Vapor Heat: A Potential Treatment to Disinfest Tropical Cut Flowers and Foliage

James D. Hansen¹ Arnold H. Hara, and Victoria L. Tenbrink

Hawaii Institute of Tropical Agriculture and Human Resources,
University of Hawaii at Manoa, 461 West Lanikaula Street, Hilo,
HI 96720

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Abstract. Vapor heat treatments to disinfest tropical cut flowers and foliage were evaluated using a commercial facility. Efficacy was determined for specific durations against representative Hawaiian quarantine pests on their plant hosts. Nymphs and adults of aphids, soft and armored scales, mealybugs, and thrips were killed after 1 hour at 46.6°C, and both life stages of aphids and armored scales along with mealybug nymphs after 2 hours at 45.2°C. Injury to several varieties of Hawaiian floral commodities (Araceae, Musaceae, Zingiberaceae, Heliconiaceae, Orchidaceae, Marantaceae, Lycopodiaceae, Agavaceae, Proteaceae) during these treatments was determined. Large heliconias, most red ginger, bird-of-paradise flowers and leaves, and most foliage were not damaged; anthuriums, pincushion protea, and orchid flowers and foliage were very sensitive to vapor heat. Treatment modification was needed to reduce plant injury to these commodities without losing efficacy. The number of shelf-life days of the treated plant material was estimated from the visual ratings.

The Hawaiian floral industry, to expand its markets to mainland United States and Japan, must comply with quarantine regulations that prevent the export of insect-infested plant material. Field control can reduce insect populations (Hara et al., 1987), but does not guarantee insect-free cut flowers and foliage. Current quarantine treatments approved for cut flowers by the Animal and Plant Health Inspection Service (APHIS) (1978, 1986) are hand removal, chemical dips, and methyl bromide fumigation.

Various types of postharvest treatments

have been evaluated for use on cut flowers (Seaton and Joyce, 1988a, 1988b). Vapor heat (heated, water-saturated air) is currently used to disinfest fruits and vegetables of fruit flies (APHIS, 1985) but has not been applied to commercial cut flowers and foliage (Seaton and Joyce, 1988a). With the recent social emphasis on worker safety and prevention of environmental contamination by pesticides, vapor heat is advantageous in that only heat (43 to 50°C) is the killing agent.

The objectives of our study were to test the efficacy of vapor heat at various time-temperature combinations against certain insect pests, to determine plant injury at these regimens on assorted tropical commodities, and to develop methods to reduce heat damage without losing efficacy.

Treatment procedures. Four trials were conducted in a commercial vapor heat chamber (Takenaka Corp., Tokyo) used for papayas. No papayas were treated while our studies were conducted, and any residual ethylene emitted by previously treated papayas was dissipated by the time of our trials or when air was circulated in the vapor heat chamber during the initial pretrial run-up period. Relative humidity was maintained between 90% to 98%. The initial air temperatures selected were based on that used for destroying fruit fly larvae within the papaya fruit (47.2°C) (Armstrong et al., 1989), but were lowered because the target insects were external and the floral material was considered more susceptible to heat than papayas. Average temperatures during the trials were: Trial A, 46.5°C; Trial B, 46.5°C; Trial C, 46.7°C; Trial D, 45.2°C. The standard error of mean for air treatment temperature of each trial was <0.1°C.

For the first three trials, each sample for

the efficacy and phytotoxicity tests was randomly selected and placed horizontally in groups inside stackable plastic bins (118 x 36 x 18 cm) (J. Sun Enterprises, Honolulu). During a trial, each row of the stack was monitored to verify that all bins were uniformly heated. For each treatment period, bins were removed every 10 min starting at 10 min for Trial A and at 30 min for Trials B and C. In Trial D, randomized plant material for both efficacy and phytotoxicity tests was placed vertically in plastic buckets containing water to reduce both mechanical and heat injury, and each treatment cohort was removed every 30 min starting at 2 h. In all trials, when material was removed for a particular treatment, a recovery period of several minutes was needed for the chamber to return to a specified temperature before the start of the next treatment. Immediately after the heat treatment, all samples were cooled by submersion in a water bath (≈ 25°C) until the samples were cool to the touch (≈ 10 min for most commodities).

Efficacy tests. Insects typifying those species on the California Dept. of Food and Agriculture (1983) rejection list were obtained from natural populations (Table 1). As quarantine pests, scales and mealybugs attack gingers, heliconias, bird-of-paradise, palms, and various foliage; aphids and thrips are found in flowering gingers and some orchids. To determine efficacy of a treatment against a particular pest, 10 infested samples were used. Most pests occurred on exposed surfaces of their host plant. Coconut mealybugs [*Nipaecoccus nipae* (Maskell) (Homoptera: Pseudococcidae)] were treated on palm (*Rhapis* sp.) leaves, and green scales [*Coccus viridis* (Green) (Homoptera: Coccidae)] were on gardenia (*Gardenia* sp.), both grown in a shadehouse. The armored scales were found on leaves of bird-of-paradise (*Strelitzia reginae* Ait.). Aphids and a complex of mealybug species were within bracts of red ginger [*Alpinia purpurata* (Vieill.) K. Schum.].

Infestation rates were sometimes highly irregular because of field conditions (Table 1), but only those inflorescences with at least eight nymphs or adults of the target pest species were used for each treatment period. Pest-infested plant material used as controls was handled the same as the treated, including submersion in the cooling bath, but was not placed in the chamber. Although a few adult mealybugs were removed by the water baths, post-trial comparisons of the total populations between the treated and the controls indicated no appreciable loss. Aphids and scales remained with their host material and none were seen in the bath water.

After treatment, nymphs and adults were observed by using a binocular microscope, and mortality was recorded. Because immediate death of scales was difficult to recognize, the scales were evaluated at least 4 days after treatment. Efficacy data per treatment were pooled because insect counts among the samples were not normally distributed (e.g., high standard deviation relative to the mean). Mortality data are typically

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¹Current address: U.S. Dept. of Agriculture, Agricultural Research Service, Subtropical Horticulture Research Laboratory, 13601 Old Cutler Rd., Miami, FL 33158.

Fig. 1. Percent mortality for various treatment times of vapor heat ($46.6 \pm 0.1^\circ\text{C}$). (A) Banana aphid in red ginger bracts. (B) Green scale on gardenia leaves. (C) Magnolia white scale on bird-of-paradise leaves. (D) Mealybug species complex composed of the citrus mealybug, the obscure mealybug, and the longtailed mealybug.

pooled to demonstrate efficacy in quarantine heat treatments (Armstrong et al., 1989; Hallman and Sharp, 1990; Sharp, 1990; Yokoyama et al., 1991). Efficacy among treatments was determined by the highest percentage of mortality.

Phytotoxicity. A variety of Hawaiian cut flowers and foliage were assessed for heat damage (Table 2). To evaluate for phytotoxicity in each floral commodity, five samples were used per treatment (including the controls). Different samples were used for the efficacy and phytotoxicity tests. The plant

material was maintained under ambient room conditions [$25 \pm 4^\circ\text{C}$, $50\% \pm 10\%$ relative humidity (RH)] in buckets containing tap water that was changed weekly. Daily sunlight conditions were 12 h light/12 h dark with an annual seasonal variation of 2 h. Lighting was indirect because the plant material was maintained in enclosed areas.

Two observers used a lo-point scale to visually evaluate the quality of each piece before treatment and twice weekly (3 to 4 days between observations) after treatment (Table 3). The damage score for an item was

the sum of the ratings of the two observers. A damage score of 0 represented no damage, 8 was the limit of shelf life, and 18 was complete discoloration or death.

Damage scores were summarized by using MEANS procedures of SAS (SAS Institute, Cary, N.C.). Significant differences in plant damage between controls and treated plant material were determined by using the SAS procedure TTEST. Shelf life for each treatment of every floral commodity was estimated by plotting the average damage score per observation with the amount of time

Table 1. Insect species and number of insects ($\bar{x} \pm \text{SD}$) on plants used in vapor heat trials.

				Trial			
Family	Species	Common name	Life stage	A (46.5C)	B (46.5C)	C (46.7C)	D (45.2C)
				Insects (no.)			
Aphididae	<i>Pentalonia nigronervosa</i> Coquerel ²	Banana aphid	Nymphs	173 ± 63	100 ± 101	868 ± 550	244 ± 163
			Adults	100 ± 103	202 ± 162	233 ± 173	62 ± 37
Diaspididae	<i>Pseudaulacaspis cockerelli</i> (Cooley) ^y	Magnolia white scale	Nymphs	---	94 ± 77	115 ± 49	---
			Adults	---	156 ± 24	195 ± 32	---
Coccidae	<i>Coccus viridis</i> (Green) ^x	Green scale	Nymphs	35 ± 20	142 ± 101	3034 ± 2299	---
			Adults	11 ± 3	27 ± 14	1127 ± 574	---
Pseudococcidae	<i>Nipaecoccus nipae</i> (Maskell) ^w	Coconut mealybug	Nymphs	---	---	42 ± 24	---
			Adults	---	---	73 ± 20	---
	<i>Planococcus citri</i> (Risso) ^{z,v}	Citrus mealybug	Nymphs	150 ± 72	225 ± 99	203 ± 186	128 ± 152
			Adults	54 ± 17	79 ± 43	44 ± 28	29 ± 11
	<i>Pseudococcus affinis</i> (Maskell) ^{y,v}	Obscure mealybug	Nymphs	---	---	---	---
			Adults	---	---	---	---
	<i>Pseudococcus longispinus</i> (Targioni-Tozzetti) ^{z,v}	Longtailed mealybug	Nymphs	---	---	---	---
			Adults	---	---	---	---
Thripidae	<i>Sciothrips cardamomi</i> (Ramakrishna) ^z	Cardamom thrips	Nymphs	---	20 ± 7	---	---
			Adults	---	13 ± 9	---	---

²In red ginger flowers.³On bird-of-paradise leaves.⁴On gardenia leaves.⁵On palm fronds.

Data combined among these three species.

Table 2. Species list of tropical cut flowers and foliage tested for phytotoxicity to vapor heat.

Commodity	Family	Species ²
Anthurium		
Ozaki	Araceae	<i>Anthurium andraeanum</i> Linden
Midori	Araceae	<i>Anthurium andraeanum</i> Linden
Heliconia		
Jacquinii	Heliconiaceae	<i>Heliconia bihai</i> L. f.
Caribaea	Heliconiaceae	<i>H. caribaea</i> Lam.
Wagneriana	Heliconiaceae	<i>H. wagneriana</i> Peterson
Andromeda	Heliconiaceae	<i>H. psittacorum</i> L. f.
Parrot	Heliconiaceae	<i>H. psittacorum</i> x <i>H. spathocircinata</i> hybrid
Other flowers		
Dendrobium	Orchidaceae	<i>Dendrobium phalaenopsis</i> Fitzg.
Red ginger	Zingiberaceae	<i>Alpinia purpurata</i> (Vieill.) K. Schum.
Bird-of-paradise	Strelitziaceae	<i>Strelitzia reginae</i> Ait.
Pincushion	Proteaceae	<i>Leucospermum</i> sp.
Foliage		
Lycopodium (stem)	Lycopodiaceae	<i>Lycopodium cernuum</i> L.
Green ti (leaf)	Agavaceae	<i>Cordyline terminalis</i> (L.) Kunth
Massangeana	Agavaceae	<i>Dracaena fragans</i> (L.) Ker-Gawl.
Bamboo orchid (leafy stem)	Orchidaceae	<i>Arundina graminifolia</i> (D. Don) Hochr.
Bird-of-paradise (leaf)	Strelitziaceae	<i>Strelitzia reginae</i> Ait.

²Species names from Liberty Hyde Bailey Hortorium (1976).

elapsed following treatment (in days) and determining the point where the graph intersected "8" on the vertical axis. Partial days were rounded to nearest whole day.

Efficacy. Mortality of nymphs and adults of each of the pest species was similar at $46.6 \pm 0.1\text{C}$ during all trials. Because of the high efficacy of the vapor heat temperatures, intermediate points were not available to regress mortality with treatment time. Aphids were highly susceptible to the heat treatments after only 10 min (Fig. 1A). Green scales were also very sensitive to the heat (Fig. 1B). Extensive mortality in magnolia white scales occurred after 40 min (Fig. 1C). The mealybugs inside ginger flowers required 1 h before reaching almost complete mortality (Fig. 1D). All coconut mealybugs and thrips were destroyed by 1 h. In the longer trial at 45C (Trial D-45.2), all aphids and armored scales (Fig. 2 A and B) and mealy-

bug nymphs in ginger (Fig. 2C) were eliminated by 2 h; complete mortality for adult mealybugs required 3 h (mortality at 2 h: 97.5%, at 2.5 h: 94.1%).

These efficacy tests suggest that aphids and surface insects of tropical cut flowers and foliage can be eliminated by treating with vapor heat (46.6C) for 1 h. Perhaps this same treatment can be used for potted plants to disinfest them of scales. Pests that live inside inflorescences, such as mealybugs, require a longer treatment time, especially with a lower temperature. Further studies should examine the effect of vapor heat on various stem borers, leaf miners, and other internal feeding insects.

Phytotoxicity. The large heliconias, bird-of-paradise flowers and leaves, and most of the other foliage withstood $\approx 46.5\text{C}$ for as long as 80 min (Table 4). Also, bird-of-paradise flowers and leaves were not damaged

at 45.2C for 3 h (Table 5). In some cases, individual red ginger and *Dendrobium* flowers showed much damage, whereas others did not. Anthuriums, pincushion protea, and bamboo orchid foliage were highly sensitive to heat.

These heat relationships were also reflected in the estimated shelf life (Figs. 3 and 4). All treated heliconias, massangeana foliage, bird-of-paradise flowers and leaves, lycopodium foliage, and green ti leaves persisted about as long as their controls. Shelf life was greatly reduced for treated anthuriums, red ginger, and bamboo orchid foliage. Treated pincushion protea were short-lived due to severe mold infestation, probably originating from the water submersion and generally humid conditions.

Regarding the treatments necessary to destroy potential pests, our research indicates that all foliage plants (except bamboo orchid), bird-of-paradise, and heliconias likely will endure uninjured. Plant size is evidently not always a factor, because heat tolerance is exhibited from the delicate lycopodium stems to the massive wagneriana heliconia flowers. Red ginger inflorescences, which accommodate concealed feeders such as mealybugs, may not withstand heating periods (45.2C, 3 h) that eliminate these insects. Postharvest conditioning with heat may improve the thermal tolerance for gingers, orchids, and anthuriums.

We conclude that vapor heat is a promising postharvest treatment to disinfest tropical cut flowers and foliage of insects. Vapor heat for 1 h at 46.5C eliminated practically all insect pests, yet was safe for large heliconia, bird-of-paradise flowers and leaves, and other foliage. Hand removal, now required by APHIS regulations (APHIS, 1978) 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 ship-

Table 3. Description for phytotoxicity ratings of plant materials. Total damage score for an item was calculated by adding the ratings of two observers.

Rating	Attributes of plant parts	
	Flower	Foliage
0	No damage to petals or bracts.	No damage to stem and leaves.
1	Slight discoloration or very minor flaws.	Few leaves have slight damage (<10%), good appearance.
2	Some discoloration, still marketable.	More leaves than for 1 with slight damage (10% to 20%), generally good appearance, still marketable.
3	Discoloration expanding ($\approx$ 10%); not marketable, but still suitable for vase.	Many leaves ($\approx$ 30%) with slight damage or few leaves (10% to 20%) with major damage, still with good appearance.
4	More discoloration than for 3 (10% to 20%); vase life questionable.	More leaves than for 3 ($\approx$ 40%) with major damage, appearance fair; vase life questionable.
5	Increased discoloration ($\approx$ 30%); definitely not suitable for vase.	Most leaves (>50%) with some damage, appearance fair to poor; not suitable for vase.
6	Some discoloration throughout ($\approx$ 50%).	Most leaves (>60%) with major damage, appearance poor.
7	Much discoloration throughout ($\approx$ 70%).	Much of foliage damaged or dead ($\approx$ 70%), appearance very poor.
8	Major discoloration throughout ($\approx$ 90%).	Most foliage dead ($\approx$ 90%), few undamaged areas.
9	Entire flower discolored.	Foliage dead.

Table 4. Total damage scores ($\bar{x} \pm \text{SD}$) of floral commodities 1 week after vapor heat treatment at 46.5 to 46.7C for 60 and 80 min computed by summing the damage ratings of two observers, and Student's *t* test comparisons with the control ($n = 5$ per treatment).

Commodity	Study	Damage ratings			<i>t</i> Value	
		Control	60 min	80 min	60 min	80 min
Anthurium						
Ozaki	B	2.8 $\pm$ 0.8	8.6 $\pm$ 3.2	15.4 $\pm$ 1.8	3.91**	14.09**
Midori	C	2.8 $\pm$ 0.8	10.6 $\pm$ 2.3	8.6 $\pm$ 2.3	7.12**	5.29**
Heliconia						
Caribaea	B	3.8 $\pm$ 1.3	4.8 $\pm$ 1.8	3.6 $\pm$ 0.5	1.01	0.32
Jacquinii	B	4.6 $\pm$ 1.5	5.2 $\pm$ 0.8	5.0 $\pm$ 1.9	0.77	0.37
Wagneriana	B	2.0 $\pm$ 1.0	2.2 $\pm$ 0.8	2.6 $\pm$ 0.5	0.34	1.18
Other flowers						
Dendrobium	B	3.4 $\pm$ 1.1	6.6 $\pm$ 1.8	8.6 $\pm$ 1.7	3.34**	5.74**
Red ginger	C	6.0 $\pm$ 1.9	8.6 $\pm$ 4.8	9.8 $\pm$ 2.4	1.12	2.80*
Bird-of-paradise	C	7.2 $\pm$ 2.3	9.4 $\pm$ 1.1	9.0 $\pm$ 1.4	1.93	1.50
Pincushion	B	5.8 $\pm$ 3.3	14.2 $\pm$ 1.3	16.0 $\pm$ 1.3	5.33**	6.60**
Foliage						
Lycopodium	B	3.0 $\pm$ 1.4	5.0 $\pm$ 4.2	6.6 $\pm$ 4.9	1.07	1.57
Green ti	B	6.2 $\pm$ 1.3	5.4 $\pm$ 1.1	5.2 $\pm$ 1.6	1.03	1.06
Massangeana	C	4.0 $\pm$ 0.7	4.0 $\pm$ 0.0	3.8 $\pm$ 1.1	0.00	0.34
Bamboo orchid	B	6.0 $\pm$ 3.2	9.8 $\pm$ 4.4	12.6 $\pm$ 3.0	1.57	3.36**
Bird-of-paradise	B	2.2 $\pm$ 0.5	2.2 $\pm$ 0.5	2.6 $\pm$ 0.5	0.00	1.26

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

Table 5. Total damage scores ($\bar{x} \pm \text{SD}$) of floral commodities 1 week after vapor heat treatment at 45.2C (Trial D) for 2 and 3 h computed by summing the damage ratings of two observers, and Student's *t* test comparisons with the control ($n = 5$ per treatment).

Commodity	Damage ratings			<i>t</i> Value	
	Control	2 h	3 h	2 h	3 h
Anthurium					
Ozaki	3.2 $\pm$ 1.8	11.2 $\pm$ 1.8	15.8 $\pm$ 0.4	7.07**	15.28**
Heliconia					
Andromeda	2.8 $\pm$ 1.1	4.4 $\pm$ 1.1	6.2 $\pm$ 0.4	2.26	6.42**
Parrot	4.6 $\pm$ 0.9	6.6 $\pm$ 0.9	5.6 $\pm$ 1.7	3.54**	1.18
Other flowers					
Dendrobium	4.2 $\pm$ 2.4	7.0 $\pm$ 0.7	9.6 $\pm$ 2.2	2.51	3.73**
Red ginger	6.4 $\pm$ 2.2	7.4 $\pm$ 1.8	9.4 $\pm$ 2.4	0.79	2.06
Bird-of-paradise	3.2 $\pm$ 1.1	4.8 $\pm$ 2.3	4.8 $\pm$ 2.2	1.41	0.18
Foliage					
Bamboo orchid	4.2 $\pm$ 1.8	8.0 $\pm$ 2.1	14.4 $\pm$ 1.7	3.06*	9.31**
Bird-of-paradise	1.8 $\pm$ 0.4	2.0 $\pm$ 1.4	2.0 $\pm$ 1.2	0.30	0.34

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

Fig. 2. Percent mortality for various treatment times of vapor heat (45.2C). (A) Banana aphid in red ginger bracts. (B) Magnolia white scale on bird-of-paradise leaves. (C) Mealybug species complex composed of the citrus mealybug, the obscure mealybug, and the longtailed mealybug.

ments are not delayed unnecessarily.

Treating commodities vertically with stem ends immersed in water may relieve some of the heat stress. Further research is needed to decrease heat stress in temperature-sensitive floral commodities. Hydrocooling, besides reducing heat stress, may also remove dead insects from the plant material. Future research should delimit the thermal tolerances of specific floral commodities. Treatment modifications, such as lower temperatures for longer periods, may be suitable for anthuriums, orchids, and other heat-sensitive commodities.

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Fig. 3. Estimated shelf life of various tropical cut flowers and foliage following 60 or 80 min of exposure to vapor heat ($46.6 \pm 0.1^{\circ}\text{C}$).

Fig. 4. Estimated shelf life of various tropical cut flowers and foliage following 0, 2, or 3 h of exposure to vapor heat ($45.2 \pm 0.1^{\circ}\text{C}$).

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