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Radiation Physics and Chemistry 71 (2004) 161–164
Exhibit 2b, #50
Radiation Physics and Chemistry
www.elsevier.com/locate/radphyschem

Irradiation to control insects in fruits and vegetables for export from Hawaii

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Abstract

Phytosanitary or quarantine treatments are often required to disinfest host commodities of economically important arthropod pests before they are moved through market channels to areas where the pest does not occur. Irradiation is an accepted treatment to control quarantine pests in 10 fruits and five vegetables for export from Hawaii to the US mainland. Irradiation is the ideal technology for developing generic quarantine treatments because it is effective against most insect and mite pests at dose levels that do not affect the quality of most commodities. A generic dose of 150 Gy has been proposed for tephritid fruit flies. Contrary to the 150 Gy dose, approved irradiation quarantine treatment doses for Mediterranean fruit fly, melon fly, and oriental fruit fly in Hawaii are 210–250 Gy. Irradiation studies were conducted to determine if the approved doses were unnecessarily high and could be reduced. Irradiation is also a viable alternative to methyl bromide fumigation to disinfest Hawaii sweetpotatoes, and studies are in progress to identify an effective dose for two key sweetpotato insect pests. Results indicate that irradiation doses <150 Gy will control Hawaii's fruit flies, which supports the proposed generic dose. The idea of generic doses is appealing because it would greatly accelerate the process of approving irradiation quarantine treatments for specific crops, and thereby rapidly expand exports. Preliminary results show that 250–300 Gy will control Hawaii's sweetpotato pests.
Published by Elsevier Ltd.

Keywords: Quarantine treatment; Fruits flies; Sweetpotato pests; Generic doses

1. Introduction

Fruits and vegetables grown in Hawaii are subject to federal quarantine regulations because of four exotic tephritid fruit flies—Mediterranean fruit fly, *Ceratitis capitata* (Wiedemann), oriental fruit fly, *Bactrocera dorsalis* (Hendel), and melon fly, *B. curcurbitae* (Coquillet) and solanaceous fruit fly, *B. latifrons* (Hendel) (Diptera: Tephritidae)—and other pests. Quarantine treatments such as heat, cold, irradiation, and fumigation disinfest host commodities of insect pests before they are exported to the US mainland where the pests do not occur. Hawaii has approved quarantine treatments for 14 different tropical fruits and five vegetables (Table 1). In nearly all cases, quarantine treatments were developed against tephritid fruit flies. Irradiation is an accepted treatment to control fruit flies in 10 fruits and five vegetables, and is also an accepted treatment for mango seed weevil in mangoes (Federal Register, 2002). Whereas development of heat, cold, and fumigation treatments involves generating data for each fruit-pest combination, irradiation treatments are developed for a pest species irrespective of commodity. This is possible because most commodities can tolerate irradiation at doses that kill the pest, whereas developing heat and cold treatments, for example, involves finding the balance between killing the pest and minimizing the adverse effects of the process on commodity quality.

Irradiation is the ideal technology for developing "generic" treatments because it is effective against most insects and mites at dose levels that do not affect the

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0969-806X/$ - see front matter Published by Elsevier Ltd.
doi:10.1016/j.radphyschem.2004.03.074

Table 1
Commodity quarantine treatments for Hawaii's fruits and vegetables

Abiu	I	Longan	I, H
Atemoya	I	Lychee	I, H
Avocado	C	Mango	I
Bananas	N	Papaya	I, H
Bell pepper	I, H	Pineapple	I, N, H
Carambola	I, C	Rambutan	I
Citrus	H	Sapodilla	I
Durian	N	Sweetpotatoes	I, F
Eggplant	I, H	Tomatoes	I, H
Italian squash	I, H		

I = irradiation, C = cold, N = non-host status, H = heat (hot water immersion or vapor heat), F = fumigation.

quality of commodities. A generic quarantine treatment is one that provides quarantine security for a broad group of pests. For example, a generic treatment could be applied to all Diptera (flies), or to flies in the family Tephritidae (fruit flies), or to tephritid fruit flies in the genus *Bactrocera*. Before generic treatments can be recommended, information is needed on effective irradiation doses for a wide range of insects within the taxon.

The International Consultative Group on Food Irradiation was the first group to formalize a recommendation for a generic treatment. In 1986, based on irradiation data for many tephritid fruit fly species and a limited number of other insect pests, they proposed a dose of 150 Gy for fruit flies and 300 Gy for other insects (ICGFI, 1991). To date these doses have not been adopted, partly because earlier research showed that fruit flies in Hawaii required 210–250 Gy to prevent adult emergence from infested fruit (Seo et al., 1973). Based on results in Seo et al. (1973), the USDA-Animal Plant Health Inspection Service (APHIS) approved irradiation doses of 250, 225 and 210 Gy for oriental fruit fly, Mediterranean fruit fly, and melon fly, respectively, for exporting fruits and vegetables from Hawaii (Federal Register, 1997). Further irradiation studies were needed with Mediterranean fruit fly, melon fly, and oriental fruit fly in Hawaii to determine whether the approved doses are unnecessarily high and could be reduced (Follett and Armstrong, in press).

Hawaii's sweetpotato [*Ipomoea batatas* (L.) Lam.] growers produce several unique varieties of sweetpotatoes, including a purple-fleshed type, that are in high demand. Hawaii growers are unable to ship sweetpotatoes to the US mainland without a quarantine treatment because of the presence of two quarantine pests: West Indian sweetpotato weevil, *Euscepes postfasciatus* (Coleoptera: Curculionidae), and sweetpotato vine borer, *Omphisa anastomosalis* (Lepidoptera: Pyralidae). Recently, growers have been exporting sweetpotatoes to the US mainland using a fumigation treatment, with production averaging 70,000–100,000 lbs per week or over 3.5 millions lbs per year. Fumigation adversely affects root quality and has become costly.

Irradiation research has been carried out on West Indian sweetpotato weevil in Okinawa as part of a sterile insect release program to eradicate the weevil from the island of Kume. Unpublished reports indicate that an irradiation dose of 150 Gy sterilizes female West Indian sweetpotato weevils. No irradiation research has been performed with sweetpotato vine borer. On July 14, 2003, USDA-APHIS published an interim rule allowing export of irradiated sweetpotato from Hawaii to the US mainland using a conservative irradiation dose of 400 Gy until research demonstrates that a lower dose is effective.

In this paper, I discuss irradiation research in progress in my laboratory (1) to lower the approved irradiation doses to control Hawaii's fruit flies and (2) to identify an effective irradiation dose for two quarantine insect pests of sweetpotato in Hawaii.

2. Materials and methods

2.1. Tephritid fruit flies

Dose–response tests were conducted with wild and lab strains of the melon fly, Mediterranean fruit fly, and oriental fruit fly, both in diet and in fruit. The primary goal was to find an irradiation treatment that would prevent adult emergence when mature third instar fruit flies were irradiated in fruit. For each test, larvae were introduced to the cavity at the center of a papaya (1/4–1/2 ripe), or placed on standard larval rearing diet. Larvae were transferred to papaya or diet 24 h before irradiation to allow larvae to distribute themselves in the media. Irradiation treatment was conducted at Hawaii Pride, a commercial X-ray irradiation facility, using an electron linear accelerator. Detailed dose mapping was conducted before initiating the experiments (Follett and Lower, 2000), and ROW dosimeters (Opti-chromic detectors, FWT-70–83 M, Far West Technology, Goleta, California) were placed in a representative fruit or diet tray at each dose in each replicate to measure dose variation. Depending on the species, dose response tests consisted of 5–8 doses at 10 Gy increments within a range from 20 to 110 Gy. The dose uniformity ratio was <1.2 for all tests. Tests included 300 larvae per dose (150 larvae in each of two fruit and a third fruit with a dosimeter) replicated 4–8 times. After irradiation treatment, fruit were held for 3 weeks while recording adult emergence and testing adult female fertility.

Melon fly was the most radiation-tolerant species. Large-scale confirmatory tests with melon fly involved

irradiation of late third instars in papayas (as described above) at 120 and 150 Gy. Each test included approximately 4800 larvae and tests were repeated more than 10 times at each dose. Treatments were calibrated so that the maximum absorbed dose was always less than the target dose. Additional large-scale tests with melon fly were conducted using naturally infested papayas containing late third instars. Large-scale tests are being repeated with oriental fruit fly and Mediterranean fruit fly.

Dose–response data were subjected to linear regression and analysis of covariance using the standard least-squares model. Data used in the linear regression model included any irradiation dose causing mortality between 0% and 100%, and the lowest dose causing 100% mortality. For each replicate, mortality values $<100\%$ were adjusted for control mortality. Percentage mortality data were arcsine transformed to help normalize the distribution before statistical analysis (SAS Institute, 2000). Covariance analysis requires the slopes of the regression lines fitted to each group to be parallel, so the assumption of parallelism (non-significant treatment $\times$ dose interaction effect) was tested for all groups before comparing intercepts (treatment effects).

2.2. Sweetpotato insects

Naturally infested sweetpotato roots were collected from an abandoned field and irradiated the following day. Roots infested with sweetpotato vine borer were identified by inspection for small "windows" at the root surface that indicate the presence of late instars or pupae. An equal number of roots were randomly assigned to four nominal treatment doses (0, 100, 200 and 400 Gy). The experiment was repeated on four dates, which served as replicates. Collectively all roots treated at each dose weighed approximately 2.8 kg in the first replicate and 3.4 kg in subsequent replicates. Irradiation treatment was conducted at a commercial X-ray irradiation facility (Hawaii Pride LLC, Keeau, Hawaii), using an electron linear accelerator. Dosimeters were placed inside two representative roots at each dose in each replicate to measure dose variation. Measured doses were 94 (range 85–97), 186 (range 176–197), and 365 (range 356–383), for the 100, 200 and 400 Gy treatments, respectively. Data were taken on adult emergence.

3. Results and discussion

3.1. Tephritid fruit flies

The three fruit fly species differed in their tolerance of irradiation when treated in papaya (Fig. 1). Slopes of the regressions on transformed data were not significantly

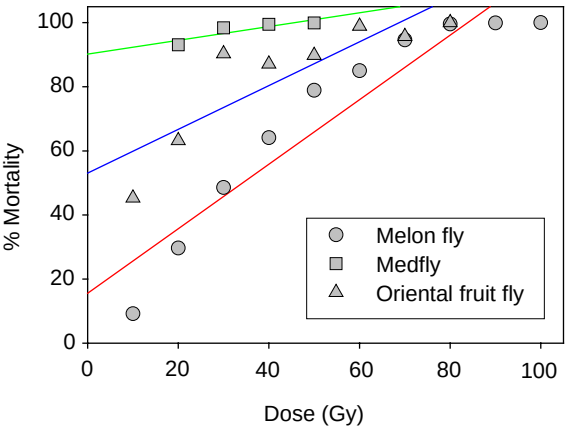

Fig. 1. Effect of irradiation dose applied to mature third instars on fruit fly mean mortality (prevention of adult emergence).

different for comparisons between melon fly and oriental fruit fly ($F = 3.2$, $df = 1,3$, $P = 0.08$), melon fly and Mediterranean fruit fly ($F = 3.1$, $df = 1,3$, $P = 0.08$), and oriental fruit fly and Mediterranean fruit fly ($F = 0.7$, $df = 1,3$, $P = 0.40$), indicating that slopes were parallel. Intercepts were highly significantly different for all pairs; melon fly was significantly more tolerant of irradiation than oriental fruit fly ($F = 31.8$, $df = 1,2$, $P = 0.001$) and Mediterranean fruit fly ($F = 56.6$, $df = 1,2$, $P = 0.0001$), and oriental fruit fly was more tolerant of irradiation than Mediterranean fruit fly ($F = 43.9$, $df = 1,2$, $P = 0.0001$). The predicted doses to achieve 100% mortality were 83.8, 67.0, and 45.6 Gy for melon fly, oriental fruit fly, and Mediterranean fruit fly, respectively. Melon flies and oriental fruit flies used in the tests were wild strains, and Mediterranean fruit flies were the "Maui med 2000" laboratory strain.

Analysis also showed that wild and laboratory strains of melon fly were not significantly different in their tolerance of irradiation ($F = 1.8$, $df = 1,2$, $P = 0.18$) suggesting these strains could be used interchangeably in irradiation tests. Melon fly was significantly more tolerant of irradiation when treated in fruit compared with diet ($F = 23.2$, $df = 1,2$, $P = 0.001$), indicating that irradiation tests should always be conducted using insects in the host commodity (Follett and Armstrong, in press).

Based on dose response data, 120 Gy was selected for large-scale confirmatory testing with wild melon fly (the most tolerant species) in papaya. Approximately 50,000 melon fly mature third instars were treated and 1 adult capable of flight survived and several pupae were partially emerged. An irradiation dose of 150 Gy applied to 62,400 artificially inoculated and an estimated 31,266 naturally infested melon fly third instars (93,666 total)

Table 2
Emergence of adult sweetpotato vine borers after irradiation of mixed-age larvae and pupae naturally infesting sweetpotatoes

No. of adults emerged					
Dose (Gy)	Replicate				Mean (±SE)
	1	2	3	4	
0 (control)	36	56	48	56	49.0 (±4.7)a
100	4	2	0	2	2.0 (±0.8)b
200	1	0	2	4	1.8 (±0.9)b
400	0	0	0	0	0.0 (±0.0)b

Means followed by different letters are significantly different ($P<0.05$) by Tukey's test.

resulted in 0 survivors to the adult stage and no pupae were partially emerged.

An irradiation dose of 150 Gy is approved for eight species of tephritid fruit flies (Federal Register, 2002). Our data suggest 150 Gy is also an effective dose to control melon fly, oriental fruit fly, and Mediterranean fruit fly, and supports a generic dose of 150 Gy for all tephritid fruit flies (Hallman and Loaharanu, 2002; Follett and Armstrong, in press). Approving lower doses may be advantageous to lower the costs of treatment and increase product throughput by decreasing the required time for treatment. Although most fruits are tolerant of irradiation (e.g. Follett and Sanxter, 2003), lowering doses may also permit the treatment of radiation sensitive fruits such as avocado. The idea of generic doses is appealing because it would greatly accelerate the process of approving irradiation quarantine treatments for specific crops, and thereby rapidly expand exports.

3.2. Sweetpotato insects

Irradiation of sweetpotato roots resulted in a significant reduction ($P<0.05$) in emerged adult moths at all doses tested (Table 2). At 400 Gy no moths emerged. Detailed tests are in progress to determine the most tolerant life stage of the sweetpotato vine borer and the West Indian sweetpotato weevil, and to identify specific doses for large-scale confirmatory testing. Rates of sterility will be measured in addition to adult emergence. Results from ongoing studies with the adult stage of the two pests suggest <250 Gy may be sufficient to prevent reproduction. Irradiation treatment is a viable alternative to chemical fumigation for sweetpotato growers.

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