Preplant Copper-based Compounds Reduce *Erwinia* Soft Rot on Calla Lilies

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ADDITIONAL INDEX WORDS. alkyl benzene sulfonate, copper oxychloride, copper sulfate pentahydrate, dimethyl benzyl ammonium chloride, dimethyl ethyl benzyl ammonium chloride, quaternary ammonium

SUMMARY. Four sterilants-bactericides (Phyosan-20, Fixed Copper, Phyton-27, and Virkon) were compared as preplanting dips of *Zantedeschia elliottiana* Engl. W. Wats 'Yellow' (a susceptible cultivar) rhizomes to reduce plant losses due to latent field-infected *Erwinia carotovora* soft rot during greenhouse forcing as a flowering potted plant. All sterilant solutions were prepared in combination with Promalin, a commercially available product containing gibberellic acid (GA) used to enhance flowering. An additional group of rhizomes was inoculated with *E. carotovora* sp. as a preplanting dip in combination with the GA treatment but were not treated with a bactericide. Rhizomes were wounded by making two cuts on the distal part of the rhizome or left unwounded before application of the preplant dip treatments. After potting, plants were fertilized with either a high (3.0 mmol·L⁻¹) or a low (1.0 mmol·L⁻¹) calcium nutrient solution through subirrigation. More than 90% of the inoculated rhizomes collapsed within 5 weeks after potting due to bacterial soft rot. With the

uninoculated rhizomes, the copper-based compounds (Fixed Copper or Phyton-27) provided better control of bacterial soft rot than either Phyosan-20 or Virkon only during the first 6 weeks of forcing. During the remainder of the forcing period, there were no differences in weekly losses of rhizomes with the four sterilants. Confirmation of *Erwinia carotovora* subsp. *carotovora* (Jones) Bergey et al. as the causal organism was made throughout the experiment. Incisions on the rhizome before planting or calcium nutrition during forcing did not have any significant effect on disease severity. Rhizomes treated with solutions of the copper-based compounds produced 0.5 flowers less per rhizome than either Phyosan-20 or Virkon. High calcium fertilization resulted in an increase of 0.5 flowers per plant compared to low calcium nutrition.

Bacterial soft rot of calla lilies caused by *Erwinia carotovora* sp. is a serious disease that frustrates commercial forcers attempting to expand the floral market for this plant (Funnell, 1993). The disease is characterized by the foul, pungent odor associated with above-ground shoot collapse and rhizome (or tuber) decay. Visible symptoms first occur within 2 to 4 weeks from planting and continue throughout the 10- to 14-week forcing period, often resulting in substantial plant losses (>30%). However, in some plantings the disease remains in check (<3% loss) or only becomes apparent later in the forcing period. In North America, no effective preplant treatment that will suppress or eradicate this bacterial disease in the field is registered (Funnell, 1993). Some calla species (*Zantedeschia elliottiana*) are more susceptible to the disease than others (*Zantedeschia aethiopica*). Historically in Ontario, higher losses occur in later (March to July) rather than earlier (November to February) plantings. Age of rhizome (reduced disease resistance), duration of rhizome storage (reduced carbohydrate and moisture content of rhizome), higher irradiance, and higher greenhouse temperatures may contribute to the severity of the disease (Kamerman, 1975). Also, increased severity of the disease appears to be associated with larger rhizomes (T. Lukens, personal communication).

The *E. carotovora* bacterial soft

rot organism is usually considered a secondary, wound, or storage pathogen, but it can be virulent in forced calla lilies and appears to be present often as a latent infection in the rhizome. Stress to the rhizome, such as exposure to temperature or osmotic extremes for a given time, or by physical or other pathogenic damage, may cause electrolyte leakage, creating a nutrient source for colonization by the bacteria. Calcium fertilization during field production (before forcing) as well as during greenhouse forcing may also play a role in the development of potato soft rot caused by *Erwinia* (Palta, 1996).

The objectives of this research were 3-fold. 1) To determine the effectiveness of four bactericides-sterilants applied as a preplant dip. 2) To determine whether physical damage through incisions of the rhizome influences the incidence of soft rot. 3) To determine whether the level of calcium fertilization during forcing influences the severity of the bacterial soft rot.

Materials and methods

Rhizomes of 'Yellow' calla lily, each 5.0 to 6.5 cm in diameter, were shipped in open bulb crates by Golden State Bulb Growers, Watsonville, Calif., during the middle of May 1996. These rhizomes were grown in fields suspected of being infected with *Erwinia*. Visually infected rhizomes were discarded. On 23 May, one-half of the rhizomes were either wounded with two incisions (4 cm long each) on the upper surface of the rhizomes using a regular peeling knife or left unwounded. The knife was sterilized in ethanol, flamed and cooled in cold water between the wounding of each rhizome. Immediately after this treatment, wounded and unwounded rhizomes were dipped separately for 5 min in a solution containing 3.75 mL of Promalin (1.8% benzyladenine w/w and 1.8% GA₄ + GA₇ w/w; Abbott Laboratories, N. Chicago, Ill.) per 1 L of water (standard greenhouse practice to stimulate flower production) in combination with one of the following compounds: Phyton-27 (copper sulphate pentahydrate at 2.5 mL·L⁻¹; Source Technology Biologicals, Minneapolis), Virkon (alkyl benzene sulfonate salt at 5 g·L⁻¹; Vétoquinol Canada, Joliette, Que., Canada), Fixed Copper (copper oxychloride at 3 g·L⁻¹; United Agri Products, Dorchester, Ont., Canada), Phyosan-20 (quaternary

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ammonium compound at 5 mL·L⁻¹; Maril Products, Tustin Calif.), or a suspension with *Erwinia carotovora*. It should be noted that, at the time of this trial, Physan-20 was widely used commercially as a preplant dip.

The *Erwinia* culture was prepared from diseased calla lilies from a commercial greenhouse located in Vineland Station, Ont., Canada, by macerating the diseased areas of eight thoroughly rinsed rhizomes in a food blender. The slurry was then strained through cheesecloth and 750 mL of the leachate was mixed in 20 L of water before dipping the rhizomes. The pathogenicity of the *Erwinia* suspension was confirmed using potato slices in petri dishes. Diagnosis of pathogens was not made from the slurry. The rhizomes of each treatment were allowed to air dry in open bulb crates for 4 d at 18 to 20 °C, after which each rhizome was planted into a 11.5-cm-diameter pot designed for subirrigation using a peat-based substrate formulated by a commercial greenhouse operation in Vineland Station. Rhizomes were planted with the distal part ≈2 to 3 cm below the surface of the growing substrate and then hand watered. The following day, the pots were placed randomly on nonrecirculating subirrigation troughs at a spacing of 40 pots/m² of bench area in a double acrylic greenhouse with an 18/18 °C (day/night) temperature regime. One-half of the plants was fertilized (three troughs) with a high-Ca solution containing (in mmol·L⁻¹) 15.0 NO₃⁻ N, 0.5 H₂PO₄⁻, 6.0 K⁺, 3.0 Ca⁺², and 1.5 Mg⁺², while the remaining plants (also three troughs) were irrigated with a low-Ca solution containing (in mmol·L⁻¹) 15.0 NO₃⁻ N, 0.5 H₂PO₄⁻, 8.0 K⁺, 1.0 Ca⁺², 1.5 Mg⁺², and 2.0 Na⁺. With the subirrigation troughs, the nutrient solution was injected at the high end of each sloping (0.5%) trough that allowed a shallow depth of solution (3 to 5 mm) to flow over the bottom before draining at the low end of the trough. The substrate in each pot absorbed the solution through capillary action (subirrigation). The electrical conductivity of both calcium solutions was 2.1 dS·m⁻¹. One week after planting, all pots received a fungicide drench (150 mL/pot) containing 1.7 g of Quintozene 75WP (terrachlor) and 0.037 mL of Ridomil 240EC (metalaxyl) per 1 L of water. When shoots were 8 to 10 cm tall, two 100-

mL applications of 10 ppm paclobutrazol per pot were applied 1 week apart.

Twice weekly inspections for visually diseased plants (stem toppling or black discoloration) were done until flowering. Plants with these symptoms were removed from the greenhouse bench and dissected to determine visually and by odor whether the rhizome was infected with *Erwinia* soft rot. Random samples were sent to the Ontario Pest Diagnostic Clinic for laboratory identification and confirmation of *Erwinia* as the disease pathogen using the Biologsystem (Bochner, 1989; Jones et al., 1993). Twelve weeks after planting, the number of flowers and shoots per pot were counted and the health of the root system was rated visually.

The experimental design was a 2 (wounded vs. unwounded) × 5 (pretreatments) × 2 (high vs. low calcium fertilization) factorial with 50 plants per experimental unit or 1000 rhizomes. All plants were randomly placed on a bench with six troughs. The experiment was repeated 1 week later using the same procedures, except that plants were grown in the same greenhouse on two ebb-and-flow benches, one for each calcium concentration. Subirrigation was achieved by flooding the tables to a depth of 25 mm for 10 min and then allowing to drain. The two irrigation systems were also considered replications.

Results and discussion

PREPLANT TREATMENT AND DISEASE SEVERITY. Calcium nutrition during

forcing and/or wounding the rhizome before planting did not significantly affect the number of diseased plants. Therefore, the data for these treatments were combined. Compared with a total accumulated plant loss of >98% at flowering obtained with the artificially inoculated rhizome treatment, the noninoculated rhizomes treated with Physan-20 or Virkon preplant resulted in plant losses of ≈60%, and the copper-based (Fixed Copper or Phyton-27) treatments resulted in plant losses of ≈30%. When combining the two irrigation systems, weekly plant counts showed the *Erwinia*-inoculated treatment had the greatest losses during weeks 3 and 4, and by week 5 almost all (87%) of the treated plants had been removed (Fig. 1). It should be emphasized that the inoculated rhizomes were exposed to an unnaturally high concentration of bacteria, while the other four chemical treatments used naturally field-infected rhizomes. It is assumed that the latter may have had latent or quiescent infections. Among the chemical preplant treat-

Fig. 1. Weekly plant losses (%) of *Zantedeschia elliptica* 'Yellow' that were either preplant dipped with a bactericide or inoculated with *Erwinia carotovora* sp. Each bar represents the mean of 400 plants. Columns with the same letter within a week are not significantly different according to Duncan's multiple range test, $P = 0.05$, on transformed (arcsin) ratios between the number of diseased and original rhizomes.

Fig. 2. Accumulated plant losses (%) of *Zantedeschia Elliottiana* 'Yellow' that were either preplant dipped with a bactericide or inoculated with *Erwinia carotovora* sp. for the trough irrigation and the ebb-and-flow system.

ments, the greatest losses (7% to 12% per week) occurred with Virkon or Physan-20, with losses peaking during weeks 4 to 6 from planting. In comparison, during the first 6 weeks, the two copper-based chemicals (Fixed Copper and Phyton-27) significantly reduced the incidence of the disease (Fig. 1). After week 7, no differences were observed between the preplant treatments, although an overall increase in plant losses was experienced during weeks 11 and 12. The latter increase was caused primarily by the number of infected plants removed from the replicate planting irrigated with the ebb-and-flow system (Fig. 2). Figure 2 shows that no plant losses occurred for any of the preplant treatments after week 9, when plants were irrigated using troughs. However, there was a significant increase with the ebb-

and-flow system. There are two possible explanations for this difference. Although recirculation of the nutrient solution did not take place for either irrigation system, small amounts of nutrient solution, which may have harbored the inoculum, remained in the channels and grooves of the preformed ebb-and-flow tables between irrigations. This was not the case with the trough irrigation system. The inoculum may also have leached from the inoculated plants or from collapsed plant tissue (toppling stems and leaves) on the ebb-and-flow bench causing

later or secondary infections.

Visual symptoms were similar for all discarded plants throughout the experiment. All plants exhibited the mushy, watery breakdown of the rhizome, the translucent roots, and the foul pungent odor characteristic of *Erwinia* soft rot. Diagnosis of plant samples consistently determined *Erwinia carotovora* subsp. *carotovora* as the causal agent, except when samples were kept for >4 weeks in cold storage (5 °C) before processing. In the latter case, a wide variety of saprophytic bacteria were determined. No precursor or primary fungal pathogens were isolated from *Erwinia*-infected roots.

PLANT QUALITY AND FLOWER NUMBER. Preplant dip treatments and calcium fertility during forcing affected the total number of flowers. Rhizomes artificially infected with *Erwinia* had the lowest number of flowers per plant of all the pretreatments. Plants receiving the high calcium (3.0 mmol·L⁻¹) fertilization rate produced 0.5 more flowers than those receiving the low calcium (1.0 mmol·L⁻¹) fertilization rate. The treatments with copper-based compounds reduced the number of flowers by 0.5 per rhizome compared to the treatments with noncopper-based compounds (Table 1).

In this preliminary study, copper-based compounds applied as preplant dip effectively reduced the severity of *Erwinia* soft rot during greenhouse forcing of calla lilies compared to either Physan-20 (control) or Virkon. Perhaps, the effectiveness could be further improved by increasing the concentration of the cupric ions (Scheck and Pscheidt, 1998), duration of the preplant dip, and/or the use of a surfactant (Safter et al., 1997). Further questions remain on the effectiveness of these compounds during the latter part of the forcing. Future

Table 1. The effect of preplanting treatments and low (1.0 mmol·L⁻¹) or high (3.0 mmol·L⁻¹) Ca concentration during forcing on the number of flowers of *Zantedeschia Elliottiana* 'Yellow' determined on healthy (862) plants at flowering. The standard errors of the means are in parentheses. Effects of Ca concentration and preplant treatment were significant at $P < 0.001$.

Ca	No. of flowers/rhizome				Ca mean
	Physan-20	Virkon	Fixed Copper	Phyton-27	
Low	5.1	4.8	4.8	4.3	4.7 (±0.09)
High	6.0	5.1	5.3	4.8	5.2 (±0.10)
Preplant mean	5.6 (±0.18)	5.0 (±0.15)	5.1 (±0.12)	4.5 (±0.12)	5.0 (±0.07)

studies will determine the survival of *E. carotovora* subsp. *carotovora* exposed to different copper-based compounds over time and assess the effectiveness of postplant applications of copper-based compounds. Also, studies should be conducted on the survival of *Erwinia* bacteria in subirrigation systems. Wounding the rhizomes with a sterile knife before planting or calcium fertilization during forcing did not increase the disease incidence. The calcium nutrition may have been applied too late in the production cycle, as calcium applied during the field growth phase of potatoes increased the resistance against *Erwinia* sp. affecting potatoes in storage (Palta, 1996).

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Fertilizer Substitutions in Hydroponically Grown Greenhouse Tomatoes

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ADDITIONAL INDEX WORDS. **nutrient film technique, added salts**

SUMMARY. Experiments were carried out to evaluate two salts, K_2SO_4 and NaCl, as materials to supplement the electrical conductivity (EC) of the basic nutrient solution in nutrient film technique (NFT). The effects of these materials on the growth, yield and fruit quality of greenhouse tomato (*Lycopersicon esculentum* Mill.) grown by NFT were quantified. These effects were tested by increasing the recirculating solution EC from a base value of $1500 \mu S \cdot cm^{-1}$ to that suitable for the crop growth stage with normal feed (macronutrients), 0.38 M (0.53 lb/gal) K_2SO_4 or 1.14 M (0.55 lb/gal) NaCl, at a common pH of 6.2. In 1995 and 1996, there were no significant effects of the treatments on crop growth. In 1995, the early marketable yield was significantly lower when K_2SO_4 was used but the yield at the end of the season did not differ among the treatments. Furthermore, with K_2SO_4 , the proportion of grade #1 fruit in early total yield was lower than in the control, while, fruit biomass content was higher than in the NaCl treatment. In 1996, the cumulative marketable fruit weight was unaffected by the treatments. A trend toward high number of large grade fruit occurred with the NaCl treatment. The pH and EC of the fruit homogenate were favorably affected by the NaCl treatment. Adding K_2SO_4 or NaCl in partial substitution of macronutrients in the

recirculating solution may have a role in NFT systems in not only reducing environmental pollution (from nitrates and phosphates) and fertilizer costs, but also in improving fruit quality and, therefore, profit margins.

For environmental and economical reasons, reducing the supply of nutrients to tomatoes grown in hydroponic systems, including the nutrient film technique (NFT) culture, is desirable. As the supply of macronutrients is reduced, either K_2SO_4 or NaCl, salts that are financially and environmentally more attractive, may be added to raise the electrical conductivity (EC) of the recirculating solution to appropriate levels according to plant needs. A practical question is whether the addition of above salts, when used as partial substitutes for common greenhouse fertilizers, will affect the growth, yield, and fruit quality of tomato grown by NFT.

In soil-grown greenhouse tomato, low levels of K_2SO_4 reduced yields (Winsor et al., 1967) while, increasing rates of K_2SO_4 reduced the incidence of ripening disorders and of puffy fruit, and increased the acidity of the fruit juices and the firmness of the fruit (Winsor, 1979). In tomato grown by NFT, Adams and Grimmett (1986) reported that although K_2SO_4 levels did not affect fruit yields, the number of fruit per plant increased as the concentration of K^+ was raised. Fruit biomass and the titratable acidity of fruit juice increased with the concentration of K^+ supplied.

In closed hydroponic systems such as NFT, the efficient exclusion of Na^+ by horticultural crops (Baas et al., 1995; Sonneveld and van der Burg, 1991) may cause an accumulation of Na^+ in the root environment. Salinity can inhibit plant growth by a) lowering external osmotic potential and thus inducing water stress b) ion toxicity, or c) ion imbalance (Greenway and Munns, 1980). Increasing the NaCl concentration in the circulating solution of an NFT system for tomato from 0 to $200 mg \cdot L^{-1}$ (0 to 200 ppm) resulted in small fruit, the greatest effect corresponding to the highest conductivity of the circulating solution (Attenburrow and Waller, 1980). Sonneveld and van der Burg (1991) suggested that the favorable effect of

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