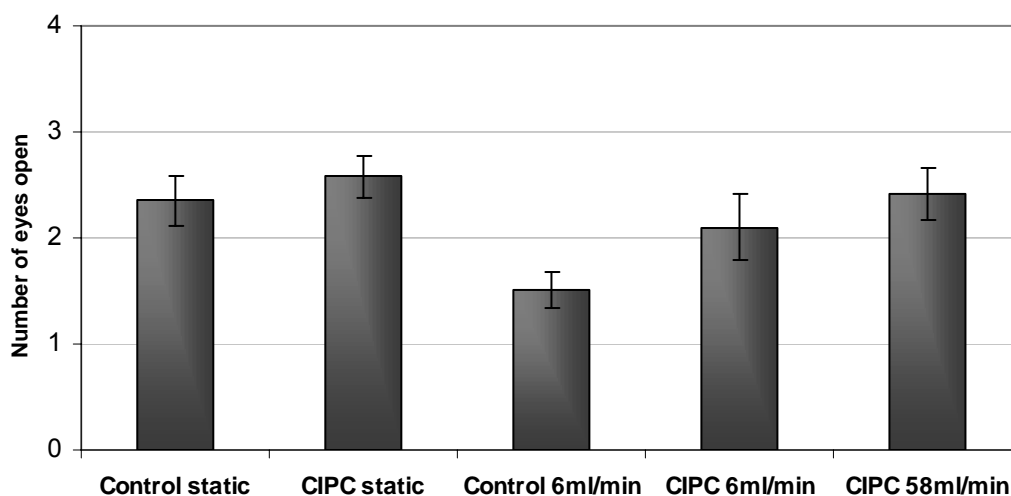


FIGURE 17 EFFECTS OF CIPC VAPOUR TREATMENT ON MEAN NUMBER OF EYES OPEN



The 6ml/min control treatment encouraged elongation of sprouts rather than appearance of new sprouts at other eyes. The addition of CIPC to airflow prevented this from happening. Instead the maximum sprout length remained small and the number of eyes opened remained similar to the static treatment.

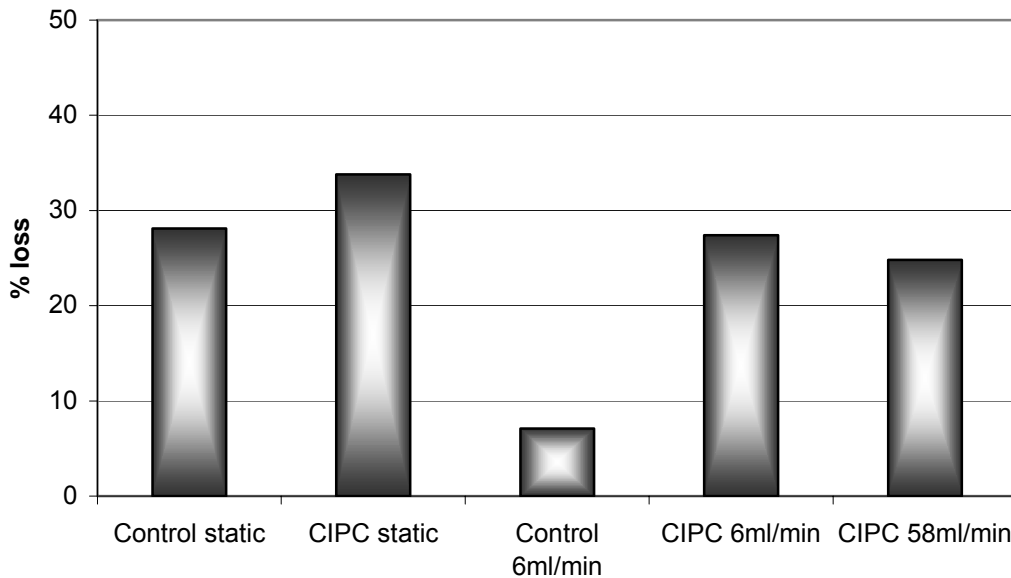


FIGURE 18 TOTAL PERCENT OF TUBERS LOST BY ROT

A considerable proportion of tubers were lost due to rotting in this experiment (this is accounted for in the data presentation). Deliberate recirculation of air within boxes was beneficial in reducing losses, but the presence of CIPC appeared to have nullified this effect. As these were a loose skinned crop it is likely that CIPC was interfering with the suberization process and leaving these tubers more susceptible to rot.

## Discussion

CIPC treatment reliant upon vapour movement did exert sprout control with and without added airflow, but was most effective at the airflow rate of 58ml/min. The results indicate that when airflow was at 6ml/min the CIPC did not perform as well as it had within the static system.

The air movement in the dynamic treatments helped to even out the CIPC distribution around the baskets, but did not significantly increase the deposit values.

The rate at which sublimation of CIPC from source into vapour occurs is influenced by air speed and by the existing vapour concentration (not measured in this experiment). It is clear that at 58ml/min sprout control was improved but it is not certain whether this was solely the result of better distribution of vapour or if it was in combination with an enhanced sublimation rate. In theory deliberate airflow would increase the rate of formation of vapour above that in a static system. Initially this would have been the case, however the limitation occurs when the saturated vapour

concentration is reached (approximately 0.1ug/l at 10°C). For vapour formation to continue CIPC has to be taken out of the existing vapour and cause the concentration to reduce, therefore the incentive for source CIPC to sublimate still exists. Hence when CIPC is taken up by tubers the equilibrium tends towards vapour generation from particulate CIPC. In practice a constantly dynamic situation of CIPC vapour generation and uptake by tubers (or any other potential absorption site) develops. Airflow rate and pattern dictate the degree to which this evens out distribution.

The effect of air movement at the edges of the basket is likely to have been less than in the centre (the pump intake was positioned in the centre of each basket and was pulling air in through the tubers). Thus if airflow was not even throughout the baskets, CIPC vapour movement would not have been even either. However the sprout suppressant activity of CIPC still benefited from the uneven air movement at 58ml/min.

The preparation of the support material (scrim) could have caused a glazing effect of the CIPC and thus reduced the surface area somewhat. The outcome would be slower sublimation and potentially a delay before adequate CIPC vapour levels were established to actively curb sprouting. If this were the case it would affect all of the CIPC treated baskets and in the early period of storage (when eyes were starting opening) only the air movement would have influenced the sprouting pattern.

It is concluded from this data that CIPC vapour treatments of this type can be effective in combination with air recirculation. However the success of a treatment may be increased with a higher flow rate/better recirculation and an improved CIPC source that is immediately available (providing crop is not loose skinned) and in the form of discrete high surface area particles.

Based on the results of this work another storage experiment was conducted at GU. In this trial action was taken to reduce rotting by using more physiologically mature crop with well set skin. Ventilation and air recirculation were increased. The CIPC source was altered to incorporate a further controlled release element that also helped to maintain the CIPC in discrete particles avoiding any potential glazing effect.

## **Experiment 2 Investigation of a modified vapour formulation of CIPC in a dynamic airflow**

### **Objective**

Continued: To assess the suitability of Cotton Scrim material as a support and release media for CIPC in a short-term storage trial.

And further;

To determine if the CIPC release profile and subsequent pattern of sprout growth inhibition was different when the CIPC was formulated in a 2% Alginate solution compared with a methanol solvent.

### **Experimental design**

Alginate (alginic acid) is a natural viscous gum extracted from the cell walls of brown seaweed. Its properties are utilized in foods, pharmaceuticals, dentistry, prosthetics and textiles. Alginate is one of the most versatile biopolymers. Its many uses include mould-making, film forming, gelling, stabilizing and thickening. In this experiment it is used as a support media for CIPC in the form of a gel.

The availability of CIPC will be different from each formulation.

Alginate: CIPC is steirically held within the chemical structure (between monomers). in discrete form throughout the matrix of the alginate gel. It should therefore have a relatively larger surface area when applied as an alginate formulation compared with a methanol formulation. As the alginate dries over time fresh CIPC is exposed at the surface of the gel, hence the alginate performs as a slow release agent.

Methanol: CIPC is dissolved in the solvent and both are applied as a uniform solution. This may result is a fine glaze of CIPC on the cotton after the methanol has evaporated, hence a relatively smaller surface area, making vapourisation of CIPC a slow arduous process. The results from the previous experiment suggested that application in methanol in this way could have resulted in a fine glaze of CIPC across the surface of the cotton fibres. In this situation only the surface area of the scrim would be assisting the rate of CIPC vapourisation. Hence the rate of sublimation from the surface area of a 'glaze' will be slower that it would be from the equivalent amount of CIPC in the form of discrete particles. All of the CIPC is exposed from the start of the trial and only the rate of vapourisation will determine how soon the pool is depleted.

**Hypothesis:** the CIPC in alginate will be more readily available because of the greater surface area and will provide a source of CIPC for a longer period of time.

5kg of tubers (cv Sante) was placed into each of the nine ventilated plastic aquatic planting baskets. These were wrapped with 5.75m of cotton scrim material (either treated with CIPC in methanol, CIPC in Alginate, or an untreated control). The cotton scrim has been shown to effectively release CIPC at approximately 10°C when sprayed with a methanol CIPC formulation (expt 1).

Each treatment was replicated three times.

The treatments were:

Untreated control

Cotton scrim/CIPC in methanol (1.75mg/kg application rate-see Appendix 2)

Cotton scrim/CIPC in a 2% Alginate solution (1.75mg/kg application rate)

Each basket was placed inside an outer plastic container therefore each lot of tubers had their own air space to prevent cross contamination of CIPC vapour between treatments and replicates. There were nine containers in total.

A constant supply of fresh air was delivered into each container and the air was constantly stirring with a fan.

The potatoes were stored in the dark for an 8-week period between May –June 2005.

## Materials and Methods

The appropriately treated cotton scrim material was wrapped around the sides of each basket to cover the entire height of the sides. It was secured in place with thin wire. The baskets were labelled and placed into larger containers.

Each basket of tubers was placed inside a 47.38l plastic container [Inner dimensions 470mm (l) x 360mm (w) x 280mm (h)] on top of two foil-covered feet. The feet elevated the baskets from the base by approx 2cm, allowing air flow around and through the bottom of the basket.

A fresh air line was positioned in the centre of each basket and feed through the wall of the outer container from the airflow control regulator. The lid was placed on top of each container and sealed properly to ensure complete isolation of the container air from ambient.

There was an air outlet hole in the side of the outer boxes to permit airflow and prevent a build up of pressure in the containers. The containers that held a CIPC treatment were fitted with a Tenax-TA trap to collect any CIPC leaving when the container atmosphere was exchanging. This further prevented any contamination of ambient air with CIPC.

Fresh air was delivered into each plastic container at a rate of 33ml/minute. This was supplied from a compressed air cylinder (size S, 34kg, 3.5m<sup>3</sup>) via a Gas Chromatography flow controller (PYE Unicam) with additional flow regulators fitted inline to further reduce the flow. Two manifold connectors had to be used to provide air to all nine containers. The air cylinder was replaced weekly to provide adequate supply for all containers throughout the trial (33ml/min x 60 minutes x 24 hours = 47.520l/day/container). The daily air consumption was 47.520l/container, equalling 427.68l/day. Therefore in seven days the volume of air required was 2993.76l.

A ball bearing axial fan (Sunon, 220Volts, 14Watt, 120x120x25mm, 37dBA, 79.8m<sup>3</sup>/h, RS, Electrical & Automation, 380-6019) was positioned in the centre of the underside of each of the container lids. The fan diameter covered 120mm of the 280mm wide baskets (tuber surface). The air thrown from the fan (positive pressure-air blown over the potatoes) covered almost all of the 280mm square basket area, save the very corners, which may not have been hit directly with the first stream of air from the fan. The fan throughput (79.8m<sup>3</sup>/hour  $\equiv$  79800l/hour) was sufficient to recirculate the container air more than 1500 times per hour.

The fans were on continuously and the high flow rate maintained a dynamic airflow around the containers throughout storage.

The temperature in the storage room was monitored throughout storage by dual readings taken every 14 minutes (one at low level and one at high level in the store). Temperature fluctuated with ambient conditions as seasons changed. Starting at approximately 15°C and by the end of the trial the maximum reached was 23°C, with diurnal fluctuations.

After 8 weeks of storage every tuber from each basket was assessed for efficacy by means of:

Number of eyes open

Maximum sprout length

Percentage weight of sprouts

Percent of tubers sprouting (per basket)

Depending on tubers numbers remaining 11 or 12 tubers were collected per basket (CIPC treated baskets only) for CIPC concentration. These were solvent extracted using a standard GU soxhlet method and analysed by GC-FID.

Weight loss was also measured for each basket.

## Results

Where error bars are shown on graphs they are +/-95% Confidence Intervals. Different letters above columns denote significant differences (95% confidence level).

CIPC vapour was transported from the scrim material through the vapour phase and accumulated on the surface of the tubers throughout the boxes. Both CIPC treatments had a mean residue value of less than 0.5mg/kg. The variability of residual CIPC levels was greater with the methanol treatment than it was on those tubers treated with the alginate formulation.

Research Report: Review & development of the CIPC application process and its impact on potatoes stored for processing

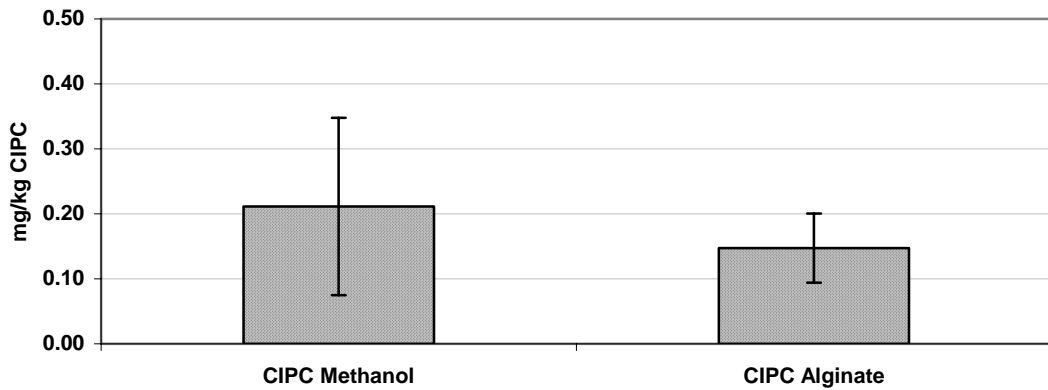


FIGURE 19 MEAN CIPC RESIDUE CONCENTRATION

Mean weight loss throughout the 8 weeks of storage varied across treatments between c.17 and 22.5%.

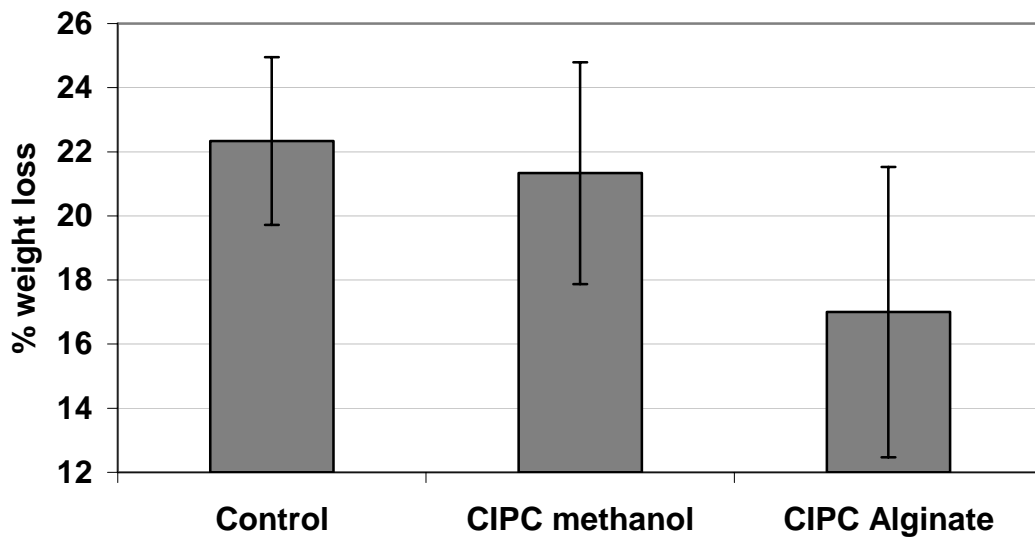


FIGURE 20 MEAN WEIGHT LOSS DURING STORAGE

100% of the crop sprouted in each treatment. When the crop was received it was noted that it was all ready to sprout imminently because of the time of year and the lack of any previous sprout suppressant treatment.

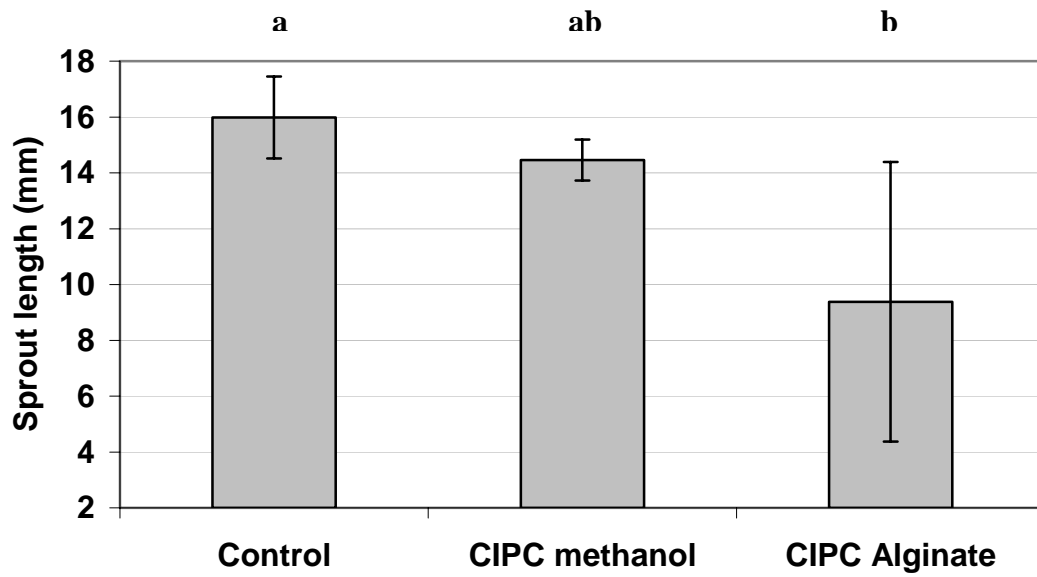


FIGURE 21 MEAN MAXIMUM SPROUT LENGTH (MM)

The CIPC alginate treated tubers had significantly shorter sprouts than the control treatment. Therefore even with the considerable variability observed within the alginate treatment it was still an effective method of curbing sprout growth.

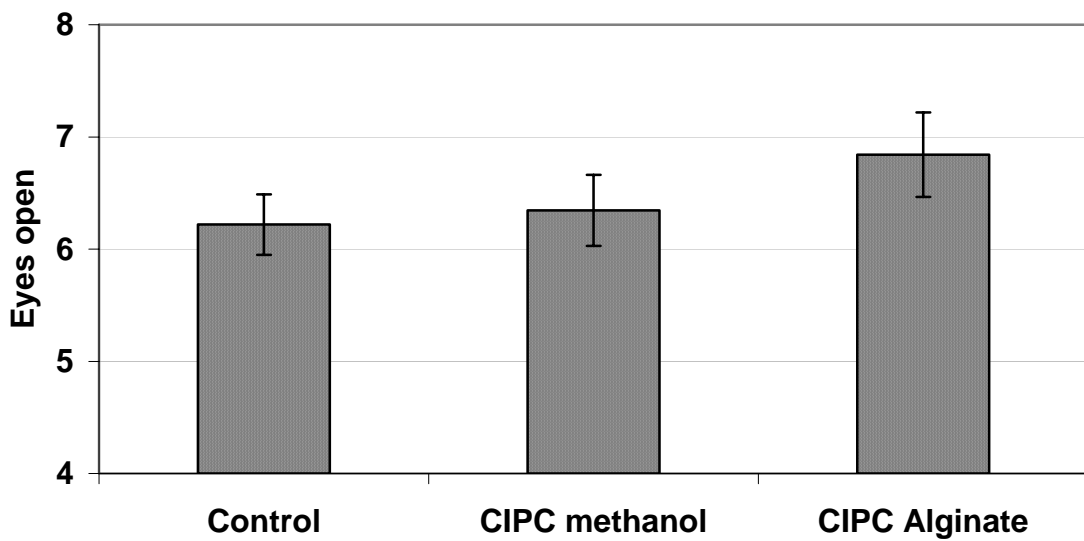


FIGURE 22 MEAN NUMBER OF EYES OPEN

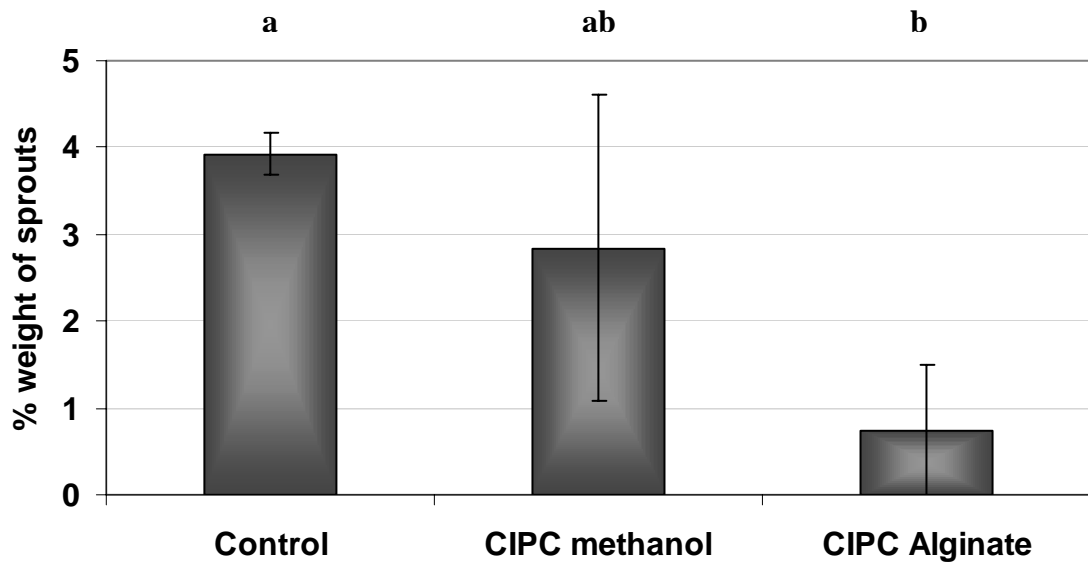


FIGURE 23 MEAN WEIGHT OF SPROUTS

The CIPC/alginate treatment resulted in a significantly lower percentage weight of sprouts than the control treatment.

The variability in this measurement for the alginate treatment is much less than in the sprout length assessment. This is likely to be a consequence of the status of the crop at the start of the trial in that sprouting was imminent in 100% of tubers. Thus the number of eyes open in each treatment was statistically the same and the variability in the sprout lengths was more widespread. However the actual energy given over to sprouting by the tubers in terms of weight of sprouts was far less in the alginate treatment. Therefore measuring % sprout weight was more meaningful in this trial.

The cotton scrim material from around each basket was analysed after the end of the trial for the remaining CIPC content. The results given below are expressed as the percentage weight of CIPC available compared with the application concentration at the start of the trial.



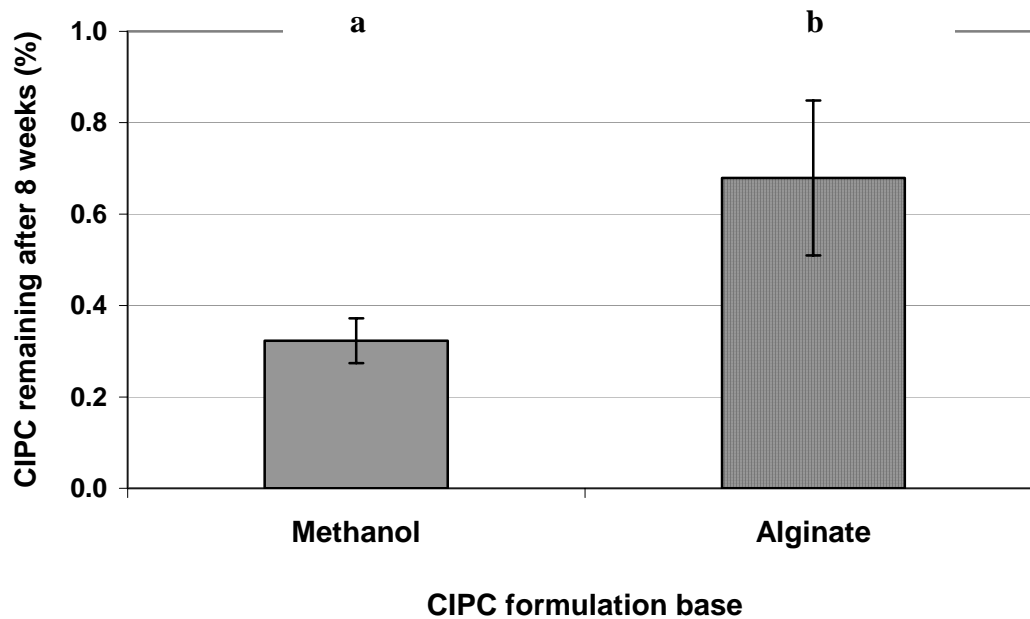


FIGURE 24 MEAN CIPC CONCENTRATION REMAINING AVAILABLE AT THE END OF THE TRIAL (%)

By the end of the trial both formulations still contained a proportion of the CIPC they were initially treated with (methanol formulation had c.0.3% and alginate formulation had c.0.7%). Although both values are generally quite low the alginate formulation did retain significantly more CIPC than the methanol formulation over the eight-week period because of its aforementioned controlled release properties.

## Discussion

The high rate of air movement contributed to the low residue values on the tubers themselves. The excessive air speed would have negatively influenced the ease with which CIPC was absorbed by the tubers, essentially blowing it straight past without allowing an equilibrium to establish.

The operating fan speed was calculated to be approximately two hundred times faster than that in a normal commercial store (*Adrian Cunnington, personal communication*). At the time of trial set up the options were limited for suitable fans that would fit into the containers already existing from the previous trial. It was important to get as even a flow as possible, and to do this as wide a fan diameter as would fit onto the underside of the outer box lids was used, however this was limited by the load bearing capacity of the lids. In May it was impossible to delay the start of the trial because the crop was already straining to be kept under control. Therefore there was no time allocated to reducing the fan output by restricting the intake volume. Ideally this would have been in place before the trial started. Also it would have been preferable to have the fans pulling air through the tubers rather than the positive pressure system of blowing it over them. However there was plenty of air recirculation throughout the entire box including all the corners.

There was very little spread in the CIPC residue results for both treatments. The high throughput of air has caused a fairly even distribution of CIPC albeit at lower levels than expected.

In terms of sprout control ability the CIPC/alginate formulation performed well under these conditions of high and fluctuating temperatures, particularly high airflow rate and tubers that already had eyes open.

The alginate formulation resulted in a significantly lower maximum sprout length and more importantly a significantly lower percentage weight of sprouts than the control. It performed better than the methanol/CIPC formulation although it could not be shown to be a significant improvement. The methanol formulation was not on any occasion significantly different to the control treatment.

The controlled release properties of the alginate and the greater surface area of available CIPC held within its matrix have led to a marked improvement in the effective sprout control possible with vapour-type CIPC formulations.

Normally alginate gels are prepared by cross linking the alginate polysaccharides using multicharged inorganic cations, commonly calcium salts (*Shchipunov et al, 2002*). During the initial studies of possible materials calcium alginate beads had been prepared and tested at 10°C and moderate humidity levels, but dried out over the course of a week preventing the CIPC from being released with ease. Therefore in the controlled release studies in the third year no cross linking agent was used. Without it all of the exposed alginate formulation should be able to release CIPC without drying out or having to overcome any physical or chemical barrier. Preliminary tests were carried out and found that the alginate as used in these experiments did not dry out too rapidly in the conditions it was exposed to.

If the conditions were more conducive to commercial scale potato storage (stable temperature, good airflow and crop still in the dormant state) the alginate formulation would have more opportunity to exhibit its expected potential. However it should be noted that maximum benefit would likely be achieved with movement of air that encourages distribution of vapour and maintains a saturated or near saturated dynamic vapour concentration.

The CIPC release profile at 10°C was examined in a quick response cress seed bioassay experiment (Experiment 3, parts A and B). Tubers along with scrim were also briefly tested as a support media for the CIPC alginate formulation. This was undertaken to determine that CIPC would still be released from the alginate formulation while supported on the scrim (or tuber) when it was not exposed to the elevated temperature experienced in this storage trial (15°C +).

### **Experiment 3 Further investigations of a modified CIPC vapour formulation using cress seed bioassays**

#### **Objective**

**Part A:** To determine if the CIPC release profile and subsequent pattern of growth inhibition was different when the CIPC was formulated in a 2% Alginate solution compared with a methanol solvent at 10°C.

**Part B:** To determine whether the ease of release of CIPC from the 2% Alginate solution may be affected by the support material and/or the method of application of the solution.

Potato tubers were used as a support material in this trial to compare the method of application.

#### **Experimental Design**

Cress seeds were used as a quick response indicator of CIPC presence in both trials. The cotton scrim used has been shown to effectively release CIPC at approximately 10°C and 80% relative humidity (RH) and 15°C when sprayed with a methanol CIPC formulation or an alginate CIPC solution respectively.

Each treatment was either duplicated or triplicated depending on equipment and time. There were 15 seeds measured for every replicate.

The lids were opened and the air was allowed to refresh weekly. There was no other air movement involved in this trial; therefore the release of CIPC is not aided by deliberate airflow in either of these experiments.

An equivalent amount of CIPC was applied to each treatment within a trial. It was relatively high on the tubers (c.5250µg), but lower on the cotton scrim wrap material (c.83µg).

Part A: treatments were:

Cotton scrim/CIPC in methanol

Cotton scrim/CIPC in a 2% Alginate solution

Control- no CIPC treatment, no wrap or tubers

Part B: treatments were:

Tuber/CIPC in a 2% Alginate solution-sprayed

Tuber/CIPC in a 2% Alginate solution-dipped

Control- no CIPC treatment, no wrap or tubers

Assessments were taken at two-week intervals for percent germination and shoot length. Each time assessments were done 15 fresh seeds were placed back into the tubs but the CIPC source was not refreshed at any stage.

For assessment the containers were removed from the incubator, opened and all of the cress seeds measured individually. 15 fresh seeds were placed in each container and some additional salt and/or water added to the reservoir if required. The containers were sealed and placed back into the incubator. Each container was not out of the incubator for more than an hour (to minimize CIPC losses from the source material at this higher room temperature, approximately 22°C).

## **Materials and Methods**

The 2 litre plastic, airtight (lock & lock) containers were lined with aluminium foil to minimize the absorption of CIPC onto the walls and base. A reservoir of 30ml of distilled and deionised water was placed in the bottom of each container. Whatman no.1. Filter paper (Ø185mm) was wrapped around the inner shelf (secured with adhesive tape) of each tub to create a flap under each side that sat into the reservoir of water. Before placing the covered shelves in the base of the container a grid was scored into the filter paper using the blunt side of a scalpel to mark the paper without tearing it. A grid of 15 squares, 30 by 30mm, was marked out on the paper (five boxes across at the long side and three boxes across at the short side). The top of each filter paper was wetted with 30mls of water that then drained down the sides and remained in the base as the reservoir. This now performs as a wick system to keep the paper moist and will prevent the cress seeds from drying out.

A cress seed was placed in the centre of each square (15 seeds per container). Using a pattern like this allows the seeds to spaced out and easily identified and assessed for sprout length.

15mls of an aqueous saturated salt solution (di-sodium hydrogen orthophosphate-BDH, analytical grade) was placed inside a small beaker positioned in the corner of each container. This solution will maintain a high RH in the storage air of approximately 80%.

### CIPC applications

Three 20cm lengths of cotton scrim were treated with the one application of CIPC formulation. Both the methanol and the alginate applications were conducted under the same conditions.

Compressed air (~40psi) was used to propel an airbrush applicator (Harbor Freight Tools, Camarillo, CA 93010, Stock no. 1500, airbrush kit). Two separate fume hoods were lined with plastic sheeting and set at low flow while the applications were carried out inside them. The nozzle on the airbrush applicator was fully depressed and pulled back therefore creating the highest throughput of liquid and the largest particle size possible using this system.

The time taken to apply 5ml of 3000ppm CIPC in 2% Alginate solution was considerably longer than taken to apply 5ml of 3000ppm CIPC in methanol due the

difference in solution viscosity. After treatment the strips were left to vent in the fume hood for between 10-30 minutes, before placing into the containers and sealing the lids, ready for storage. A maximum uptake rate of 16.67% is estimated (see Appendix 1 and 2).

#### Tubers-CIPC dipped

Two individual, lightly brushed tubers (cv. Sante) were placed into 9mm diameter crystallizing dishes. 3.5ml of the 3000ppm CIPC in 2% alginate solution was applied drop wise over the surface of each tuber, ensuring complete coverage of the skin. The excess in the bottom of the dish was reapplied over the surface of the tubers using a Pasteur pipette and the tubers themselves rotated to maximize contact between the solution and the skin.

The dishes with tubers in were left in the fume hood at room temperature for approximately 5-10 minutes to allow the alginate to set (dry to the touch) on the tubers surface. The tubers were transferred to pre-cut weighing boats and placed inside the storage containers as described.

#### Tubers-CIPC sprayed

Two lightly brushed tubers (cv. Sante) were placed onto the plastic lining inside a fume hood set at low flow. 3.5ml of 3000ppm CIPC in 2% alginate solution was applied using a compressed air propelled airbrush at 40psi. The lever was fully depressed and pulled back throughout application. The tubers were rotated and turned over to ensure complete coverage of the tuber surface. After application the tubers were left in the airflow of the fume hood for approximately 10 minutes before being transferred into the storage containers as previously described.

The cotton scrim was secured (treated side facing downwards) with a small piece of adhesive tape at either end to the underside of the container lids and the lids replaced on the containers and they were sealed.

The tubers were each placed onto small pre-cut plastic weighing boats that allowed the tuber to rest easily inside. These were placed at the opposite end to the salt solution and acted as a physical barrier preventing CIPC on the surface of the tuber coming into contact with the cress seeds or the filter paper below. The container lids were replaced and sealed.

All the labels were checked and the containers placed into the incubator to start the trial.

The germination rate of the seeds was tested in earlier work and found to be satisfactory (approximately 95-99%).

## Results

The graphs are shown with 95% confidence intervals as error bars.

The mean germination rate was high on all occasions. Although it did drift between 86 and 100% over time and between treatments, no statistical differences in germination rate occurred throughout the trial.

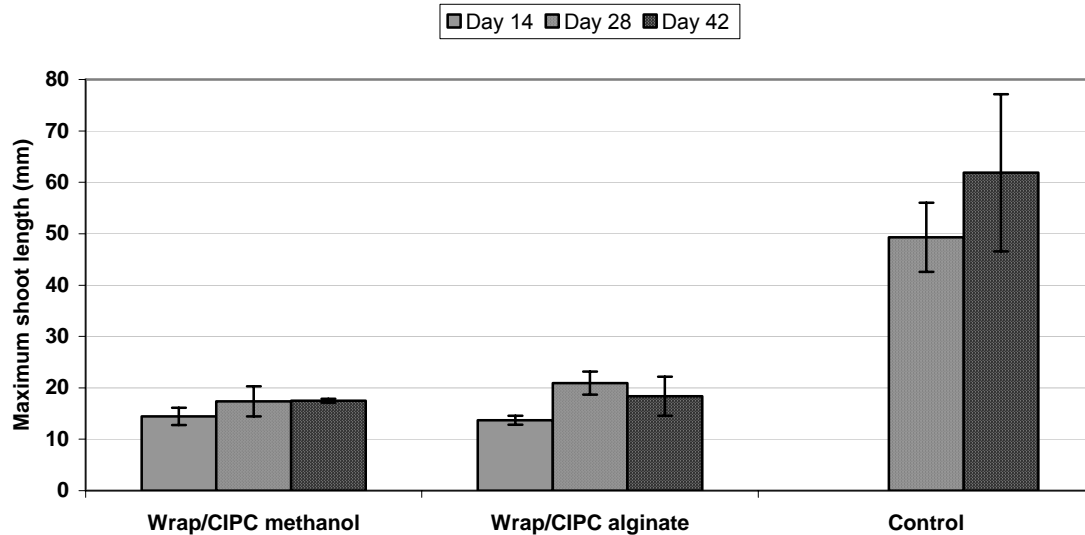


FIGURE 25 PART A: MEAN MAXIMUM SHOOT LENGTH OF CRESS SEED RESULTING FROM CIPC VAPOUR TREATMENT

Both formulations inhibited shoot length by comparison to the control from mean levels of c.50mm to c. 16 – 21mm on day 28 and from c.61 to c.18mm on day 42.

CIPC was released from both methanol and alginate treatments under environmental conditions of 10°C and c.80% RH for the full six-week test period.

The lack of a control treatment in the first 14-day period makes it difficult to decipher whether both formulations performed better in this initial stage of storage or whether there was a common situation of overall less growth throughout this time.

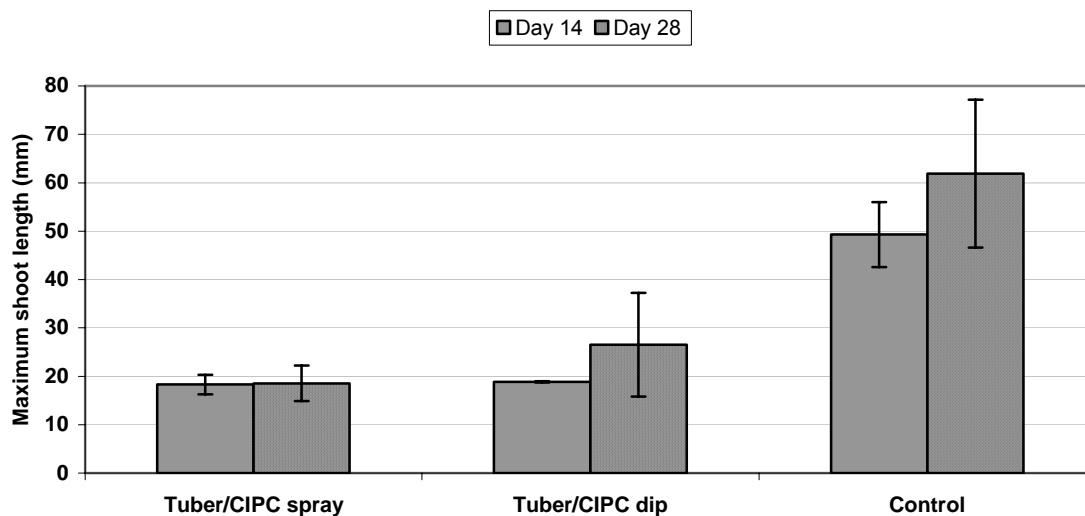


FIGURE 26 PART B: MEAN MAXIMUM SHOOT LENGTH OF CRESS SEEDS RESULTING FROM DIFFERENT APPLICATION METHODS OF CIPC/ALGINATE VAPOUR TREATMENT

The tuber skin was a suitable support for the alginate formulation as it allowed CIPC to be released under the set environmental conditions for the full 28-day testing period.

It is not possible to compare the efficacy here to that of the scrim wrap material used in part A, because more CIPC was applied to the tubers. This was a practical limitation of the experiment.

Both CIPC tuber treatments were statically different from the control, but could not be distinguished from each other. Sprayed and dipped application of CIPC in alginate formulation inhibited mean cress shoot growth by c.64% on day 14 and c.71% and c.57% respectively on day 28.

Inhibition of shoot length by the sprayed tubers was more repeatable over the time course suggesting that spraying creates a more suitable source of CIPC.

## Discussion

In the 6-week test period the release of CIPC from the methanol and alginate formulation was not hindered by environmental conditions expected in a commercial potato store (10°C and c.80%RH).

Normally in commercial facilities regular air movement occurs. The rate of CIPC sublimation is expected to be greater when air movement is introduced to these formulations at this temperature and RH level. Therefore given the lack of air movement both vapour formulations performed sufficiently well in these circumstances.

Both CIPC formulations limited the maximum shoot length of the cress seeds equally well. It is possible that for control of cress seeds the critical concentration of CIPC is less than that for tubers (unknown value). However it is more likely that if it had been possible to include air movement in the experiment the extra benefit of the alginate formulation (higher CIPC surface area) would have resulted in a clearer distinction in efficacy.

Ideally a controlled release formulation would be applied without direct contact with tubers to minimize residues and limit potential damage to the skin. Point sources of CIPC within reasonable proximity to the crop and good control of air movement are the preferred approach.

The possibility of having a concentrated source in one area of an experimental store is being investigated in a linked research project (Study 258). To date it has demonstrated that the effects of air speed, temperature and contact with surfaces (floors, boxes etc) are very important to the behaviour of vapour phase CIPC. While the question of how effective non-tuber applied formulations can be remains unclear, gathering as much information as possible about how potential tuber applied formulations behave is essential.

The alginate/CIPC formulation when applied to tuber skin did release CIPC sufficiently to cause limited growth in emulated potato storage conditions for a 28-day duration.

Spraying creates separate droplets of formulation that set into gel-like spots on the tuber surface whereas dipping creates a continuous cover over the tubers surface. Discrete sections of formulation yield a higher surface area from which CIPC can sublimate than would be the case with a uniform layer. The CIPC from the sprayed application was a more readily available source because of the greater surface area compared with the dipped tubers.

The properties of alginate gels can be modified by the use coatings, filler substances, addition of enzymes etc (*Ertesvag & Valla, 1998, Iskakov et al, 2002, Rassis et al, 2002, Strand et al, 2002*) but it depends upon the starting material and the selection and use of a cross linking agent. If Alginate were considered to be a feasible option for a potential CIPC formulation, a gel could be prepared that was tailored specifically for application at loading and persistence throughout storage.

Controlled release alginate formulations have been tested and found to be helpful in reducing leaching and mobility of a different carbamate pesticide, carbofuran, in soil profiles (*Marei et al, 2000*). Hence there could potentially be an environmental benefit to using alginate formulation of CIPC.



## References

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**Watkins, C.B., J.F. Nock and B.D Whitaker (2000):** Responses of early, mid and late season apple cultivars to postharvest application of 1-methylcyclopropene (1-MCP) under air and controlled atmosphere storage conditions, *Postharvest Biology and technology*, 19, 17-32

## Appendices

The concentration given in the experimental sections is that which the crop was treated with. Similar to a thermal fog application it does not guarantee that the concentration on the material resulting from the application is the same as was applied. Although in this tightly controlled situation it is likely to be close to the applied concentration. The actual residue on crop was tested at the end of the experiment and not immediately after application

### Appendix 1

**CIPC solution: 100ml of 3000ppm CIPC in methanol.** 0.300g CIPC was dissolved in ~50ml methanol in a small beaker with continuous stirring. This was transferred to a 100ml volumetric flask (grade B) with washings (~3-5 times) and made to volume. The solution was shaken end over end several times to ensure complete mixing.

This solution was stored in a fridge at approximately 4°C until required for use. It was brought to room temperature and shaken vigorously end on end before use.

The grid of the scrim was approximately square with some variation. The material is 7.5cm wide. The strand is approximately 0.25mm width with spaces between each strand of approximately 2mm. There are 40 strips across the width of the material therefore 10mm of strand per unit length (40 x 0.25mm). Across 1cm of length of scrim there are 5 strands, equal to 1.25mm of surface area (5 x 0.25mm). Hence in 1cm of strand at width 7.5cm there is 12.5mm<sup>2</sup> of surface area of material.

A 575cm strip of material was used for each basket. It was sprayed with CIPC formulation on one side only. Therefore the surface area of the scrim treated was approximately 7187.5mm<sup>2</sup> (575cm x 12.5mm<sup>2</sup>/cm of length).

If the material sprayed was solid and not a grid type then the surface area would have been 43125mm<sup>2</sup> (575mm x 75mm).

12.5ml of the appropriate 3000ppm CIPC formulation was sprayed over the entire area of each of the cotton scrim strips of 575cm length. This provided a maximum of 37500µg of CIPC. The surface area of the cotton scrim was much less than the treated area and limited the uptake of CIPC.

Scrim surface = 7187.5 mm<sup>2</sup>

Total surface area sprayed = 43125mm<sup>2</sup>

The maximum percentage uptake = (7187.5/43125)\*100 = 16.67%

Therefore of the total volume sprayed only 16.67% could possibly have landed on the materials. 16.67% of 37500µg is approximately 6251.25µg CIPC.

6251.25µg ≡ 6.25125mg CIPC applied to 5kg of tubers, gives an approximate application rate of 1.25ppm (on a fresh weight basis).

Potential sources of loss of CIPC:

CIPC vapour lost as the air is refreshed, unquantified

Uptake of CIPC from the vapour onto/into the plastic surfaces, unquantified

## **Appendix 2**

CIPC solutions

**100ml of 3000ppm CIPC in methanol.** 0.300g CIPC was dissolved in ~50ml methanol in a small beaker with continuous stirring. This was transferred to a 100ml volumetric flask (grade B) with washings (~3-5 times) and made to volume. The solution was shaken end over end several times to ensure complete mixing.

**100ml of 3000ppm CIPC in 2% Alginate solution.** 0.300g CIPC was dissolved in ~2ml methanol in a small beaker with continuous stirring. This was transferred into a 5ml volumetric flask with washings and made to volume, giving a solution of 6% CIPC (60,000ppm). The solution was shaken end over end several times to ensure complete mixing.

The entire 5ml of 6% CIPC in methanol was added slowly with continuous stirring to 2g (pre-weighed) Sodium Alginate (Keltone LV-food grade, International Speciality Products). This suspension was left stirring for a further 45 minutes until all of the methanol was absorbed/evaporated. At this point the semi-solid was broken up in the bottom of the beaker using a spatula to allow a greater surface area to be exposed and more methanol to evaporate. When satisfied that the majority of the solvent had been evaporated off approximately 70ml of water (deionised & distilled) was added slowly with vigorous stirring to create high shear. This mix was left to stir at a high rate until all of the alginate was dissolved. It was then transferred with washings to a 100ml volumetric flask and made to volume. The flask was shaken end on end several times until a viscous solution of uniform consistency was produced.

Both of these solutions were stored in a fridge at approximately 4°C until required for use. The alginate solution should only kept for a period one or two days before use, however the methanol solution will keep for longer. Both solutions were brought to room temperature and shaken vigorously end on end before use.

As before the grid of the scrim was approximately square with some variation. The material is 7.5cm wide. The strand is approximately 0.25mm width with spaces between each strand of approximately 2mm. There are 40 strips across the width of the material therefore 10mm of strand per unit length (40 x 0.25mm). Across 1cm of length of scrim there are 5 strands, equal to 1.25mm of surface area (5 x 0.25mm). Hence in 1cm of strand at width 7.5cm there is 12.5mm<sup>2</sup> of surface area of material.

A 575cm strip of material was used for each basket. It was sprayed with CIPC formulation on one side only. Therefore the surface area of the scrim treated was approximately 7187.5mm<sup>2</sup> (575cm x 12.5mm<sup>2</sup>/cm of length).

If the material sprayed was solid and not a grid type then the surface area would have been 43125mm<sup>2</sup> (575mm x 75mm).

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17.5ml of the appropriate 3000ppm CIPC formulation was sprayed over the entire area of each of the cotton scrim strips of 575cm length. This provided a maximum of 52500 $\mu$ g of CIPC. The surface area of the cotton scrim was much less than the treated area and limited the uptake of CIPC.

Scrim surface = 7187.5 mm<sup>2</sup>

Total surface area sprayed = 43125mm<sup>2</sup>

The maximum percentage uptake = (7187.5/43125)\*100 = 16.67%

Therefore of the total volume sprayed only 16.67% could possibly have landed on the materials. 16.67% of 525000 $\mu$ g is approximately 8751.75 $\mu$ g CIPC.

8751.75 $\mu$ g  $\equiv$  8.75175mg CIPC applied to 5kg of tubers, gives an approximate application rate of 1.75ppm (on a fresh weight basis).

Potential sources of loss of CIPC:

CIPC vapour lost as the air is refreshed, unquantified

Uptake of CIPC from the vapour onto/into the plastic surfaces, unquantified

## Achievement of Milestones

Below is a checklist of all the milestones that were to be met or progressed during the final year of the project, between December 2004 and November 2005. All of these milestones were completed.

|   |   |   |
|---|---|---|
| <b>Expt 1 CIPC rate of application:</b> | Store loading/liquid application        | ✓ |
|   | Initial fog applications                | ✓ |
|   | Sprouting assessments completed         | ✓ |
|   | Interim report to BPC/PPA               | ✓ |
|   | Final study report/TT output for Expt 1 | ✓ |
| <b>Expt 3 Ethylene Blocker:</b>         | Store loading                           | ✓ |
|   | Sprouting assessments completed         | ✓ |
|   | Quality assessments completed           | ✓ |
|   | Interim report to BPC/PPA               | ✓ |
|   | Final report/TT output for Expt 3       | ✓ |
| <b>Expt 4 Application trials:</b>       | Interim report to BPC                   | ✓ |
|   | Store loading                           | ✓ |
|   | Quality assessments completed           | ✓ |
|   | Final report/TT output for Expt 4       | ✓ |
| Expt 5 Controlled release studies:      | Store loading                           | ✓ |
|   | Interim report to BPC                   | ✓ |
|   | Efficacy assessments completed          | ✓ |
|   | Final report/TT output for Expt 5       | ✓ |

Experiment 2 was removed from the list of milestones into the second year of the project based on the findings of the experiment in the first year.

## Summary of Technology Transfer and project deliverables

### Publications/Conferences

Article in Potato Storage International, June 2005 (Geraldine M<sup>c</sup>Gowan)

International Potato Convention, Prince Edward Island, June 2005

Presentation, Issues arising from thermal fogging of CIPC (Geraldine M<sup>c</sup>Gowan)  
Publication of presentation on conference CD

European Association of Potato Research conference, Bilbao, 17-22 July 2005

Presentation, Developments in CIPC application and its effects on processing quality (Adrian Briddon, Geraldine M<sup>c</sup>Gowan, Ajay Jina, Adrian Cunnington, Harry Duncan)  
Publication of presentation abstract in conference book

Potato 2005 Congress, Emmeloord, Netherlands 7 September 2005

Poster, Processing quality and CIPC research (Adrian Briddon, Geraldine M<sup>c</sup>Gowan, Ajay Jina, Adrian Cunnington, Harry Duncan)

### Meetings/Workshops

BPC/ Potato Processors Association, Technical meetings

12<sup>th</sup> February 2004 Presentation, Review and development of the CIPC application process and the impact on potatoes stored for processing (Geraldine McGowan)  
Presentation, CIPC application and processing quality (Adrian Briddon)

8<sup>th</sup> July 2004 Written summary (Geraldine M<sup>c</sup>Gowan)

12<sup>th</sup> February 2005 Presentation of results (Geraldine M<sup>c</sup>Gowan)

27<sup>th</sup> July 2005 Presentation, Update on CIPC application and its effects on processing quality (Adrian Briddon)

Written summary (Geraldine M<sup>c</sup>Gowan)

8<sup>th</sup> May 2003 Presentation to BPC Storage Discussion Group, CIPC use & management in potato stores (Adrian Briddon)

29<sup>th</sup> October 2003 Presentation to Fritolay Agronomy Group, CIPC (Adrian Briddon)

12<sup>th</sup> December 2003 Presentation to Fritolay Agronomy Group, CIPC (Adrian Briddon)

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7<sup>th</sup> January 2004 Presentation to Greenvale AP Grower Group, Fry quality during storage (Adrian Briddon)

April 2004 Presentation to Higgins Agricultural Grower Group, CIPC application and processing quality (Adrian Briddon)

Events

BP 2003, Newark, September 2003

Potato Storage Event, Sutton Bridge Experimental Unit, May 2004  
Practical demonstration and general presentation of results

BP 2005, Harrogate, November/December 2005