COMMODITY TREATMENT

Hot-Water Immersion as a Potential Quarantine Treatment Against *Pseudaulacaspis cockerelli* (Homoptera: Diaspididae)

ARNOLD H. HARA, TRENT Y. HATA, BENJAMIN K. S. HU, AND VICTORIA L. TENBRINK

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

J. Econ. Entomol. 86(4): 1167–1170 (1993)

ABSTRACT Lethal immersion in water at 47, 48, and 49°C from 0 to 10 min at 1-min intervals was determined for the crawler, nymph, and female adult stages of *Pseudaulacaspis cockerelli* (Cooley) on bird of paradise, *Strelitzia reginae* Aiton, leaves. Crawlers appeared more tolerant to hot-water immersion than female adults. Increased exposure time resulted in a linear increase in mortality for all temperatures. Exposure to 49°C water for 5, 5, and 6 min resulted in 100% mortality of adults, nymphs, and crawlers, respectively. Our proposed quarantine hot-water treatment can be adjusted to any specific risk level, including zero tolerance.

KEY WORDS *Pseudaulacaspis cockerelli, Strelitzia reginae,* thermal death

Pseudaulacaspis cockerelli (Cooley) can be a serious pest of >50 species of ornamental plants in Florida and Georgia (Reinert 1974). *P. cockerelli*, a major pest of bird of paradise, *Strelitzia reginae* Aiton, is responsible for most shipment rejections by California Department of Food and Agriculture (CDFA) of flower and foliage products exported from Hawaii (CDFA 1988). Because of increased interceptions of scale-infested plant material from Hawaii, CDFA issued a warning to the Hawaii flower industry that destination treatment is no longer permitted and shipments infested with scales will be returned to the shipper or destroyed (A. G. Clark, CDFA, Sacramento, CA, personal communication).

Currently, flower exporters scrub the flower stems with soapy water and a scouring pad to remove the scales. This practice does not guarantee pest-free flowers or foliage and is both time-consuming and labor-intensive. Reinert (1974) showed that two applications of either acephate, dimethoate, monocrotophos, or oxydemeton-methyl caused up to 95% mortality of the scale population within 8 wk. Hata & Hara (1992) reported that three biweekly applications of chlorpyrifos reduced the adult female *P. cockerelli* population only 65%. Hansen et al. (1992b) reported that an insecticidal dip after harvest using a combination of insecticidal soap (potassium salts of fatty acids) and fluvalinate caused 85.2 and 69.2% mortality of adult females and nymphs, respectively. Those percentages, however, were actually lower than reported because natural mortality caused by parasitism and fungal disease was 31.3% for nymphs and 65.2% for adults in that study. Hansen et al. (1992a) also reported >87% mortality of *P. cockerelli* after a 40-min vapor-heat treatment at 46.5°C. In addition, Hansen et al. (1991) demonstrated that fumigation with hydrogen cyanide (HCN) at concentrations of 3,700 ppm and 4,600 ppm killed all nymphs and adult females, respectively. However, HCN is not a registered fumigant in the United States, and vapor-heat treatment requires expensive and sophisticated equipment, which is too costly for individual packing houses.

For many insects the lethal temperature for short-term exposure is between 40 and 50°C (Chapman 1969). The use of hot-water immersion is well documented for disinfesting fruit flies from papayas (Couey & Hayes 1986, Hayes et al. 1987, Heard et al. 1991), bananas (Armstrong 1982), cucumbers (Chan & Linse 1989), and mangoes (Sharp et al. 1988, Nascimento et al. 1992). Another study (unpublished data) showed that some flowers, including bird of paradise in the bud stage, and leaves can withstand hot-water immersion at 49°C for 10 min with little (≤15%) or no loss of vase life. We report here the thermal time-mortality of *P. cockerelli* at certain temperatures.

Materials and Methods

Bird of paradise leaves infested with *P. cockerelli* were collected during November 1991 to February 1992 from a commercial farm located in Umauma, HI (elevation, 104 m), where no field pest management was practiced for *P. cockerelli*. A field survey of *P. cockerelli* on bird of paradise flowers was conducted by sampling >700 flowers during June 1992. Percentage of flowers infested with *P. cockerelli* and number of scales per flower were calculated.

Only female adult scales with no parasitoid exit holes and no apparent signs of fungal infection were selected for our hot-water immersion tests. These scales were identified by encircling the scale with water-resistant ink. Scale-infested leaves were immersed in a 106-liter stainless-steel tank (catalogue no. 3738K34, McMaster-Carr Supply, Los Angeles, CA) containing 75.7 liters of tap water. A rubber mat prevented the flowers from contacting the stainless-steel tank. A grid constructed from polyvinyl chloride pipe (1.3 cm inside diameter) was used to hold the leaves below the water surface. Constant high temperature was maintained and monitored using two isotemp immersion circulators (model 730, Fisher Scientific, Pittsburgh, PA). The water temperature was raised 0.1°C before immersion to compensate for the temperature decrease caused by immersing leaves at ambient temperature. Water temperature was periodically confirmed using a digital thermometer (catalogue no. 15-078-1, Fisher Scientific) equipped with a small surface temperature probe (catalogue no. 15-176-35, Fisher Scientific) and a certified ±0.04°C liquid in glass thermometer (Ever Ready Thermometer, New York). Immediately after each treatment, the leaves were cooled in a water bath at ambient temperature (25.7–27.3°C) for 5 min to minimize heat effects on plant tissue. Controls were immersed in a water bath at ambient temperature (25.7–27.3°C) for 5 min.

Study 1. Scale-infested leaves were treated at 47, 48, and 49°C for 0–10 min at 1-min intervals. Each treatment consisted of 100 female adult scales and associated eggs, crawlers, and nymphs on infested leaves. Infested leaves were immersed in the treatment tank in lots of 25 female adults. Each treatment was replicated three times at each time, except 47°C, which was replicated twice. The mortality of crawlers, nymphs, and adults was assessed 1 wk after treatment to: allow live scales to recover from possible heat stupor, an immobile state caused by heat (Chapman 1969); allow a minimum of 3 d (Tippins 1968) for egg hatch; and allow easy identification of dead scales. Mortality was determined by removing the scales from the leaf surface with a dissecting needle and observing various stages under a binocular dissecting microscope. Live female adult scales were yellow, whereas dead scales were brown or shriveled. Live nymphs were yellow or green, and dead nymphs were brown or black. The criterion for crawler mortality was lack of leg movement, and the criterion for egg mortality was no crawler emergence. Numbers of live and dead adults, nymphs, crawlers, and eggs were recorded.

Study 2. Tests were conducted to verify treatment efficacy at 49°C for a 10-min immersion. Scale-infested leaves were treated in lots of 25 female adults using immersion procedures as previously described. Treatment efficacy was determined 1 wk after treatment using the same criteria as described in study 1.

Data Analysis. Numbers of eggs, crawlers, and nymphs per female adult were variable; thus, the data were pooled to ensure adequate numbers of immature stages per exposure time. Natural mortality was corrected by Abbott's formula (Abbott 1925). Regression relationship between the time of heat exposure (independent variable) and the percentage mortality (dependent variable) of immature stages and female adults of *P. cockerelli* was determined (SAS Institute 1987).

Results and Discussion

At the commercial farm, our field survey showed that without any field pest management, 56.6% of harvested flowers (n = 738) were infested with an average of 4.8 female adults of *P. cockerelli* per flower (n = 418 flowers).

Temperature decreased an average of 0.2°C after immersion of infested leaves for all temperature × time treatments and recovered within 30 s. Water temperature was maintained within ±0.1°C of target temperature after initial recovery.

Study 1. An increase in exposure time resulted in a linear increase in mortality for all temperatures tested (Table 1). At 49°C, 100% mortality of adults, nymphs, and crawlers occurred after 5, 5, and 6 min, respectively (Table 2). Absence of crawlers hatching from eggs after exposure of >6 min at 49°C (n = 27,799 eggs) demonstrated efficacy of the treatment against eggs. Of the tested female adults (n = 8,795), 44.0% contained eggs, and each female adult (n = 500) had an average of 23.8 eggs (range, 1–79 eggs).

Mortality at tested temperatures appeared to indicate that eggs and crawlers were more tolerant to heat than female adults (Table 2). This higher survivorship may be a result of the load factor (numbers per unit area), where each female adult had an average of 24 eggs, or to exposure of eggs and crawlers to less heat than the female adult that covered them.

Study 2. Exposure to 49°C water for 10 min resulted in 100% mortality of adults (n = 11,150), nymphs (n = 22,622), crawlers (n = 14,077), and eggs (n = 54,506). This temperature × time treatment was 5, 5, and 4 min above the minimum time necessary for 100% mortality of crawlers, nymphs, and adults, respectively. All treated male nymphs observed in this study were dead. Mortality of adult males was not critical because male adults live for only a few hours (Beardsley

Table 1. Linear regression of the relationship between exposure time (*x*) of *P. cockerelli* crawlers, nymphs, and adults in hot water versus percentage mortality (*y*)

Temp	Stage	Regression equation	n^a	r^2	MSE[b]	*P*
47°C	Adult	$y = -13.27 + 9.66\ (\pm 1.15)^c\ x^d$	11	0.89	144.87	0.0001
	Nymph	$y = 2.04 + 9.67\ (\pm 0.95)\ x$	11	0.92	98.29	0.0001
	Crawler	$y = -7.20 + 6.15\ (\pm 1.16)\ x$	11	0.76	148.93	0.0005
48°C	Adult	$y = -9.67 + 12.30\ (\pm 1.20)\ x$	11	0.92	157.36	0.0001
	Nymph	$y = 4.88 + 11.53\ (\pm 1.52)\ x$	11	0.86	255.57	0.0001
	Crawler	$y = -14.60 + 10.49\ (\pm 1.01)\ x$	11	0.92	111.45	0.0001
49°C	Adult	$y = -9.32 + 22.78\ (\pm 3.02)\ x$	6	0.93	159.52	0.0017
	Nymph	$y = 16.28 + 19.08\ (\pm 4.10)\ x$	6	0.84	294.84	0.0097
	Crawler	$y = -12.59 + 18.53\ (\pm 2.27)\ x$	7	0.93	144.81	0.0005

[a] Number of data points in regression; each data point represents percentage mortality (0–100%) at a specific exposure time.
[b] Mean square error.
[c] Standard error of slope.
[d] Exposure time (min).

& Gonzalez 1975), and reproduction could not occur in absence of females.

Most quarantine protocols require a probit 9 level of security by the treatment (Baker 1939, Landolt et al. 1984, Jang 1991). The sample size needed for probit 9 is not realistic with natural infestations on exported minor commodities, such as bird of paradise. In these situations, calculation of a 95% confidence interval would require a sample size of 93,616 scale with no survivors (Chew & Ouye 1985, Couey & Chew 1986). In this study we used heavily infested leaves of *S. reginae*, although *S. reginae* flowers with field pest management are not exported with a severe *P. cockerelli* infestation.

Chew & Ouye (1985) and Jang (1991) suggested that quarantine treatments based on load or degree of infestation would relate more realistically to a given treatment for quarantine security. A grower shipment usually consists of 360 flower stems per location. If this shipment had a 56.6% field infestation level (without pest management as determined in our field survey), a probit 9 hot-water immersion treatment would allow less than one, or 0.0313 scale, per shipment (360 stems × 0.566 field infestation level × 4.8 scales per flower: 360 × 0.566 × 4.8 × 0.999968). Therefore, with a field pest management program for bird of paradise when infestation levels are closely monitored and controlled with or without pesticides (e.g., sanitation), the resulting low levels of scale infestations after harvest should be managed without difficulty. In addition, Beardsley & Gonzalez (1975) stated that the probability of crawlers establishing a new infestation by nonpropagative plant material is unlikely because crawlers must be in close proximity to suitable growing hosts. Our proposed quarantine hot-water treatment can be adjusted to any specific risk level, including zero tolerance.

The advantages to a hot water immersion treatment after harvest for *P. cockerelli* over other quarantine treatments include less pesticide residue, worker exposure, and waste disposal as compared with insecticidal dips after harvest; no development of pesticide resistance; and no need for expensive equipment as opposed to vapor-heat or irradiation treatment. Also, because of the difficulty in distinguishing live scales from dead scales, hot-water treatment will

Table 2. Percentage mortality of adult, nymph, and crawlers of *P. cockerelli* after hot-water immersion

Exposure time (min)	47°C			48°C			49°C		
	Adults (200)[a]	Nymphs	Crawlers	Adults (300)	Nymphs	Crawlers	Adults (300)	Nymphs	Crawlers
0	0.0[b]	0.0 (2,307)	0.0 (611)	0.0	0.0 (1,410)	0.0 (763)	0.0	0.0 (3,535)	0.0 (681)
1	3.8	16.5 (1,454)	0.0 (359)	5.5	18.8 (1,383)	1.8 (614)	11.1	38.1 (2,620)	4.6 (590)
2	4.9	32.1 (1,422)	18.8 (461)	5.5	5.5 (1,103)	0.9 (682)	18.8	65.1 (2,494)	18.3 (711)
3	14.1	22.5 (1,677)	6.8 (626)	10.4	43.3 (1,923)	7.1 (594)	59.1	97.4 (1,368)	27.3 (699)
4	8.7	33.1 (1,273)	0.0 (587)	28.0	41.5 (882)	24.5 (798)	96.7	83.3 (1,676)	55.3 (591)
5	23.4	38.7 (1,081)	15.5 (383)	54.2	86.5 (1,302)	21.4 (814)	100.0	100.0 (919)	95.5 (437)
6	25.5	59.3 (888)	11.4 (733)	83.9	96.0 (1,011)	37.6 (1,010)	100.0	100.0 (1,436)	100.0 (508)
7	62.5	90.0 (720)	48.0 (396)	88.0	96.3 (1,675)	68.7 (613)	100.0	100.0 (1,492)	100.0 (382)
8	74.5	75.8 (1,001)	45.2 (801)	96.3	99.9 (1,957)	78.8 (681)	100.0	100.0 (909)	100.0 (285)
9	84.2	93.1 (807)	62.5 (843)	99.7	99.9 (2,750)	86.6 (712)	100.0	100.0 (2,726)	100.0 (546)
10	83.7	92.9 (1,282)	50.6 (704)	98.5	100.0 (1,092)	88.9 (607)	100.0	100.0 (1,261)	100.0 (482)
Natural mortality	8.0	8.1	18.5	11.1	12.7	10.9	9.7	8.8	13.5

[a] Total number of scales treated are given in parentheses.
[b] Natural mortality corrected by Abbott's formula (Abbott 1925).

eliminate the need for timely inspection of every shipment.

Acknowledgments

We thank Ryan Kaneko (University of Hawaii at Manoa, College of Tropical Agriculture and Human Resources) for technical assistance and Hawaii Paradise Farms, Umauma, HI, for providing bird of paradise leaves. This research was supported in part by the USDA, Cooperative State Research Service under Floriculture Research Grant No. 89-34199-4420. This is Hawaii Institute of Tropical Agriculture and Human Resources Journal Series No. 3780.

References Cited

Abbott, W. S. 1925. A method of computing the effectiveness of an insecticide. J. Econ. Entomol. 18: 265–267.

Armstrong, J. W. 1982. Development of a hot-water immersion quarantine treatment for Hawaiian-grown 'Brazilian' bananas. J. Econ. Entomol. 75: 787–790.

Baker, A. C. 1939. The basis for treatment of products where fruit flies are involved as a condition for entry into the United States. U.S. Dep. Agric. Circ. 551.

Beardsley, J. W., Jr., & R. H. Gonzalez. 1975. The biology and ecology of armored scales. Annu. Rev. Entomol. 20: 47–73.

CDFA (California Department of Food and Agriculture). 1988. Quarantine Calif. pest interceptions, summer, 1988. Plant Pest Dis. Rep. 7: 32–50.

Chan, H. T. & E. Linse. 1989. Conditioning cucumbers for quarantine heat treatments. HortScience 24: 985–989.

Chapman, R. F. 1969. The insects: structure and function. American Elsevier, New York.

Chew, V. & M. T. Ouye. 1985. Statistical basis for quarantine treatment schedule and security, pp. 70–74. *In* J. H. Moy [ed.], Radiation disinfestation of food and agricultural products. Hawaii Institute of Tropical Agriculture and Human Resources, University of Hawaii, Honolulu.

Couey, H. M. & V. Chew. 1986. Confidence limits and sample size in quarantine research. J. Econ. Entomol. 79: 887–890.

Couey, H. M. & C. F. Hayes. 1986. Quarantine procedure for Hawaiian papaya using fruit selection and a two-stage hot-water immersion. J. Econ. Entomol. 79: 1307–1314.

Hansen, J. D., A. H. Hara, H. T. Chan & V. L. Tenbrink. 1991. Efficacy of hydrogen cyanide fumigation as a treatment for pests of Hawaiian cut flowers and foliage after harvest. J. Econ. Entomol. 84: 532–536.

Hansen, J. D., A. H. Hara & V. L. Tenbrink. 1992a. Vapor heat: a potential treatment to disinfect tropical cut flowers and foliage. HortScience 27: 139–143.

1992b. Insecticidal dips for disinfesting commercial cut flowers and foliage. Trop. Pest Manage. 38: 245–249.

Hata, T. Y. & A. H. Hara. 1992. Control of armored scales on bird of paradise, Hawaii, 1990. Insectic. Acaracide Tests 17: 317.

Hayes, C. F., H.T.G. Chingon, F. A. Nitta & A.M.T. Leung. 1987. Calculation of survival from double hot-water immersion treatment for papayas infested with oriental fruit flies (Diptera: Tephritidae). J. Econ. Entomol. 80: 887–890.

Heard, T. A., N. W. Heather & R. J. Corcoran. 1991. Dose-mortality relationships for eggs and larvae of *Bactrocera tryoni* (Diptera: Tephritidae) immersed in hot water. J. Econ. Entomol. 84: 1768–1770.

Jang, E. B. 1991. Thermal death kinetics and heat tolerance in early and late third instars of the oriental fruit fly (Diptera: Tephritidae). J. Econ. Entomol. 84: 1298–1303.

Landolt, P. J., D. L. Chambers & V. Chew. 1984. Alternative to the use of probit 9 mortality as a criterion for quarantine treatments of fruit fly (Diptera: Tephritidae)-infested fruit. J. Econ. Entomol. 77: 285–287.

Nascimento, A. S., A. Malavasi, J. S. Morgante & A.L.A. Duarte. 1992. Hot-water immersion treatment for mangoes infested with *Anastrepha fraterculus*, *A. obliqua*, and *Ceratitis capitata* (Diptera: Tephritidae) in Brazil. J. Econ. Entomol. 85: 456–460.

Reinert, J. A. 1974. Management of the false oleander scale, *Pseudaulacaspis cockerelii* (Cooley). Proc. Fla. State Hortic. Soc. 87: 518–520.

SAS Institute. 1987. SAS/STAT guide for personal computers, version 6 ed. SAS Institute, Cary, NC.

Sharp, J. L., M. T. Ouye, R. Thalman, W. Hart, S. Ingle & V. Chew. 1988. Submersion of 'Francis' mango in hot water as a quarantine treatment for the West Indian fruit fly and the Caribbean fruit fly (Diptera: Tephritidae). J. Econ. Entomol. 81: 1431–1436.

Tippins, H. H. 1968. Observations on *Phenacaspis cockerelli* (Cooley) (Homoptera: Diaspididae), a pest of ornamental plants in Georgia. J. Ga. Entomol. Soc. 3: 13–15.

Received for publication 11 August 1992; accepted 25 March 1993.