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Controlling sprouting in potato tubers using ultraviolet-C irradiance

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ABSTRACT

Legislation limiting the use of chlorpropham (CIPC), the major potato sprout suppressant, has led to a need for new technologies to extend storage life of tubers. Ultra violet C (UV-C) has been used postharvest to reduce disease incidence on many crops, yet its use and efficacy as a sprout suppressant has not been investigated. The aim of this project was to identify the optimum dose and treatment timing of UV-C treatment on potato tubers as an alternative method of sprout suppression to reduce the dependence on chemical sprout suppressants. Up to six potato cultivars over two seasons were treated with varying doses of UV-C ranging from 0 to 30 kJ m^{-2} either at harvest or at first indication of dormancy break. The tubers were stored at 9 °C and sprout growth and incidence assessed. Treatment with moderate UV-C doses (5–20 kJ m^{-2}) suppressed sprout length and sprout incidence in a range of cultivars. Periderm DNA damage and programmed cell death were not detected in response to any of the UV-C doses. The inactive ABA metabolite, ABA-GE, increased in response to 10 or 20 kJ m^{-2} within 72 h of treatment. Multivariate analysis showed a negative relationship between ABA metabolites and sprout growth/incidence during storage. This study found that UV-C reduced sprout growth in potato with no deleterious effects on tuber quality. This suggests potential for further development as an alternative or supplement to conventional sprout suppressant technologies.

1. Introduction

The quality of stored potatoes is maintained by controlling the temperature and airflow within stores and in most cases, the application of sprout growth suppressing treatments. The principal potato sprout suppressant treatment currently used is chlorpropham (CIPC), on which the potato industry is still heavily reliant. CIPC received European Annex I clearance under Directive EC/91/414 and, as part of the process, a Maximum Residue Level (MRL) of 10 mg kg^{-1} was set which came into force in April 2007. New legislation coupled with general retailer pressure to reduce pesticide use (and thereby residues of pesticides on foods) are driving the need for alternative sprout suppressant technology. Alternative chemical sprout suppressants include essential oils and monoterpenes in particular carvone which is derived from caraway seed and is sold under the trade name, Talent. With repeated applications, carvone can inhibit sprout growth for up to a year as well as reduce fungal and bacterial rots. Yet, due to its volatility, repeated applications are required which can increase costs by 10-fold compared to that of CIPC (NPCS Board of Consultants & Engineers, 2007). Low temperature storage and continuous ethylene are two methods which do not leave pesticide residues in treated tubers, but each can give rise to high sugar concentrations that reduce the processing quality of potatoes (Sowokinos, 2001; Daniels-Lake et al., 2005; Foukaraki et al., 2014). CIPC acts by damaging the meristematic tissue of tuber eyes by modifying spindle formation and inhibiting mitosis (Campbell et al., 2010), whereas continuous ethylene has been shown to break endodormancy yet extend ecodormancy (Pruski et al., 2006).

Physical methods of controlling sprout growth are limited. Gamma irradiation is effective, but it can have detrimental effects on potato quality (Ezekiel and Singh, 2007) and its use is currently prohibited in the EU. UV-C has been shown to reduce disease incidence in fresh produce, either through direct germicidal activity or by elicitation of natural disease resistance (NDR) mechanisms (Terry and Joyce, 2004). UV-C irradiation causes DNA damage including cyclopyrimidine dimers (CPD), single and double stranded breaks and chromosome aberrations (Botchway et al., 2010) and has been shown to reduce surface microorganisms (Erkan et al., 2001). A UV-C dose of 15 kJ m^{-2} completely suppressed (for 3 months at 8 °C) dry rot and soft rot in potato tubers wound inoculated with *Fusarium solani* (incubated in a sealed bag for 1 day at 28 °C) and *Erwinia carotovora* (incubated for 6 h at 37 °C), respectively (Ranganna et al., 1997). Although the effect of

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UV-C on tuber sprouting and biochemistry was not assessed in this study, Ranganna (1996) found that the proportion of sprouted eyes per total eyes was negatively correlated with UV-C dose after 12 weeks storage of cv. Russet Burbank at 8 °C. A dose of 8 kJ m^{-2} resulted in 16% sprouted eyes whereas 15 kJ m^{-2} completely inhibited sprout growth (Ranganna, 1996). Recent research (Burns and Terry, unpublished data) found that 10 kJ m^{-2} of non-ionising UV-C irradiation suppressed sprouting in cv. King Edward stored for 4 months at 6 °C. The optimal timing of UV-C application has not yet been determined. The mechanism by which UV-C suppresses potato sprout growth is unknown but could be a result of physical damage and/or changes in tuber biochemistry.

Potato endodormancy is thought to be regulated by the relative concentrations of plant growth promoters and inhibitors (Coleman, 1987); however the role of abscisic acid (ABA) in determining dormancy state is not yet fully understood. ABA is a growth inhibitor which is generally high at harvest when the tubers are dormant but declines as dormancy weakens (Destefano-Beltran et al., 2006). Coleman and King (1984) found that ABA declined as dormancy ended in cvs. Kennebec and Nooksack but not in cv. Sebago during storage at 10 °C; therefore no minimum threshold level for the commencement of sprouting was identified. Similarly, (Biemelt et al., 2000) found that ABA content did not correlate with sprouting behaviour even though a decline was observed during dormancy.

This study identified the optimum dose and treatment timing of UV-C to suppress sprouting of potato tubers. In addition, tuber physiology, specific plant growth regulators, content of individual sugars and phenolic compounds, and DNA damage were assessed to help elucidate the mechanism by which UV-C affects tuber sprouting and to determine whether UV-C irradiation affects tuber quality.

2. Materials and methods

2.1. Plant material

In 2010, six cultivars of potato (*Solanum tuberosum* L.) grown at various sites in the UK were tested. These included cvs Cabaret (Sacker Potatoes, Grantham, Lincs.), Saturna, Hermes and VR808 (Chennels, North Scarle, Lincs.) and Maris Piper and Russet Burbank (McCain, Lincs., UK) (Supplementary Table 1). Potatoes were sourced from various commercial sites to assess the treatment efficacy. These tubers were not washed prior to treatment.

Supplementary Table 1 related to this article can be found, in the online version, at http://dx.doi.org/10.1016/j.postharvbio.2014.07.005.

In 2011, three potato cultivars were tested, i.e. Saturna and VR808 from the same site in Yorkshire and Maris Piper from Cambridgeshire. The tubers were divided into two groups; washed and unwashed. Washing was carried out by hand using gentle rubbing in clean water at room temperature. The tubers were air dried prior to treatment and subsequent storage.

2.2. Experimental design and sampling

A completely randomised design was employed in both years, with four UV-C treatments; 0, 5, 10 and 15 kJ m^{-2} during 2010 and 0, 10, 20 and 30 kJ m^{-2} during 2011. The UV-C treatments were applied either at harvest or at 10% eye movement (peeping) (Foukaraki et al., 2012a, 2012b, 2014). The 10% eye movement was judged to be when 10% of the control tubers showed signs of sprout development (Foukaraki et al., 2012a, 2012b, 2014). In 2010, tubers were assigned to an open paper bag according to the experimental design; 6 cultivars × 4 UV-C dose rates × 2 UV-C application times × 3 replicates (144 bags). Three tubers were removed from each bag at each sampling point during storage at 9 °C. In 2011, fewer cultivars were tested and washing was added as a treatment factor; the design included 3 cultivars × 4 UV-C dose rates × 2 UV-C application times × 2 washing levels (washed/unwashed) × 4 replicates (192 trays). Tubers were placed in commercial chitting trays (Sutton Bridge Crop Storage Research (SBCSR), 600 × 400 × 183 mm, polypropylene) in 2011 due to an increase in the number of sampling points; in 2011, samples were taken immediately after treatment, after 24 and 72 h. In 2010, samples were taken and analysed 10 weeks after 10% eye movement whereas two sampling points were taken in 2011 at 5 and 10 weeks after 10% eye movement.

Treatment of tubers with UV-C (254 nm) was conducted using a custom-built UV-C conveyor (Applied Food Technologies, Oxon., UK) with a control unit. The conveyer rotated the tubers to enable even exposure to the UV-C. The irradiance emitted by twenty two lamps (80 W, No. 709, 254 nm, Hanovia, Berks., UK) mounted above the conveyor was measured using an optical radiometer (Multisense-100, Ultra Violet Products, Cambs., UK). The duration of each UV-C treatment was less than 1.5 min and the temperature within the conveyer and on the surface of the tuber was unaffected. A subset of tubers was withheld from UV-C exposure and acted as the control. All tubers were stored at 9 °C at SBCSR (Lincs., UK). In 2011, the tuber subsamples were returned to Cranfield University for biochemical and physiological assessment. Since Maris Piper was tested in both years, and significant differences between treatments were observed, it was the only cultivar for which the biochemical analyses were reported. Tuber skin was analysed separately from tuber flesh. The washed tubers were assessed for sprout length, sprout incidence and eye movement only.

2.3. Physiological measurements

2.3.1. Respiration rate

In 2010, tubers were placed in 3 L jars with air tight lids and septum. Each jar contained three tubers of cv. Maris Piper, Cabaret and Hermes, with 3 replicate jars for each cultivar and treatment. The jars were sealed for 4 h at room temperature and gas samples removed using a 30 mL plastic syringe as described by Foukaraki et al. (2012b). CO_2 content was analysed using gas chromatography (GC model 8340, DP800 integrator, Carlo Erba Instruments, Herts., UK) with hot wire detection. The hot wire detector and oven were operated at 120 and 80 °C, respectively. The 2 m long by 4 mm column was packed with 60–80 mesh size Porapak Q (Jones Chromatography, Mid Glamorgan, UK). The respiration rate was calculated in mmol kg^{-1} h^{-1} (Chope et al., 2007).

In 2011, respiration rate of cvs. Maris Piper, VR808 and Saturna was measured using a Sable Respirometry System (Model 1.3.8 Pro, Sable Systems International, Las Vegas, USA) according to Collings et al. (2013) with modification. Air was subsampled at 1 L min^{-1} from each jar via a 'push mode' method using an SS4 subsampler. The subsample from each jar was analysed over a 5 min period, three times, and these three measurements were averaged. Before each sample was analysed, a 2 min baseline measurement was recorded. Final values (mL CO_2 h^{-1}) were adjusted for tuber weight to determine the respiration rate in mL kg^{-1} h^{-1}.

2.3.2. Sprout length, sprout incidence and dry weight

In 2010, for each cultivar, sprout length and sprout incidence was measured 10 weeks after 10% eye movement of the control tubers. In 2011, sprout length, sprout incidence and eye movement status of the tuber eyes was recorded 3, 5 and 10 weeks after 10% eye movement in the control tubers. Sprout length (mm) and number of sprouts (incidence) was measured for each tuber in a sample, and the averages per tuber were recorded. Each combination of replicate, cultivar, treatment dose and treatment timing was represented by a sample of three tubers. In both years, each sample