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Review

A review of postharvest disinfestation of cut flowers and foliage with special reference to tropicals

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Abstract

The commerce of floricultural commodities is very important to the economy of the producing locations. To protect the agriculture of consumer countries, import regulations require that the product be free of insects. Successful disinfestation eliminates the pest without damage to the commodity. Current postharvest approaches to disinfestation are hand removal, irradiation, fumigation, insecticidal dips, temperature treatments, and the use of biological control agents. In this review, the advantages, disadvantages and status of each method are discussed with examples provided.

Key words: Quarantine; Irradiation; Fumigation; Insecticidal dip; Cold storage; Hot water bath; Vapour heat; Biological control

1. Introduction

Floricultural commodities have pest problems unique among the agricultural crops. The traditional concept of economic threshold used in determining protection for many horticultural products (NAS, 1969) does not apply in most cases because the aesthetic value of the floral commodity tolerates no or very little pest damage (Parrella and Jones, 1987). Floral products usually are not consumed which allows some tolerance in chemical residues. Many different pest control strategies are needed because of the biological variation among the different species of cut flowers and foliage and their insect pests.

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The international commerce in cut flowers and related products serves a large market. For example, in 1987 the total value of all imported floricultural commodities worldwide was greater than US$ 2.0 × 10^9 (Tayama, 1991). Furthermore, exports of tropical floricultural materials are important to the economies of some locations. In 1989, Thailand exported US$ 1.6 × 10^7 worth of orchid flowers (Sanguthai, 1991). The total wholesale value of Hawaii's cut flowers and nursery products industry was about US$ 6.0 × 10^7 in 1988 (Hanaoka, 1991), with much of this intended for export to the mainland United States and foreign markets. Thus, quarantine regulations of the importing countries have a considerable impact on the cut flower industry. In 1986, 32.5% of the cut flowers imported from Australia to Japan (total value was A$ 4.4 × 10^6) were fumigated (Seaton et al., 1989). During 1989–1990, the value of cut flowers imported to the United States that required postharvest treatments was US$ 3.1 × 10^8 (NAPIAP, 1993).

The first course of pest control occurs where the floral crops are grown, in the fields and greenhouses among the bedded and potted plants. Yet, economic and environmental considerations impel reduced pesticide use without harming production and marketability. Sparnaaij (1991) examined the prospects of breeding for insect resistance in floricultural crops. The problems of establishing integrated pest management (IPM) for floral commodities have been discussed by Parrella and Jones (1987). Recent programs in IPM have been noteworthy by reducing pesticide applications without loss in production and marketability (e.g., Hara et al., 1990), yet, IPM alone may not be successful in meeting quarantine requirements because quarantine regulations require complete disinfestation. Also, pesticide registration, particularly for minor crops, is often discontinued.

Tropical locations that produce commercial cut flowers and foliage are particularly prone to quarantine regulations of other agricultural regions because these places often have important quarantine pests such as fruit flies and exotic homopterans. Importing countries try to prevent the introduction of insect pests that may damage their own agricultural crops. Importing countries desire insect-free floricultural materials to prevent the establishment of any exotic species, even if that species is not considered a pest in the country of origin (Myburgh et al., 1973). Although preventive measures may be very expensive, the local economies of the exporting countries may be so dependent on the cut flower industry that they may have no choice but to invest in disinfestation treatments.

The elimination of insects by postharvest treatments requires its own set of criteria along with economic, environmental, and safety restraints. These criteria include disinfestation of all life stages of existent and potential pests, which can be extensive, without loss in marketability in a wide assortment of floricultural commodities. Many approaches to develop effective postharvest treatments for the cut flower industry have been tried (Seaton and Joyce, 1988, 1989; Seaton et al., 1989). Current quarantine treatments approved in the United States for cut flowers by the United States Department of Agriculture–Animal Plant Health Inspection Service (APHIS) are limited to hand removal (APHIS, 1992f), chemical dips (APHIS, 1992d), and methyl bromide fumigation (APHIS, 1992g). Other approaches should also be considered and evaluated.

In this review, we examine different approaches to disinfestation. Knowledge of alternative postharvest methods is important in order to compete in an expanding world market for tropical floricultural commodities and to adapt to changing pest control regulations. We broadly use the term "tropical" to include plant materials such as protea and bird-of-paradise because these are frequently grown in tropical areas. Also, we explore procedures used for related products, such as potted and greenhouse plants, to expand their potential application to cut flowers and foliage. Finally, we encourage others to investigate innovative methods of postharvest treatments to promote an increasingly important commercial industry.

2. Methods

Hand removal

An effective method for eliminating insects from cut flowers and foliage is removal by hand (Seaton and Joyce, 1988). Every piece is examined and all insects physically removed. No expensive equipment or complicated technology is involved. However, this method is time- and labor-intensive which costs the grower. Also, the handling may damage the product and reduce vase life. Although hand removal is an alternative treatment for plants sensitive to fumigation, it is not recommended for controlling mature scale insects (APHIS, 1992e).

Irradiation

Disinfestation by gamma irradiation is rapid, effective, and can be used with sealed containers (Seo et al., 1974). However, treatments using irradiation require a secure, complex facility with highly trained personnel (Watters, 1984; O'Beirne, 1991). Besides the great expense of establishing an irradiation facility, other concerns are worker safety, community acceptance, and environmental protection (Sommer and Mitchell, 1986; O'Beirne, 1991).

Both floral materials and pest species vary in their sensitivity to radiation. For example, all larvae and pupae of the agromyzid leafminer, *Liriomyza trifolii* (Burgess), are killed at 100 krad (Yathom et al., 1990), but significant deleterious effects on orchid vase life occur at 50 to 100 krad (Piriyathamrong et al., 1985). Seaton and Joyce (1988, 1992) reported that insect pests require an exposure between 200 to 1000 krad to obtain quarantine security, but this dose causes damage to or reduces vase life of most cut flowers. For example, gamma irradiation as low as 5 krad and as high as 100 krad significantly reduces the vase life of the Australian cut flowers, Geraldton wax, *Chamelaucium uncinatum* Schau., and kangaroo paw, *Anigozanthos* spp., respectively (Seaton and Joyce, 1992). Also, some plant species show seasonal sensitivity to irradiation (Wit and van de Vrie, 1985a).

Investigations in the use of gamma irradiation to disinfest cut flowers have produced inconsistent results, even with the same pest. Cavalloro and Piana (1972) needed 250 krad to destroy mature larvae of *Epichoristodes acerbella* (Walker) (Lepidoptera: Tortricidae), a pest of carnation, but Bestagno et al. (1973) reported that 15 krad caused complete larval mortality with no plant injury among fourteen carnation cultivars. Cirio and Gentili (1978) found 13 krad exposure on eggs of

E. acerbella sufficient to kill all immatures by the pupal stage. Köllner (1977) recommended that a dose of 13 krad for all life stages was sufficient to pass quarantine requirements.

If quarantine regulations can be changed so that insects are required only to be sterilized, much lower doses would be used and additional plant species could be treated without damage. Goodwin and Wellham (1990) successfully controlled all life stages of the twospotted spider mite, *Tetranychus urticae* Koch (Acarina: Tetranychidae), on cut roses at 30 krad by killing the eggs or causing subsequent sterility in the adult females. Efficacy tests on other pests of floriculture crops, including the beet armyworm, *Spodoptera exigua* (Hubner) (Lepidoptera: Noctuidae), the green peach aphid, *Myzus persicae* (Sulzer) (Homoptera: Aphididae), and a thrips, *Frankliniella pallida* (Uzel) (Thysanoptera: Thripidae), have demonstrated that dosages of 10 to 20 krad are needed to arrest development or reproduction (Wit and van de Vrie, 1985a). Emergence of *L. trifolii* adults is prevented at doses of 7.5, 7.5, and 75 krad for eggs, larvae, and pupae, respectively (Yathom et al., 1990).

Before sterilization by irradiation is acceptable as a postharvest treatment, methods must be developed to assure that target pests are innoxious. Inspectors encountering live insects must have methods to recognize correctly treated commodities. This could be done by incorporating radiation-sensitive substances with the packaging or examining for indicators of radiation in the pest insect such as anatomical and cytogenetic changes (Rahman et al., 1990), physiological aberrancies (Hayashi et al., 1992), or the presence of a protein (Koval, 1986) that could be used as a biomarker (Hightower, 1993). Although sterilization by irradiation has promise as a quarantine treatment, the problems of encountering living insects must be resolved.

Fumigation

Fumigation has been the treatment of choice to disinfest floral commodities (Naegele and Jefferson, 1964). Several fumigants are very effective for many pests, even at short-duration exposures. The disadvantages of fumigation are that well-trained technicians are needed to operate the complicated equipment handling the highly toxic substances, phytotoxicity occurs in some floral material, and residues of some of the fumigants are retained in the final product.

Methyl bromide (MeBr) without chloropicrin is widely used by many countries as a standard quarantine treatment for floral commodities (APHIS, 1988). Pure MeBr, circulated thoroughly, is used by Thailand on orchids exported to Europe and America (Sanguthai, 1991). In the United States, cut flowers are fumigated at a concentration of 40 g/m^3 of MeBr for 2 h at 20°C to meet quarantine requirements (APHIS, 1992g). In Australia, the treatment is the same but with a concentration of 32 g/m^3 of MeBr (Seaton and Joyce, 1988), although complete pest mortality may require 18 h (Maughan, 1986). However, 24 g/m^3 of MeBr for 2 h controlled larvae of *Arotrophora arcuatalis* (Walker) (Lepidoptera: Torticidae) on *Banksia prionotes* Lindl. without reducing vase life (Seaton and Woods, 1991). In Pakistan, Junaid and Nasir (1955) destroyed all *Rhipiphorothrips cruentatus* H. (Thysanoptera: Thripidae) using 16 g/m^3 for 90 min without damage to rose, tulip, or carnation cut flowers; they used twice that concentration for 2 h to kill all *Icerya* spp. scales (Homoptera: Margarodidae) with no injury to rose cuttings.

Although MeBr is highly effective (APHIS, 1992a), some plant species are sensitive to its use, resulting in a delayed response particularly with fumigations above 20°C (Wit and van de Vrie, 1985b). The types of damage may be reduced shelf life (as in some carnations, asters, lilies, proteas, and yarrows), burning on leaves and petals (as in safflower, China-aster, chrysanthemums, sunflowers, and other asters), and failure of the flowerbuds to open (as in some roses, peonies, and kangaroo paws). Yathom et al. (1990) concluded that MeBr fumigation on cut flowers, such as baby's-breath, *Gypsophila paniculata* L., poses problems because the margin between the effective and phytotoxic doses is narrower than for other plant material.

The use of MeBr will be discontinued worldwide near the end of this century because it is a suspected ozone depleter. The U.S. Environmental Protection Agency has stated in the Clean Air Act that MeBr has an ozone depletion potential (ODP) between 0.44 and 0.69, and the Clean Air Act requires all Class I ozone depleters (an ODP >0.2) phased out of production no later than the year 2000 (Pesticide and Toxic Chemical News, 1992).

Another fumigant, hydrogen cyanide (HCN), has been used by the Japanese to treat imported plant material (Japanese Fumigation Engineering Society, 1981). HCN fumigation has been effective against an assortment of pest insects such as: scales (Camp and Wilmot, 1932; Hansen et al., 1991b); the Fuller rose beetle, *Asynonychus godmani* Crotch (Coleoptera: Curculionidae), (Houck et al., 1989); aphids (Hansen et al., 1991b); and some mealybugs (Hansen et al., 1991b). Orchid weevils, *Orchidophilus aterrimus* (Waterhouse) (Coleoptera: Curculionidae), are resistant to 5.1 g/m^3 of HCN for 30 min (Hansen et al., 1991b). The toxic effects of HCN should be evaluated for other insects.

As with MeBr, HCN is regarded as phytotoxic to some plant materials, particularly those with moist surfaces, because it readily dissolves in water to form a dilute acid (Monro, 1969; APHIS, 1980). Wit and van de Vrie (1985b) cited that "Anita" carnations, *Dianthus caryophyllus* L., were damaged by HCN fumigation when the flowers contained small droplets of water. Hansen et al. (1991a) found that wet red ginger, *Alpinia purpurata* (Vieill.) K. Schum., flowers were damaged at 2.8 g/m^3 of HCN for 30 min, and wet "Ozaki" anthuriums, *Anthurium andraeanum* Linden, at 5.1 g/m^3 of HCN for 30 min, but moist lycopodium, *Lycopodium cernuum* L., and bamboo orchid, *Arundina graminifolia* (D. Don) Hochr., foliage were unaffected. They also reported that a fumigation at 2.8 g/m^3 of HCN for 30 min injured pincushion protea flowers, but was safe with heliconia, ginger flowers, anthuriums, and a variety of foliage materials.

Phosphine is an effective insect-killing gas (Lindgren and Vincent, 1966). Long exposures are needed to achieve sufficient control compared to other fumigants (APHIS, 1980; Wit and van de Vrie, 1985b). Wang and Lin (1984) in Taiwan, using a combination of xylene (8.5 ml/m^3) and magnesium phosphide (16.6 g/m^3) for 4 h killed 100%, 96.9% and 98% of thrips, aphids and spider mites, respectively, with no phytotoxicity to chrysanthemum cut flowers; higher concentrations were phytotoxic, and magnesium phosphide without xylene was not as effective. Phytotoxicity will probably be a limiting factor on other flowers.

Dichlorvos (DDVP) at 32 to 64 mg/m^3 for 2 h at 20°C was listed as a postharvest disinfestation treatment for cut flowers and foliage (Seaton and Joyce, 1988). Hamlen and Henley (1979) obtained $\geq$95% reduction of a solanum mealybug, *Phenacoccus solani* Ferris (Homoptera: Pseudococcidae), the green peach aphid, and the twospotted spider mite by using 20% DDVP polychloride resin strips for 24 h exposures within sealed polyethylene bags. The most effective method of DDVP application is multiple fumigations at 7-day intervals in sealed polyethylene bags (Hamlen and Henley, 1979). Coetzee and Wright (1992) reported that DDVP fumigation of protea flowers for 16 h resulted in 91.6% mortality of insect pests. When protea flowers were treated in an enclosed chamber for 2 h with a combination of pyrethrin and DDVP, both propelled by CO_2, the combination was more efficacious than either of the insecticides used alone (Wood and Wood, 1991). MacFarlane and Franz (1989) found that DDVP (38 mg/m^3) with permethrin (36 mg/m^3) was more effective against the European earwig, *Forficula auricularia* L. (Dermaptera: Forticulidae), in cut *Protea* flowers than permethrin alone or in combination with pyrethrins (8 mg/m^3). DDVP is phytotoxic to certain foliage plants (Hamlen, 1976; Hamlen and Henley, 1979): the parlor palm, *Chamaedorea elegans* Mart.; an acanthus, *Aphelandra squarrosa* Nees; a swamp fern, *Nephrolepis exaltata* (L.) Schott; a bromeliad, *Aechmea fasciata* (Lindl.) Bak.; an asparagus fern, *Asparagus sprengeri* Regel; a succulent, *Crassula argentea* Thumb.; a *Dieffenbachia* sp.; the money tree, *Dracaena marginata* Lam.; the weeping fig, *Ficus benjamina* L.; the wax plant, *Hoya carnosa* (L.) R. Br.; pothos, *Epipremnum aureum* (Linden and André) Bunt; and a jade plant, *Peperomia obtusifolia* (L.) A. Dietr.

Polyethylene bags impregnated with 1% chlorpyrifos were used to wrap flowers of *Banksia menziesii* R. Br. in shipping boxes to control Argentine ants, *Iridomyrmex humilis* (Mayr) (Hymenoptera: Formicidae); nearly all ants were killed after a day of exposure without flower injury (A.H. Hara, unpublished data). Tjosvold and Ali (1989) tested chlorpyrifos-impregnated polyethylene bags and showed that western flower thrips populations were reduced by half without damage to carnation flowers. These impregnated bags can provide a safe and effect postharvest treatment for certain insect pests on flowers, but the bags are not currently registered for use in the United States and the probability of registration for their use with flowers is low.

Further research has been done with other fumigants, particularly in the greenhouse (Webb et al., 1977; Webb and Cawley, 1978; Fons et al., 1979; Neal et al., 1980). Sulfur dioxide fumigation of pink mink protea, *Protea neriifolia* R. Br., resulted in 73% mortality of earwigs after a 1.5 h exposure with some bleaching of flowers and foliage (Maughan, 1986). Aerosols, such as pyrethrin at 5.2 mg/m^3 for 2 h, did not injury cut flowers, but were ineffective against insect pests (Seaton and Joyce, 1989). Pyrethrin (8 mg/m^3) alone or with DDVP (38 g/m^3) can provide about 93% control for pests in *Protea* (Maughan, 1986), but permethrin (36 mg/m^3) in combination with DDVP (38 g/m^3) is more effective (Seaton and Woods, 1991). A thermal fogging device with forced air was tested on *Dendrobium* orchids infested with western flower thrips; effective control without flower injury was obtained with abamectin (56 mg/m^3 as emulsifiable concentrate) and chlorpyrifos (0.447 g/m^3 as emulsifiable concentrate) with 94% and 99% thrips reduction, respectively, after 3 h of fumigation (A.H. Hara, unpublished data). Also, forcing pyrethrin (8 mg/m^3) through boxes of *Banksia speciosa* R. Br. flowers was 99% effective (Seaton and Woods, 1991). Wang and Lin (1984) tested organophosphates and synthetic pyrethroids delivered as fogs for control of aphids and thrips on chrysanthemums; they concluded that deltamethrin, fenvalerate and permethrin were the most effective. Fumigants in combination with another treatment, such as cold storage, should also be examined (Seaton and Joyce, 1988).

Insecticidal dips and sprays

Insecticidal dips (Criley, 1989; APHIS, 1992d) are practical for disinfesting tropical floral material because government-registered chemicals can be used, the operation is simple, and no complex equipment is required. These chemical dips or baths can be easily incorporated into a packing house operation to eliminate unwanted insects from floral products. Frequently chemical dips are used with hand removal (Criley and Broschat, 1992; APHIS, 1992f). The disadvantages of insecticidal dips are that they are labor-intensive, that worker safety and environmental concerns must be satisfied, that efficacy varies with pest species and life stage, and that the potency of the dips decreases with repeated use if fresh insecticide is not added.

Various chemicals have been evaluated as insecticidal dips for floral materials. Herbaugh and Mosteller (1980) measured egg mortality of the sugarcane rootstalk borer, *Diaprepes abbreviatus* (L.) (Coleoptera: Curculionidae), on *Dracaena* canes due to different concentrations of dips in various insecticides and determined that propoxur was the most effective. Schroeder et al. (1977) reported 72% mortality in sugarcane rootstalk borer eggs after applying citrus oil. Schroeder and Green (1983) found that eggs of the sugarcane rootstalk borer became detached from *Dracaena* leaves after an application of oil spray. Simanton and Bullock (1973) evaluated a series of chemicals as root-dip larvacides against the sugarcane rootstalk borer; they considered none sufficiently effective or safe to use. Robb et al. (1985) dipped bromeliad plants, *Aechmea fasciata* (Lindl.), in dimethoate to examine efficacy against the pineapple scale, *Diaspis bromelia* (Kerner) (Homoptera: Diaspididae), and the Boisduval scale, *Diaspis boisduvalii* Signoret (Homoptera: Diaspididae) and obtained 90% control a month after treatment. Osborne (1986) dipped cuttings of tropical ornamental foliage plants in fluvalinate to control the twospotted spider mite, a solanum mealybug, *P. solani*, the green peach aphid, and the greenhouse whitefly, *Trialeurodes vaporariorum* (Westwood) (Homoptera: Aleyrodidae). Tenbrink et al. (1990) analyzed the effectiveness of four insecticidal dips against the banana aphid in red ginger flowers and recommended fluvalinate. Soderstrom and Brandl (1988a) examined various chemicals as dips to control Fuller rose beetle eggs, and concluded that none satisfied quarantine requirements. Hara et al. (1989) studied the efficacy of various chemical dips to control fifth instars of the green garden looper, *Chrysodeixis eriosoma* (Doubleday) (Lepidoptera: Noctuidae) on ti leaves; they determined that methomyl and permethrin were the most effective. Butler et al. (1993) tested an insecticidal soap, 15 laundry detergents, and two horticultural oils against the sweetpotato whitefly, *Bemisia tabaci* (Gennadius) (Homoptera: Aleyrodidae), a pest of poinsettia, *Euphorbia pulcherrima* Willd., and found that all but three detergents caused at least 85% mortality. Bethke and Parrella (1990) obtained 98% mortality of the sweetpotato whitefly by using an insecticidal soap. Waller (1990) found that an insecticidal soap reduced numbers of onion thrips, *Thrips tabaci* Lindeman (Thysanoptera: Thripidae), by 97%. Osborne and Petitt (1985) observed complete mortality in populations of the twospotted spider mite, *Tetranychus uriticae* Koch, with an application of an insecticidal soap. Hansen et al. (1992a), after screening various chemicals separately and in combination, selected a soap/fluvalinate combination dip as effective against the banana aphid, magnolia white scale, the green scale, and several species of mealybug. In Australia, deltamethrin is now registered as a dip for cut flowers (Seaton and Woods, 1991).

Except for immediate injury, phytotoxicity due to chemical dips is often exhibited by increased aging or a decline in vase life. There is no uniform vase life expectancy among untreated floral products because even similar types of plant materials have different rates of aging. Some floral materials rapidly deteriorate while others maintain quality for a long time period, then suddenly decline. For example, leaves of pothos deteriorate within a week, but those of massangeana, *Draceana fragans* (L.) Ker-Gawl., can maintain their quality for more than two months (Hansen et al., 1992a). Likewise, cultivars of the same species can display a great range of sensitivity to a particular chemical (Hata and Hara, 1988; Tenbrink et al., 1991).

In general, chemicals registered as sprays do not cause plant damage when used as dips. For example, Parrella and Morishita (1982) found no plant injury among five broadspectrum insecticides used as dips for bromeliads, *Tillandsia* spp., which are known for insecticide sensitivity. Robb and Parrella (1984) detected no plant injury among tropical foliage plants in tests with nine insecticides. Seaton and Joyce (1989) observed low phytotoxicity with permethrin and deltamethrin, but noted that 1-min dips of carbaryl reduced vase life of Geraldton wax flowers (Seaton and Joyce, 1988). Hata and Hara (1988), in evaluating 20 insecticides and acaricides at four times the recommended rate, found a range of phytotoxic responses among 13 cultivars of anthuriums; such information is important for the selection of a chemical as a dip. Furthermore, oils and insecticidal soaps may not be useful as dips because of their phytotoxic effects. Locke and Larew (1990) tested for phytotoxicity of an insecticidal oil on a range of tropical foliage and found damage in the weeping fig. Tenbrink et al. (1990) noted that an insecticidal oil used as a dip caused discoloration in red ginger. Tenbrink et al. (1991) found that a dip of fluvalinate combined with a soap formulated as an insecticide caused injury to only the sago palm, *Cycas revoluta* Thunb., among 10 spp. of foliage cuttings, to "Jacquelyn Thomas" orchid flowers, *Dendrobium phalaenopsis* Fitzg, and to four cultivars of anthuriums. Hansen et al. (1992a) concluded that the damaging agent was the insecticidal soap (Fig. 1). This product has also caused unacceptable damage to four species of bedding flowers (Cranshaw and Meyer, 1986). Although Bethke and Parrella (1990) observed no phytotoxicity

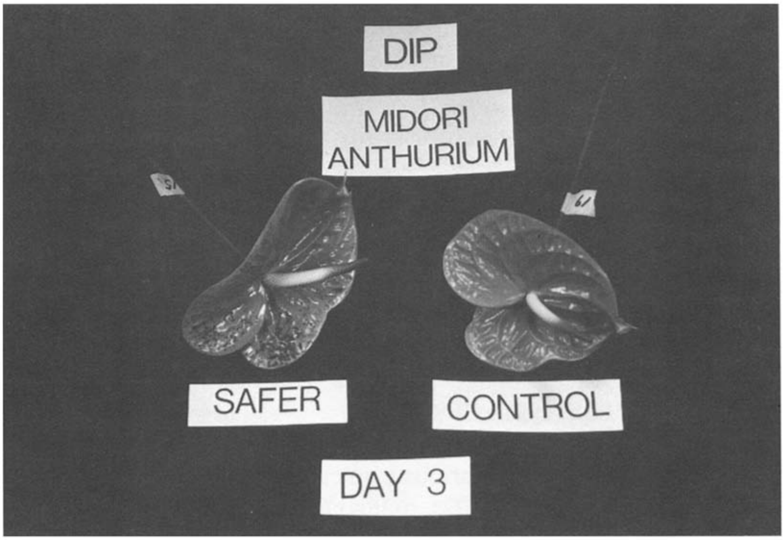

Fig. 1. Phytotoxic injury in 'Midori' anthurium, *Anthurium andraeanum*, from an insecticidal soap dip observed 3 days after treatment; treated on left, control on right.

from the insecticidal soap on poinsettias, Thompson (1989) reported plant damage from use of the insecticidal soap in ornamentals such as gardenia, poinsettias, and maidenhair fern. Insecticidal oils and soaps, though non-toxic to mammals, may provide suitable pest control; yet, they should be carefully applied to untested floral materials to prevent plant injury. Adjustments in the rates used for these materials, especially in combinations with other insecticides, may also be considered.

Cold storage

In the United States, cold storage of various fruits has been an approved quarantine treatment against different species of tephritid fruit flies (APHIS, 1992c). Unfortunately, there have been few attempts to develop similar procedures for tropical cut flowers and foliage. Although reduced vase life is always a concern, a suitable cold storage treatment would assist in the transportation of floral products from the tropical production areas to temperate market regions. Jones and Faragher (1991) found some likely candidates when they studied the effects of cold storage on the vase life of some members of the Proteaceae and Australian native cut flowers. Seaton and Joyce (1988) reported that cold storage (0 to 1°C) was effective in eliminating pest insects; however, this treatment was not feasible because the treatment required two weeks and flowers of Geraldton wax and kangaroo paw deteriorated during that time. Cold storage in combination with a high carbon dioxide atmosphere reduced the treatment time to one week (Seaton and Joyce, 1988).

Many tropical floral materials are unsuited for cold storage (Reid, 1991). Below 5°C, bird-of-paradise produced necrotic lesions and buds failed to open (Halevy et al., 1978). In heliconia, the inflorescence blackens and the foliage dies below 10°C

(Broschat and Donselman, 1983). Red ginger flowers should be stored above 12°C (Broschat and Donselman, 1988). Other tropical flowers (such as *Anthurium* spp., *Zingiber* spp., and *Cattleya* spp.) and most common foliage plants are very sensitive to temperatures below 7°C (Reid, 1991).

Hot water baths

Two approaches can be considered in developing heat treatments; either warm temperatures (≤43°C) for very long periods (≥5 h) (APHIS, 1992b; Sharp, 1993) or intense heat (≥48°C) for short durations (≤60 min) (APHIS, 1992e; Sharp, 1993). As a quarantine procedure, hot water baths involve simple technology, require energy to provide heat, produce uniform treatment of the commodity, can be combined with chemical treatments, and can be modified to include disease control. Often a cooling process immediately follows a heat treatment to prevent thermal injury of the plant (APHIS, 1992b, 1992e).

In the United States, hot water quarantine treatments have been examined to eliminate different fruit flies from various tropical fruits such as banana (Armstrong, 1982), guava (Gould and Sharp, 1992), mango (Sharp, 1986, 1988), and carambola (Hallman and Sharp, 1990). Tropical floral products may also be suited to this procedure. Soderstrom and Brandl (1988b) found that all eggs of the Fuller rose beetle were destroyed at 55°C for 2 min. Simanton and Bullock (1973) reported that all larvae of the sugarcane rootstalk borer died after submersion in 49°C water for 5 min. Seaton and Joyce (1988) obtained effective control of pest insects with a 20 min dip at 46°C or a 10 min dip at 56°C; however, they reported damage to *Banksia* and Geraldton wax flowers. Aphids in red ginger were destroyed in hot water baths (47°C) for 5 min without plant injury (Hansen et al., 1991c). Hara et al. (1993) obtained quarantine security against the magnolia white scale, *Pseudaulacaspis cockerelli* (Cooley) (Homoptera: Diaspididae) without limiting vase life by submerging bird-of-paradise in 49°C water for up to 10 min; vase life was reduced by one day if treated in the bud stage and two days if treated in the open stage. Additional research is needed to evaluate whether hot water baths are suited to other tropical floral products.

Vapour heat

Vapour heat (or heated water-saturated air) is currently used in the United States to disinfest fruits and vegetables of fruit flies (APHIS, 1992b). Although vapour heat was used to control bulb flies, *Eumerus* sp.(Diptera: Syrphidae), on narcissus bulbs (Spruijt and Blanton, 1933) and the gladiolus thrips, *Thrips simplex* (Morison) (Thysanoptera: Thripidae), on gladiolus corms, it has not been applied to commercial cut flowers and foliage until recently. With the recent social emphasis on worker safety and environmental contamination by pesticides, vapour heat is advantageous in that only heat is the killing agent (Sharp, 1993). The disadvantages are that vapour heat requires an expensive facility with computerized temperature control operations with appropriate sensors and software, posttreatment cooling procedures, precise maintenance of all equipment, and highly trained personnel (APHIS, 1985).

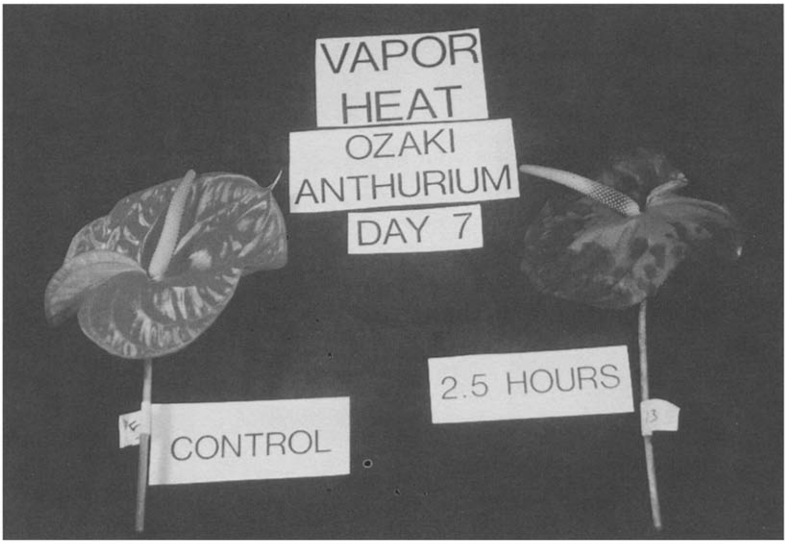

Fig. 2. Phytotoxic injury in 'Ozaki' anthurium, *Anthurium andraeanum*, from a 2.5 h exposure to vapour heat (45.2°C) observed a week after treatment; control on left, treated on right.

Temperature is important when treating cut flowers and foliage with vapour heat. *Banksia* flowers were damaged when treated for 10 min at 56°C (Seaton and Woods, 1991). Hansen et al. (1992b), in evaluating the use of forced vapour heat at a commercial papaya facility in Hawaii, eliminated infestations of banana aphid, *Pentalonia nigronervosa* Coquerel (Homoptera: Aphididae), green scale, magnolia white scale, various mealybugs, and cardamom thrips, *Sciothrips cardamomi* (Ramakrishna) (Thysanoptera: Thripidae), with a treatment of 46.6°C for 1 h. Phytotoxicity in different species of cut flowers and foliage was examined; anthuriums (Fig. 2), pincushion protea (Fig. 3), and orchid flowers and foliage were very sensitive to the treatment whereas large heliconias, red ginger flowers, bird-of-paradise flowers and leaves, and most foliage species remained undamaged.

Further vapour heat experiments have been conducted in Florida USA (J.D. Hansen, unpublished data). Immature stages of the banana moth, *Opogona sacchari* (Bojer) (Lepidoptera: Tineidae), were treated with vapour heat at 44°C for cumulative 15 min periods; none survived at 30 min or beyond. To determine thermal injury to the host plant, *Dracaena fragans*, uninfested canes underwent the same treatment, but no damage was detected when assessed several weeks later (Fig. 4). After several cultivars of *Chrysanthemum* cuttings were treated for 10 min periods at 45°C, all treated cuttings deteriorated in propagation (J.D. Hansen and A.D. Ali, unpublished data).

Controlled atmospheres

Controlled atmospheres (CA) involve increasing the concentration of carbon dioxide (CO_2) or nitrogen while reducing that of oxygen (O_2). Advantages of CA are

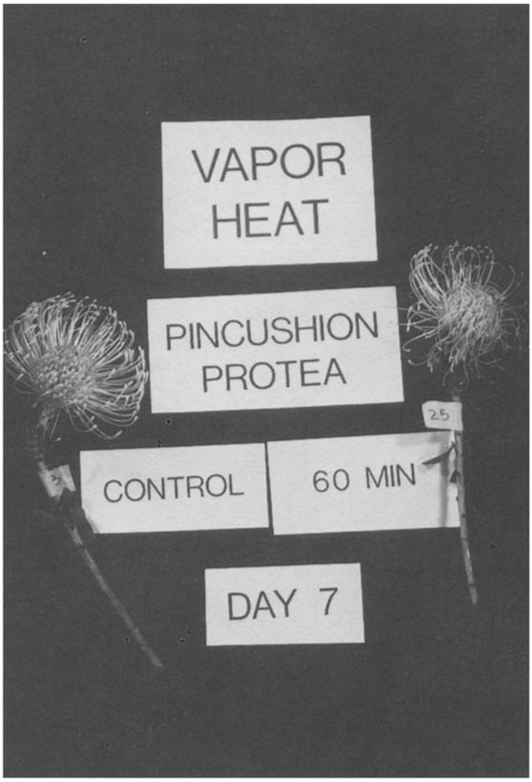

Fig. 3. Phytotoxic injury in pincushion protea, *Leucospermum* sp., from a 1 h exposure to vapour heat (46.6°C) observed a week after treatment; control on left, treated on right.

that there are no residues in the fresh commodities, no toxic materials are released into the environment, and are often used in association with commodity storage (Ke and Kader, 1992). Disadvantages are that CA are frequently done in large facilities and usually require exposures longer than several days for complete efficacy (Ke and Kader, 1992). Currently, there is no application of CA to eliminate insect pest from floral products. Because of the vase life limitations of many floricultural products, CA may be unsuitable for postharvest disinfestation. However, CA methods have been discussed for postharvest control of insect pests of fruits and vegetables (Batchelor, 1992; Ke and Kader, 1992). The use of CA for cut flowers and foliage has been confined to storage of selected floral products and research to increase vase life (Zagory and Reid, 1991).

An innovative approach is to use heat in combination with controlled atmospheres. Soderstrom et al. (1992) demonstrated almost complete larval mortality of the red flour beetle, *Tribolium castaneum* (Herbst) (Coleoptera: Tenebrionidae), at 42°C for 6 h in CO_2-enriched (>99.5%) or O_2-deficient (<1.0%) atmospheres.

Fig. 4. Comparison of *Dracaena fragans* foliage from a 30 min exposure to vapour heat (44°C) observed 40 days after treatment; control on left, treated on right.

Similar tests should be done with pests of cut flowers to determine feasibility. Heat treatments in combination with insecticides should also be examined.

Biological control agents

The use of pathogens of insects to eliminate pests from floral commodities has been limited, perhaps due to the time involved to obtain mortality. *Bacillus thuringiensis*, its derivative thuringiesin, and spores of the fungus *Verticillium lecanii* are registered for ornamentals in the United States (Thompson, 1989). Field control of the black vine weevil, *Otiorhynchus sulcatus* (F.) (Coleoptera: Curculionidae), a pest of ornamental plants, has been studied on the use of steinernematid nematodes (Hanula, 1993; Mráček et al., 1993) and a fungal pathogen (Easterbrook et al., 1992). Additional investigations are required to determine the suitability in applying biological agents, including entomopathogenic nematodes, in postharvest treatments.

3. Conclusions

In many cases, current methods show promise for effective disinfestation of insect pests in floral products intended for export. Vapour heat and hot water immersion are potential postharvest treatments for controlling insects in tropical cut flowers and foliage. An hour of vapour heat at 46.5°C eliminates practically all insect pests, yet is safe for large heliconia, bird-of-paradise leaves, and other foliage. Insecticidal dips, particularly in conjunction with field control, should destroy residual infestations. Hand removal, now required by United States federal regulations for material not fumigated, should be retained to maintain product quality. However, inspectors must be educated to recognize dead pest insects, particularly scales, so that shipments are not delayed unnecessarily.

No single approach will solve all insect disinfestation problems. Each pest situation is unique and must be evaluated separately. Floral commodities vary in their ability to withstand different treatments. Yet, efficiency may be improved by combining treatments.

Another strategy, the systems approach, is fashioned by linking the knowledge of pest biology, field control, cultural practices, and postharvest treatments. The systems approach, by using a sequence of methods to reduce the numbers of potential pests, is based on measurable information rather than on a specific level of theoretical efficiency. Quarantine security was set at 99.9968% mortality (or probit-9) by Baker (1939) who was proposing efficacious durations of temperature treatments of commodities heavily infested with fruit flies; neither validation data nor tests for suitability at the probit-9 level were given in the original paper. However, other quarantine researchers (Landolt et al., 1984; Baker et al., 1990; Vail et al., 1993) have criticized Baker's probit-9 standard because Baker's methods ignored the impact of field control or of pests with reduced rates of infestations. Furthermore, it is often impossible to determine the probit-9 level of precision with disinfestation of floricultural products because of low pest infestation or small amounts of the treated commodity.

Thus, because of the inherent problems with applying probit-9 security to cut flowers and foliage, the systems approach has the best opportunity of guaranteeing pest-free products. For example, Hata et al. (1992) demonstrated in Hawaii that field control of eight pest species and an insecticidal postharvest dip assured pest-free ginger flowers for export. Similar system approaches need to be developed for other floral commodities. Advances in pest control of tropical cut flowers and foliage with the continued development of postharvest treatments will secure an expanded market for these products.

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End note

Mention of a commercial or proprietary product does not constitute an endorsement by the U.S. Department of Agriculture or the University of Hawaii at Manoa.

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