SPROUT INHIBITION BY $\alpha,\beta$-UNSATURATED CARBONYLS – METABOLISM AND MODE OF ACTION

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Background

Sprout inhibition during long term storage of potatoes is required to preserve fresh weight, dry matter, processing quality, and consumer acceptability. In Washington State alone, an estimated 4.6 billion pounds of stored potato tubers are treated with sprout inhibitor annually. Currently, the most widely used and effective compound registered for this purpose is the carbamate herbicide, CIPC (isopropyl N-(3-chlorophenyl) carbamate). In recent years, the EPA has lowered tolerance levels for CIPC residue on potatoes and tolerance levels in many export markets are substantially lower than in the U.S., requiring more frequent applications of CIPC at lower concentrations to maintain sprout inhibition. Alternative inhibitors for prolonged sprout control are thus being investigated. Biological alternatives to CIPC, such as clove oil and 1,4-dimethylnaphthalene, are available; however, the duration of sprout control is relatively brief with these agents, requiring multiple applications to achieve season-long sprout control.

Chemistry & Efficacy

$\alpha,\beta$-unsaturated carbonyl compounds constitute new chemistry for the suppression of sprouting in potato tubers. Small scale studies have demonstrated that full season sprout control (7-9 months) can be effectively achieved with 2-3 applications of $\alpha,\beta$-unsaturated carbonyl compounds having the general structure shown (Fig 1). Many compounds containing this specific arrangement of functional groups are biological in origin. For example 6- to 10-carbon trans-2-aldehydes and ketones are components of the aroma and flavor of fruits, vegetables, and some mushrooms. Numerous compounds of this chemical family are approved for use as food additives in the U.S., Canada, EU, and Japan.

![Fig. 1. General structure of an $\alpha,\beta$-unsaturated carbonyl.](image)

Thirty-eight, 7- to 10-carbon aliphatic compounds representing 9 different chemistries were tested for their toxicity to potato sprouts. ‘Single-eye’ seedcores (Fig. 2) were exposed to equimolar concentrations of individual compounds for 24 h at room temperature. Sprout fresh weight from treated and non-treated seedcores was compared following 21 days at 16°C. The compounds are ranked in order of decreasing efficacy (Fig. 2). Although most compounds produced at least some injury, $\alpha,\beta$-unsaturated aldehydes and ketones

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**Fig 2.** Relative toxicity of aliphatic compounds to potato sprouts. Toxicity is defined as % inhibition of growth compared to non-treated sprouts. Numbers in parentheses denote the number of individual chemicals tested. All compounds were applied at 200 μmol L$^{-1}$ headspace to sprouting single-eye seed cores. Seed cores in the inset depict sprouts showing a range of damage from most (top) to least (bottom).
were among the most damaging to sprout tissue in this assay. 3-Nonen-2-one and \(E\)-2-nonenal were used as representative \(\alpha,\beta\)-ketones and aldehydes, respectively, for subsequent investigations of mode of action.

Research with the 9- and 10-carbon ketones has demonstrated that the duration of inhibition of sprouting depends on the timing of application, cultivar, and storage temperature. Maximum efficacy is achieved when applied after dormancy break when sprouts are peeping (Fig. 3).

This is in contrast to CIPC, which must be applied prior to sprouting when tubers are dormant. Hence, the ‘window of application’ for the new inhibitors is narrower than for CIPC, demanding greater diligence to application timing for maximum efficacy. Using these compounds to control sprouting thus leverages the natural dormancy period of a particular cultivar.

The \(\alpha,\beta\)-unsaturated carbonyls are volatile and can be fogged into commercial storages using conventional fogging equipment. Unlike CIPC and several other commercially available inhibitors, maintaining minimum residue levels is not important for efficacy of these compounds. Residue levels decline rapidly in tubers when ventilated with fresh air and residues are barely detectable three weeks after treatment. The precipitous decline in residue levels is due to high volatility of the compounds combined with their rapid metabolism to saturated aldehydes, ketones and ultimately alcohols.
Physiological Responses & Mode of Action

Meristematic tissues are most sensitive to being injured by the $\alpha,\beta$-unsaturated carbonyl compounds. Sprouting tubers respond to treatment with a concentration-dependent transitory increase in respiration rate; a response that likely reflects injury to the developing sprouts. Tuber respiration rate then decreases progressively to pre-treatment levels within 7 to 10 days. Cells within sprouts experience a rapid loss of membrane integrity and increased peroxidation of membrane lipids, which results in oxidative stress. The metabolic pathways responsible for neutralizing reactive oxygen species and controlling cellular redox potential (e.g. glutathione system) are directly compromised by these compounds. The loss of membrane function, rapid water loss, and reduced ability to neutralize reactive oxygen species and modulate cellular redox potential collectively leads to unabated oxidative stress, cell death and tissue necrosis. Sprouts thus exhibit a “burnt out” appearance within 24 h of exposure to $\alpha,\beta$-unsaturated carbonyl compounds (Fig. 4).

Summary

- Seven- to ten-carbon $\alpha,\beta$-unsaturated carbonyl compounds are highly toxic to sprouts and are undergoing development as commercial sprout inhibitors.
- When volatilized into storage, full-season sprout suppression can be achieved with 2-3 applications, depending on cultivar and storage temperature.
- Rapid decline in residues are due to the high volatility of these compounds in combination with their rapid metabolism to various products which, when applied at higher concentrations, are also toxic to sprouts.
- The $\alpha,\beta$-unsaturated carbonyls disrupt membrane integrity and the ability of cells to regulate oxidative stress in their mode of action.
- WSU licensed exclusive patents to AMVAC Chemical Corp. - SmartBlock™ (3-decen-2-one) is currently being developed for commercial use.

Fig. 4. Visible symptoms of the toxicity of 3-nonen-2-one (3N2) to sprouts. A sprouting tuber was exposed to 3N2 vapors for 19 h. Sprouts begin to darken within 3 h of exposure with accompanying loss of turgidity, starting at the sprout apex and moving downward. The progressive loss in turgidity results in collapse of tissue by 19 h. These symptoms are a primary consequence of reduced membrane integrity.