Efficacy of Hydrogen Cyanide Fumigation as a Treatment for Pests of Hawaiian Cut Flowers and Foliage After Harvest

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ABSTRACT Efficacy of 30 min fumigations at 2,500, 3,700, and 4,600 ppm of hydrogen cyanide (HCN) was tested in the laboratory as a treatment against representative Hawaiian quarantine pests. Effective results were obtained for nymphs and adults of the banana aphid, *Pentalonia nigronervosa* Coquerel, in red ginger flowers; an armored scale, *Pseudaulacaspis cockerelli* (Cooley), on oleander leaves; the green scale, *Coccus viridis* (Green), on ixora leaves; and nymphs of the coconut mealybug, *Nipaecoccus nipae* (Maskell), on palm. Other species of mealybugs and ants also were susceptible to the treatment, particularly at the highest concentration. Most nymphs and adults of a thrips, *Sciothrips cardamomi* (Ramakrishna), in red ginger flowers survived all concentrations of fumigation. All adults of an orchid weevil, *Orchidophilus aterrimus* (Waterhouse), survived the treatment. The suitability of HCN fumigation is discussed.

KEY WORDS Insecta, fumigation, cut flowers, pests

BECAUSE OF ITS isolation and tropical climate, Hawaii has insect pests not found elsewhere in the United States. Federal agencies and agricultural states such as California have compiled lists of quarantine insects, some of which occur in Hawaii (CDFA 1983, APHIS 1985). Failure by Hawaiian floral shippers to comply with quarantine regulations can result in severe fines and loss of shipping privileges to the mainland United States. Japan has similar quarantine restrictions. Thus, Hawaiian cut flowers and foliage are routinely inspected for insects before and after shipment, compelling the Hawaiian floral industry to export pest-free commodities.

Growers of Hawaiian cut flowers and foliage can reduce insect populations in the field (Hara et al. 1987). However, elimination of all insects on flowers and foliage is very difficult to achieve. Also, growers often are unprepared to treat for sporadic infestations of minor pests or newly introduced insects. Finally, some types of foliage have not yet been propagated and are collected in the wild where no pest control is possible.

Potential postharvest treatments for unwanted insects on Hawaiian flowers and foliage include irradiation and fumigation with methyl bromide and hydrogen cyanide (HCN). Commercial irradiation facilities are unavailable in Hawaii, and not all flowers are tolerant of low radiation levels (e.g., 5 krad) (Wit & van de Vrie 1985a). The federally approved methyl bromide treatment (APHIS 1978), which requires at least 2 h of fumigation, causes damage or reduces shelf life of certain floral products (Wit & van de Vrie 1985b, Seaton & Joyce 1988, 1989).

HCN is a highly toxic fumigant that has been used to control insects in dormant nursery stock, ornamentals, and glasshouse plants (Monro 1969). In Japan, during the warm growing season, imported living plants and fresh fruits are fumigated with 2,500 ppm HCN for 30 min; the rate is doubled during the colder winter months (Japanese Fumigation Engineering Society 1981). In the United States, HCN has been a quarantine fumigant for insects such as thrips, scales, and the Fuller rose beetle, *Pantomorus cervinus* (Boheman) (Houck et al. 1989) on the surface of citrus. Approved HCN treatments (AHIS 1986) are for bollworms in cotton; khapra beetle, *Trogoderma granarium* Everts, in grain; insects in tobacco; and insects in broom corn. Mortality from HCN fumigation has been studied in medically important insects (Busvine 1943, Richardson 1943), granary insects (Shepard et al. 1937), and scales (Camp & Wilmot 1932, Lindgren 1938, Lindgren & Sinclair 1944, Geier et al. 1949).

Because HCN has been effective against different types of insects, we explored its possible use as a postharvest treatment for Hawaiian cut flowers and foliage. In a previous study (Hansen et al. 1991), we determined the phytotoxicity of HCN fumigation on Hawaiian cut flowers and foliage. In the study described here, we determined the efficacy of HCN against major quarantine pests

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Table 1. Insects fumigated with HCN for 30 min

Family	Species	Common name	Life stage
Aphididae	*Pentalonia nigronervosa* Coquerel	Banana aphid	Nymphs, adults
Diaspididae	*Pseudaulacaspis cockerelli* (Cooley)	—	Nymphs, adults
Coccidae	*Coccus viridis* (Green)	Green scale	Nymphs, adults
Pseudococcidae	*Nipaecoccus nipae* (Maskell)	Coconut mealybug	Nymphs, adults
Pseudococcidae	*Planococcus citri* (Risso)	Citrus mealybug	Nymphs, adults
Pseudococcidae	*Pseudococcus affinis* (Maskell)	Obscure mealybug	Nymphs, adults
Pseudococcidae	*Pseudococcus longispinus* (Targioni-Tozzetti)	Longtailed mealybug	Nymphs, adults
Thripidae	*Sciothrips cardamomi* (Ramakrishna)	—	Adults
Curculionidae	*Orchidophilus aterrimus* (Waterhouse)	—	Adults
Formicidae	*Monomorium floricola* (Jerdon)	—	Adults
Formicidae	*Paratrechina vaga* (Forel)	—	Adults
Formicidae	*Plagiolepis alluaudi* Emery	Little yellow ant	Adults

Materials and Methods

Fumigation Chamber. All fumigations were conducted in 28.3-liter fiberglass chambers (Labconco, Kansas City, Mo.) under a ventilated hood in the laboratory. The door for each unit had an airtight seal; each chamber was tested for leaks by using a smoke-screen generator or a soapy leak-detection solution. An electric fan for mixing, a beaker holder, and a latex septum for injection were placed inside each chamber. Valved input and exhaust ports connected the units to each other and to a pressurized air source.

For fumigation, a measured amount of solid NaCN for a particular rate (e.g., 0.153 g of NaCN for 2,500 ppm of HCN) was placed in a beaker, then placed on the holder within the chamber. The chamber door was sealed, valves were closed, and an excess amount of concentrated sulfuric acid (e.g., 0.5 ml of H_2SO_4 for 0.153 g of NaCN) was injected through the septum into the beaker to release HCN gas. The fan was on during the fumigation. HCN was not absorbed by the chamber because it was constructed of inert resin material.

To end fumigation, valves were opened so that pressurized air flowed through the chambers. The air left through a latex tube submerged in water outside the laboratory. After 15 min, chamber doors were opened and allowed to ventilate for at least 15 min, after which the fumigated material was removed.

Efficacy Tests. To determine efficacy of HCN at different concentrations (2,500 ppm, 3,700 ppm, 4,600 ppm of HCN), insects representative of the species on the CDFA's (1983) rejection list were collected from natural infestations in the field (Table 1). More homopterans were tested in the efficacy tests because they have caused many rejections of Hawaiian floral products. For each test, control insects were placed in a fumigation chamber for the treatment duration, but were not exposed to HCN. Most of the insects were on the exposed surfaces of foliage and flowers. Aphids and some of the mealybugs were treated as they occurred within the bracts of flowering red ginger, *Alpinia purpurata* (Vieill.) K.; other mealybugs were treated exposed on bracts in a Petri dish. Mortality of nymphs and adult females of these insects was observed and recorded no sooner than 1 d after treatment. Because of difficulty in recognizing immediate death, soft and armored scales were observed at least 4 d after treatment.

Data Analyses. Each species was tested three times; the numbers of live and dead nymphs and adults were counted for each treatment (including controls). Mortality data were pooled among the replicates because the populations were highly variable among the flowers. Data were managed, summarized, and analyzed with SAS (Statistical Analysis System; SAS Institute, Inc.; Cary, N.C.) for the personal computer. Averages were calculated with procedure MEANS (SAS Institute 1982).

Results

Efficacy of the fumigation treatments are shown in Table 2. Among the control insects, death was from natural field mortality, parasitism, disease, and postharvest handling. Among the fumigation treatments (2,500, 3,700, and 4,600 ppm of HCN), no concentration–response was observed. Mortality was either nearly complete or did not occur. HCN fumigation was highly effective at all concentrations against banana aphids, *Pentalonia nigronervosa* Coquerel, in red ginger flowers; armored scales, *Pseudaulacaspis cockerelli* (Cooley), on oleander leaves; and green scales, *Coccus viridus* (Green), on ixora leaves. Mealybug nymphs were fairly susceptible, and all adults were destroyed at the highest concentration. The treatment was effective for most ants; however, all weevils, *Orchidophilus aterrimus* (Waterhouse), (a pest of orchids), but most thrips, *Sciothrips cardamomi* (Ramakrishna), (a pest of red ginger) survived regardless of concentration.

Discussion

HCN fumigation demonstrated its potential as a postharvest treatment to eliminate insects from cut flowers and foliage before shipment. In our study, 30-min fumigations at 2,500 ppm of HCN were highly effective against magnolia white scales. This treatment was also very effective against aphids

Table 2. Percentage mortality ($\bar{x}$ ± SEM) of insects fumigated at different rates of HCN for 30 min

Insect	Life stage	Rate, ppm	Replicates, n	Total insects	% Mortality, $\bar{x}$ ± SEM
Banana aphids	Nymphs	0	4	749	16.5 ± 5.7
	Nymphs	2,500	4	1,993	100.0 ± 0.0
	Nymphs	3,700	4	1,862	100.0 ± 0.0
	Nymphs	4,600	4	1,384	100.0 ± 0.0
	Adults	0	4	188	24.5 ± 6.7
	Adults	2,500	5	516	100.0 ± 0.0
	Adults	3,700	4	418	100.0 ± 0.0
	Adults	4,600	4	247	100.0 ± 0.0
Mealybugs (various spp.) in ginger	Nymphs	0	4	275	17.0 ± 13.5
	Nymphs	2,500	4	154	94.7 ± 3.2
	Nymphs	3,700	4	126	100.0 ± 0.0
	Nymphs	4,600	4	293	98.4 ± 1.1
	Adults	0	4	94	20.8 ± 7.4
	Adults	2,500	4	43	78.3 ± 13.3
	Adults	3,700	4	39	91.7 ± 8.3
	Adults	4,600	4	46	98.3 ± 1.7
Mealybugs (various spp.) exposed	Nymphs	0	2	38	10.7 ± 10.7
	Nymphs	2,500	2	36	100.0 ± 0.0
	Nymphs	3,700	2	19	100.0 ± 0.0
	Nymphs	4,600	2	35	78.6 ± 12.0
	Adults	0	3	35	16.2 ± 5.0
	Adults	2,500	3	31	53.6 ± 12.1
	Adults	3,700	3	38	94.4 ± 5.6
	Adults	4,600	3	28	100.0 ± 0.0
Coconut mealybugs on palm	Nymphs	0	4	399	13.9 ± 5.5
	Nymphs	2,500	4	541	96.9 ± 1.5
	Nymphs	3,700	4	580	99.0 ± 0.8
	Nymphs	4,600	4	933	99.6 ± 0.4
	Adults	0	4	461	18.0 ± 3.4
	Adults	2,500	4	498	77.7 ± 9.2
	Adults	3,700	4	554	84.6 ± 9.3
	Adults	4,600	4	656	100.0 ± 0.0
Armored scales on palm	Nymphs	0	3	121	50.4 ± 13.5
	Nymphs	2,500	3	48	98.8 ± 1.2
	Nymphs	3,700	3	36	100.0 ± 0.0
	Nymphs	4,600	3	52	100.0 ± 0.0
	Adults	0	3	594	58.4 ± 14.1
	Adults	2,500	3	703	99.9 ± 0.1
	Adults	3,700	3	615	99.4 ± 0.6
	Adults	4,600	3	553	100.0 ± 0.0
Green scales on ixora leaves	Nymphs	0	3	1,107	29.1 ± 19.8
	Nymphs	2,500	3	1,457	99.7 ± 0.2
	Nymphs	3,700	3	1,138	99.6 ± 0.4
	Nymphs	4,600	3	1,005	100.0 ± 0.0
	Adults	0	3	828	38.7 ± 25.3
	Adults	2,500	3	690	100.0 ± 0.0
	Adults	3,700	3	954	100.0 ± 0.0
	Adults	4,600	3	728	100.0 ± 0.0
Thrips in ginger flowers	Nymphs	0	3	51	6.7 ± 4.5
	Nymphs	2,500	3	54	19.3 ± 19.3
	Nymphs	3,700	3	35	12.7 ± 0.2
	Nymphs	4,600	3	70	26.9 ± 12.3
	Adults	0	3	30	8.3 ± 6.0
	Adults	2,500	2	24	0.0 ± 0.0
	Adults	3,700	3	24	43.1 ± 13.7
	Adults	4,600	3	17	57.1 ± 29.3
Weevils from orchids	Adults	0	3	30	0.0 ± 0.0
	Adults	2,500	3	29	0.0 ± 0.0
	Adults	3,700	3	30	0.0 ± 0.0
	Adults	4,600	3	29	0.0 ± 0.0
Ants (various spp.)	Adults	0	4	116	23.4 ± 11.7
	Adults	2,500	4	246	80.9 ± 2.6
	Adults	3,700	4	339	91.1 ± 8.5
	Adults	4,600	4	417	93.8 ± 6.2

and green scales, and, at higher concentrations, mealybugs. These insects have been responsible for most of the rejections of Hawaiian floral shipments to California (Gardner 1991). In earlier tests, Lindgren (1938) reported 84–91% mortality for the California red scale, *Aonidiella auranti* (Maskell) from 40-min fumigations at 500 ppm of HCN. Geier et al. (1949) killed nearly all female adults of the San Jose scale, *Quadraspidiotus perniciosus* (Comstock), with 2,500 ppm of HCN for 30 min. Camp & Wilmot (1932) destroyed green scales using 400–500 ppm of HCN for 1 h.

However, thrips were not severely affected, and orchid weevils survived HCN fumigations at all concentrations. Tolerance to HCN fumigation has been observed in other weevils. For example, the granary weevil, *Sitophilus granarius* L., required 5 h at 9,200 ppm of HCN for 99% of the test population to be killed (Shepard et al. 1937).

Previous studies on phytotoxicity of HCN fumigation have shown that many Hawaiian floral products withstand 30-min fumigations at 4,600 ppm of HCN with neither damage nor decrease in shelf life (Hansen et al. 1991). As a result, different types of cut flowers and foliage can be treated safely together. This method is suitable for the Hawaiian floral industry because material delivered by the growers to the shippers typically consists of a variety of tropical floral and foliage products rather than large lots of one commodity. Tests on a commercial scale are needed to verify that HCN fumigation is feasible.

HCN fumigation is suitable as part of an integrated approach to pest management. Cultural practices (e.g., field sanitation) and traditional methods (e.g., chemical applications and classical biological control) would reduce the number of insect pests on products before harvest. HCN fumigation could then be used before shipment to eliminate residual pest insects. Producing commodities free of insects would be beneficial to the grower, shipper, consumer, and agriculturalists at the location of entry.

Application of HCN fumigation is not now possible because HCN is no longer registered by the U.S. Environmental Protection Agency as an insecticide fumigant. Lack of registration is due not to safety or efficacy but to disuse. If a "Special Local Needs" label was granted, the HCN treatment could be used for Hawaiian cut flowers and foliage.

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