Potential Use of Chlorine Dioxide to Control Diseases in Ornamental Plant Production Systems©

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Diseases are a common problem in many ornamental plant production systems (Jones and Benson, 2001; Chase, 1997). Foliar diseases, such as gray mold, powdery mildew, and downy mildew, can cause significant damage to a number of different plants. In addition, there are a number of soil and/or waterborne diseases, such as Fusarium root rot, black root rot, Pythium root rot, and Phytophthora root rot, that can cause extensive losses on a wide range of ornamental plants. Some pathogens, such as *Botrytis cinerea* also can cause extensive postharvest losses during the handling and shipment of many types of cut flowers and greenery products.

Management of ornamental plant diseases is generally based on a combination of cultural practices, environmental manipulations, use of biologicals, and application of fungicides (Bilderback and Jones, 2001; Dreistadt, 2001; Jeffers et. al, 2001; Krause, 1991). Recently, there has been an increased interest in using general biocides or disinfectants for the control of diseases in ornamental production systems. This is particularly true where recirculating water systems are used (Broembsen et. al., 2001; Mebalds et. al, 1996; Simone, 2001). Most fungicides only inhibit spore germination or growth of fungi, whereas disinfectants can kill cells upon contact and thus are well suited for reducing inoculum levels and the carryover of disease organisms from one crop or one source to the next.

There are several types of disinfectants being used on ornamentals. Although not commonly used in ornamental production systems, chlorine dioxide (ClO_2) is being used increasingly as a replacement for chlorine to kill microorganisms in drinking water and various meat and fruit/vegetable processing facilities (Han et al., 1999; Han et al., 2000; Kaczur and Cawfield, 1993; Olsen et al., 1999; Roberts, 1994; Roberts and Reymond, 1994; and Spotts and Peters, 1980). It is also used as a general water disinfectant in many industrial applications (Amy et al., 2000; Dychdala, 1991; Olsen et al. 1999). Chlorine dioxide is replacing use of hypochlorites because it is less affected by pH, less reactive to organic and inorganic materials (e.g. ammonium, chloramines, bromines, etc.), removes phenolic tastes and odors, and produces fewer to no toxic or carcinogenic by-products (e.g., trihalomethanes and haloorganics) (Amy et. al., 2000; Benarde et al., 1965; Dychdala, 1991). In addition, ClO_2 has a higher biocidal activity on a ppm basis than sodium hypochlorite, iodine, quaternary ammonium compounds, glutaraldehyde, and phenol (Bundgaard-Nielson and Nielson, 1996; Tannger, 1989).

Working with several postharvest pathogens of tree fruits, Roberts and Reymond (1994) showed that spores of *Cryptosporiopsis perennans* were killed when exposed to 1 mg ClO_2 ml^{-1} for 30 sec. Spores of *Mucor piriformis* were killed after a 4-min exposure at 1 mg ClO_2 ml^{-1} or 30 sec exposure at 3 mg ClO_2 ml^{-1}, and spores of *Penicillium* *expansum* were killed after a 2-min exposure at 3 mg ClO_2 ml^{-1} or a 30 sec exposure at 5 mg ClO_2 ml^{-1}. Spores of *B. cinerea* were killed after a 2-min exposure at 5 mg ClO_2 ml^{-1}. Roberts and Reymond (1994) concluded that a concentration of about 3 to 5 mg ClO_2 ml^{-1} chlorine dioxide in the dump tank water should provide an effective control of spores and thus reduce the potential for various postharvest diseases.

Mebalds et al. (1996) have reported that ClO_2 was highly effective against a range of plant pathogens, including *Fusarium oxysporum*, *Alternaria zinniae*, *Colletotrichum capsici*, and *Phytophthora cinnamomi*. They found that an exposure of 8 min at 3 mg ClO_2 ml^{-1} was required to control waterborne fungal pathogens. In addition they showed that higher concentrations were required when impurities were present in the water.

In most instances, ClO_2 is generated on site (Amy et al. 2000). Where water is recirculated, such as with dump tanks, the generating system is part of a constantly circulating water system connected to the tank or wash line. In the return line, the water stream is shunted through a bypass loop where ClO_2 concentration is measured with an oxidative-reduction potential probe and monitored by a small computer system. At a low-limit set point, sodium chlorite and an acid, such as hydrochloric acid, are proportionally metered into a mixing chamber. The two chemicals react and generate ClO_2, which is injected into the water line that goes back to the dump tank or wash line.

Companies, such as, CH_2O International, are currently marketing automated systems to generate ClO_2 for a range of agricultural uses. Using sensors and a computer-controlled mixing system, CH_2O International's Fresh-Pak chlorine dioxide system is able to generate and maintain specific concentrations of chlorine dioxide for use in dipping tanks and wash lines. Although most of these systems are being used in the fruit and vegetable industry, recent work has shown that this system provided an effective alternative to using formaldehyde to prevent the spread of basal rot during the hot water treatment of daffodil bulbs (Chastagner and Riley, 2002).

Historically, formaldehyde has been used extensively by bulb growers to prevent the spread of basal rot (*F. oxysporum* f. sp. *narcissi*) during the hot water treatment (HWT) of daffodil bulbs (Byther and Chastagner, 1993; Chastagner and Byther, 1985; Moore, 1980). During the 1990s, one of the most important disease management problems facing the bulb industry in the United States was the loss of formaldehyde due to EPA restrictions on the agricultural uses of this product.

Working to identify potential alternatives to formaldehyde, Chastagner and Riley (1996; 2002) found that chlorine dioxide effectively controlled the spread of *Fusarium* inoculum during the HWT of daffodil bulbs and thus protected bulbs from the spread of basal rot during HWT. A concentration of 5 mg ClO_2 ml^{-1} was as effective as 0.5% formaldehyde in protecting bulbs during a 4-h long HWT. The use of automated systems to monitor and maintain the concentration of ClO_2 provides growers with a pest management process that consistently controls the spread of basal rot during the HWT of bulbs.

Chastagner and Riley have also tested the effectiveness of ClO_2 dips in controlling Botrytis gray mold on flowers of 'Double Delight' roses. Sets of inoculated and non-inoculated flowers were dipped in water for 5 min or in a 6.5 mg ClO_2 ml^{-1} solution for 1 or 5 min and then incubated for 48 h in sealed plastic boxes.

After 48 h, symptoms consisted of brown-colored spots or blighted areas on the flower petals. Less than 1% of the petal tissue was diseased on the non-inoculated flowers that were dipped in water only. On inoculated flowers dipped in water, the percentage of blighted petal tissue ranged from 43.7% for the outer petals to 12.5% for the fourth or innermost petals that were sampled. Overall, 31.9% of the petal surface on the inoculated flowers dipped in water showed symptoms or damage from disease. Inoculated flowers that were dipped in ClO_2 for 1 or 5 min had damage on less than 1% of the petal tissue. There was also no evidence of injury to the flower petals on any of the flowers that were dipped in the ClO_2.

Work is also underway at Washington State University and USDA/ARS in Poplarville, Mississippi to determine if systems such as the CH_2O International Fresh-Pak ClO_2 system could be adapted for the ornamental plant production industries to control inoculum in irrigation water and to kill inoculum on foliage.

The activity of specific concentrations of ClO_2 in noncirculating water systems would depend on the demand load of the local water source (Amy et al., 2000; Dychdala, 1991; Mebalds et al., 1996). A demand load comes from the presence and type of reactants that reduce the activity of a disinfectant (Dychdala, 1991). All disinfectants react quickly with various elements and molecules (e.g., hydrophilic acids, ionic solutes (nutrient leachates), organic matter, phenols) although the type and rate of reactions vary with the disinfectant (Amy et al., 2000; Dychdala, 1991). The reactive nature of a disinfectant as well as degradation due to light and volatility are some of the reasons for a lack of residual protection (Amy et al., 2000; Dychdala, 1991). Disinfectants must be added at a concentration that compensates for the demand load, so the remaining concentration will be high enough to kill problematic microorganisms.

Copes et al. (2001) have conducted a series of studies to determine the relative effect that pH and several inorganic ions [ammonium (NH_4), nitrate (NO_3), copper (Cu), iron (Fe), manganese (Mn), zinc (Zn), "synthetic" hard water (sHW = calcium (Ca) and magnesium (Mg) carbonates (CO_3)], that may be encountered in ornamental plant production systems have on the biocidial activity of ClO_2 as a function of concentration with a set exposure period (30 sec) against several types of fungal propagules, including conidia of *B. cinerea* (used as the primary bio-indicator organism), micro- and macroconidia of *F. oxysporum* f.sp. *narcissi*, and endoconidia and aleuriospores of *Chalara basicola*.

Copes et al. found that 5 mg ClO_2 ml^{-1} solution killed more than 95% of *B. cinerea* conidia in the presence of all ionic factors except Mn, which required 15 mg ClO_2 ml^{-1}. Chlorine dioxide activity was unaffected by NH_4, NO_3, Cu, Zn, and pH 4; slightly reduced by pH levels 5 and 6; moderately reduced by Fe and sHW, and pH levels 7 and 8; highly reduced by Mn; and severely reduced by pH 9 and 10. When all factors were combined, Mn was the predominate factor reducing activity of ClO_2 when pH was 8 or below, while pH and sHW significantly shifted the rate to a lesser degree. Depending on the levels of Mn, pH, sHW, and Fe, as much as 10 to 20 mg ClO_2 ml^{-1} were required to kill more than 95% of conidia of *B. cinerea*.

Ionic water amendments and pH significantly affected ClO_2 activity in a similar way for all fungal species, but the lethal dose of ClO_2 varied by fungal species and spore type (Copes et al. 2001). Ranges of 1 to 9 mg ClO_2 ml^{-1} were needed to kill more than 95% of conidia of *F. oxysporum* f. sp. *narcissi* and endoconidia of *C. basicola*, and 46 to 70 mg ClO_2 ml^{-1} were needed to kill aleuriospores of *C. basicola*, with a 30-sec contact time.

To kill plant pathogens in irrigation water, rates of ClO_2 and any other disinfectant would have to be calibrated to water flow rates and time of exposure from the injection point to emission from sprinkler heads or flood systems. Adjusting the rate relative to specific ionic properties and pH level associated with the local water source and pathogens of most concern should provide for proper disinfectant activity and limit waste.

Although only a small number of plant species have been tested to date, research has shown that it is not likely that ClO_2-treated water will damage many plant species at rates required to kill common plant pathogenic fungi (Carrillo et al., 1996; Copes et al., unpublished data; Mebalds et al., 1996). Working with eight types of bedding plants and nine types of woody shrubs, Copes et al. (unpublished) tested the tolerance of these plants to multiple foliar applications of ClO_2. No significant injury was observed on the foliage or flowers of any of the plants at rates up to 20 mg ClO_2 ml^{-1}. Studies are currently in progress to determine the efficacy of mist applications of ClO_2 in controlling development of foliar disease under simulated production systems.

Studies are also underway at Washington State University to evaluate the effectiveness of alternative approaches in applying ClO_2 for use in horticultural systems. ICA TriNova, LLC is a marketing and development company seeking to commercialize controlled-release systems to produce ClO_2 for a number of uses, including the horticultural industry. They are developing products for gas- and liquid-phase release of ClO_2 that do not require specialized equipment. Their Z-Series ClO_2 delivery systems include single-media extended-release products involving low-level gas and direct powders, extended-release products involving low- and high-level indirect sachets that produce ClO_2 gas for direct or solution applications, and application of electrostatically charged solutions. If proven effective without any crop injury, some of these application technologies could provide the opportunity to use ClO_2 to control production and postharvest diseases of a number of horticultural crops. These technologies could also provide a convenient way to produce ClO_2 for sanitizing the surfaces of facilities and equipment used in the production of many horticultural crops.

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