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Research Review

The use of ethylene for sprout control

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1. Summary

Effective control of sprouting is a fundamental requirement of potato storage. In the packing sector in particular, demands are such that treatments must ensure a virtual absence of sprouts. This can be accomplished by very low temperature storage, the use of established pesticides (CIPC or maleic hydrazide) or, since the 2003 publication of a commodity approval for the substance, the natural plant growth regulator, ethylene.

Sprout growth suppression with ethyene was first reported in the 1930s, some time after the publication of its sprout promoting properties. These apparently contradictory effects can be explained simply in terms of ethylene management, with temporary exposure resulting in a 'dormancy-breaking' effect. Extended exposure can also result in dormancy break, but with actual sprout growth inhibited when ethylene is maintained at a sufficient concentration.

There is little information in the published works as to what constitutes a sufficient concentration of ethylene to inhibit sprout growth during storage. Laboratory studies of limited duration are of little use in this regard. The only published works identified, that were carried out using appropriate combinations of storage duration and temperature, were those reporting research carried out at Agriculture and Agri-Food Canada, Kentville, starting in the 1990s, on the long term sprout suppressing properties of ethylene. This work resulted in the registration of ethylene for sprout suppression of the cv Russet Burbank, for processing, in Canada. While it is reported to result in satisfactory levels of sprout suppression (it has not been used commercially), sprout growth is not fully inhibited. Indeed, treatment with ethylene at 4ppm, the rate at which experimental work was conducted and the target rate of the registered product, results in numerous small sprouts although these can be detached easily during handling operations.

Effective sprout control at 10ppm ethylene at a storage temperature of 3.5°C (typical for pre-packing) has been demonstrated on an experimental scale. It is unclear, however, over what storage temperature range this level would remain satisfactory or how this interacts with cultivar.

Commercial storage using ethylene as a sprout suppressant was introduced in Great Britain, by Greenvale-AP, in 2001. A commodity approval controlling its use in the UK on potatoes was published in 2003. The adoption of ethylene into commercial use has, to date, been entirely in storage for the potato pre-packing sector, primarily due to its 'residue-free' status. Until the 2006 revision of the commodity approval, the target headspace ethylene concentration, for potato storage, was 10ppm. Although there is no published evidence justifying the use of specifically 10ppm ethylene, the level appears at least to be a satisfactory one for sprout suppression, under typical low temperature storage conditions used for the commercial storage of pre-packing potatoes.

A revision of the UK commodity approval in May 2006, increased the target headspace ethylene concentration for potato storage to 50ppm. This change is reported to have taken place to allow use of ethylene for treatment of seed potatoes. However, there is little support in the literature, or from commercial uses, to justify the higher rate of use in ware stores.

While sprout control by ethylene, in low temperature stores, appears to be robust, other quality attributes are known to have been affected, with several occurrences of 'off flavours' and changes in texture reported. Adverse effects are most evident in, and may be limited to,

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the varieties King Edward, Maris Piper and Marfona. These effects appear to have been detected for the first time in the 2004/05 storage season. It is considered that elevated carbon dioxide levels, in store, may be associated with the occurrence of these defects. King Edward, Maris Piper and Marfona are all very important pre-packing varieties in Great Britatin, so restricting the use of ethylene on these is likely to disproportionately curtail ethylene use as there is limited segregation of varieties in storage for this sector.

There are currently two companies, *BioFresh* and *Restrain*, supplying equipment for ethylene control in potato stores in Great Britain. These differ in their management of ethylene, with *BioFresh* recommending that ethylene control is enabled early in storage (prior to dormancy break) while *Restrain* recommend enabling control at the time of dormancy break. Although these differences are expected to result in changes of dormancy status of crops, it is unclear if other qualities vary as a result of the two management approaches.

Exposure to ethylene is also expected to result in an increase in sugar concentration of tubers and an increase in respiration rate. Increases in reducing sugar levels can be sufficient to have a substantial, deleterious effect on processing quality but, not necessarily, an irreversible one. The effects of ethylene on sweetness in ware potatoes stored at low temperature have not been published. However, the repeated commercial use of ethylene in the pre-packing sector suggests that excessive sweetness has not been a particular problem for this market.

Increases in respiration rate from exposure to ethylene, have been published for potatoes and other crops. Any increase in respiration rate requires additional cooling capacity to remove additional heat generated by the potatoes. Although the literature indicates that the main effect (a respiratory “spike”) is short-lived, it is not clear if long term basal respiration rates are changed and if this will give rise to a significant increase in demand for cooling and, hence, storage costs.

Ethylene is an effective sprout suppressant and represents an opportunity for the British potato industry, not least because treated crops are widely regarded as ‘residue-free’. However, this opportunity is very unlikely to be fully exploited until data from a comprehensive range of independent studies on ethylene use in potato storage are generally available.

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2. Introduction

Effective sprout control is an important part of successful potato storage. In the ‘pre-pack’ market in particular, an absence of sprouts is an important visual indicator of quality. Until recently, sprout control could only be accomplished by very low temperature storage (<c.3°C) or use of chlorpropham or maleic hydrazide sprout suppressants (Anon., 2004). However, the use of these pesticides results in residues which are considered undesirable by some consumers[1].

Ethylene has been used in potato stores in Great Britain on a commercial scale since 2001, and a commodity approval controlling its use was introduced in 2003. Maintained at an appropriate concentration in the store headspace, ethylene acts as a sprout suppressant. There is no Maximum Residue Level for ethylene[2], and crops treated with it are widely regarded as ‘residue-free’. There is little information in the public domain regarding use of ethylene, particularly with regard to effects during long term storage. This review was commissioned to summarise information in the public domain.

[1] http://www.food.gov.uk/multimedia/pdfs/consattpesticideres.pdf

[2] http://www.pesticides.gov.uk/uploadedfiles/Web_Assets/PSD/MRL_Spreadsheet.xls

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3. Background

Ethylene is a simple, unsaturated hydrocarbon (formula C_2H_4) which is a gas at room temperature. It is a naturally occurring plant growth regulator which readily diffuses through plant tissues, and is associated with a wide range of plant responses, which may be stimulatory or inhibitory (see Table 1). Plant responses to ethylene are usually mediated through ethylene receptors present in all higher plants (Sisler & Serek, 1999).

TABLE 1. PLANT RESPONSES TO ETHYLENE (SALTVEIT, 1999)

Stimulation responses	Inhibition responses
ethylene synthesis (positive feedback)	ethylene synthesis in vegetative tissue and non-climacteric fruit
fruit ripening	flower development in most plants
pigment synthesis	auxin transport
cholorophyll destruction	shoot and root elongation
seed germination	normal orientation of cell wall microfibrils
adventitious root formation	
respiration	
abscission	
senescence	

Synthesis of ethylene (endogenous), requires oxygen and is sensitive to carbon dioxide (Saltveit, 1999) and generally occurs at a low rate except in climacteric tissues (eg apples), where ripening is associated with a marked increase in carbon dioxide and ethylene production.

Production of ethylene by potato occurs at a very low rate ($<0.1\mu L\ kg^{-1}\ h^{-1}$, Knee *et al*., 1985). Creech *et al*. (1973) reported ethylene production rates in the range $<5 \times 10^{-4}\ \mu L\ kg^{-1}\ h^{-1}$ to $3 \times 10^{-1}\ \mu L\ kg^{-1}\ h^{-1}$, for cv Russet Burbank, with higher levels associated with the onset of sprouting, physiological breakdown and following pathogen inoculation. Wills and Warton (2003) reported a concentration of $0.04\mu L\ L^{-1}$ (ppm) ethylene in cartons of potatoes in a wholesale market.

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4. Commercial aspects of ethylene use

Current and future regulatory aspects of ethylene use

Currently, use of ethylene in the UK is controlled by the Pesticide Safety Directorate under a commodity approval. Ethylene is being supported through the EU pesticide approvals system (EU 91/414 fourth stage), and when successful (i.e. included in Annex 1), this will supersede the current national controls.

Commodity materials are chemicals with a range of non-pesticidal uses, but also minor uses as pesticides. The sale, supply, storage and advertisement of a commodity substance *as a pesticide* (for example as a sprout suppressant of stored potatoes) is prohibited.

A commodity approval for ethylene was first published in 2003 (Anon., 2003). The current approval (issued May 19th 2006) has as main conditions of use, a target headspace ethylene concentration of 50ppm and a withholding period (or ‘harvest interval’) of three days. The current approval is shown at Appendix 1.

In previous versions of the approval, the target ethylene concentration was 10ppm. The increase in the target headspace concentration in the most recent approval is reported to be to accommodate the use of ethylene as a seed potato treatment (G. Bainbridge, personal communication).

There are currently two GB suppliers of ethylene control systems (see section 2.2). Operating according to the same commodity approval, the two companies differ in their recommendations regarding management of ethylene.

The *BioFresh* control system, it is recommended, should be enabled early in storage, (potentially some time prior to tuber dormancy break), when target storage temperature is achieved (Barnes, 2006). With the *Restrain* system, it is recommended, ethylene control should be enabled only when early signs of dormancy break are observed (P. Coleman, personal communication). With both systems, control is not immediately enabled with a set point of 10ppm, but ethylene concentration is ‘built up’ gradually over a period of days. Additionally, with the *Restrain* system, it is recommended that fans recirculate store air continuously while ethylene is increased to the target concentration.

Ethylene has been registered as a sprout suppressant, in Canada, for use on the cultivar Russet Burbank for processing since 2002 (see Appendix 2). The approval requires a target ethylene concentration of 4ppm to be maintained “between cycles of ventilation” and “throughout storage”. Although ethylene is available, marketed under the *Eco Sprout Guard* brand name, it is not in commercial use (Daniels-Lake and Prange, 2006). See also section 4.

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Suppliers of ethylene control systems

Two systems, for introducing and controlling ethylene in potato stores, are currently commercially available in Great Britain.

BioFresh Ltd. is a 'spin-out' company from Newcastle University involved in the development of new technologies for the agri-food sector. The *BioFresh* system (http://www.bio-fresh.com/index), under control of a chemi-luminescent detection system, introduces pure ethylene from cylinders of the gas. The *BioFresh* ethylene control system is integrated either into the stores' fan/refrigeration control system or to an auxiliary fan and is configured to only allow introduction of ethylene when the fans are operating.

FIG. 1. CONTROL EQUIPMENT FOR *BIOFRESH* ETHYLENE CONTROL SYSTEM.

FIG. 2. 'CAGED' ETHYLENE CYLINDER STORAGE FOR *BIOFRESH* CONTROL SYSTEM.

The *Restrain* system (www.restrain.eu.com), utilises an electrochemical cell for sensing ethylene, and generates the gas, catalytically, from an ethanol based fuel, held in an integral storage tank. The *Restrain* company is a joint venture between Greenvale-AP and International Controlled Atmosphere.

The nature of the *BioFresh* system requires installation to be relatively permanent. More than one store can, however, be controlled by a single detector/controller. *Restrain* systems are completely portable but can only be used to control ethylene in a single storage unit.

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FIG. 3. *RESTRAIN* ETHYLENE CONTROL SYSTEM. ETHYLENE IS GENERATED CATALYTICALLY USING ETHANOL FROM AN INTEGRAL STORAGE TANK.

Both systems involve potentially hazardous operations and will require consideration of additional health and safety measures and equipment. As a minimum, specialist storage facilities will be required (secure cage for ethylene cylinders for *BioFresh* system and secure 'flammable' liquids cabinet for *Restrain* fuel). Further information should also be obtained from the Health and Safety Executive (Operational Circular OC 535/2, Banana [and other fruit] ripening rooms[3]). There are no restrictions on store access with ethylene at the commodity approval rate.

[3] http://www.hse.gov.uk/LAU/LACS/31-2.htm

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5. Ethylene and sprout growth of potatoes

Sprout growth stimulation and sprout growth suppression are both published effects of ethylene. Although these properties have long been identified, little work has been published between the initial findings and research conducted in Canada, led by Robert Prange and Barbara Daniels-Lake, which dominates the recent literature. Their selection of ethylene, as a sprout suppressant, appears to have been a fortunate one (Prange *et al.*, 2005a). It was to be used initially to induce sprouting of potatoes in preparation for the assessment of other sprout suppressants, but observations of sprout suppression (under conditions of continuous exposure) were pursued and their work subsequently resulted in the registration of ethylene as a sprout suppressant product.

Sprout suppressant properties of apple ‘vapours’ were first reported in 1932 and subsequently, ethylene and apple ‘vapours’ in 1933 (Elmer and Huelin, respectively). This was preceeded, however, by work demonstrating a ‘dormancy breaking’ effect of ethylene (Rosa, 1925). These apparently conflicting responses to ethylene were resolved with the publication of work showing both effects, but under different ethylene exposure conditions.

The apparently opposing effects of ethylene (dormancy breaking and sprout suppressing properties) are explained by Rylski *et al.* (1974), using freshly harvested crops. These showed that short term (72h) exposure to ethylene (in the range 0.02-20ppm) resulted in a more rapid initiation of sprouting (dormancy break) during subsequent storage in air, compared with untreated samples. All concentrations tested were effective, but sprout initiation was most rapid after exposure to 2ppm ethylene and responses were more rapid in cv Russet Burbank than cv White Rose. In a separate experiment, the effect of duration of exposure (to 2ppm ethylene) was investigated. Exposure periods as small as 8hrs were observed to significantly enhance dormancy break, but 24hrs was reported as the most effective exposure time. Importantly, continuous exposure was reported to “completely inhibit sprouting” of cv White Rose, with sprout growth only resuming when ethylene supply was discontinued. Rate of sprout growth, upon discontinuation of ethylene, was reported to be similar to that of non-dormant tubers. Thus, while exposure to ethylene is expected to break dormancy, maintaining tubers in an atmosphere with ethylene may also be expected to suppress sprout growth.

In addition to its dormancy breaking effect, ethylene also influences the number of sites of sprouting of tubers, indicating an effect on apical dominance. Increased sprout numbers per tuber, following ethylene exposure, are reported by Wills and Warton (2003), Prange *et al.* (2005a and 1998) and Kalt *et al.* (1999), though these are reporting on ware potato storage trials.

The use of ethylene as a seed treatment was investigated in field trials by Pruski *et al.* (2006), the authors postulating that increased sprout numbers could result in an increase in stem number, when planted, and thus increase progeny tuber number. They suggested that this would be useful for increasing the yield of small tubers in seed production. Indeed, it is probable that this could logically be extended for ‘punnet’ potato production, a major sector within the fresh market in Great Britain. Pruski *et al* (2006) reported that long term storage (at 4°C) of seed in 4ppm ethylene resulted in earlier emergence and more stems per seed piece in cvs Russet Burbank and Shepody, and an increase in progeny tuber numbers in cv Russet Burbank, compared with untreated samples.

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The principle of overcoming apical dominance and dormancy breaking using ethylene is the basis of a seed treatment service provided by Greenvale-AP under the *Accumulator* brand name (P. Coleman, personal communication).

After screening a range of alternatives to CIPC (Prange *et al*., 1997), Prange *et al*. (1998) reported results of laboratory and commercial scale trials with cv Russet Burbank held at 9^{o}C and using ethylene supplied continuously at 4ppm. In laboratory scale studies over six seasons, the use of ethylene resulted in a delay of 5-15 weeks in the apperance of sprouts, compared with samples stored in air. After this time, there was a gradual establishment of sprouting (increasing sprout number and sprout length), but with the majority remaining in the small sprout category (<5mm). After 25 weeks' storage mean maximum sprout length, except when experimental conditions were not met, was in the range 5.9-11.4mm. In commercial trials (with data for sprouting for just one season) sprout control was superior using CIPC for up to 22 weeks in store. After 29 weeks' storage however, sprout mass and sprout length was less in ethylene treated crop while sprout number was similar to CIPC. Data were also presented demonstrating that while sprouts were usually more prevalent following ethylene treatment, these were relatively easily detached from tubers. The use of ethylene, however, resulted in a darker fry colour than CIPC. The authors concluded that ethylene was a viable alternative to CIPC (for cv Russet Burbank) for markets where fry colour was not important and that it remained an option for processing, providing the effect on fry colour could be controlled or the effect was acceptable to consumers.

In an investigation to overcome processing quality difficulties associated with ethylene, Daniels-Lake *et al.* (2005a) looked at ethylene concentrations in the range 0.4 to 400ppm for their effects on sprout control and fry colour. The authors concluded there were dose-dependent responses to ethylene for different aspects of sprouting, and that "saturation" concentrations varied according to characteristic. Effects on dormancy break were considered to have become 'saturated' with an ethylene concentration in the range 0.4-4ppm (concurring with the 2ppm observed by Rylski *et al.* 1974), and effects on sprout mass with ethylene in the range 4-40ppm. However, sprout elongation was not inhibited fully, except in the 400ppm treatment. It should be noted that the "saturation" concentrations mentioned, refer to data obtained. These are likely to vary with storage temperature and cultivar. Adverse effects of ethylene, other than darker fry colour, were reported not to have been detected. The observation that storage in 1ppm ethylene retarded, but did not inhibit sprout growth of cv Russet Burbank (Timm *et al.* 1986) agrees with the above findings.

Suppression of sprout growth (using 4ppm ethylene with crop at 9°C) is also reported for the cv Shepody (Prange *et al.*, 2005b), but with sprouting becoming established earlier than in cv Russet Burbank, which was attributed to Shepody's shorter dormancy.

It should be noted in the above trials (Prange *et al.* 1998, Daniels-Lake *et al.* 2005a and Prange *et al.*, 2005b) that sprout suppression by ethylene is not complete and treatments may result in numerous, small sprouts which are easily detached. Indeed, analysis of some data excluded results for the CIPC control, as this treatment often resulted in complete sprout control with many zeroes making valid statistical analysis difficult. While this approach may be satisfactory for some processing crops, it does not represent a sufficient level of sprout control for use on fresh market crops where an absence of sprouts is a requirement. Some justification for the selection of a target concentration of 4ppm ethylene for commercial storage (see Appendix 2) is given in Prange *et al.* (2005b).

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The only reported work carried out under conditions representative of commercial pre-packing storage is from semi-commercial scale trials (12-tonne capacity stores) carried out at Sutton Bridge Experimental Unit (Briddon *et al.*, 2005). In this work, ethylene was used at a rate of 10ppm and successfully delayed appearance of sprouts in cvs Estima, King Edward and Maris Piper stored at 3.5^{o}C. Sprouting was maintained at a very low level during storage for up to 8 months. In untreated samples, sprouting was initiated earlier and sprout growth reached unacceptable levels after 8 months storage. Skin blemishing diseases were unaffected by the use of ethylene.

Mode of action

The mode of action of ethylene is poorly understood and it is likely, in view of the diverse nature of responses, that different mechanisms are involved.

Jeong *et al.,* (2002) demonstrated an increase in spermidine concentration and a change in the ratio of other polyamines (which are involved in the regulation of cell division and growth) during continuous exposure of cvs Russet Burbank and Shepody to ethylene (4ppm). Such changes are associated with sprout growth in potatoes (Kaur-Sawhney *et al.,* 1982 in Jeong *et al.,* 2002). Differences in absolute levels also corresponded with dormancy characteristics of (short dormant) Shepody and (long dormant) Russet Burbank (Jeong *et al.*, 2002). However, while changes in polyamine concentrations were rapid (Jeong *et al.,* 2002), the onset of sprouting was delayed. This, it was suggested, could be as a result of separate modes of action, with ethylene encouraging sprout growth by way of its effects on polyamines, but with sprout elongation limited by a different mechanism. In the same paper, the authors quoted unpublished data (using 1-MCP ethylene blocker) suggesting that effects on tuber polyamines are mediated by ethylene receptors. This, if confirmed, suggests alternative modes of action (for dormancy breaking/loss of apical dominance and sprout growth suppression) as 1-MCP has little or no effect on the success of sprout control under ethylene (Prange *et al.,* 2005b). Different mechanisms are also suggested by contrasting concentrations of ethylene for dormancy breaking (0.4-4ppm) and sprout growth inhibition (400ppm) (Daniels-Lake *et al.,* 2005a).

Although a better understanding of the mode(s) of action of ethylene is important, in practice it should be considered any treatment being used for sprout suppression in storage is likely to 'break' dormancy of stored crops and cessation of ethylene treatment will be followed by sprout growth.

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6. Other attributes associated with the use of ethylene

Respiration

Ethylene has a profound effect on potato tuber respiration. Exposure to ethylene results in a rapid increase in respiration rate which is followed by a more gradual return to values close to, or the same as, original levels.

The magnitude of the respiratory response increases with concentration up to a maximum rate at storage in circa 2ppm ethylene (Rylski *et al.*, 1974; Reid and Pratt 1972) and at this concentration a considerable difference in respiration rate between cvs Russet Burbank and White Rose was reported (Rylski *et al.*,1974). Peak respiratory activity was approximately six times that of untreated crops.

Reid and Pratt (1972) reported a lag time of approximately 8 hours, irrespective of ethylene concentration, after which time respiratory responses occurred which were positively correlated with duration of ethylene exposure and concentration of ethylene exposure, and negatively correlated with crop temperature in the range 5°C to 35°C. Exposure to higher concentrations of ethylene (up to 90ppm) did not result in further stimulation of respiratory activity above that recorded at 2ppm.

Although continuous treatments with ethylene were assessed (Rylski *et al.*, 1974; Reid and Pratt 1972), these were not of a sufficient duration to determine if storage in ethylene results in a significant long term or permanent change in ‘basal’ respiration rate.

Exposure to ethylene results in a loss of sensitivity to subsequent exposures of ethylene, as measured by respiratory response. Storage of cv White Rose in alternating atmospheres of air or air supplemented with ethylene, resulted in a respiratory ‘spike’ after intial exposure, but little change following subsequent exposures to ethylene. This contrasts with climacteric fruit (oranges), where repeated exposures resulted in a repeated stimulatory effect on respiration rate. Respiratory responses of potato, to subsequent ethylene exposures gradually increased after a ‘recovery’ period and reached circa 70% of the initial response after 19 days (Reid and Pratt, 1972). Increased respiratory activity in stored potatoes is also reported by Wang and Pritchard (1997), as a result of contamination of CIPC fog with ethylene.

In the treatment of other (climacteric) commodities the additional energy output, associated with increased respiratory activity from ethylene exposure, is recognised as providing an additional refrigeration requirement that must be met for satisfactory temperature control (Saltveit, 1999).

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Fry colour

Exposure of potatoes to ethylene results in deterioration (darkening) of fry colour as a result of an increase in the concentration of reducing sugars (Wang and Pritchard, 1997). Where exposure is transient, such as where ethylene is introduced as a contaminant of CIPC fog (due to incomplete combustion of fuel used as propellant in the application process), deterioration is rapid, occurring within 24 hours of exposure, and is, to a large extent, limited by reducing crop-ethylene exposure time by ventilating stores as soon as CIPC fog has deposited on crop (Briddon *et al.*, 2002). The impact of ethylene from CIPC application on fry colour can also be reduced by pre-application of 1-methylcyclopropene (Briddon *et al.*, 2005), an ethylene 'blocker' that binds specifically to ethylene receptors and prevents transduction of the ethylene response (Blankenship and Dole, 2003).

In longer term studies where the activity of ethylene as a sprout suppressant was assessed, deterioration in fry colour was also reported. Kalt *et al.* (1999), when assessing a range of alternatives to CIPC sprout suppressant (using Russet Burbank at 9^{o}C with ethylene at 4ppm), reported a substantial deterioration in fry colour. The effect was greatest early in storage and was followed by a sustained period of recovery, but quality remained poorer than CIPC control samples throughout the duration of storage. In commercial and experimental scale trials over several seasons, Prange *et al*. (1998) concluded that ethylene-treated tubers "almost always" fried darker than tubers treated with CIPC, but considered that the effects were not permanent, and storage was characterised by fry colour 'recovery' from deterioration that occurred after ethylene was initially introduced. Research carried out to ameliorate the effects of ethylene has shown that processing quality of ethylene treated tubers can be improved by reconditioning (Prange *et al*., 2005a), and the use of the ethylene 'blocking' compound 1-methylcyclopropene, application of which does not interfere with the sprout suppressant action of ethylene (Prange *et al*., 2005b). "Manipulation of the exposure regime" was also reported to have been researched but details were not shown (Prange *et al*., 2005a).

Daniels-Lake *et al.* (2005a) investigated processing quality of cv Russet Burbank during storage in ethylene at concentrations in the range 0.4 to 400ppm and considered the threshold concentration for deterioration in fry colour to be <0.4ppm, with the effect having become 'saturated' at or below 4ppm.

Deterioration in fry colour from ethylene exposure is reported to be exacerbated in the presence of carbon dioxide (Daniels-Lake *et al.*, 2005b). In this work, deterioration in fry colour from ethylene exposure (as a consequence of an increase in reducing sugar levels) was made worse in the presence of carbon dioxide. Interestingly, however, in a number of trials, results showed no significant effect of carbon dioxide alone (at concentrations of 2%) on fry colour. While there are probably no practical implications of this for ethylene use, it does conflict somewhat with the prominence given to lowering carbon dioxide levels in the management of processing potato stores.

Although ethylene is registered as a sprout suppressant in Canada (Section 2.1), it has not been adopted on a commercial scale for processing as a result of its effects on fry colour (Daniels-Lake and Prange, 2006).

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Bruise susceptibility

Treatment of potatoes (cv Russet Burbank) with 1ppm ethylene for 24 hours was reported to reduce bruise susceptibility and this effect was countered by carbon dioxide (Timm *et al*,1974). Further work (Timm *et al*, 1976 using cv White Rose) confirmed a reduced severity of bruising in tubers previously exposed to ethylene, compared with tubers stored in air. The authors speculated that exposure to ethylene predisposed tuber tissues to a more rapid wound-healing response resulting in a smaller volume of damaged/discoloured tissue.

Brierley *et al.* (1998) also showed a reduced bruise severity in cvs Maris Piper and Pentland Dell from repeated samplings from extended storage at 10°C, when crops were pre-treated for 72 hours with 15ppm ethylene. The authors could not relate this to changes in tyrosine or polyphenol oxidase levels however. Exposure to ethylene after induction of the bruise response, by falling bolt, did not affect severity of bruise symptoms.

Endogenous ethylene production is increased in damaged tissue and this is likely to be involved in plants' natural wound-healing response (Creech *et al.*, 1973). Increased endogenous concentrations of ethylene are considered to be instrumental in the higher respiration rates observed in damaged plant tissues (Reid and Pratt, 1972).

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7. Experiences from recent, commercial uses of ethylene

The first GB commercial scale trials, to exploit the sprout suppressant properties of ethylene were carried out in 2001 by Greenvale-AP (P. Coleman, personal communication), in response to increasing pressure to reduce detectable pesticide residues in foods. Commercial scale trials by *BioFresh* were started in 2003 (Barnes, 2006). Early work was conducted in stores at low temperature (close to 3.5^{o}C) with the aim of using ethylene to replace the use of CIPC in pre-pack storage. The trials were considered successful, and were scaled up over subsequent seasons.

In the 2004/05 season, however, the use of ethylene in some stores was associated with texture and flavour changes in some crops (P. Coleman and R. Barnes, personal communications). In some stores where ethylene was being used an increase in firmness/waxiness of some crops of the cvs King Edward and Maris Piper, and the development of a “nutty” flavour in cv Marfona were reported (Barnes, 2006). Changes in quality may be associated with high carbon dioxide levels occurring in stores, potentially as a result of a stimulation of respiratory activity from ethylene introduction, but also related to store construction/quality and store management. It is considered that maintenance of low store carbon dioxide levels may be important in avoiding changes in quality, in response to ethylene and/or carbon dioxide, in susceptible varieties (P. Coleman, personal communication). Management of ethylene was changed for the 2005 season, with ethylene being introduced gradually, instead of being immediately enabled at 10ppm, in an attempt to control carbon dioxide accumulation in stores.

In addition to changes in tuber quality, ethylene treatment was also considered to result in an increased refrigeration requirement of some stores (E. Anderson, personal communication). This is likely, at least in part, as a result of an increased (respiratory) heat output of crops, after initial ethylene introduction. In the treatment of other (climacteric) commodities the additional energy output, associated with increased respiratory activity from ethylene exposure, is recognised as providing an additional refrigeration requirement that must be met to maintain satisfactory temperature control (Saltveit, 1999).

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8. Conclusions

- Ethylene is an effective sprout suppressant of low-temperature stored potatoes. Although ethylene is controlled by a commodity approval and its use has become fairly regular, there is little published information regarding its sprout control efficacy and how other quality factors are affected. Growers/store managers should discuss in detail the use of ethylene ‘in their situation’ before entering into agreements on purchasing ethylene control systems.

- The use of ethylene has recently been associated with texture and flavour defects in cvs Maris Piper, Marfona, King Edward and Vale’s Sovereign. Defects may be of a magnitude sufficient to cause rejection by purchasers. The use of ethylene on these varieties should be treated as a risk and should only be carried out after discussions with the appropriate ethylene control supply company. Defects have been associated with elevated store carbon dioxide levels - growers should not however assume that control of carbon dioxide to low levels, will control defects in susceptible varieties, until this has been established.

- When ethylene control is initially enabled, this should not be set for 10ppm, which is expected to result in a rapid stimulation of respiration. Where stimulation of respiration occurs, this will result in an increased energy and carbon dioxide output of crops. Effects on respiration can be mitigated by increasing ethylene concentration gradually, when control is initially enabled. Details regarding the concentrations of ethylene to be used at start-up should be sought from the appropriate ethylene control supply company.

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9. Research needs (R&D Gaps)

Ethylene is an effective sprout suppressant and its commercial use on potatoes in GB appears to be the first. For the potato industry generally, and the pre-pack sector in particular, ethylene represents a significant opportunity to reduce the number of crops with a pesticide residue being supplied to consumers. Although ethylene is an effective sprout suppressant, there is little published work on its effects on stored potatoes. While independent research is limited, uptake of ethylene into commercial usage is also likely to remain limited.

The following areas are recommended for research:

Flavour and texture implications

Ethylene was used successfully as a sprout suppressant on low-temperature stored potatoes prior to the appearance (or a more widespread incidence) of flavour and texture defects in the 2004 crop. Defects are reported to be limited to the cultivars Maris Piper, Marfona, King Edward and Vale's Sovereign. The 'first' appearance in 2004, also indicates a possible seasonal nature to the defects.

It is considered that elevated store carbon dioxide levels may have been implicated in these defects. Elevated carbon dioxide levels are more likely when using ethylene, because of its stimulatory effect on respiration rate.

Research should be carried out to determine the effects of ethylene on texture and flavour and the possible interaction of these with store carbon dioxide levels.

Exposure to ethylene is associated with localised firming of tissue texture (hardcore syndrome) in cooked sweet potato (Timbie and Haard, 1977).

General ethylene management

Although the sprout suppressant properties of ethylene, in GB commercial storage, have been established, they are not well documented, and the principal sources of information are from companies supplying ethylene control systems. In addition, the effect on other tuber 'qualities' such as sugar content, where an effect could be anticipated, are not documented.

Independent research should be carried out examining the scope of sprout suppression by ethylene particularly with regard to ethylene concentration, storage temperature and variety interactions (which are an important feature of published work). More information is also required on other aspects of basic potato quality. Information of this kind may be useful for optimising storage conditions for specific problems: eg use of a higher storage temperature to reduce skin spot development in cv King Edward and use of higher storage temperatures to reduce sugar accumulation in long-term stored crops.

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The two companies supplying ethylene control systems in GB differ in their management of ethylene control, and the source of ethylene. Management differences are certainly likely to result in 'measurable' differences in stored crops.

The importance (if any), of the contrasting ethylene control strategies recommended by the two ethylene control system suppliers warrants investigation as these are anticipated to result in significant differences in properties of the stored crop. Differences are anticipated in terms of dormancy status (which may impact on shelf-life due to the reversible nature of sprout control by ethylene) and costs of storage. Independent, 'best-practice' type information is not generally available and is likely to limit use of ethylene commercially.

Differences in flavour (but not preferences) have been reported for tomatoes ripened using cylinder supplied ethylene and ethylene produced catalytically (Blankenship & Sisler, 1991).

Processing quality

Satisfactory sprout suppression of cvs Russet Burbank and Shepody for the processed chip (French fry) market has been reported, and research is progressing on how to minimise fry colour implications of such treatments. With this sector to a large extent dependent on the sprout suppressant CIPC (which is under EU review) the apparent lack of research effort in GB is somewhat surprising. Ethylene has scope for reducing the reliance of the processing sector on CIPC as well as, potentially, reducing the incidence of pesticide residues in processed products.

Research should be carried out to evaluate the sprout suppressant potential of ethylene, using GB cultivars held at processing storage temperatures and to determine to what extent ethylene could be used to replace CIPC, should use of the latter be limited during its current review.

10. Acknowledgements

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Appendix 1

Current commodity approval for ethylene use in the UK

Schedule: Commodity Substance: 99.9% v/v Ethylene

Food and Environment Protection Act 1985
Control of Pesticides Regulations 1986 (SI 1986 No. 1510): Approval

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Date of issue: 19 May 2006. Date of expiry: 31 December 2013 (unless earlier decisions are made or further prescribed extensions are granted).

Notice is hereby given that in exercise of the powers conferred by Regulation 5 of the Control of Pesticides Regulations 1986 (SI 1986/1510) (as amended) and of all other powers enabling them in that behalf, the Secretary of State, and the Scottish Ministers (as regards Scotland) and the National Assembly for Wales and the Secretary of State (acting jointly as regards Wales) have given full approval for use of the following commodity substance: Commodity substance: being 99.9% v/v Ethylene.

This Approval is Subject to the Following Conditions

Field of use

Only as a plant growth regulator in food storage practice.

Situations

Post harvest crops.

Target atmospheric ethylene concentrations

- 150 ppm (172.5 mg/m^3) in fruit ripening;
- 100 ppm (115 mg/m^3) in onion storage;
- 50 ppm (57.5 mg/m^3) in potato storage.

Operator protection

1. Engineering control of operator exposure must be used where reasonably practicable in addition to the following personal protective equipment: Operators must wear suitable self-contained breathing apparatus in atmospheres with an ethylene concentration exceeding 1000 ppm (0.1% v/v; 1150 mg/m^3).
2. However, engineering controls may replace personal protective equipment if a Control of Substances Hazardous to Health (COSHH) assessment shows they provide an equal or higher standard of protection.

Other Specific Restrictions

1. Handling and release of ethylene must only be undertaken by operators suitably trained and competent to carry out the work.
2. Operators must vacate treated areas immediately after ethylene introduction.
3. Unprotected persons must be excluded from the treated areas until atmospheres have been thoroughly ventilated (for 15 minutes minimum before re-entry).
4. Ambient atmospheric ethylene concentration must not exceed 1000 ppm (0.1% v/v; 1150 mg/m^3). Suitable self-contained breathing apparatus must be worn in atmospheres containing ethylene in excess of 1000 ppm.
5. A minimum 3 day post treatment period is required before removal of treated crop from storage.
6. Ethylene treatment must only be undertaken in fully enclosed storage areas that are air tight with appropriate air circulation and venting facilities.

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Advisory Notes
See also HSE Local Authority Circular 31/2 July 2000 (Revised November 2004).

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Appendix 2.

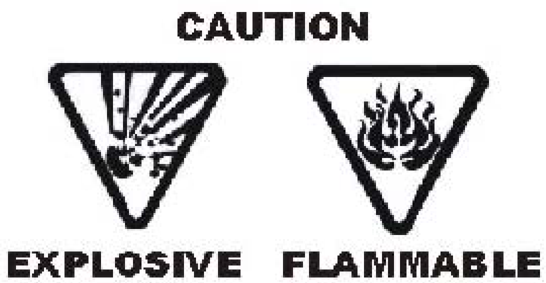
Eco Sprout Guard label for 100% ethylene

30-APR-2002

Eco Sprout Guard (EP) 100% ethylene Plant Growth Regulator

AGRICULTURAL sprout suppressant gas

CAUTION: EXPLOSIVE Flammable compressed gas Do not use in presence of open flame or spark Ground cylinders Secure cylinders in upright position Store below 50°C May be a suffocation hazard May cause frostbite Wear appropriate personal protective equipment.



READ THE LABEL AND TECHNICAL BULLETIN BEFORE USING

GUARANTEE:

Compressed ethylene gas, 100% (by weight).

REGISTRATION NUMBER 27083 PEST CONTROL PRODUCTS ACT

NET CONTENTS: 13.6 kg

McCain Foods Limited,
317 Main Street,
Florenceville,
New Brunswick E7L 3G6
telephone (506) 392-5541

© British Potato Council 2006

Eco Sprout Guard (EP) 100% ethylene Plant Growth Regulator

DIRECTIONS FOR USE

General:

Eco Sprout Guard is a plant growth regulator which reduces the sprout growth on tubers of Russet Burbank potatoes, during long-term storage prior to processing.

Method of Application:

Refer to the Eco Sprout Guard (EP) Plant Growth Regulator Technical Bulletin for application details, including rates and use restrictions.

Eco Sprout Guard Plant Growth Regulator is applied as a gas to Russet Burbank potatoes in the storage building.

Eco Sprout Guard Plant Growth Regulator is delivered from a compressed gas cylinder into the ventilation airstream of a closed potato storage building. The mixture in the cylinder to be used (percentage ethylene, balance nitrogen or air) and delivery rate must be sufficient during each ventilation cycle to attain a target ethylene concentration of up to 4 ppm in the storage atmosphere.

The storage building should be relatively free of air-leaks to retain the gas between ventilation cycles, but need not be absolutely air-tight. The concentration of Eco Sprout Guard in the storage building must be monitored to ensure that it remains near the target level continuously throughout the storage term, for effective sprout control.

A supplementary information package is available to describe the appropriate equipment for delivery, control and monitoring of Eco Sprout Guard Plant Growth Regulator in potato storages. Information can also be obtained from the supplier or agents of Eco Sprout Guard Plant Growth Regulator.

PRECAUTIONS

KEEP OUT OF REACH OF UNAUTHORIZED PERSONNEL

DO NOT USE IN PRESENCE OF OPEN FLAME OR SPARK

Personal Protective Equipment:

When cylinders are being connected and disconnected from the application system, wear long-sleeved shirt, long pants, goggles or a face-shield, and appropriate gloves to protect from freezing burns in the event of a leak.

Respiratory protection should be worn for entry to storage chambers or control rooms if the concentration of Eco Sprout Guard Plant Growth Regulator is unknown.

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Fire Hazard Precautions:

Eco Sprout Guard Plant Growth Regulator is a flammable compressed gas as delivered, and must be handled as a flammable gas until diluted below 0.3% in air (i.e. below 10% of the lower explosive limit). Store cylinders securely in an upright position, away from heat, spark or open flame. Handle compressed gas cylinders carefully. Ground cylinders.

Use only with delivery and regulating equipment approved for flammable gases, including flashback arresters and explosion-proof electrical equipment in any areas which may be exposed to flammable concentrations. Locate and eliminate all leaks of concentrated gas. Monitor gas levels in the vicinity of diluting and delivery apparatus. Maintain adequate ventilation in work areas and around delivery apparatus.

In the event of a gas leak, close valve if this can be accomplished safely. Eliminate all ignition sources and ventilate contaminated area thoroughly to atmosphere. Store leaking cylinders outside, prior to their return to supplier for disposal.

ENVIRONMENTAL HAZARDS:

May cause premature abscission of leaves, flowers, or fruit of growing plants in very close proximity (<50 m) to ventilation exhaust vents of treated storage structures during treatment.

If this pest control product is to be used on a commodity that may be exported to the U.S. and you require information on acceptable residue levels in the U.S., contact 1-866-375-4648 or www.cropro.org.

FIRST AID:

Exposure of bare skin to rapidly escaping gas, or contact with control apparatus during rapid gas delivery, may cause frostbite.

Exposure to concentrations of Eco Sprout Guard Plant Growth Regulator in air below 3% (30,000 ppm v/v) is not expected to cause adverse health effects. Not reported to be toxic or irritating to skin or eyes.

Exposure to extremely high concentrations (>20% or 200,000 ppm v/v) may cause oxygen deficiency, resulting in anaesthesia or possibly suffocation. Symptoms include drowsiness, narcosis or unconsciousness. While ensuring your own safety, eliminate contamination or move victim to fresh air. If breathing has ceased, trained personnel should IMMEDIATELY apply artificial respiration, or CPR if heart has stopped. Seek medical attention IMMEDIATELY.

Take container, label or product name and Pest Control Product Registration Number with you when seeking medical attention.

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TOXICOLOGICAL INFORMATION:

Treat symptomatically.

DISPOSAL:

For disposal, the empty cylinders and any cylinders containing unused or unwanted product may be returned to the point of purchase, i.e. picked up by the supplier in accordance with provincial requirements. It must be refilled by the supplier with the same product. Do not reuse this container for any other purpose.

In the event of a gas leak, close valve if this can be accomplished safely. Eliminate all ignition sources and ventilate contaminated area thoroughly to atmosphere. Store leaking cylinders outside, prior to their return to supplier for disposal. For additional details, contact the provincial regulatory agency or the manufacturer.

NOTICE TO USER:

This control product is to be used only in accordance with the directions on this label. It is an offence under the *Pest Control Products Act* to use a control product under unsafe conditions.

NOTICE TO BUYER:

Seller's guarantee shall be limited to the terms set out on the label and, subject thereto, the buyer assumes the risk to persons or property arising from the use or handling of this product and accepts the product on that condition.

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