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Preventing Alien Species Invasion by Pre-shipment Disinfestation Treatments

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Abstract—Globalization of growing and marketing agricultural crops has increased the invasion of alien species in many parts of the world. A prime example is the spread of the agromyzid leafminer *Liriomyza trifolii*, originally a major pest of chrysanthemums in Florida. Furthermore, the leafminer was difficult to control because the original population in Florida had already developed resistance to many insecticides. To prevent the spread of alien species, governments must have strict quarantine regulations and consistently reject incoming shipments that are contaminated. Pre-shipment disinfestation treatments are a critical component in the battle to prevent the spread of alien pest species, especially to uninfested areas, throughout global agricultural markets. Promising alternatives to methyl bromide fumigation, such as controlled atmosphere, heat treatment, irradiation, and combinations of treatments, can effectively disinfest perishable commodities, especially tropical cut flowers and foliage and potted plants. Collaboration between academic, government and industry efforts will provide the most effective means of pest detection and exclusion.

Introduction

Since 1975, invasive alien pest species have been documented to globally cause serious, economical, marketing, and political problems. For example, the agromyzid leafminer, *Liriomyza trifolii* (Burgess), originally a major pest of chrysanthemums in Florida, spread throughout the world to Israel, England, France, Netherlands, South Africa, Japan and Taiwan to gain the status of an international ornamental and vegetable pest. The source of the worldwide spread was infested chrysanthemum cuttings that were inadvertently introduced from Florida to a major propagating nursery in Kenya (Minkenberg 1988). Parrella & Kiel (1984) determined that the major reasons for the rapid spread of *L. trifolii* included: (1) misidentification of the *Liriomyza* species, (2) failure of quarantine procedures, (3) lack of basic biological studies, and (4) development of insecticide resistance in its native home (Florida).

The Worldwide Spread of *Thrips palmi:* A Case Study

Another invasive alien species, the melon thrips, *Thrips palmi* Karny, was first described as a new species from Sumatra by Karny in 1952 on tobacco and considered an insect without economic importance for more than 50 years (Castineira et al. 1997). The emergence of *T. palmi* as a destructive pest was first observed in 1977 in the Philippines destroying watermelon and cotton, and in 1978 in Thailand destroying cotton (Hirose 1991). Simultaneously, *T. palmi* invaded Japan in 1978 and New Caledonia in 1979. In Hawai'i, *T. palmi* was first observed in 1982 and devastated numerous vegetable crops. Nakahara et al. (1984) reported that *T. palmi* was commonly intercepted on cut orchid flowers from the Orient (Thailand). Subsequently, *T. palmi* spread to several other Indian and Pacific Ocean islands, the Caribbean (1985), into India, Northern Africa and more recently to Australia (1991) and the mainland USA (Florida, 1991) (Layland et al. 1994). In May 1997, Cuba formally accused the United States government of a "biological attack" in which *Thrips palmi* insects were allegedly dropped from a crop-dusting plane in October 1996 and resulted in serious outbreak of infestations on corn, beans, pumpkins, cucumbers and other crops. (Workers World News Service 1997). However, Dr. Rick Roush of Waite Institute, Australia, in response to the biological warfare allegation, stated that *T. palmi* is a very common pest that is getting spread around the world (along with at least two species of whiteflies and another species of thrips) in the international flower, fruit and vegetable trade; dropping it from an airplane would be a very inefficient way of introduction.

Most recently, a number of European Union members, including Italy, France, Germany and Spain, banned the import of Thailand orchids after it was discovered that they were infested with *T. palmi* (Anon. 1997). Mound (1998) stated that very large numbers of *T. palmi* have been imported regularly into Europe for several years on dendrobium cut flowers, particularly the white varieties. These orchid flowers are marketed through the Dutch auction houses, where conditions allow movement of *T. palmi* to other host plants. A member of THRIPSNET (Anon. 1998) reported that *T. palmi* were collected from purchased plants and from flower carts at a Dutch auction house; world-renowned experts confirmed identification. Layland et al. (1994) reported that the presence of *T. palmi* in Japan at latitudes of up to 34º N suggest that it has the potential to colonize not only tropical but also temperate regions.

Internationally, agricultural producers and natural resource managers should not be burdened with more invasive alien pests, such as *T. palmi* and *L. trifolii*, destroying their crops and the native fauna and flora.

Need for Pre-Shipment Disinfestation Treatments

To prevent the spread of alien species, governments must have strict quarantine regulations and reject incoming shipments that are contaminated with alien pest species. Another very important aspect of alien species prevention is the use of pre-shipment treatments. Pre-shipment treatments implemented at the origin or post entry can be very effective in preventing the establishment of alien species in an uninfested area. In the past, chemical fumigants, such as methyl bromide, played an important role as an effective biocide against alien species. However, methyl bromide is considered an ozone depleter and will eventually be banned for quarantine and pre-shipment uses (EPA 2001). Alternatives to methyl bromide for perishable commodities include cold, heat, irradiation, controlled atmosphere, other pesticides or fumigants and systems approach. This presentation will discuss controlled atmosphere, heat, irradiation, and systems approach as effective disinfestation treatments for perishable commodities, with special focus on tropical cut flowers and potted plants.

Controlled Atmosphere

Controlled atmosphere (CA) is the removal or addition of gases resulting in an atmospheric composition around the commodity that is different from that of air (78% nitrogen, 21% oxygen and 0.03% carbon dioxide) (Kader 1992). Controlled atmospheres of inert gases (usually nitrogen), low oxygen (1% or less), high carbon dioxide (5 to >80%) or a combination of these is required. for insect control (Cantwell & Mitcham 1995). High carbon dioxide concentrations (10 to 30%) have been found effective in killing adult thrips, *Thrips obscuratus* (Crawford), and aphids, *Myzus persicae* (Sulzer), within 7 to 14 days at low temperatures and very high carbon dioxide levels (60%) killed aphids and thrips within 5 days at 0–1º C (32–33º F). At higher temperature of 35º C (95º F), complete mortality of the western flower thrips, *Frankliniella occidentalis* (Pergande), occurred at 48 hr in 1.5% oxygen with less damage to orchids than at 12 hr in 55% carbon dioxide (Simpson et al., U.C. Davis, unpublished data). Controlled atmosphere appears to be a promising postharvest disinfestation treatment for fruits, flowers and vegetables because most commodities will tolerant short exposures (4 to 24 hr) to high concentrations of carbon dioxide and high temperatures (Cantwell & Mitcham 1995). *Vanda* orchids in 2% carbon dioxide for 2 to 3 days reduced fading of flowers (Akamine & Goo 1981), however, *Dendrobium* orchids appear to be sensitive to high carbon dioxide (>30%) with significant reduction in vase life (Mitcham & Hara, unpublished data).

Heat Treatments

The use of vapor heat and hot water is well documented for treatment of fruit flies on various fruits (Sinclair & Lindgren 1955; Seo et al. 1974; Armstrong 1982; Sharp & Spaulding 1984; Sharp 1986; Couey & Hayes 1986; Hayes et al. 1987; Sharp et al. 1988; Chan & Linse 1989; Heard et al. 1991; Nascimento et al. 1992), but not as well studied on floriculture crops. One of the early uses of heat for control of insect pests on floriculture crops was vapor heat for the control of bulb flies, *Eumerus* sp., on narcissus bulbs at 43.3º C (110º F) for three hours (Spruijt & Blanton 1933) and control of the gladiolus thrips, *Thrips simplex* (Morison) (=*Taeniothrips gladioli*), on gladiolus corms at 43.3º C for 20 to 30 minutes (Doucette 1933). Hansen et al. (1992) investigated vapor heat treatments to disinfest tropical cut flowers and foliage using a commercial facility designed for disinfesting papayas of fruit flies. At 46.6º C (116º F), 90 to 98% relative humidity for one hour, 90 to 100% of nymphs and adults of banana aphid *Pentalonia nigronervosa* Coquerel, green scale *Coccus viridis* (Green), Cockerell scale *Pseudaulacaspis cockerelli* (Cooley), cardamom thrips *Sciothrips cardamomi* (Ramakrishna), and mealybugs, *Nipaecoccus nipae* (Newstead), *Planococcus citri* (Risso), *Pseudococcus affinis* (Maskell) and *P. longispinus* (Targioni-Tozzetti), were killed. Most *Heliconia* spp., red ginger *Alpinia purpurata*, bird of paradise *Strelitzia reginae* flowers and leaves, and most tropical foliage are not damaged; anthurium, pincushion protea *Leucospermum oleifolium*, and *Dendrobium* orchid flowers are very sensitive to vapor heat. Hansen et al. (1992) concluded that vapor heat is a promising postharvest treatment to disinfest tropical cut flowers and foliage, with research needed on decreasing heat stress in temperature-sensitive floral commodities.

U.S. Dept. of Agriculture, Animal and Plant Health Inspection Service (APHIS) (1994) recommends hot water at 44º C (111.2º F) for 20 min for plant material not tolerant to fumigation but warns that this treatment may not be effective against all insects and some plants may not be tolerant. Most insects on or in flowers, foliage and roots, including ants, foliar and root aphids, armored scales, soft scales, foliar and root mealybugs and whiteflies are killed at 49º C (120º F) from 5 to 12 minutes (Hara et al. 1993, 1994a, 1996). The root mealybug *Rhizoecus hibisci* Kawai & Tagaki in potted *Rhapis* palms is eradicated when the internal root ball temperature reaches 46º C, with no significant phytotoxic injury to the potted *Rhapis* (Hu et al. 1996). In addition, hot water treatment at 49 to 50º C for 10 min. is highly effective against burrowing, citrus, lesion and root knot nematodes (Kaplan 1982). Hot water dip is more effective against many cryptic insect and mite pests because heat penetrates plant tissue while insecticidal dips are only contact in action.

Hot water treatment stimulates rooting and shooting of propagative materials including plumeria, anthurium, gardenia *Gardenia jasminoides*, and *Dracaena* spp. When propagative cuttings are treated at 49º C for 10 min. followed by a basal application of 0.8% IBA (indole-3-butyric acid) rooting and/or shooting of cuttings are significantly enhanced (Hata et al. 1994). Unrooted chrysanthemum cuttings survive 49º C for up to 6 min., but root mass is lowered after a 1 to 2 min. dip (Hara et al 1994b). Most (95 to 99%) foliar aphids, thrips, spider mites, and *Liromyza* leafminers infesting chrysanthemum cuttings should be killed after 2 min. in 49º C. Hot air at 44.4º C (112º F), 60% r.h. for ≥ 1 hour, reduced western flower thrips *F. occidentalis*, >94% in chrysanthemum flowers (Hara et al. 1997a).

Hot water will increase, decrease or have no effect on the vase life of flowers and foliage. Hot water treatment has been observed to improve the postharvest quality of certain cut flowers and foliage (e.g., *Heliconia* spp., *ti Cordyline fructicosa*) by protecting against physiological disorders, enhancing natural resistance to pathogen infection and/or reversibly inhibiting maturity (Klein & Lurie 1992; Tsang et al. 1995; Hara et al. 1996; Hara unpublished data). The limiting factor for disinfesting cut flowers and foliage with hot water is phytotoxicity to certain plant species including anthurium, *Dendrobium* orchid, and protea. Certain cut flowers, such as red ginger, are more susceptible to heat injury during the cold, rainy season. Conditioning flowers in hot air at 39 to 40º C (102º F) for 2 h or in hot water at 40º C for 15 min before hot water treatment (49–50º C for 10–12 min.) eliminates acute phytotoxicity in red ginger during the cold, rainy season and in certain cut foliages (Hara et al. 1999; Hara et al. 1996, 1997b, Chantrachit & Paull 1998). Probably, heat shock proteins in flowers and foliage are produced by conditioning in hot air; these induce heat tolerance (Chan & Lindse 1989). 'Preconditioning' commodities to withstand otherwise injurious heat disinfestation treatments can also induce heat tolerance in insects (Yocum & Denlinger 1992; Jang 1992; Hara et al. 1997b). Therefore, a method to increase plant tolerance to hot water without conditioning or the use of hot air, which is less phytotoxic than hot water, to control insects would provide a more effective heat disinfestation treatment. One method to increase vase life without conditioning is the use of a plant hormone, benzyladenine (BA) (BAP-10, Caudill Seed Co., Louisville, Kentucky, USA). A 5-min. dip in 200 ppm solution of BA after hot water treatment increased the vase life of red ginger flowers and *ti* leaves 1.6 to 2.0 times compared with treatments that did not include BA (Hara et al. 1999).

Because hot water research showed much promise as an effective disinfestation treatment, a collaborative, team effort of research, extension and industry personnel was formed to develop a commercial-size hot water dip system (300 gallons) that met the affordability and practicality demands of the growers (Tsang et al. 1995; Hara et al. 1999). An investment of about $5000 by the grower resulted in an environmentally sound and cost-effective alternative to toxic pesticides. The adoption of hot water treatment systems by three commercial floriculture exporters in Hawai'i provides effective quarantine treatment for insect pest and reduces quarantine rejection rates from 50–100%. As a result, the hot water treatment system has been recognized and approved as a quarantine treatment by the USDA, APHIS, California Dept. of Food and Agriculture and the Hawai'i Dept. of Agriculture. It is incorporated in the California-Hawai'i Origin Inspection Program that allows cut flowers and foliage to enter California without quarantine inspection. Growers who adopted the system report increased benefits with lower labor cost and increased environmental protection. With the implementation of the hot water treatment, disposal of pesticide solutions have been reduced by 175 gallons per week.

Irradiation

Ionizing radiation is a promising insect disinfestation treatment that is approved by the USDA, APHIS as a quarantine treatment against fruit flies attacking tropical fruits (APHIS 1998). Administering a minimum absorbed ionizing radiation dose of 250 Grays (Gy) (25 krad) allows interstate movement of abiu *Pouteria caimito,* atemoya *Annona cherimoya x A. squamosa,* carambola *Averrhoa carambola*, litchii *Litchi chinensis*, longan *Dimocarpus longan*, papaya *Carica papaya*, rambutan *Nephelium lappaceum* and sapodilla *Manilkara zapota* from Hawai'i to U. S. mainland. To eliminate the pest risk associated with arthropod pests other than tephritid fruit flies, fruit destined to California may be treated with a minimum absorbed dose of 400 Gy based on documented efficacy studies (California Department of Food and Agriculture, personal communication). The beet armyworm *Spodoptera exigua* (Hubner), the green peach aphid *M. persicae*, and a thrips, *F. pallida* Uzel, require dosages of 100 to 200 Gy to arrest development or reproduction (Wit & van de Vrie 1985). The comstock mealybug, *P. comstocki* (Kuwana), were affected with sterility at a minimum dose of 400 Gy (Dohino & Masaki 1995). Higher doses are necessary for acute mortality. For example, 400 Gy sterilizes the melon thrips, *T. palmi,* but 1500 Gy is needed to kill *T. palmi,* inside *Dendrobium* orchid flowers (Dohino et al. 1996; Piriyathamrong et al. 1985). Yalemar et al. (2001) demonstrated that 250 Gy caused non-emergence of eggs and pupae, failure of larval development and sterility of adults of the yellow flower thrips, *F. schultzei* (Trybom). Certain tropical flowers may be irradiated with no effects on vase life or quality, including red ginger flowers and green *ti* leaves (Chen & Paull 2000).

Systems Approach

A systems approach of preharvest crop pest management, postharvest culling, and final product inspection is successful against several quarantine pests on various fruit crops (Moffitt 1989; Jang & Moffitt 1994). This approach to quarantine security unifies pest management practices and treatments both before and after harvest into a unified system. Treatments or management procedures that are not effective alone can therefore meet quarantine security. Wood & Wood (1991) emphasized the necessity to combine an effective fumigation procedure with a regular and effective spray program in protea plantations, since any signs of scales or borers, dead or alive, does not pass Japanese quarantine inspectors. Coetzee & Wright (1992) emphasized that no postharvest fumigation treatment tested on protea flowers gives 100% mortality; however if used in conjunction with preharvest spraying, less insects will be present, and acceptable results can be achieved. Hata et al. (1992) demonstrated the systems approach using a tropical floriculture crop, red ginger. The systems approach to quarantine security is based on the fact that control measures before harvest, for example, applying chemical insecticides can reduce pests to a level at which an insecticidal dip after harvest is 100% effective. This management strategy requires that pests be identified, population levels assessed, and the determination made if the levels are above quarantine thresholds. If a pest population is at or above quarantine thresholds, the pest population should be made the target of a specific, effective control measure, for example, application of an effective chemical insecticide. Thereafter, the harvested flowers should be treated with an effective postharvest treatment followed by a final visual inspection to ensure quarantine security.

Global marketing and trading is the future economy for most developing and developed countries. With global economy comes increase in the volume and speed of air and ocean transport, which dramatically heightens the risk of introducing alien invasive species into an uninfested country, state or county. Within the past 20 years, no country that regularly imports goods and services has escaped a constant invasion of alien pests. For example, during the 1980's and 1990's Hawai‘i suffered from the invasion of an average of 15 to 20 alien species become established in Hawai‘i. In order to slow down and prevent the invasion of pests, academic, government, and industry must collaborate to develop the most effective pest exclusion and pest detection methods and programs. Other than thorough inspection and certification, the implementation of both field pest management and postharvest treatments in a systems approach must be developed to prevent the spread of invasive alien species.

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