Reducing post-harvest losses and wastage in UK potato storage due to sprouting

Final report to Defra: Project FO/0217

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*Work on objective 4 is continuing, funded by AHDB Potato Council (ref R438), for a further year until August 2013

Executive summary

This research project was commissioned by Defra, in collaboration with many industry partners, to investigate areas under four different objectives each with the collective aim of reducing post-harvest losses and wastage in UK potato stores due to sprouting.

An additional, primary aim of this work is to reduce the dependence on and the amount of the sprout suppressant CIPC (chlorpropham) required for suppression of post-harvest sprouting in stored potato tubers.

Routine monitoring by Government basket surveys identified, in late 2007, that the maximum residue level for CIPC was at risk of exceedance in a small number of cases. After consultation, the industry was asked to put an Industry Stewardship scheme in place to introduce closer controls on CIPC use. The Potato Industry CIPC Stewardship Scheme was initiated and further information on the Scheme can be found at www.potato.org.uk/cipc .

Currently, *c.* 1.7 million treated tonnes of stored potatoes receive CIPC in the UK each year[1], with treatments limited to 63.75 g/tonne for processed potatoes destined for washing and/or peeling and 36 g/tonne for fresh market crops under the Stewardship scheme.

Within the project, Objective 1 addressed improvement in the effectiveness of existing CIPC usage and, in particular, the challenge of achieving more uniform distribution of CIPC fog in box stores, to supplement a raft of control measures brought in under the Stewardship scheme to lower the risk of MRL exceedance.

A small-scale model was successfully developed by the Applied Aerodynamics Group at Cranfield University to accurately simulate CIPC use in semi-commercial potato stores. Collaborating with Sutton Bridge

[1] Garthwaite, D.G. *et al.* (2011) Pesticide Usage Survey report 236: Potato stores in the UK, 2010. Defra. p13.

Crop Storage Research, the work identified some areas where CIPC application could potentially be modified in commercial practice to improve distribution. However, there is further work required to accurately validate the model before it can be applied to fully commercial potato stores to assess likely CIPC distribution.

Objective 2, which was commercially funded by two CIPC approval holders, Aceto and Certis, looked to remove CIPC residue from potatoes by removing the deposition of the chemical onto the tuber surface. The work undertaken by University of Birmingham in collaboration with Sutton Bridge Crop Storage Research , sought to control sprouting purely using the vapour action of CIPC through release from remote sources of the chemical within the potato store.

Controlled release of vapour CIPC was achieved from remote sources. However, it has proved difficult to practically move sufficient vapour, once released, through potatoes across even quite short distances to achieve uniform distribution of the chemical required to give adequate sprout control.

Objective 3 evaluated a physical control, using UV-C, as an alternative to chemical treatment.

In this project, UV-C has been identified by Cranfield University Health as a potentially effective sprout control method in trials undertaken on a pilot scale. An understanding has been built up of how control is achieved. However, the treatment's impact on other attributes of the potato and its commercial viability and applicability have yet to be fully assessed.

Objective 4, funded by AHDB Potato Council and conducted at Sutton Bridge Crop Storage Research, has assessed the relative performance of a range of alternative sprout suppressants (some of which have become registered for commercial use) in comparison with a liquid formulation of CIPC applied at store loading.

Control of sprouting has been achieved on a small, experimental scale with a range of different products but none has performed as well as the liquid CIPC used as a control. Scaled up, semi-commercial storage of crops under experimental conditions using caraway oil failed to achieve uniform sprout control. This work is continuing in 2012/13 with a semi-commercial assessment of spearmint oil (registered in 2012).

Whilst there have been some very positive developments from this programme, it must be acknowledged that none of the areas investigated in this project offers an *immediate* means to achieving major reductions in, or replacement of, CIPC use.

Nevertheless, there is sufficient scope within the findings to form a basis for further development of solutions. Modelling commercial CIPC use is an important area for further development and can potentially offer some rapid reductions in residue risk. Pursuit of alternatives, including non-chemical options, can complement work being conducted in other areas, e.g. industry-funded research on the use of ethylene for control of sprouting in processing potatoes[2].

It is evident that there are some key developments coming through, notably in the release of alternative sprout suppressant compounds on to the market, which offer significant scope for the industry to continue to manage and reduce post-harvest losses and wastage in UK potato storage due to sprouting.

[2] AHDB Potato Council project R464 www.potato.org.uk

Introduction

This project was commissioned by Defra, in collaboration with many industry partners, to investigate a number of different objectives each with the collective aim of reducing post-harvest losses and wastage in UK potato sores due to sprouting.

Potatoes need to be held in storage in order to maintain continuity of supply for this staple food and to maximise the potential for all year round processing. Storage periods for UK crop typically range from 2 to 10 months.

Unless potatoes are held at cool temperatures to fully suppress growth or chemically treated, the crop will normally germinate (sprout) as part of the potato plant's natural regeneration process at the end of a period of dormancy, which varies across cultivars from a few days to a few weeks.

Storage at cool temperatures (2-4°C) is widely practised in the fresh potato sector as this coincides with the suppression of diseases which can blemish the potato's skin and detract from its appearance. However, this requires the use of refrigeration which adds to the cost of storage (up to £50 per tonne per annum) and also adds significantly to the carbon footprint for those crops.

Cool storage is, however, not appropriate for potatoes destined for processing into fried or roast potato products. This is because, during storage at lower temperatures, the potato converts much more starch to sugar to fuel respiration and generate heat (as part of its natural self-preservation process). High sugar content results in the formation of undesirable Maillard browning during processing, detracting from the product's saleability.

The solution is to hold processing crops at a warmer temperature (in the range 6-12°C) and use chemical treatment, such as CIPC, to prevent sprout growth. This process has been used in commercial potato storage for *c.* 50 years but tighter controls on its use have been introduced in recent years to lower CIPC residues and to comply with the EU-wide maximum residue level (MRL) of 10 mg/kg introduced in 2007.

Routine monitoring by Government basket surveys identified in late 2007 that the MRL was still at risk of exceedance and the industry was asked to put a Stewardship scheme in place to introduce closer controls on CIPC use.

Currently, c. 2 million treated tonnes of potatoes receive CIPC in the UK each year, with treatments limited to 63.75 g/tonne for processed potatoes destined for washing and/or peeling and 36 g/tonne for fresh market crops.

Objectives & Milestones

This project is being undertaken in work packages centred around the four primary objectives:

Objective 1: To improve effectiveness of current CIPC usage

Technical & scientific aims:

- Modelling: Development of an experimental (scale) model that faithfully predicts airflows and particulate CIPC flows & distribution in commercial stores and will allow the effect of modifications to store systems to be predicted.
- Validate predictions of model by chemical deposit analysis

Milestones:

- Development and Initial Testing of R&D Potato Store Scale Model
- Validation of R&D Potato Store Flow Characteristics
- Validation of Commercial Potato Store against Model Scale Flow Characteristics
- Redefine application techniques to establish current practice for CIPC optimum distribution
- Complete analysis of CIPC residues

Objective 2: To develop CIPC vapour as a potential sprout control method

Technical & scientific aims:

- Develop the use of vapour CIPC as an effective and viable sport suppressant option
- Model vapour desorption, adsorption and flow

Milestones:

- Testing of vapour release formulations
- Assessment of modelling vapour CIPC distribution
- Validate model in semi-commercial stores
- Complete analysis of CIPC residues

This work under this objective is to develop a new vapour-release formulation of CIPC is being undertaken at the University of Birmingham's Department of Chemical Engineering and is being funded by the CIPC approval holders, Aceto Agrochemical Corporation and Certis Europe.

Objective 3: To develop an alternative or complementary sprout suppression technology based on a physical control

Technical & scientific aims:

- Investigate non-chemical alternatives to CIPC and assess their effectiveness and viability as commercial sprout suppressants.

Milestones:

- Complete efficacy testing use of UV-C to suppress sprouting
- Complete optimisation of UV-C treatment (timing and dose)
- Complete physiological and biochemical assessments as affected by treatments

Objective 4: To evaluate alternative chemical treatments to replace or complement CIPC

Technical & scientific aims:

- As part of an integrated management strategy for sprout suppression in stored potatoes, assess likely alternatives to CIPC and their potential for use in place of, or in combination with, CIPC to provide enhanced control and/or reduced chemical usage associated residues.

This work under this objective is funded by AHDB Potato Council under its project number R438.

Milestones:

- Assess performance of alternative sprout suppressant test treatments on a small scale against an untreated control.

A summary of achievements against milestones is given at Annex A.

Key findings

Objective 1: Improve effectiveness of current CIPC usage

[Full report, video footage and data set at Annex B1]

For this objective, the Applied Aerodynamics Group at Cranfield University was tasked with the development and assessment of a novel, experimental sub-scale simulation of the flowfield within potato stores during the application of CIPC sprout suppressant in order to better understand the treatment process and factors that might influence its effectiveness.

Flow velocity and temperature measurements were taken of a CIPC application in a 12-tonne capacity research store at the Potato Council's Sutton Bridge Crop Storage Research facility (SBCSR). These measurements were used in conjunction with full scale video footage and reduced scale smoke tracer measurements to design a 30% scale model of the research store which behaves in an aerodynamically similar way. This model made use of small potato tubers in the storage pallets.

The resulting model utilised the release of a tracer gas to replicate the application of CIPC and concentration measurements, over varying time periods, were used for comparison with full scale CIPC absorption data. Reasonable agreement was found between model and scale concentrations for a measurement period of 2100 seconds after which the simulation was found to diverge.

The 30% scale model was used to study the effect of configuration changes including: (i) pallet horizontal and vertical spacing, (ii) CIPC fog input temperature and (iii) pallet base porosity. A lowering of fog input temperature was found to be the most effective in terms of tracer concentration distribution, however it is not possible to say whether the improvement seen for a limited data-set in a research store would carry through to a full commercial store environment.

A noticeable improvement was also found with an increase in base porosity of individual pallets particularly in terms of the transport of tracer gas to the bottom of the pallet stacks. The benefit of this modification is viewed as most likely to be effective with CIPC fog in a commercial store, although the practicalities of achieving this remain to be addressed.

In order to remove the need for the use of a real crop during scale testing, a pallet plus potato model was replicated using materials that gave the same aerodynamic pressure drop across the volume. These simulated storage pallets were found to compare well to the baseline case when measured for the same 2100 second application period.

Extension of this model from the 12-tonne experimental scale to larger, commercial potato stores requires significant further work in validation and refinement before full and accurate modelling of commercial scale CIPC application can be achieved.

Objective 2: Develop CIPC vapour as a potential sprout control method

[Full report, video footage and data set at Annex B2]

CIPC growth inhibitor, which stops growth by preventing cell division (mitosis), is currently applied as fine solid particles to control sprouting during long-term storage of potatoes. The mode of action of the applied chemical involves sublimation of the deposited (solid) particles and subsequent transportation of vapour CIPC to the eyes of the tubers, inducing the required sprout suppression.

Although it is an efficient means of distribution, deposition of CIPC solid particles on the potatoes' surfaces significantly increases the residue levels on the tubers. In work under this objective, funded by Aceto Agrochemical Corporation and Certis Europe, the effectiveness of delivering CIPC in vapour form from a remote source (ie not on the potatoes) was investigated.

In particular, work packages were delivered on:

- (i) developing and validating a method for characterisation of the amount of CIPC released from different sources;
- (ii) studying the effect of the formulation on the rate and amount of vapour CIPC released;
- (iii) systematically investigate adsorption of CIPC vapour by tubers from different sources, including a range of hydrocolloid gels;
- (iv) evaluating the efficacy of vapour treatments;
- (v) studying the effects of time, distance from source, and presence of multiple vapour sources on the distribution of vapours in pilot scale experiments.

Results indicated that vapour release rates could be successfully controlled by carefully designing the formulation of the delivery system. Gellan gum gels showed, overall, higher release rates (up to 40% greater amount of CIPC released in 3 months at 8°C, RH 90%) than other hydrocolloids (agar, κ-carrageenan, alginate). Increasing salt concentration (from 2mM to 10mM calcium) in gellan gum preparations resulted in 25% reduction in the amount of CIPC released, while the presence of a CIPC-free agar gel (1mm thickness) induced a further 30% average reduction. The effect of CIPC loading methods (either as a powder or dissolved in methanol) on release rate were found to be only marginally different. However, increasing hydrocolloid concentration significantly reduced release rates (virtually no release occurred at 5% agar concentration). Under commercially-relevant storage conditions (8°C, RH>90%), vapour release was found to significantly decrease whilst adsorption of vapour CIPC by the tubers was found to increase linearly with time during 28 days of exposure. Importantly, higher deposition of the chemical was demonstrated on exposure of tubers to solid beads (up to 10 times higher deposits in 28 days of exposure) when compared with all the gel formulations investigated.

Results also indicated that factors such as presence of soil, humidity of the environment, and dormancy stage of the tuber, can affect the levels of adsorption.

Vapour treated tubers were further assessed for sprout growth. In agreement with previous work conducted in this field (Potato Council project R288, www.potato.org.uk/publications), vapour CIPC application was found to provide efficient sprout suppression in small scale experiments. Importantly, sprout inhibition was found to be effective at CIPC levels as low as 0.2 mg CIPC/kg potatoes.

Pilot scale experiments were conducted, in collaboration with SBCSR, to evaluate the effects of time, distance from the vapour source, and presence of multiple sources on both vapour distribution and associated CIPC adsorption by tubers stored in pipes within an experimental store at SBCSR. However, results showed poor distribution of vapour across the relatively short pipe length (1500 mm) demonstrating that achieving adequate vapour movement, even at very high air flow volumes, is likely to be the limiting step in the process. This would, therefore, be problematic in any potential commercial use of remote CIPC vapour sources for efficient sprout control in potato stores.

Objective 3: To develop an alternative or complementary sprout suppression technology based on a physical control

[Full report and data set at Annex B3]

The aim of the work carried out under this objective was to assess the effectiveness of exposure of potato tubers to UV-C as a sprout suppressant treatment, to reduce the dependence on the chemical sprout suppressant, CIPC. Further, the work package looked to identify the optimum dose and timing of UV-C treatment for effective sprout control.

Crops, sourced by SBCSR, were treated in two seasons (2010/11 and 2011/12) and sprout suppression was achieved using UV-C at doses of 10, 15 and 20 kJ m^{-2} applied at harvest or at 10% eye movement in a range of cultivars (Maris Piper, Russet Burbank, VR808, Cabaret and Saturna).

UV-C treatment at 10% eye movement was more successful at reducing sprout growth in potato than when applied immediately after harvest. This may have been due to a combined systemic and physical response to the UV-C treatment or, alternatively, a different stage of tuber dormancy at the times of treatment.

Evidence gathered in year 2 suggested that UV-C was effective for controlling sprouting when tubers were washed or unwashed.

Multivariate analysis revealed that phenolic content was not affected by UV-C treatment long term; however, an immediate effect was noted within 72 h of treatment with the highest UV-C dose.

Treatment at 10% eye movement resulted in different sugar and phenolic profiles compared with potatoes treated at harvest, suggesting different mechanism(s) for sprout suppression.

Results indicated that treatment at harvest, rather than at 10% eye movement, may minimise increases in sugar content and therefore avoid darkening upon frying.

ABA, ABA-GE and Z (zeatin) increased between harvest and 10% eye movement, corresponding with the transition from endodormancy to ecodormancy.

Physical damage by UV-C was confirmed by quantification of CPD-DNA which was highest following treatment with doses of 10 or 20 kJ m^{-2}.

Objective 4: To evaluate alternative chemical treatments (to replace or complement CIPC)

[Interim reports at Annexes B4 & B5]

Work conducted under this work package, funded by AHDB Potato Council, has focused on assessment of a range of sprout suppressant compounds as potential alternatives to the use of CIPC applied as a thermal fog to control sprouting in potato storage.

Comparative data from two seasons of small-scale trials indicated that sprout control was most effective after use of CIPC, applied as a liquid treatment at store loading. Of the alternative compounds assessed, weekly applications of caraway oil gave relatively effective sprout control. In year 2 (2011/12), sprout control with caraway oil was very effective, and similar to that achieved with liquid CIPC. This was the case under both combinations of variety/storage conditions evaluated, i.e. long-dormant crop (cv. Russet Burbank) held at 6°C and more demanding sprout control conditions with short-dormant crop (cv. Saturna) stored at 9°C.

However, a similar treatment regime using caraway oil resulted in poor sprout control in a larger scale trial (16 tonne experimental bin) with evidence of control only apparent in top boxes, close to the chemical applicator. Poor efficacy elsewhere in the store indicates limited transport of the sprout suppressant into the block of boxes. With the overhead-throw ventilation principle, which is most prevalent in the UK, air (and any treatments applied using air) is not moved directly through crop, but is reliant on distribution through the pallet apertures of boxes, with delivery to the crop being effected by convection currents.

Results from this first assessment on a larger scale (in year 2 of the work) suggested that simply using a sprout suppressant with high volatility will not easily overcome limitations of the overhead-throw store design. The likely availability of caraway oil (*Talent*) for commercial use on ware potatoes in the UK is currently unclear.

3-decen-2-one (SmartBlock™) was used for the first time in the 2011/12 season in the small-scale trial. With this compound, the number of applications needed (triggered by the onset of sprouting) as a result of storage temperature was notable;

just a single application was required at 6°C compared with four applications at 9°C. The compound has just received registration in the US and is currently undergoing registration trials in Europe.

Sprout control from spearmint oil *(Biox-M)* in this trial has been effective over shorter term storage (*c.* 3 months) or at the lower storage temperature assessed (6°C), in both seasons. However, it has failed to prevent sprout development in longer term storage and/or at a more demanding, warmer temperature (9°C). In the final season (year 3) of this levy-funded trial, which is on-going at the time of writing, spearmint oil is being assessed in the large scale (16 tonne) trial using positive ventilation which, it is anticipated, may improve the efficacy of sprout control.

Discussion

The work carried out in this project has yielded a number of positive developments in the quest to improve control of post-harvest losses and wastage in UK potato storage due to sprouting whilst lowering the likely reliance on CIPC sprout suppressant in the medium to long term.

The work undertaken in Objective 1 has potential for further development to create a model for use in commercial potato box stores which will further understanding of airflows and distribution of CIPC fog. This project has provided some excellent building blocks at small and semi-commercial scale from which this development can be taken forward.

Objective 2 has highlighted the scope available to manipulate the controlled release of CIPC vapour to optimise use of the chemical and the expertise available at University of Birmingham for work in this field. Unfortunately, the work on vapour also confirmed the difficulties which exist in trying to move CIPC vapour from a remote source to the crop over even short distances, even at a relatively warm storage temperature of 10°C. This difficulty will be accentuated in cold stores (2-4°C) used for fresh market potatoes, due to a reduced rate of volatilisation of CIPC at the lower temperature[3].

This finding is disappointing as it limits the likelihood of being able to use remote sources of CIPC commercially. It perhaps also explains why CIPC is currently applied as a thermal fog as this essentially puts tiny, solid particles of CIPC on to the potatoes which act as localised reservoirs to release CIPC vapour for sprout control close to the point of growth. Getting a uniform distribution of those particles throughout a store therefore remains the primary objective in optimising CIPC use.

The results from Objective 3 offer potential for further investigation of UV-C as a physical control of sprouting. Other forms of irradiation have been shown previously

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[3] Cunnington, A.C., Park. L.J., Duncan, H.J., Briddon, A. *et al* (2006). Predicting the distribution of vapour and particulate CIPC in potato stores - Final Report, Potato Council project R258, www.potato.org.uk/publications

to control sprouting[4,5] but were never commercialised due to unwanted side-effects plus logistical and financial constraints. However, with capability now available to develop a much more detailed understanding of the mechanisms involved there may be valuable potential in pursuing UV-C as a non-chemical option for sprout control in the medium to long term.

The work in Objective 4 to evaluate novel sprout suppressant compounds has highlighted the value of some of the newly-available molecules in providing alternatives which might replace, or perhaps more likely complement, the use of CIPC.

Some compounds such as ethylene (not evaluated in this project) and spearmint oil have entered the market in recent years but require more work to find optimal ways of using them, especially if they are to be efficacious in processing potato stores. Others, for example 1,4-dimethylnapthalene and 3-decen-2-one, are approved overseas (both are registered for use in the USA) and commercial use is increasing, but often in association with CIPC[67]. If registrations can be secured in Europe in the next year or two, these new compounds will provide scope in the coming seasons to alleviate dependency on CIPC and, currently, offer the best, short term solution to reduce CIPC use for control of sprouting in storage.

CIPC itself is currently under review by the Advisory Committee on Pesticides[8] at the end of the first 5-year Stewardship term. The Stewardship Group and the CIPC Approval Holders have submitted proposals for continued support of the compound designed to further reduce the risk of MRL exceedance. It is hoped that these will be accepted to permit time to pursue some of the solutions identified in this project for

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[4] Wilson, L.A., Boyd, I.M.G., Muir, J. & Duncan, H.J. (1987) The effect of sprout suppressant treatments on weight loss of potato tubers during storage. In: Abstracts of Conference Papers & Posters, European Association for Potato Research, 10th Triennial Conference, Aalborg, Denmark, pp337-8

[5] Anon. (1988) Sutton Bridge Experimental Station Annual Review 1987, Potato Marketing Board, London, pp35-41.

[6] Personal communication: J Forsythe, 1-4 Group Inc., Meridian, Idaho, USA www.14group.com

[7]Personal communication: J Immaraju, Amvac Corporation, Newport Beach, California, USA. www.amvac-chemical.com

[8] www.pesticides.gov.uk/guidance/industries/pesticides/advisory-groups/acp

managing and reducing post-harvest losses and wastage in UK potato storage due to sprouting.

Annex A: Defra project FO/0217

MILESTONES

Target Date		Month	Description	Status End of project
1	17/06/2011	9	Undertake development & initial testing of R&D potato store scale model	Achieved
2	31/08/2011	12	Validate R&D potato store scale model flow characteristics	Achieved
3	27/04/2012	19	Validate commercial store against model data flow characteristics	Achieved
4	30/06/2012	21	Redefine application techniques to establish current practice for optimum distribution	Achieved (recommendations made)
5	30/06/2011	9	Complete year 1 efficacy testing of use of UV-C to suppress sprouting	Achieved
6	30/06/2012	21	Complete optimisation of UV-C treatment (timing & dose)	Achieved
7	31/08/2012	24	Complete physiological and biochemical assessments as affected by UV-C treatments	Achieved
8	30/09/2011	13	Undertake analysis of CIPC residues (obj 1): year 1	Achieved
9	31/08/2012	24	Undertake quality assessments (obj 1): year 2*	Achieved Nov 12
10	30/09/2011	13	Undertake analysis of CIPC residues (obj 1): year 2	Achieved
11	31/08/2012	24	Undertake quality assessments (obj 2): year 2*	Achieved Nov 12
12	21/12/2010	4	Hold project meeting: project start	Achieved
13	30/09/2011	13	Hold project meeting: year 1	Achieved
14	31/08/2012	24	Hold project meeting: year 2*	Achieved Feb 13
15	31/08/2012	24	Deliver final report*	Achieved Mar 13

*Objectives 1 & 2 subject to no-cost extensions.