Sanitation for Management of Florists' Crops Diseases

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Contents

Abstract

Sanitation involves efforts aimed to prevent introduction of pathogen propagules into a production facility, remove sources of propagules from active production areas to substantially slow disease development, and eliminate pathogen propagules from future production areas. Sanitation includes many practices such as using disease-free certified seed and propagative material, maintaining weed-free zones around production areas, use of screens to block entry of insects, use of

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double doors and foot paths, cleaning and sanitizing production areas between crops, sanitizing tools and equipment, and early removal of diseased plant material. General sanitation should be a matter of routine good agricultural practices. Because it is so important to do a thorough job, key sanitation practices should be selected that control the pathogens that routinely affect plants at a facility and those that are prevalent and would severely impact production if introduced. Good records are an important tool to select which pathosystems are problems, to determine cost benefit decisions, and to select subject matter for worker training modules. The information in this chapter represents an overview of methods known to be effective.

Keywords
Sanitation • Sanitize • Disinfect • Disinfectant • Disinfest • Disinfestant • Cleanliness

1 Introduction

The plant pathogens that cause plant diseases include fungi, oomycetes, bacteria, viruses, and nematodes. These organisms are spread as various types of propagules (mycelia, conidia, ascospores, basidiospores, chlamydospores, sclerotia, zoospores, sporangia, oospores, bacterial cells, virus particles, viroid particles, nematodes, and nematode eggs). The propagules can be in an active growing state, which is easier to kill, or in a resting state, which can be difficult to kill. Even though the vast majority of propagules have no ability to move under their own power, plant pathogens are very adept at passively taking advantage of the mobility of other creatures and the forces of nature to move short and long distances. Propagules are often produced in large numbers and may be carried by air currents, water, insects, animals, humans, equipment, or contaminated plant tissue. For the most part, the only possibility of detecting their movement is by seeing plants with symptoms that may contain pathogen structures. The biology and epidemiology of pathogens are extremely diverse. In the context of plant production, not understanding these processes can cause devastating financial losses.

For disease to occur, three main components are needed: a susceptible plant, a virulent pathogen, and a favorable environment; this represents the classic disease triangle. Sanitation targets the second component of the disease triangle, by engaging in a direct assault on the pathogen. Sanitation can be performed at multiple production stages to achieve several goals: preventing introduction of pathogen propagules into a production facility, removing sources of propagules from active production areas to substantially slow disease development, and eliminating pathogen propagules from future production areas. Sanitation practices involve generating clean plant material (e.g., plant indexing, chemical or heat treatment); sanitizing production areas, tools, and equipment (e.g., discarding infected plant tissues, washing, and the use of disinfestants, fungicides, and bactericides); and using

barriers to restrict entry to specific parts of a facility (e.g., screening of fan and vent openings, protective doorways, positive pressure houses, weed-free zones, distance, wash stations, and work flow patterns). Sanitation is a proven disease management method in ornamental plant production (Daughtrey and Benson 2005) and can be one of the most reliable control measures available because it can completely or nearly eliminate the pathogen at strategic points. Economically, it is unreasonable to apply all these procedures to all production areas, so a strategy is required that identifies critical production points that are responsive to select control practices (see section "Integrated disease management").

The information in this chapter represents an overview of methods known to be effective. Where they exist, specific disease control recommendations that include sanitation will be given in individual florists' crop chapters. Although sanitation is perceived as simple control methods, information that fully addresses all the complexities is not always available and that will be evident in the presentation of some topics.

2 Disinfestants

Disinfestants are biocides that kill microorganisms on the surface of living and dead tissues and on inert materials, such as wood products, galvanized metal benches, plastic containers, etc. Safety and environmental regulations pertain to these products just as to other pesticides. Recommendations listed on disinfestant labels should be followed. The disinfestants commonly used in plant production are listed in Tables 1–8. Each product has advantages and disadvantages that affect their suitability for particular microorganisms, uses, and environmental conditions. Relevant usage and efficacy information are given in Tables 1–8 based on available data. The following section will focus on factors affecting the efficacy of disinfestants.

A common misconception is that disinfestants are broad spectrum sterilants; that kill all microorganisms present. Microorganisms vary in sensitivity to any given chemical, and as a result different disinfestants and/or rates may be needed to properly inactivate or kill propagules of a specific pathogen genus or species. This information is not broadly documented but has been clearly demonstrated (Koponen et al. 1992; Mebalds et al. 1996, 1997; Nichols and Jodon 1972). Mebalds et al. (1997) reported that the lethal activity of sodium hypochlorite varied from 0.2 % to 5.25 % for viruses, 1% to 10 % for fungi, and from 10 % to 12.5 % for bacteria. Additionally, microorganisms can vary in their sensitivity to disinfestants due to environmental conditions (e.g., temperature, pH, dissolved oxygen). Microorganisms generally absorb disinfestants rapidly between 20 °C (68 °F) and 30 °C (86 °F). Use disinfestant recommendations developed for specific microorganisms, when available. The term "inactivate" is commonly used in scientific literature because the term addresses uncertainties in measuring recovery and viability of microorganisms and in dealing with different organisms' habits, such as viruses that only propagate in living host cells. The general term "kill" will be used in place of "inactivate" in this chapter.

Table 1 Summary information for chlorine releasing disinfestants

Classification	Halogen releasing, oxidizing agents			Percent a.i.	8.25 for bleach products (sodium hypochlorite as example)	
Active ingredient (a.i.)	Sodium hypochlorite, calcium hypochlorite, or chlorine gas (chlorine releasing agents, CRA); chlorine dioxide (has different properties than the CRAs)			Rate range	7 % bleach solution (8.25 % NaOCl) (=1 part bleach : 14 parts water; as example)	
Trade name	Chlorox® and many bleach products (sodium hypochlorite as example) Chlorine gas is a different product Chlorine dioxide is a different product			Contact time	10–15 min	
pH range of good activity Hypochlorite and Cl^- gas: Chlorine dioxide:		5.0–7.0 2.0–10.0	Water hardness activity[a] Hypochlorite and Cl^- gas: Chlorine dioxide:		++ –	
Corrosiveness[b] Hypochlorite and Cl^- gas: ++ Chlorine dioxide: +		Residual activity[c] – –		Phytotoxicity[d] Hypochlorites and Cl^- gas: + Chlorine dioxide: ±		
Human concerns	Volatile, irritating to skin and eyes					
User sites	Greenhouses, pots, and benches need specified contact time of 10 min; dip pruners for 10 s and allow to dry (one source says to not rinse pruners, another says to rinse tools like pruners because residue may cause phytotoxicity on sensitive plant species); irrigation systems (flooded floors, flooded benches, recycled water systems, capillary mats, humidification, and misting systems)					
Comments	Use product labeled for greenhouse use. Mix fresh sodium hypochlorite solutions every 2 h because efficacy will drop as chlorine gas is lost at the liquid surface. Chemical decomposition of a.i. increases above pH 7.0, above 15.6 °C (60 °F), in the presence of inorganic (e.g., nitrogen, potassium, iron, manganese, sulfur, arsenic) and organic compounds, and due to the exposure to sunlight. The microorganism's response rate to inactivation diminishes as the temperature drops moderately below 20 °C (68 °F) and rapidly above 37.8 °C (100 °F). At higher concentrations bleach can be sporicidal. The active moiety of hypochlorite and Cl^- gas is hypochlorous acid that has activity by electrophilic substitution (chlorination) and oxidation. The active moiety of chlorine dioxide is dissolved chlorine dioxide gas that has activity by oxidation. Chlorine dioxide reacts slower with many inorganic and organic compounds, is less corrosive, and has smaller changes in activity due to temperature than hypochlorous acid					
Pathogens controlled[e]	Fungi	Vegetative bacteria	Bacterial spores	Enveloped viruses	Nonenveloped viruses	Algae
Level of control	+	+	+	+	+	+

[a]Water hardness reactivity with a disinfestant resulting in loss of sanitizing activity as categorized by symbols: (++) high demand, (+) moderate demand, (±) weak demand, (−) no measurable demand, (NIF) no information found

[b]Corrosiveness as categorized by symbols: (++) highly corrosive, (+) moderately corrosive, (±) somewhat corrosive, (−) weakly corrosive, (NIF) no information found

[c]Residual activity as categorized by symbols: (+) hours of residual activity after the surface dries, (±) short-lived residual activity after the surface dries, (−) no residual activity after the surface dries, (NIF) no information found

[d]Phytotoxicity as categorized by symbols: (++) high risk of phytotoxicity, (+) potential to be phytotoxic, (±) phytotoxicity unlikely but possible, (−) infrequently phytotoxic, (NIF) no information found

[e]Susceptibility of microorganisms to chemical disinfestants as categorized by symbols: (++) highly effective, (+) effective, (±) limited or variable, (−) no measurable activity, (NIF) no information found

Table 2 Summary information for peroxygen compounds

Classification	Peroxygen, oxidizing agents			Percent a.i.	27.1 % and 2 % (ZerTol® 2.0 as example)	
Active ingredient (a.i.)	Hydrogen dioxide (=hydrogen peroxide), and peroxyacetic acid (ZerTol® 2.0 as example)			Rate range	3.9–19.5 ml/L (0.5–2.5 fl oz/gal) Rate depends on use, so read label (ZerTol® 2.0 as example)	
Trade name	ZerTol® 2.0, Sanitdate, Oxidate®, X3™			Contact time	1–10 min	
pH range of good activity		4–6.5	Water hardness activity[a]		NIF	
Corrosiveness[b]	+	Residual activity[c]	±	Phytotoxicity[d]	±	
Human concerns	Concentrated form can cause irreversible eye damage, skin irritant, potentially fatal if swallowed					
User sites	Benches, work areas, pots, flats, trays, cutting tools, foot bath mats, evaporative coolers, irrigation systems (flooded floors, flooded benches, recycled water systems, capillary mats, humidification and misting systems), soil or media drench, plant material (foliage, cuttings, stock, seed) seed beds, soil treatment					
Comments	Can be used in chemigation as it is compatible with macronutrients (e.g., nitrogen, phosphorus, potassium); however, not recommended with chelated micronutrients (e.g., copper, manganese, zinc). High organic and biological loads can place demand on the product. Peroxyacetic acid contains acetic acid that can lower water pH if water has a low buffering capacity (alkalinity). Never tank mix with pesticides. Slightly corrosive to aluminum					
Pathogens controlled[e]	Fungi	Vegetative bacteria	Bacterial spores	Enveloped viruses	Nonenveloped viruses	Algae
Level of control	+	+	+[f]	+	±	++

[a]Water hardness reactivity with a disinfestant resulting in loss of sanitizing activity as categorized by symbols: (++) high demand, (+) moderate demand, (±) weak demand, (−) no measurable demand, (NIF) no information found

[b]Corrosiveness as categorized by symbols: (++) highly corrosive, (+) moderately corrosive, (±) somewhat corrosive, (−) weakly corrosive, (NIF) no information found

[c]Residual activity as categorized by symbols: (+) hours of residual activity after the surface dries, (±) short-lived residual activity after the surface dries, (−) no residual activity after the surface dries, (NIF) no information found

[d]Phytotoxicity as categorized by symbols: (++) high risk of phytotoxicity, (+) potential to be phytotoxic, (±) phytotoxicity unlikely but possible, (−) infrequently phytotoxic, (NIF) no information found

[e]Susceptibility of microorganisms to chemical disinfestants as categorized by symbols: (++) highly effective, (+) effective, (±) limited or variable, (−) no measurable activity, (NIF) no information found

[f]Hydrogen peroxide combined with a strong oxidizing agent, such as peracetic acid, is sporicidal

Table 3 Summary information for quaternary ammonium disinfestants

Classification	Quaternary ammonium compounds (QAC), cationic surfactants			Percent a.i.	7.5 % (KleenGrow as an example)
Active ingredient (a.i.)	Didecyl dimethyl ammonium chloride (KleenGrow as an example), many different QAC active ingredients are available			Rate range	(KleenGrow as an example) 7.8 ml/L (1.0 fl oz/gal) nonporous surfaces. Range of 0.23–15.6 ml/L (0.03–2.0 fl oz/gal) depending on use, so read label
Trade name	Consan Triple Action 20, Formula 409 Orange Cleaner Degreaser, Formula 409 Antibacterial All Purpose Cleaner, Green-Shield®, KleenGrow®, Lysol Disinfectant Antibacterial Kitchen Cleaner, MAQUAT 128-MT, Physan 20®, Simple Green d Pro 3, others			Contact time	10–15 min
pH range of good activity		Good: >7 Best: 9 to 10 Poor: <3.5	Water hardness activity[a]		+ Third generation QACs, such as Green Shield, and earlier have reduced efficacy at the upper range, greater than 200 mg/L calcium carbonate ± Newer (4th generation) QACs maintain activity in the upper range
Corrosiveness[b]	±	Residual activity[c]	+	Phytotoxicity[d]	±
Human concerns	Corrosive, eye and skin irritant that can cause burning and tissue damage depending on product. Harmful if swallowed				
User sites	Nonporous surfaces: packing facility, equipment, greenhouse walls, trucks, trailers, transportation equipment, plastic containers, benches, walkways, tools, plant, irrigation lines				
Comments	Later generation QAC, like KleenGrow, are more germicidal, less foaming, and more tolerant to organic loads. Similar, but not equal, efficacy between commercial QAC products. Plant application is label specific. Poor activity on porous materials, such as wood benches and in presence of soap				

(*continued*)

Table 3 (continued)

Pathogens controlled[e]	Fungi	Vegetative bacteria	Bacterial spores	Enveloped viruses	Nonenveloped viruses	Algae
Level of control	+	++	–	±	–	+

[a]Water hardness reactivity with a disinfestant resulting in loss of sanitizing activity as categorized by symbols: (++) high demand, (+) moderate demand, (±) weak demand, (−) no measurable demand, (NIF) no information found

[b]Corrosiveness as categorized by symbols: (++) highly corrosive, (+) moderately corrosive, (±) somewhat corrosive, (−) weakly corrosive, (NIF) no information found

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Table 4 Summary information for alcohol disinfestants

Classification	Alcohols			Percent a.i.	70–90 % ethanol, >90 % less effective 60–95 % ispropanol	
Active ingredient (a.i.)	Ethanol or isopropanol			Rate range	Product used directly	
Trade name	Many names			Exposure time	5–10 min; tools 10 s for select pathogens	
pH range of good activity		NIF[a]	Water hardness activity[a]		NIF	
Corrosiveness[b]	–	Residual activity[c]	–	Phytotoxicity[d]	NIF	
Human concerns	Irritating to injured skin					
User sites	Propagation tools, e.g., knives and pruning tools, allow to dry, do not rinse					
Comments	Flammable, evaporates quickly, greater than 90 % ethanol is less effective because water content is too low for required activity. Limited activity in presence of high concentrations of organic matter. Ineffective against some viruses on metal tools. Can damage rubber and plastic. Phytotoxic to plants					
Pathogens controlled[e]	Fungi	Vegetative bacteria	Bacterial spores	Enveloped viruses	Nonenveloped viruses	Algae
Level of control, Ethanol	+	++	–	+	+	NIF
Level of control, Isopropanol	+	++	–	+	–	NIF

[a]Water hardness reactivity with a disinfestant resulting in loss of sanitizing activity as categorized by symbols: (++) high demand, (+) moderate demand, (±) weak demand, (−) no measurable demand, (NIF) no information found

[b]Corrosiveness as categorized by symbols: (++) highly corrosive, (+) moderately corrosive, (±) somewhat corrosive, (−) weakly corrosive, (NIF) no information found

[c]Residual activity as categorized by symbols: (+) hours of residual activity after the surface dries, (±) short-lived residual activity after the surface dries, (−) no residual activity after the surface dries, (NIF) no information found

[d]Phytotoxicity as categorized by symbols: (++) high risk of phytotoxicity, (+) potential to be phytotoxic, (±) phytotoxicity unlikely but possible, (−) infrequently phytotoxic, (NIF) no information found

[e]Susceptibility of microorganisms to chemical disinfestants as categorized by symbols: (++) highly effective, (+) effective, (±) limited or variable, (−) no measurable activity, (NIF) no information found

Table 5 Summary information for potassium peroxymonosulfate plus sodium chloride

Classification	Oxidizing agents			Percent a.i.	21.41 % plus 1.5 %	
Active ingredient (a.i.)	Potassium peroxymonosulfate plus sodium chloride			Rate range	1:100 dilution [2.7 ml/L (1.3 fl oz/gal)] 1:50 dilution if not precleaned	
Trade name	Virkon-S®			Exposure time	10 min	
pH range of good activity		NIF	Water hardness activity[a]		+	
Corrosiveness[b]	–	Residual activity[c]	–	Phytotoxicity[d]	+	
Human concerns	Concentrated form is corrosive; causes irreversible eye damage and skin burn. 1 % solutions are nonirritating to the eye and skin					
User sites	Inanimate environmental surfaces, such as floors, walls, glasshouse structures, ventilation equipment, other equipment, tools, containers, flats, trays, evaporative pads, vehicles					
Comments	Not approved in California for use against plant pathogens. Efficacy of 1 % solution was determined in 400 ppm hard water and 5 % organic matter. Solutions are stable for 7 days. Ventilate buildings					
Pathogens controlled[e]	Fungi	Vegetative bacteria	Bacterial spores	Enveloped viruses	Nonenveloped viruses	Algae
Level of control	+	+	+	+	±	+

[a]Water hardness reactivity with a disinfestant resulting in loss of sanitizing activity as categorized by symbols: (++) high demand, (+) moderate demand, (±) weak demand, (−) no measurable demand, (NIF) no information found

[b]Corrosiveness as categorized by symbols: (++) highly corrosive, (+) moderately corrosive, (±) somewhat corrosive, (−) weakly corrosive, (NIF) no information found

[c]Residual activity as categorized by symbols: (+) hours of residual activity after the surface dries, (±) short-lived residual activity after the surface dries, (−) no residual activity after the surface dries, (NIF) no information found

[d]Phytotoxicity as categorized by symbols: (++) high risk of phytotoxicity, (+) potential to be phytotoxic, (±) phytotoxicity unlikely but possible, (−) infrequently phytotoxic, (NIF) no information found

[e]Susceptibility of microorganisms to chemical disinfestants as categorized by symbols: (++) highly effective, (+) effective, (±) limited or variable, (−) no measurable activity, (NIF) no information found

Table 6 Summary information for phenolic disinfestants

Classification	Phenols			Percent a.i.	See product label	
Active ingredient (a.i.)	o-phenylphenol			Rate range	See product label	
Trade name	Several products			Exposure time	10 min	
pH range of good activity		NIF	Water hardness activity[a]		–	
Corrosiveness[b]	NIF	Residual activity[c]	±	Phytotoxicity[d]	NIF	
Human concerns	Eye and skin irritant. Penetrates latex gloves					
User sites	Equipment, containers, flats, benches, walkways					
Comments	Has activity in hard water and in presence of organic matter. Good activity in presence of soaps, commonly formulated with soap to increase penetration ability. A 2 % concentration is highly toxic to animals, especially cats. Household products: Lysol (contains phenol plus quaternary ammonium compound)					
Pathogens controlled[e]	Fungi	Vegetative bacteria	Bacterial spores	Enveloped viruses	Nonenveloped viruses	Algae
Level of control	+	++	–	±[f]	–	NIF

[a]Water hardness reactivity with a disinfestant resulting in loss of sanitizing activity as categorized by symbols: (++) high demand, (+) moderate demand, (±) weak demand, (−) no measurable demand, (NIF) no information found

[b]Corrosiveness as categorized by symbols: (++) highly corrosive, (+) moderately corrosive, (±) somewhat corrosive, (−) weakly corrosive, (NIF) no information found

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[e]Susceptibility of microorganisms to chemical disinfestants as categorized by symbols: (++) highly effective, (+) effective, (±) limited or variable, (−) no measurable activity, (NIF) no information found

[f]Varies with composition of the disinfestant

Table 7 Summary information for aldehyde disinfestants

Classification	Aldehydes			Percent a.i.	50 %	
Active ingredient (a.i.)	Glutaraldehyde			Rate range	2 % (w/v)	
Trade name	Glutex GS1, Ucarcide			Exposure time	10–30 min	
pH range of good activity		Best above 7	Water hardness activity[a]		–	
Corrosiveness[b]	–	Residual activity[c]	±	Phytotoxicity[d]	NIF	
Human concerns	Highly irritating, may cause severe irritation with corneal injury which may result in permanent impairment of vision, even blindness. Chemical burns may occur. Brief skin contact may cause burns. Toxic to humans and animals with contact or inhalation, potentially carcinogenic					
User sites	Glutex GS1 can be used in farm animal and poultry housing facilities and on industrial equipment and buildings. Ucarcide can be used as an active ingredient in commercial household products					
Comments	Noncorrosive to metals, rubber, plastic, and cement. Glutaraldehyde is more efficacious in the presence of organic matter, soap, and hard water than formaldehyde; however, it should be applied to precleaned surfaces. Can be diluted with available water without concern of water hardness. Application can be by fogging, atomizing, mopping, or spraying.					
Pathogens controlled[e]	Fungi	Vegetative bacteria	Bacterial spores	Enveloped viruses	Nonenveloped viruses	Algae
Level of control, Glutaraldehyde	+	++	–	++	+	NIF
Level of control, Formaldehyde	+	++	±[f]	++	+	NIF

[a]Water hardness reactivity with a disinfestant resulting in loss of sanitizing activity as categorized by symbols: (++) high demand, (+) moderate demand, (±) weak demand, (−) no measurable demand, (NIF) no information found

[b]Corrosiveness as categorized by symbols: (++) highly corrosive, (+) moderately corrosive, (±) somewhat corrosive, (−) weakly corrosive, (NIF) no information found

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[e]Susceptibility of microorganisms to chemical disinfestants as categorized by symbols: (++) highly effective, (+) effective, (±) limited or variable, (−) no measurable activity, (NIF) no information found

[f]Formaldehyde is sporicidal, glutaraldehyde is not

Table 8 Summary information for ozone disinfestants

Classification	Oxidizing agent			Percent a.i.	1 % (10,000 mg/L)	
Active ingredient (a.i.)	Ozone			Rate range	0.4–5 mg/L (ppm)	
Trade name	Many product names			Exposure time	4–20 min	
pH range of good activity	Best: 4–6 Good: 6–8.5		Water hardness activity[a]		–	
Corrosiveness[b]	++	Residual activity[c]	–	Phytotoxicity[d]	±, unlikely from treated water, but possible from escaped ozone near the generator	
Human concerns	Off-gases are extremely irritating and possibly toxic, so off-gases must be captured and destroyed to prevent worker exposure					
User sites	Irrigation systems (flooded floors, flooded benches, recycled water systems, capillary mats)					
Comments	Ozone generally has higher germicidal action than other disinfestants and results in increased dissolved oxygen concentration in the receiving water stream. Must be generated on site. Equipment and operating costs are high. Excess ozone must be continuously monitored and recycled within the system or destroyed. High demand occurs with high levels of suspended solids, biochemical oxygen demand, chemical oxygen demand, and organic carbon. Efficiency is reduced with increased water temperature due to slower mass transfer in water					
Pathogens controlled[e]	Fungi	Vegetative bacteria	Bacterial spores	Enveloped viruses	Nonenveloped viruses	Algae
Level of control, Glutaraldehyde	+	++	+	++	+	NIF

[a]Water hardness reactivity with a disinfestant resulting in loss of sanitizing activity as categorized by symbols: (++) high demand, (+) moderate demand, (±) weak demand, (−) no measurable demand, (NIF) no information found

[b]Corrosiveness as categorized by symbols: (++) highly corrosive, (+) moderately corrosive, (±) somewhat corrosive, (−) weakly corrosive, (NIF) no information found

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Before applying any disinfestant, it is important to remove soil, organic matter, and plant parts from equipment, production surfaces, and tools for two reasons. First, the disinfestant is weakened when it reacts with soil and organic matter. This results in a reduction in the active ingredient (a.i.) and too little a.i. remaining to kill microorganisms, which is called a demand load. Second, the soil and organic matter can physically shield microorganisms from contact with a disinfestant.

Disinfestants can lose activity due to several reasons. Chemical decomposition of a.i. can occur in seconds to minutes in response to water characteristics (e.g., pH, concentrations of mineral and organic compounds, water hardness, temperature) and reactivity to production surfaces (metal, plastic, wood). These same factors reduce longevity of the a.i. when mixing disinfestant solutions used for soaking materials (such as containers), for spray application, and for treating irrigation water. Loss of a.i. can occur over a period of hours due to some environmental conditions (e.g., wind, sunlight). This information is presented in Tables 1–8 and varies from specific to general based on available research data. In a number of cases, additional research is needed to better define some of the knowledge gaps.

Howard et al. (2007) reported several interesting comparisons between disinfestants, even though no statistical analyses were presented, which included differences in pathogen sensitivities to disinfestants, differences between disinfestants in microbial lethality, corrosiveness and plant toxicity, and differences in efficacy when applied to different material surfaces. Several plant pathologists have demonstrated differences in disinfestant efficacy due to the material surface being treated (Copes and Hendrix 1996; Copes 2004; Koponen et al. 1992; Nichols and Jodon 1972). For example, the percent *Botrytis* conidia killed was nearly equal when spraying bleach on plastic, metal, and pressure-treated wood surfaces but less effective on untreated wood (Table 9) (Copes 2004). The quaternary ammonium compound (QAC) had the highest activity on metals, slightly less on plastics, and was ineffective on untreated wood. Hydrogen dioxide was ineffective at the preventative rate but uniformly effective on plastics, metals, and pressure-treated wood at the curative rate except on untreated wood. However, a total kill of *Botrytis* conidia on production surfaces required higher than label rates for the QAC and hydrogen dioxide, especially on untreated wood. Toro et al. (2012) found *Fusarium* spp. inoculum could be eliminated from wooden stakes with high pressure washing and several sanitizing agents, including NaOCl (Fig. 1).

While most of this information focuses on loss of disinfestant activity, pathogens can also develop resistance to these chemistries. Resistance to many classes of disinfestants has been well documented in bacteria, fungi, and viruses and can be intrinsic as a natural chromosomal property or acquired through mutation or acquisition of plasmids or transposons (McDonnell and Russell 1999). Resistance has been studied with human pathogens, food contaminants, food yeasts, industrial fouling, and water line biofilms but to the authors knowledge has not been documented with plant pathogens (Araújo et al. 2011; McDonnell and Russell 1999). If needed, consult a private or university plant disease clinic to have isolates tested. If chemical resistance is suspected, a disinfestant of a different chemical class can be used.

Table 9 Effect of disinfestant label rate and substrate on mortality of *Botrytis cinerea* calculated from a lethal dose response curve (Copes 2004)

	Chlorox[a]	Green Shield[b]		ZeroTol[c]	
	1 part to 10	3.6 ml/L (1 Tbs/gal)	4.9 ml/L (1 tsp/quart)	7.9 ml/L (1 fl oz/gal)	19.8 ml/L (2.5 fl oz/gal)
Substrate	Mortality (%)				
Polyethylene fabric	98[d]	65	70	2	75
Plastic container	99	75	80	6	75
Galvanized metal	99	75	90	8	75
Stainless steel	98	85	90	2	75
Treated wood	97	65	65	20	75
Nontreated wood	90	5	8	1	35

[a]Bleach [6 % sodium hypochlorite (The Chlorox Co., Oakland, CA)]
[b]Green Shield [10 % n-Alkyl(60 %C14, 30 %C16, 5 %C12, 5 %C18 dimethyl benzyl ammonium chloride and 10 % n-Alkyl(68 %C12, 32 %C14) dimethyl ethylbenzyl ammonium chloride] (Whitmire Micro-Gen Research Laboratories, St. Louis, MO). The 3.6 ml/L (1Tbl product/gal) is labeled for greenhouse benches, containers, and irrigation water. The 4.9 ml/L (1 tsp product/qt) is labeled for cutting tools and greenhouse glass
[c]ZeroTol [30 % hydrogen dioxide (Biosafe Systems, Glastonbury, CT); Older formulation that is no longer sold]. The 7.9 ml/L (1 fl oz product/gal) is labeled for greenhouse benches, containers, and irrigation water. The 19.8 ml/L (2.5 fl oz product/gal) is labeled for cutting tools and greenhouse glass
[d]Lethal dose values (with a variable unit range: 1–10 in 1 unit increments, 15–90 in 5 unit increments, and 91–100 in 1 unit increments) from statistical output not shown in Copes (2004)

Fig. 1 Contaminated wooden stakes that have not been cleaned and sterilized could serve as a source for pathogen spread when used in production (Photo courtesy of R.J. McGovern)

When submerging products, such as clean containers free of organic matter, in a disinfestant solution, it is critical to also dislodge all air bubbles or air pockets by shaking and tilting the containers so that air bubbles escape to the surface. Air pockets prevent the disinfestant solution from contacting that part of the container, as a result the containers are not being uniformly treated. For example, stacked containers can be orientated with the large opening up, the stack swirled and tilted to dislodge air bubbles, and a heavy screen laid on top to keep containers submerged.

In this chapter, disinfestants will be referred to by the *common chemical name* when referring to them collectively or generally and by trade names when referring to a specific product. *Chemical nomenclature* will not be used in this chapter. Bleach will be referred to as NaOCl, which is a chemical abbreviation for sodium hypochlorite the active ingredient (a.i.) in bleach, and rates will be referred to as percent a.i. of sodium hypochlorite. This is to avoid confusion caused by using percent bleach, since bleach products contain different percents of NaOCl.

In both general and scientific literature, the terms "disinfectant" and "disinfestant" will be found referencing the same products and the same chemical activities. The term "disinfestant" specifically means a product is inactivating pathogens only on the surface of organisms and materials, which more accurately reflects how these products work, and will be used exclusively in this chapter.

3 Surfaces of Tools, Equipment, and Structures

Washing and applying disinfestants are the main tools used to disinfest hard surfaces. Sunlight can also contribute to the inactivation of some pathogen propagules, particularly on structures and floors exposed to sunlight for an extended period (Copes 2015).

3.1 Tools

Tools become contaminated by contact with infested rooting media, soil, or plant material. Any tool (mechanical pruners, trowels, shovels, fertilizer dispersers, motorized shears, tagging machines, etc.) that may have been exposed to pathogens should be cleaned prior to moving to another site or block of plants. Contamination of cutting tools should be a constant concern, since they easily acquire and carry pathogen propagules from infested or diseased plants to healthy plants. Shovels and trowels should be sanitized also to prevent carrying pathogens into a noncontaminated area.

The steps in sanitizing tools are (1) washing or brushing surfaces free of soil, media, and plant tissue; (2) removing films and sap with a cleanser; and (3) dipping tools in the disinfestant. It is commonly recommended that tools be dipped for 2 min.

Bleach, QACs, peroxygen compounds, and alcohols are common disinfestants used for treating tools. Contaminated pruners dipped in a 0.525 % NaOCl for 2 s killed *Erwinia amylovora* from infected apple stems, and for 1 min killed tobacco

mosaic virus (TMV) from infected petunia (Keil and van der Zwet 1967; Lewandowski et al. 2010). To minimize corrosiveness caused by bleach, all metal parts of the pruners need to be washed and coated with oil daily following bleach treatment. Alternative less corrosive choices include alcohol (isopropyl or ethanol) and QACs (Bennett et al. 2011). Some pathogens are harder to eliminate from tools. Immersing metal tools for 15 min in 0.525 % a.i. NaOCl was consistently more effective than five other disinfestants at inactivating potato spindle tuber viroid (Olivier et al. 2015); however, none of the treatments eliminated the viroid. Dipping pruners in 20 % wt/vol of nonfat dry milk plus 1 % Tween 20 was as effective as 0.525 % a.i. NaOCl in killing TMV obtained from petunia, but again, neither treatment totally prevented virus transmission to petunia on contaminated tools (Lewandowski et al. 2010). Immersion time influenced the rate required for both bleach and QAC to kill potato virus Y (PVY) particles on pruner blades (Wintermantel 2011). PVY particles were more consistently eliminated from pruners with a 2 s immersion in 0.525 % NaOCl than a 15 s immersion in 1 % QAC.

3.2 Plant Containers

Reuse of plant containers is risky, because pathogens could have produced aggregates of propagules, including difficult to kill survival structures that could tightly adhere to the container (Fig. 2). Pieces of potting mix or plant debris attached to the container can further protect pathogens from chemical disinfestants. Using new containers provides the surest way to avoid this type of contamination. Placing disposable plastic inserts into reused styrofoam transplant trays will also prevent pathogen transmission.

If soiled containers are to be reused, containers should be thoroughly washed to remove all soil, organic media, and plant tissue, which requires labor. Cleaned containers should be submerged in disinfestant for 10–30 min or treated with steam at 65.6 °C (150 °F) to 71.1 °C (160 °F) for 45–60 min. Removing debris by washing followed by soaking in a disinfectant was done in all of the following studies. Chase (2012) found QAC (KleenGrow) to be more effective at killing *Thielaviopsis basicola* spores than bleach, another QAC (GreenShield), or hydrogen peroxide (Zerotol). Warfield and Konczal (2003) killed *T. basicola* on plug trays either by spraying trays with a 1–50 ratio of ZeroTol to water solution or by submerging plug trays in 0.525 % NaOCl for 10 min. *Thielaviopsis basicola* spores infesting flats used for growing tobacco seedlings were killed with steam (Chase and Daughtrey 2013; Choudhary et al. 2006). Spray application of NaOCl at 0.525 % consistently reduced microconidial densities of *F. oxysporum* f. sp. *callistephi* on styrofoam to an undetectable level (Gilbert et al. 2007). Soaking plastic irrigation stakes in NaOCl or a QAC reduced populations of *F. oxysporum* f. sp. *radicis-lycopersici* to an undetectable level (Toro et al. 2012). McGovern et al. (1993) found *F. oxysporum* f. sp. *radicis-lycopersici* was reduced to an undetectable level from styrofoam trays with steam treatment (71.1 °C (160 °F) for 45 min) but not with QAC or bleach.

Fig. 2 Clean and soiled containers are stored together and pose an unnecessary risk for pathogen dissemination

3.3 Equipment (Conveyers, Trailers, Transplanters, etc.)

Preventing spread of pathogen propagules on large equipment to a new area where a susceptible crop is being grown is also critical. This applies to diverse pieces of equipment, such as automated seeding machines, conveyers, irrigation pipes, sprayers, tractors, trailers, and transplanters. Factors to consider include the likelihood that equipment is contaminated with a pathogen, the potential for crop loss, the rate of spread from the contaminated area, and the difficulty of eradicating the introduced pathogen. With seeders and transplanters, cleaning may be needed when plant types are changed. With conveyors, trailers, carts, and racks, cleaning and disinfesting equipment should be planned as part of the plant transfer activity after handling plants that have a history of disease and prior to handling plants prone to the same disease.

General sanitation recommendations follow, although more specific efforts may be required with certain pathogens including quarantine status pathogens. General guidelines may be available from the manufacturer, extension publications, national regulatory agencies such as the USDA Animal and Plant Health Inspection Service (APHIS), or international regulatory groups (see section "Plant Certification"). Specific guidelines for quarantine status pathogens would be mandated by local, regional, national, or international regulatory agencies. Cleaning and sanitizing may

be divided into six steps: (1) dry removal of gross contamination and solids, (2) wet washing and solvent washing, (3) rinsing, (4) drying, (5) disinfesting, and (6) machine maintenance (Anon 2013). Decontamination of important pathogens should only be done where the contamination occurred to reduce the possibility of unintentionally spreading disease to off-site locations.

1. Use brushes, scrapers, gloved hands, and/or low-pressure air sprayers to remove organic and inorganic material adhering to equipment surfaces and filling crevices (Anon 2013; Gordon and Koike 2015). High-pressurized air should not be used for cleaning because of the increased potential over low-pressure air for disseminating fine particles outside of the cleaning area. Remove unattached and loose equipment and parts, such as car mats, and any equipment or supplies that may be sitting in compartments. Flooring, panels, and the under carriage of vehicles should be thoroughly checked and disinfested.
2. Proper cleaning and washing of surfaces are critical for fully exposing pathogen propagules to the activity of disinfestants. Wet washing involves scrubbing with a soap or detergent solution. Wash from the top downward, using a hose with normal water pressure, about 30–50 psi. High-pressure water streams should not be used, because the process could produce aerosols containing pathogen propagules. Allow 10 min of soaking to allow encrusted dirt to soak up the detergent, during which time other parts of the vehicle or equipment could be cleaned. Water and detergents will remove many of the pathogen propagules, finer organic and inorganic material, and films. Use an appropriate solvent to remove sticky and oily materials adhering to equipment surfaces. If wash water needs to be collected, see the paragraph on sanitizing stations.
3. Rinsing of vehicles, equipment, or machines should be done from the top down.
4. Drying reduces potential for dilution of disinfestants. Allow at least 5 min for a vehicle or piece of equipment to drip dry, after which the remaining water will not cause significant dilution of disinfestants.
5. Select a disinfestant that has proven activity against the pathogen being targeted and is not corrosive to equipment (Tables 1–8). Quaternary ammonium compounds have been used frequently because they are less corrosive (Bennett et al. 2011). Check product labels for necessary contact time and whether an adjuvant may improve activity. Reapplication of multiple light applications is required to maintain "shiny" wet surfaces for 10 min or the specified contact time, as merely damping surfaces is not adequate (Anon 2014). Surfaces should be thoroughly wetted and crevices flushed using a low-pressure sprayer. Porous and rough surfaces will require more disinfestant than smooth surfaces. A heavy application of disinfestant that runs off and puddles is not effective. All removed components and parts should be scrubbed with a disinfestant. The inside of vehicles (e.g., dashboard, steering wheel, handbrake, gear shift, and seats), and operator controller stations, should be wiped thoroughly with an appropriate disinfestant. Wheels, wheel wells, and underside of vehicles should be sprayed with a disinfestant.

6. Equipment maintenance will depend on the equipment and product used. Many disinfestants are corrosive to rubber gaskets and metallic parts in pumps and pressure washers. Disinfestants should be rinsed from the equipment as soon as the recommended contact time has passed. Normally disinfestants will include directions for equipment cleaning as part of the label instructions. If this information is not present, equipment should be flushed liberally with fresh water followed by warm water containing light mineral oil or liquid detergent (Anon. 2014). Additionally, consider lubricating bearings, connectors, and gears as appropriate for the equipment. At this time, all removed parts can be reassembled on the equipment or vehicle.

A sanitizing station is a containment area. A sanitizing station inside a facility should be set up on an impermeable floor. If the sanitizing operation is adjacent to plant production areas, a wall of plastic sheeting should be hung either from a temporary wall frame of wood or metal tubing or from overhead structures. Depending on the pathogen, water should be directed to flow into a drainage system or sump well for later treatment and removal if needed or contained in a barrier and mopped into containers for later treatment and removal. Drums or plastic containers can be used to contain spent cleaning and disinfestant fluids. The area needs to be cleaned and disinfested after equipment treatment has been completed.

An outside sanitizing station should be separated from normal vehicle traffic flow and plant production areas. The cleaning and disinfesting procedures should be done at the site where contamination by diseased crops occurred. Sanitizing stations should consist of an impermeable layer, such as a layer of plywood covered with thicker than 2 mil plastic sheet; a berm [e.g., 10.2 × 10.2 cm (4 × 4 in.) wood, sand tubes, sand bags, etc.]; framing materials to build the containment structure; sump pump and power supply; and drums or plastic totes to contain spent cleaning and disinfesting fluids.

3.4 Production and Greenhouse Structures

Sanitation begins outside the greenhouse. All weeds around production areas should be removed to prevent refuges for pathogens and insects that can transmit them (Fig. 3) (Hilje et al. 2001). Areas of grass can be planted for a 3.1 m (10 ft) distance around a greenhouse. Insect screening should be used to cover vent and fan openings to exclude insect vectors (Snehi et al. 2015). Screen mesh sizes should be selected to optimize insect exclusion while allowing adequate airflow (Bell and Baker 2000). Additionally, plastic sheets and screening are available that maintain high transmission of visible light while blocking portions of the ultraviolet spectrum, which interferes with the ability of insects to orient and find plant hosts (Hilje et al. 2001; Hochmuth and Sprenkel 2015). Insects can easily enter through the opening of hinged doors. A simple double door entrance with a small entryway can be used. An air-lock double door further allows a positive pressure balance between outside

Fig. 3 Aquatic weeds in a recycled containment basin can serve as potential hosts and sources for pathogen disseminated in irrigation water (Photo courtesy of R.J. McGovern)

doors and pressure balance into the greenhouse facility (Hochmuth and Sprenkel 2015).

Foot baths should be located at access doors and used to prevent potential pathogen-infested soil and debris from being carried inside (Buonassisi et al. 2013; Dvorak 2008; Gullino et al. 2015). Foot baths vary from depressions in walkways to use of shoe covers that can be immersed in tubs. Prior to using a foot bath, rinse and wipe debris from shoes then immerse them in the solution for 30 s to 3 min depending on the disinfestant label. Disinfestant solutions in foot baths should be changed daily, since many products, such as QACs and peroxy compounds, are less effective when plant matter or soil is present. Phenols react less with organic matter.

Greenhouse interiors must be routinely sanitized, since some pathogens can survive for years in soil and over a month on metal, rubber, and wood surfaces (Buonassisi et al. 2013; Norman and Strandberg 2012). At least annually, wash upper greenhouse structures, walls, benches, and floors and treat with a disinfestant. For algal problems select disinfestants such as peroxy compounds, QACs, and bleach. QACs were very effective against fungal pathogens on most greenhouse surfaces, other than some synthetic materials, like polyethylene (Bennett et al. 2011; Mebalds et al. 1997). To sanitize greenhouse sections, remove all plants and organic and inorganic debris from benches and floors. This is best done routinely during production operations.

If soil floors exist under bench production, cover soil with gravel so no soil is exposed, because soil can harbor pathogens, shore flies, and fungus gnats. Areas with gravel can be first covered with ground fabric. Drips from condensation on the roof, from leaks in the roof, and from water lines can generate enough splash force to collect and carry pathogen propagules from the soil onto crops on benches or from container to container; therefore, the occurrence of drips should be minimized. Install enough hose-end holders for convenient storing of hose nozzles to keep them off the ground and uncontaminated. Hose nozzles and watering wands should never come in to contact with the floor and should be cleaned and allowed to air dry between uses.

Sanitation practices are easier to implement if pots and trays are set on top of benches. Due to the cost of benches, some businesses set pots and propagation trays directly on polyethylene or gravel floors. In such cases, sanitation is more difficult, but still can be done. Organic matter should be removed because it can serve as a habitat and food source for pathogens (Copes 2015). The bulk of organic matter can be removed with a broom or blower. Brooms should be sanitized afterwards to prevent pathogen spread to other areas of the operation. Blower direction needs to be considered so pathogens are not blown out of the house into surrounding areas of the operation. Cleaning the floor and lower walls with soap and/or water further removes small particles of organic matter. Spray application of a disinfestant on the floor and walls further reduces persistence of pathogen populations on those surfaces.

In the case of high tunnel greenhouses and some shade houses, plants are grown directly in soil. A number of plant pathogens naturally survive in the soil environment. This paragraph provides a short summary of information that is covered in more depth elsewhere (Ajwa et al. 2003; El-Shami 1990; El-Shami et al. 1990a, b; Garmendia and Goicoechea 2011; Gupta et al. 2005; Paulitz and Bélanger 2001; Tanaka et al. 2003; Tello and Bello 2002; Walker and Thompson 1950). Populations of soil-borne plant pathogens can be controlled between crops using heat, fungicides, and/or fumigants. Soil is heated by injecting aerated steam into air spaces within the soil that is covered with plastic or enclosed in a container or by soil solarization that is an option in warmer climates with regular sunlight. Success in eliminating a pathogen population in soil will be affected by the pathogen's tolerance to heat, the maximum temperature attained, the length of time heat is maintained, and the ability to avoid recontamination of the treated area from surrounding soil. A general guideline to eliminate common pathogens in soil is temperatures of 60 °C (140 °F) to 70 °C (158 °F) for 30–60 min, although not all pathogens will be killed at those settings. Attaining those temperatures by soil solarization will require covering the soil with a double layer of transparent plastic. A single layer of plastic will generate lower temperatures and require durations of 4–6 weeks. An advantage of heat is plants can be planted immediately after temperatures drop. Fungicides, such as fosetyl-Al, iprodione, mefenoxam, quintozene, thiophanate-methyl, and triflumizole, can be applied to soil to provide a broad or specific control of fungal and oomycete pathogens. Biocontrol products that contain various organisms, such as *Gliocladium virens*, *Streptomyces griseoviridis*, or *Trichoderma* spp., can suppress certain pathogen populations. Soil fumigants, such as methyl bromide and/or chloropicrin, are restricted use materials that might be considered for moderate-to-severe pathogen infestations.

4 People

Workers who contact plants can transmit pathogens. Pathogens can stick to tools, equipment, shoes, clothes, and skin, including hands. Where ever a worker goes next, they have potential to spread pathogen propagules. Workers, managers, and visitors should be instructed to avoid casually touching plants and benches.

Employees should receive in-house training to teach them how pathogens can be accidentally spread by common production activities. Supervisors should reinforce that training to help make it common practice.

Washing hands is a good basic practice between tasks or stations. Contaminated hands of workers were found to be a major means of spreading *Fusarium oxysporum* f. sp. *radicis-lycopersici* within tomato transplant facilities (Menzies and Jarvis 1994). Each worker should have a single defined task and purpose when entering a production area, such as watering, scouting for diseases and arthropods, collecting cuttings, or moving plants. Before switching to another task, workers should clean up properly at a wash station.

The primary function of soaps and detergents is to remove organic matter, soil, grease, and various contaminants, including pathogens. The use of hot water and scrubbing helps remove contaminants. Use of latex, nitrile, or vinyl gloves provides a smoother surface from which spores can more easily be washed than from skin. Gloves also protect hands from harsh detergents, disinfestants, and other chemicals. Gloves add an additional cost that can be justified in high risk activities. Cost of over-clothing may only be justifiable for high risk diseases.

Spores of many pathogens are produced in a gelatinous substance that adheres to surfaces, including clothing as people walk through production areas. Spores of *Colletotrichum acutatum*, in numbers sufficient to cause disease on leatherleaf ferns, were recovered from cotton denim fabric; the spores stayed viable for up to 4 weeks (Norman and Strandberg 1997). If possible, workers should wear clean clothes to work each day or wear over-clothing such as aprons that are cleaned by the business. For serious disease problems, such as *Fusarium* wilt at tomato transplant production facilities, over-clothing (aprons, lab coats, Tyvek suits, boot covers) should be worn in high risk areas so clothing can be removed before working in other blocks. Over-clothing adds a level of protection that can be treated with a disinfestant or removed and bagged before leaving areas (McGovern 2015). Citric and acetic acids are safe to use on clothing and skin, yet can damage the envelope of acid-sensitive viruses (Anon 2014).

People should avoid wearing bright colored clothing, such as yellow and blue that can inadvertently attract and disseminate insect vectors (Snehi et al. 2015).

5 Seeds, Tubers, Corms, Rhizomes, Stolons

When possible, seeds, tubers, corms, rhizomes, and stolons should be obtained from areas of the world where the pathogen of concern is not present or from producers that use disease-free certification programs. Literature is available describing sanitation methods, including disinfestants, thermotherapy (dry or moist heat), electrotherapy, pesticides (fungicides, bactericides, and oomyceticides), biological controls, micropropagation techniques, and plant indexing (Ascough et al. 2009; Brand 2006; Chan et al. 1996; Geneve et al. 1997; Gilad and Borochov 1993; Liu et al. 2014; Maene and Debergh 1986; Munkvold 2009; Paulitz and Bélanger 2001).

Companies that sell or generate plant selections from these sources often have developed proprietary sanitation protocols they implement at a commercial scale.

6 Plant Certification

The international seed and plant trade businesses have been affected by phytosanitary regulations that are changing faster than the supportive science (Munkvold 2009). Sanitary and phytosanitary (SPS) regulations of imported goods does impact trade and is viewed as a security concern for maintenance of the national plant health of countries. Pathogen identification technologies of increasing sophistication are allowing better standardization of internationally acceptable methods by relying on various biological and molecular methods, such as lateral flow devises (LFD), enzyme-link immunosorbent assay (ELISA), and traditional nested and quantitative PCR (Djalali Farahani-Kofoet et al. 2012; Linfield 1994; Miller et al. 2009; Sastry 2013). Inevitably, new genetic platforms, such as DNA microarrays and sequencing (DNA barcoding), and combinations of serological, nano, and nucleic acid detection technologies will further increase identification capabilities and improve the plant/seed certification process.

Seed health tests have primarily been focused on agronomic crops; such tests have been developed for over 100 pathogens. Eventually, this process will be applied to ornamental crops. Providing good seed sanitation does not exclude the possibility of latter introduction through growing media, local sources in the production area, or irrigation. This occurred with *Pythium ultimum* on seed-propagated geranium (Hausbeck et al. 1989).

The European and Mediterranean Plant Protection Organization (EPPO) has been developing schemes for certification of pathogen-free ornamentals, based on the principle of "filiation" in which nuclear stock plants of the highest health status are established and maintained, from which certified plants can be propagated under strictly controlled conditions (McNamara et al. 1996). Several certification and classification schemes have been accepted as standards for the Euro-Mediterranean region, particularly for bulb crops. In cases where filiation is not practical or necessary, a crop may be grown under near-normal conditions (e.g., in the field) then subjected to inspections where progeny are officially segregated for flower production or further propagation (McNamara et al. 1996). Dahlia crops in the Netherlands receive a visual inspection for viruses in the field, followed by serological testing for tomato spotted wilt tospovirus (TSWV) performed by the Flowerbulb Inspection Service, the Netherlands (Schadewijk et al. 1996). Growers are allowed to remove infected tubers from their stock. The scheme has led to a rapid decline of TSWV in Dutch dahlia crops.

Some plant health regulatory organizations include the National Plant Protection Organization (NPPO), the European and Mediterranean Plant Protection Organization (EPPO), the North American Plant Protection Organization (NAPPO), National Agricultural Biosecurity System (NABS) in India, and the International Plant Protection Convention (IPPC) (McNamara et al. 1996; Miller et al. 2009; Rishi 2009).

Several organizations have been involved in internationally standardizing seed health testing methods: International Seed Testing Association (ISTA), International Seed Health Initiative (ISHI), International Seed Federation (ISF), and in the United States, the National Seed Health System (NSHS) (Munkvold 2009). Action is taken through treaties involving the IPPC and the Food and Agriculture Organization (FAO) of the United Nations that operates under international standards for phytosanitary measures (ISPM) and includes at least 170 countries. Human resources to provide expertise in pathogen and disease identification include organizations such as the International Plant Diagnostic Network (IPDN); Plant Health Australia; the regulatory agency of the United States Department of Agriculture (USDA) Animal and Plant Health Inspection Service (USDA APHIS); the USDA APHIS Center for Plant Health Science Technology (CPHST); the National Plant Diagnostic Network (NPDN) in the United States; Agricultural Development and Advisory Service (ADAS) and CABI in the United Kingdom; the Global Plant Clinic (GPC) a consortium of CABI Bioscience; the National Reference Laboratories (NRLs) in the European Union; the Taiwan Agricultural Research Institute (TARI); New Partnership for Africa's Development (NEPAD); National Certification System for Tissue Culture Raised Plants (NCS-TCP), IITA Ibadan, and the Biosciences eastern and central Africa (BecA); and the Kenya Plant Health Inspectorate Services (KEPHIS), the African Union (AU), Inter-African Phytosanitary Council (IAPSC), the Center for Phytosanitary Excellence (COPE), and the Standards and Trade Development Facility (STDF) of eastern and southern Africa (Miller et al. 2009; Rishi 2009). Certification programs are being used by some companies and grower groups, such as Naktuinbouw Elite Ornamental Crops (http://www.naktuinbouw eu/node/192).

7 Stem and Leaf Cuttings

Stem and leaf tissue used for propagation can be contaminated with various pathogens. The preferable means of obtaining clean propagation plant material is to start with healthy plants and to maintain plant health with an integrated program for disease control. Stock plants should be maintained in separate greenhouses and fields at a distance from production facilities.

If disease-free stock plants are not available, several strategies may be considered to minimize pathogen introduction into propagation facilities. The strategy used will depend on crop production schedules and the biological realities of the pathogen. Three strategies are: (1) Start stock plants using micro-propagation or plant indexing techniques. (2) Plant material can be collected during periods when the pathogen is inactive. This would require knowing if defined infection periods occur and the length of latent periods, which is the time from infection to appearance of symptoms. In this scenario, new infections are unlikely and current infections have already developed symptoms. As a result noninfected healthy plant tissue can be visually identified and collected. (3) An appropriate pesticide (e.g., fungicide) can be applied

Fig. 4 Peat-based media stored on a cement floor, but left uncovered where air-borne spores can contaminate the media (Photo courtesy of R.J. McGovern)

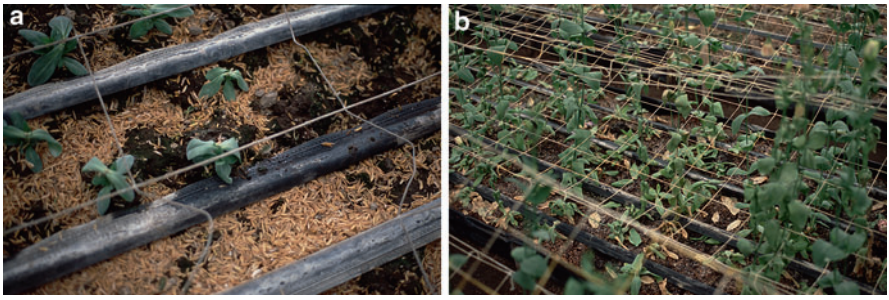

Fig. 5 (**a** and **b**) *F. oxysporum* f.sp. *eustomae* was diagnosed as the cause of seedling blight and possibly was spread because of inadequate soil fumigation and inadequate sanitation practices (Photos courtesy of R. J. McGovern)

to inhibit disease development by reducing development and spread of propagules prior to collecting cuttings. The later is more likely with fungal pathogens.

The latter two techniques do not guarantee pathogen-free propagative material. If cuttings are collected from field grown plants, caution is needed to reduce the possibility of pathogens being carried to the plant by rain splash. Stem cuttings should be collected only from the upper portion of plants, above the height where rain splash is likely to carry pathogen propagules. Larger rain drops have been shown to splatter upward of 0.9 m (3 ft), carrying pathogens such as *Phytophthora* spp., *Pythium* spp., and *Thielaviopsis* spp. Potentially this also relates to greenhouses with dirt floors under benches. Do not neglect to use clean equipments, tools, and media (Figs. 4 and 5).

8 Plants

More disinfestants are being labeled for direct application on plants, yet limited information is available to advise growers of preferred practices (Cayanan et al. 2008, 2009; Celar et al. 2007; Copes 2009). Currently, hydrogen dioxide

plus peroxyacetic acids and quaternary ammonium compounds (QAC) are two products labeled for direct application on plants in the USA. All disinfestants can cause phytotoxicity if applied at a high enough rate or at close intervals; therefore, it is important to follow label directions and test apply the material on a small number of plants before full scale application.

9 Spatial Arrangement of Plant Stock

Spatial separation of plants and worker activities can be used to restrict spread of pathogens. But this type of control requires forethought. Plant selections from different sources can be physically separated in different greenhouses or fields. The reason is to limit exposure of all plants to a pathogen present on one source of plants. This approach is commonly recommended for stock plants used as a source of cuttings. Spatial separation in a large bay may not be adequate, especially when propagules can be easily air dispersed across the bay.

10 Discarded Plant Material

Diseased plant material can become a major source of pathogen spread once propagules are produced on or in the tissue. Diseased plant material should be collected and removed as quickly as possible, at least daily, from production areas. Common recommendations are to place plant tissue in a covered container and remove the container from a production area, at least daily, and dispose of all discarded plant material. It is the author's belief that a container should have a properly but loose fitting lid, so the lid can be removed gently and infected plant tissue set, not dumped, in the container. While tight lids are more securely attached, more force is required to remove the lid which could momentarily produce a suction that aids dispersal of air-borne pathogens.

Discarded plant tissue should be enclosed in plastic bags or a closed container and removed from production areas to a distant site. The discard site should be as far from production plants as possible (Fig. 6). If it must be discarded near the production site, it minimally needs to be downhill out of the direct path of storm water flows, downwind of the production area, and preferably processed in compost piles. Use of barriers, such as tall hedges, in some cases could further diminish the impact of wind dispersal, by absorbing or diverting direct wind flow. Caution should be exercised relative to overall land topography and wind flow, as wind may rise over barriers and flow directly down on the discard pile to increase dispersal.

Discarded plant material can be a significant source of pathogen inoculum. Serious disease problems have occurred when high numbers of air-borne spores have been blown from discarded plant material near production areas onto a crop. Spore-containing water may flow downhill from discard piles and move through production blocks, causing serious plant losses.

Fig. 6 (**a** and **b**) Diseased plants discarded into a plant refuge pile, which can now serve as a source of wind-blown spores (Photos courtesy of R. J. McGovern)

In some cases, removal of diseased plant tissue has produced substantial reduction in disease. The incidence of viral diseases [Narcissus latent, macluravirus (NLV); Tobacco rattle, tobravirus (TRV); Cucumber mosaic, cucumovirus (CMV); and an unidentified corky pit virus-like agent (UCPVA)] was reduced by removing infected Gladiolus plants in the Netherlands (Asjes et al. 1997). In contrast, conidia of *Colletotrichum acutatum* remained infective for up to 49 days in leaf debris from the leatherleaf fern on the soil surface in commercial ferneries and up to 31 weeks under dry soil conditions (Norman and Strandberg 1997, 2012). In the case of *Botrytis* blight, removal of diseased plant material alone will not reduce disease without use of cultural controls and applications of fungicides; however, not collecting diseased tissue could increase disease pressure dramatically (Hausbeck and Moorman 1996).

11 Irrigation Water

Selecting a water treatment system requires consideration of equipment, installation and operation costs, maintenance requirements, source(s) of water, quality of water chemistry, and maximum daily water usage. The main components of a water treatment system include the electronic control system, filtration system, preinjection system (dependent on water quality), and disinfestant injection system. Multiple equipment and disinfestant options are available. The primary disinfestants are chlorination (chlorine gas, electro chemical activated (ECA) water, bleach); chlorine dioxide; ozone; and peroxygen compounds (hydrogen dioxide = hydrogen peroxide (H_2O_2), peroxyacetic acid). Physical disinfestation techniques are ultraviolet (UV) light, heat, and filtration. The critical factors for selection of disinfestants

have been thoroughly covered by Fisher (2014). Chlorine gas is the most commonly used disinfestant because it is effective and has the lowest cost. However, each system has advantages and disadvantages that should be considered. Multiple decisions are involved in choosing a water disinfestation system, and several web-based sites address the topic to assist growers: (http://watereducationalliance.org/; Irrigation Pathogen and Water Quality Webinar Series-http://www.irrigation-pathogens.ppws.vt.edu/webinar/ index.php).

Water treatment to eliminate pathogens involves exposure to a disinfestant at a certain rate for a minimum time. Chlorination will be used as an example. A rate of 1–2 ppm free chlorine is commonly recommended to kill zoospores of *Phytophthora* spp. in irrigation water (Cayanan et al. 2009; Hong et al. 2003), and this is less than the 2.5 ppm free chlorine considered safe for application on most ornamental plants (Cayanan et al. 2008; Skimina 1992). However, 12–14 ppm free chlorine with 6–10 min exposures was required to killed *Fusarium oxysporum* and *Rhizoctonia solani*, which is a level toxic to ornamental plants (Cayanan et al. 2009). However, hydrogen peroxide plus peroxyacetic acid may be an alternative in this application, because a rate below the label rate that is safe to most ornamental plants killed *Fusarium foetens* conidia, the cause of begonia wilt (Elmer 2008). This highlights the fact that disinfestant selection sometimes depends on the current problem (Floyd 2008).

Characteristics of the water source(s) is an important consideration in considering water treatment (Hong and Moorman 2005). Irrigation water drawn from capped deep wells and from municipal treated drinking water generally is considered to be free of plant pathogens, therefore should not require treatment (Copes et al. 2015; Hong and Moorman 2005). However, unusual cases have been documented. For example, a plant-indexing propagation operation found municipal water to be the source of *Pythium* spp. at the facility. Irrigation water drawn from natural water ways and from recycling water basins potentially contain plant pathogens, such as plant pathogenic *Erwinia* spp., *Fusarium* spp., *Pythium* spp., *Phytopythium* spp., and *Phytophthora* spp., that may require treatment (Bush et al. 2003; Del Castillo Múnera and Hausbeck 2015; Elmer 2008; Ghimire et al. 2011; Choudhary et al. 2016; Moorman et al. 2002; Parke and Grunwald 2012). Even with these seemingly risky water sources, water treatment is only required when pathogens capable of causing crop loss are being dispersed in irrigation water.

Recent research results have shown that detection of *Pythium* spp., *Phytopythium* spp., and *Phytophthora* spp. in irrigation water does not confirm a plant pathogen problem (Copes et al. 2015; Hong and Moorman 2005; Choudhary et al. 2016; Loyd et al. 2014; Parke et al. 2014; Zappia et al. 2014). Unfortunately, these results provide an additional burden for plant producers, because isolates need to be identified to species by qualified plant disease clinics and associated with past or current plant disease problems, or a high potential for disease to determine whether water treatment is required. Current knowledge demonstrates that certain species can be considered as highly pathogenic and their presence at any level is of serious concern, while many other species cause crop loss less commonly. For example, *Phytophthora nicotianae and P. tropicalis* are considered to be high risk pathogens to herbaceous plants, thus water treatment should be implemented (Hong

et al. 2014). *Phytophthora citrophthora*, *P. pini*, *P. cactorum*, *P. drechsleri*, *P. megasperma*, *P. palmivora*, *P. cryptogea*, and *P. taxon drechsleri III* are considered to be moderate risk pathogens to herbaceous plants, thus water treatment may not be required unless disease problems exist or have been a problem (Hong et al. 2014). Many other *Phytophthora* spp. are considered to be of minor risk and water treatment would not be necessary unless an active disease problem was identified. Fungal and bacterial pathogens should be evaluated similarly. In Florida, populations of *E. chrysanthemi* and *E. carotovora* subsp. *carotovora* that are pathogenic on ornamental plants in the Araceae family were shown to increase in a recycling containment basin without water treatment, thus water treatment would be needed (Norman et al. 2003).

If an outdoor recycling containment basin (= pond) is used, the system can be designed to promote the natural decline of *Phytophthora* zoospores. The main objective is to prevent the pathogen from reaching irrigation pump inlets (Ghimire et al. 2011; Hong 2011). The flow of irrigation runoff can be slowed and sedimentation promoted, which will reduce the diversity and level of pathogens reaching pump intakes for distribution in irrigation water. In a single pond system, run-off should be channeled to a single entrance point that is furthest from the pump uptake. One way to achieve this is to dig a J-shaped canal that routes water along the side of the reservoir to the opposite end from the pump house; in addition, several mounds of gravel laid perpendicular to the water path can be added in the canal to create intermittently slowed water travel that further facilitates settling of pathogen propagules (Hong 2011). A multiple pond system that includes a sedimentation pond and multiple catchment ponds will increase the travel distance and time for zoospores to settle out and increase the possibility of zoospore mortality (Hong 2011; Zhang et al. 2015b). The size of the basin system relative to daily water gallonage received will affect sedimentation capability. It is assumed that a similar decline would occur with both *Pythium* spp. and *Phytopythium* spp. Nonmotile spores of most fungi, such as *Fusarium* spp., would only be carried by currents, and as such should be susceptible to settling out when water flow is slowed and the distance increased between inflow and water uptake ports. In addition, water pH has been shown to adjust from an alkaline to a slightly acidic level after passage through multiple ponds.

Water conditions in a pond can also contribute to mortality of zoospores (Kong et al. 2012a, b; Kong and Hong 2014). Water pH levels in recycling containment ponds that were monitored 24-h per day in the mid- to south-eastern USA were found to be alkaline the majority of the time. Average pH levels only present part of the picture, as water basins in those same nurseries typically experience a vertical stratification of temperature, pH, and dissolved oxygen from May to October, even in ponds no deeper than 1 m (3.3 ft) (Zhang et al. 2015a–c). The stratification patterns in nursery ponds in other parts of the country have not been monitored yet. In Maryland and Virginia, USA, temperature, percent dissolved oxygen, and pH level are higher in the upper layer, during these stratification periods. Additionally, pH levels diurnally fluctuate several pH units in ponds, being lower and possibly acidic by early morning and being higher and possibly alkaline by early evening. A

similar diurnal fluctuation occurs with dissolved oxygen. These fluctuations occur due to the biological activity of algae and other microorganisms. Water drawn from the lower stratification, especially during early day hours, will be most suitable for chlorination without acidification treatments on most days.

It is not known if the same principles apply to containment tanks in greenhouses or if the relative water exchange is too high to retain a resident body of water that cushions or buffers against rapid changes.

12 Host Resistance

Plants that are highly and even moderately disease resistant may develop few if any disease symptoms. Durable plant resistance is often the preferred means of disease control when available. However, moderately tolerant cultivars can be carriers of pathogens without obvious symptoms. Pathogens that affect multiple crops may persist on tolerant plants and, as a result, be a possible source of the pathogen. This possibility needs to be considered when control expectations are not being achieved.

13 Integrated Disease Management

Integrated disease management (IDM) and the systems approach refers to coordinating multiple strategies, such as utilizing disease tolerant plant selections, sanitation, cultural, biological and chemical controls, and identifying key control points, to address disease concerns. Ornamental plant production has the unique challenge of producing a large number of plant selections at a single production site. IDM should be considered at two scales, integrating multiple controls to target a single disease and integrating controls at the operational scale against multiple diseases. The operational needs, resources, and production goals of the business must be considered when designing disease control procedures that allow production of high quality plants for the least input and cost outlay. Labor efforts should be planned so tasks can be implemented in a coordinated effort on multiple crops. A three step approach to selecting controls is suggested below:

1. Identify the major and common pathogens that infect the plants grown at a production facility, as these will be the target of management. Major pathogens are those that pose a threat of serious crop loss and/or regulatory involvement. Common pathogens are those that are recurring within an operation. Be diligent in inspecting new crops, because pathogens imported from other facilities may become new problems requiring intensive control efforts. A list of relevant pathogens may be available from university and private crop advisers and plant suppliers. Current literature and internet resources may be helpful but need to be evaluated as to whether the pathogens are relevant to your area. Good record keeping within a facility can aid in identifying recurring problems.

2. Identify which disease control practices are recommended for the major and common diseases pertinent to the operation and select relevant controls.
3. List and schedule the control practices on a general calendar flow chart for all crops. The purpose is to lay out a schematic diagram for organizing and consolidating labor and equipment needs in an economical approach. Determine possible scheduling conflicts so practices can be prioritized and alternative schedules and solutions written into the operation plan. If labor scheduling conflicts or excessive costs are evident, the schematic becomes an accounting tool to help prioritize and select the most valuable practices based on crop value and potential crop losses at the facility. When new disease problems occur, new control measures may need to be introduced into the plan.

14 Record Keeping

Records are an important tool for identifying and prioritizing the importance of tasks. Records can be kept in a notebook, in a computer spread sheet, or an online storage site. Images are easily taken with cell phones and can be stored in any of these filing systems. Record the date, crop, crop age or stage, location in the facility, disease symptoms and their progress over time, diagnosis, who made the diagnosis and whether it is by field recognition of symptoms or pathogen identification, name and rate of chemicals applied, total area and crops treated, and an estimation of percent crop loss (number of plants and their value per container). Records can serve as a reference for comparing current to past problems. Records are an important tool for helping to decide what control efforts may be of high, moderate, or low value. Good records can help you save money.

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