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Phytotoxic Reaction of Hawaiian Cut Flowers and Foliage to Hydrogen Cyanide Fumigation

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Abstract. **Phytotoxicity from hydrogen cyanide (HCN) fumigation was measured in several varieties of Hawaiian cut flowers and foliage (Zingiberaceae, Heliconia, Orchidaceae, Marantaceae, Lycopodiaceae, Agavaceae, Proteaceae) as a potential disinfestation treatment. Concentrations tested were 2500,3700, 4600, and 5500 ppm HCN for 30 min. All foliage and most heliconia were undamaged at fumigation levels of 5500 ppm HCN; most protea and 'Midori' anthuriums were uninjured at 4600 pm HCN; red and pink ginger were uninjured at 3700 ppm HCN; and all pincushion protea showed phytotoxicity to HCN. Red ginger was quickly damaged when exposed to sunlight immediately after treatment at 2500 ppm HCN. No injury was observed in simulated shipment tests of red ginger and 'Ozaki' anthuriums fumigated at 2500 ppm HCN. Wet, red ginger flowers longer than 6 cm were damaged at 2500 ppm HCN, whereas shorter flowers were uninjured. Wet 'Ozaki' anthuriums showed phytotoxicity only at 4600 ppm HCN. Wet, treated lycopodium and bamboo orchid foliage was not injured. The number of marketable days and shelf life of the treated plant material were estimated from the visual ratings.**

Because of its tropical island climate, Hawaii has insect pests not found elsewhere in the United States. Hence, California, to protect its agricultural industries, prevents the introduction of new pests by inspecting Hawaiian floral commodities on arrival. Likewise, the U.S. Dept. of Agriculture examines shipments to the U.S. mainland. Contaminated shipments are either destroyed, returned to the original shipper, or routed to other locations. Japan has similar quarantine restrictions, but allows for the fumigation of suspected infested shipments (-Japan. Fumigation Eng. Soc., 1981). Thus, contaminated shipments cause economically damaging disruptions and delays in marketing.

Hydrogen cyanide (HCN) is a potential postharvest treatment to rid Hawaiian flowers and foliage of residual insects. This fumigant, which is highly toxic to insects (APHIS, 1980), has been used for treating dormant nursery stock, ornamental, and glasshouse plants (Monro, 1969). Hydrogen cyanide fumigation is currently approved by APHIS (1986) for treatments against specific insect pests of cotton, grain, and tobacco; cut flowers and foliage are not included. Although HCN is very toxic to humans and mammals, it is readily detectable by a characteristic odor, and safety procedures for its use have been established (APHIS, 1980; Japan. Fumigation Eng. Soc., 1981; Monro, 1969). In Japan, from May to October, HCN at 2500 ppm for 30 min is used as a general fumigant treatment on living plants and fresh fruits; a higher rate is used in the colder months (Japan. Fumigation Eng. SW., 1981). Very little is known of the phytotoxic effects of HCN fumigation on commercial cut flowers and foliage.

The objective of our study was to explore the feasibility of HCN fumigation as a postharvest treatment for Hawaiian cut flowers and foliage by measuring the phytotoxic effects at various concentrations.

Fumigation. All fumigation was done in 28.3-liter fiberglass chambers (Labconco, Kansas City, Me.) under z-ventilated hood in the laboratory. The entrance for each unit was a latched, sealed window. Inside were an electric fan for mixing gases during fumigation and a beaker holder. A latex septum in the_ roof allowed airtight injection of solutions. The valved input and exhaust ports of each unit connected it to other chambers and to a pressurized air source.

To initiate fumigation, a measured amount of solid NaCN for the desired concentration (e.g., 0.153 g NaCN for 2500 ppm HCN) was placed in a beaker, then put on the holder within each chamber. The chamber door was sealed, valves closed, and an excess amount of concentrated sulfuric acid (e.g., 0.5 ml H_2SO_4 for 0.153 g NaCN) was injected through the septum into the beaker to release the gas. Concentrations, based on the molecular weights and amounts of the reactive components, were calculated for 2500, 3700, 4600, and 5500 ppm HCN.

When the fumigation was complete, the valves were opened to allow pressurized air to flow through the chambers. The gas exited through a latex tube, the end of which was

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Table 1. Description for phytotoxicity ratings of plant materials. Total damage score for an item was calculated by adding the ratings of two observers.

	Attributes of plant parts	
Rating	Flower	Foliage
o	No damage to petals or bracts.	No damage to stem and leaves.
1	Slight discoloration or very minor flaws anywhere.	Few leaves have slight damage, good appearance.
2	Some discoloration, still marketable.	More leaves with slight damage, generally good appearance, still marketable.
3	Discoloration expanding (≈ 10%); not marketable, but still suitable for vase.	Many leaves with slight damage or few leaves with major damage, still with good ap. pearance.
4	More discoloration (10%-20%); vase life questionable.	More leaves with major damage, appearance fair; vase life questionable.
5	Increased discoloration (≈ 30%); definitely not suitable for vase.	Most leaves with some damage, appearance fair to poor; not suitable for vase.
6	Some discoloration throughout (≈ 50%).	Most leaves with major damage, appearance poor.
7	Much discoloration throughout (≈ 70%).	Much of foliage damaged or dead (» 70%), appearance very poor.
8	Major discoloration throughout (≈ 90%).	Most foliage dead (≈ 90%), few undamaged areas.
9	Entire flower discolored.	Foliage dead.

Table 2. Species list of tropical cut flowers and foliage tested for phytotoxicity to hydrogen cyanide.

Commodity	Family	Species[z]
Ginger		
Red	Zingiberaceae	*Alpinia purpurata* (Vieill.) K. Schum.
Pink, Eileen McDonald	Zingiberacea	*Alpinia purpurata* (Vieill.) K. Schum.
Heliconia		
Andromeda	Heliconiaceae	*Heliconia psittacorum* L. f.
Parakeet	Heliconiaceae	*Heliconia psittacorum* L. f.
Parrot	Heliconiaceae	*Heliconia psittacorum* L. f.
Sassy	Heliconiaceae	*Heliconia psittacorum* L. f.
Lobster claw	Heliconiaceae	*Heliconia bihai* L. f.
Foliage		
Bamboo orchid (leafy stem)	Orchidaceae	*Arundina graminifolia* (D. Don) Hochr.
Calathea (leaf)	Marantaceae	*Calathea insignis* Petersen
Lycopodium (stem)	Lycopodiaceae	*Lycopodium cernuum* L.
Peacock ti (leafy stem)	Agavaceae	*Cordyline terminalis* (L.) Kunth
Protea		
Pink Mink	Proteaceae	*Protea neriifolia* R. Br.
Orange banksia	Proteaceae	*Banksia prionotes* Lindl.
Yellow-green banksia	Proteaceae	*Banksia speciosa* R. Br.
Pink frost banksia	Proteaceae	*Banksia menziesii* R. Br.
Safari Sunset	Proteaceae	*Leucadendron salignum* Berg. x *L. laureolum* (Lam.) Fourcade
Scarlet Ribbon pincushion	Proteaceae	*Leucospermum cordifolium* (Salisb. ex Knight) Fourcade x *L. glabrum* Phil.
Sunrise pincushion	Proteaceae	*Leucospermum cordifolium* (Salisb. ex Knight) Fourcade
Hybrid 36 pincushion	Proteaceae	*Leucospermum lineare* R. Br. x [*L. conocarpodendron* (L.) Buek x (*L. lineare* x *L. cordifolium*)]
Hybrid 51 pincushion	Proteaceae	[*Leucospermum lineare* R. Br. x *L. cordifolium* (Salisb. ex Knight) Fourcade] x *L. glabrum* Phil.
Anthurium		
Ozaki	Araceae	*Anthurium andraeanum* Lind.
Midori	Araceae	*Anthurium andraeanum* Lind.

[z]Species names from Liberty Hyde Bailey Hortorium (1976).

Table 3. Damage scores of specific floral commodities for controls and those treated at various concentrations of HCN at 30 min. (Differences in damage scores did not differ significantly for plants not listed.)

Commodity	HCN (ppm)	Day	Damage score Control $\bar{x} \pm$ SEM	Damage score Treated $\bar{x} \pm$ SEM	*t*	df
Lobster claw	5500	4	3.0 ± 0.4	5.3 ± 0.6	3.00*	7
Sunrise protea	2500	1	1.6 ± 0.2	2.8 ± 0.5	3.25*	7
Hybrid 51 protea	4600	4	4.3 ± 1.0	8.3 ± 1.0	2.74*	7
Scarlet ribbon	3700	7	1.8 ± 0.3	10.3 ± 0.9	9.55**	6
Hybrid 36 protea	2500	7	2.8 ± 0.6	8.8 ± 0.4	8.66**	8
Red ginger	4600	4	5.2 ± 0.2	10.0 ± 1.1	4.15**	8
Red ginger	4600	5	6.8 ± 0.7	6.0 ± 0.6	10.83**	6
Red ginger	5500	5	6.8 ± 0.6	16.0 ± 1.1	7.40**	6
Pink ginger	4600	3	4.7 ± 0.7	8.5 ± 1.0	3.21**	10
Pink ginger	5500	3	4.7 ± 0.7	8.3 ± 1.5	2.26*	10

,t* Test significant at $P = 0.01$ or 0.05, respectively.

Table 4. Damage scores for red ginger flowers and leaves for controls and those exposed to sunlight for 1 hr after being fumigated with 2500 ppm HCN for 30 min.

Plant part	Control $\bar{x} \pm$ SEM	Treated $\bar{x} \pm$ SEM	*t*	df
Flowers	6.0 ± 1.1	14.5 ± 1.2	5.29**	6
Leaves	5.3 ± 1.7	11.5 ± 0.3	3.62**	6

***t* Test significant at $P = 0.01$.

submerged in water outside the laboratory. Chamber doors were opened after 15 min and the chambers were allowed to ventilate at least 15 min more before the fumigated material was removed.

Phytotoxicity. Plant material was treated at increasing concentrations of HCN and compared to untreated controls to determine phytotoxic levels. Visual ratings have been used to estimate plant damage and quality in flowers and foliage (Chase and Poole, 1987; Nell and Barrett, 1986; Neumaier et al., 1987). In our study, plant quality was estimated by two observers using a 10-point scale to evaluate each item (Table 1). The damage score for every flower or foliage was the sum of the two ratings. Hence, 0 = no injury, 4 = limit of marketability, 8 = limit of shelf life, and 18 = complete discoloration or death. The plant material was rated before treatment and then twice weekly until the material was dead.

The evaluated plant material represented a variety of export Hawaiian cut flowers along with foliage leaves and stems (Table 2). Red ginger and 'Ozaki' anthuriums, high-volume export flowers, were used for several specific phytotoxicity tests. After treatment, the plant material was held in water under room conditions (≈ 20 to 25C; ≈ 40% to 60% RH). Among the floral products tested, ends of only ginger stems were removed (≈ 3 cm) before stems were placed in water. No preservative was added to the water.

Photosensitivity. Monro (1969) stated that HCN, by interfering with physiological processes, may cause plants to be susceptible to injury in daylight, and he recommended that plants should be kept out of the sun several hours after treatment. If floral materials are to undergo HCN fumigation in Hawaii, they may be exposed to the tropical sun during normal handling procedures. To determine if HCN predisposes flowers to photosensitivity, treated red ginger was evaluated for sun damage. After eight flowers were treated at 2500 ppm of HCN for 30 rein, half were exposed to afternoon sunlight for 1 hr while the other half remained in the laboratory. Both groups were held in water, and leaves and flowers rated for phytotoxicity at regular intervals.

Simulated shipping. In another test, the effect of simulated shipping on HCN-treated red ginger was evaluated. Three replications of five flowers were treated at 2500 ppm HCN for 30 min. These and five control flowers were bundled with masking tape. A plastic bag containing water-soaked cotton was attached to the stem-end of each bundle, then the bundles were placed in packing boxes containing shredded newspaper and plastic liners. Boxes were closed and held at room temperature. After 2 to 3 days, flowers were removed from the boxes, placed in water, maintained under normal room conditions (≈ 20 to 25C; ≈ 40% to 60% RH), and rated for phytotoxic damage at regular intervals.

'Ozaki' flowers were, also evaluated under simulated shipping conditions. Four groups of five flowers each were treated for 30 min at 0, 2500, 3700, or 4500 ppm HCN and

Table 5. Damage scores after 1 week for red ginger flowers of two lengths that were untreated and those fumigated wet with 2500 ppm HCN for 30 min.

Length (cm)	Control $\bar{x} \pm$ SEM	Treated $\bar{x} \pm$ SEM
<6	4.4 ± 0.6	5.2 ± 1.3
>6	4.8 ± 0.7	8.4 ± 1.0

then placed in boxes containing shredded newspaper. The contents were moistened, the box closed and stored at room temperature (≈ 20 to MC) for 3 days, then opened, and the flowers placed in water to be evaluated at regular intervals.

Wet floral products. Because Monro (1969) warns that. HCN may damage moist plant materials, phytotoxicity was examined in treated, wet flowers and foliage. In one test, red ginger flowers of various lengths were measured, then divided into groups either greater or less than 6 cm long. The flowers were submerged momentarily in water, placed into chambers, treated for 30 min at 2500 ppm HCN, removed, placed in water, and rated along with controls of comparable lengths for phytotoxic effects. In another test, groups of five 'Ozaki' anthuriums were moistened and treated for 30 min at 0, 2500, 3600, or 4500 ppm HCN, then placed in water and rated at regular intervals for phytotoxicity. Similar tests were done with lycopodium and bamboo orchid foliage except that the highest concentration was 5500 ppm HCN. These plants were placed in water after treatment and rated twice weekly for phytotoxicity.

Data analyses. For each observation, damage scores were compared among treatments by analysis of variance (ANOVA), and individual treatments were compared to controls by *t* tests to determine when and at what dosage significant damage occurred. Estimated number of marketable days and duration of shelf life after fumigation were determined by the amount of time for the average damage scores to reach 4 and 8, respectively.

Averages, ANOVAs, and t tests were calculated by using MEANS, GLM, and TTEST procedures, respectively, of SAS for the personal computer (Statistical Analysis System; SAS Institute, Cary, N.C.).

Phytotoxicity. Damage scores did not differ significantly between controls and those treated for all foliages, the 'Midori' anthuriums, all heliconia, except lobster claw heliconia at 5500 ppm HCN (Table 3), and all of the banksia sunset and pink mink proteas. All *Leucospermum* cultivars were sensitive to HCN. 'Sunrise' protea showed significant damage at 2500 ppm HCN the day after treatment, and Hybrid 51 at 4600 ppm HCN on the 4th day (Table 3). Significant differences between controls and treated were observed a week after treatment at 3700 ppm HCN for 'Scarlet Ribbon' and at 2500 pm HCN for Hybrid 36 (Table 3).

Damage ratings for red ginger, up to 3700 ppm HCN, did not differ significantly from their controls in seven tests. Significant differences occurred in flowers treated at 4600 and 5500 ppm HCN (Table 3).

Pink ginger was not significantly damaged at 2500 ppm HCN in three tests. In another test, pink ginger was not harmed at 3700 ppm HCN, but was damaged at 4600 and 5500 ppm HCN (Table 3).

Photosensitivity. Red ginger flowers and leaves showed significant damage 4 days after fumigation at 2500 ppm HCN (Table 4). Thus, the results of our study confirm that sunlight is destructive to freshly fumigated red ginger plants. To prevent potential phytotoxicity, treatment should be done in shaded areas, or treated materials should be kept away from sunlight for several hours (Monro, 1969).

Simulated shipment. In two simulated shipment tests, red ginger treated at 2500 ppm HCN was not significantly different from the controls. In another simulated test with 'Ozaki' anthuriums, only those treated at 4600 ppm HCN showed significant damage (Day 4: control damage score, $\bar{x} \pm$ SEM = 0.4 ± 0.2; treated damage score, $\bar{x} \pm$ SEM = 10.6 ± 0.4; t = 21.747; df = 8, $P < 0.01$); others treated at 2500 ppm and 3700 ppm were uninjured.

Wet plant material. In the phytotoxicity tests with wet red ginger, flowers longer than 6 cm were damaged at 2500 ppm HCN (Table 5), but treated flowers <6 cm long were not. Among wet 'Ozaki' anthuriums, only those treated at 4600 ppm HCN differed from the controls (Day 3: control damage score, $\bar{x} \pm$ SEM = 1.0 ± 0.4; treated damage score, $\bar{x} \pm$ SEM = 4.6 ± 0.8; t = 3.882, df = 8, $P< 0.01$). Wetting lycopodium and bamboo orchid foliage had no adverse effect. Hence, some moist plant materials can withstand HCN fumigation, even at high concentrations. The variation within ginger indicates that sensitivity may be due to plant morphology (e.g., size, degree of bloom, etc.) rather than genetics. Under commercial situations, representative samples should first be screened for phytotoxicity before large lots of the product are treated.

Duration of marketability days. For most of the treated plant materials, the estimated average number of days the products were marketable was unrelated to the concentration of the fumigant (Table 6). Even among the untreated, some of the commodities retained their freshness much longer than others. 'Midori' anthuriums, 'Sunset' protea, and 'Andromeda' heliconia were judged salable >10 days after treatment for all concentrations. The gingers, lycopodium, bamboo orchid, and 'Sunrise' pincushion had the least marketable time.

Duration of shelf life days. Shelf life tended to decline with increased HCN dosage (Table 7). Among the cut flowers, the 'Midori' anthuriums were the most long-lived. The peacock ti persisted, presumably because they established roots and grew new leaves. Some protea, although rated on their freshness, were attractive as dried flowers. Red ginger, 'Parrot' heliconia, and 'Sassy' heliconia were relatively short-lived. There was much variation among individuals, particularly the gingers and lycopodium; some flowers remained attractive long after others in the same treatment group had died.

The data for shelf life of the various plant materials can be interpreted to indicate the degree of sensitivity to HCN (Table 8). Most heliconia and foliages withstood up to 5500

Table 6. Average number of marketable days for various tropical cut flowers and foliage after 30 min of HCN fumigation at various concentrations.

	Period marketable (days)				
	Concn (ppm)[z]				
Commodity	0	2500	3700	4600	5500
Ginger					
Red	4	4	3	2	2
Pink	4	4	---	---	---
Heliconia					
Andromeda	11	11	11	11	---
Parakeet	8	8	8	9	---
Parrot	3	5	4	---	3
Sassy	5	5	5	---	5
Lobster Claw	5	5	8	---	3
Foliage					
Bamboo orchid	3	3	3	---	3
Calathea	7	4	6	---	4
Lycopodium	5	2	1	---	2
Peacock ti	6	7	12	---	12
Anthurium					
Ozaki	8	7	8	1	---
Midori	27	29	23	25	---
Protea					
Pink Mink	9	---	---	8	---
Orange banksia	8	---	---	8	---
Yellow-green banksia	7	---	---	7	---
Pink frost banksia	7	7	8	8	---
Safari Sunset	12	11	11	10	---
Sunrise pincushion	4	2	2	2	---
Scarlet Ribbon	16	---	4	4	---
Hybrid 36	12	4	4	4	---
Hybrid 51	4	---	1	1	---

[z]Dashed line indicates commodity not tested at concentration given.

Table 7. Average number of shelf life days for diverse tropical cut flowers and foliage after 30 min of HCN fumigation at various concentrations.

	Shelf life days				
	Dosage (ppm)[z]				
Commodity	0	2500	3700	4600	5500
Ginger					
Red	9	9	6	4	5
Pink	10	10	---	---	---
Heliconia					
Andromeda	15	16	15	14	---
Parakeet	11	11	11	11	---
Parrot	8	10	10	---	8
Sassy	6	7	8	---	7
Lobster claw	10	10	11	---	8
Foliage					
Bamboo orchid	12	16	14	---	12
Calathea	14	7	15	---	11
Lycopodium	9	3	7	---	9
Peacock ti[y]	I	I	I	---	I
Anthurium					
Ozaki	16	16	18	3	---
Midori	31	31	33	33	---
Protea					
Pink Mink	16	---	---	13	---
Orange banksia	18	---	---	19	---
Yellow-green banksia	12	---	---	12	---
Pink frost banksia	13	12	12	12	---
Safari Sunset	14	13	14	14	---
Sunrise pincushion	8	7	5	5	---
Scarlet Ribbon	21	---	6	6	---
Hybrid 36	16	10	8	7	---
Hybrid 51	13	---	14	4	---

[z]Dashed line indicates commodity not tested at concentration given.
[y]I = indefinite; cutting takes root in water.

Table 8. Phytotoxicity of various tropical cut flower and foliage plants after 30 min of HCN fumigation at various concentrations.

	Phytotoxicity[z,y]				
	Dosage (ppm)				
Commodity	0	2500	3700	4600	5500
Ginger					
Red	S	S	C	H	H
Pink	S	S	---	---	---
Heliconia					
Andromeda	S	S	S	S	---
Parakeet	S	S	S	S	---
Parrot	S	S	S	---	S
Sassy	S	S	S	---	S
Lobster claw	S	S	S	---	H
Foliage					
Bamboo orchid	S	S	S	---	S
Calathea	S	S	S	---	S
Lycopodium	S	S	S	---	S
Peacock ti	S	S	S	---	S
Anthurium					
Ozaki	S	S	S	H	---
Midori	S	S	S	S	---
Protea					
Pink Mink	S	---	---	S	---
Orange banksia	S	---	---	S	---
Yellow-green banksia	S	---	---	S	---
Pink frost banksia	S	S	S	S	---
Safari Sunset	S	S	S	S	---
Sunrise pincushion	S	C	H	H	---
Scarlet Ribbon	S	---	H	H	---
Hybrid 36	S	H	H	H	---
Hybrid 51	S	---	C	H	---

[z]S = safe, no significant damage compared to control; C = caution, some may have significant damage compared to control; H = harmful, significant damage compared to control.
[y]Dashed line indicates commodity not tested at concentration given.

ppm HCN; the banksia and 'Pink Mink' proteas up to 4600 ppm. Differences in sensitivity between 'Ozaki' and 'Midori' anthuriums indicate that cultivar variation should be considered in future tests.

Wit and van de Vrie (1985) argued against HCN fumigation of cut flowers, citing an example of phytotoxicity in 'Anita' carnations. Our study showed that some Hawaiian floral products, particularly pincushion (*Leucospermum* spp.) protea, are not suitable for HCN fumigation. However, the majority of the plant materials we evaluated clearly withstood HCN fumigation at the rate required by Japanese quarantine regulations (2500 ppm HCN).

In a commercial operation, the product should be fumigated before packaging. In our simulated shipping tests, no additional phytotoxicity was observed when nonwetted flowers were fumigated. Floral commodities packed with damp materials, such as shredded paper, should not be fumigated. Hydrogen cyanide is readily absorbed by water, and the prolonged contact during shipping may damage the product.

Our study indicates that HCN fumigation at 2500 ppm is appropriate as a potential treatment for certain Hawaiian cut flowers and foliage for export. More work is necessary to measure efficacy on major quarantine insect pests, to develop large-scale methodology suitable for production lines, and to refine procedures to maximize human safety as well as to minimize environmental risks.

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