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Gamma Radiation and Cold Treatments for the Disinfestation of the Mediterranean Fruit Fly in California-Grown Oranges and Lemons[1]

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ABSTRACT: Low-dose gamma radiation and cold treatments were tested for their effectiveness in the disinfestation of the Mediterranean fruit fly, *Ceratitis capitata*, from California-grown navel oranges and Calfame lemons. Cold treatments were applied for 7, 14, or 21 days to simulate postharvest storage and/or shipment durations and temperatures (5.5°C for oranges and 11.1°C for lemons). Low-dose gamma radiation treatments were applied at various dosages, both independent of and in tandem with cold treatments.

The results of egg hatchability and larval survival studies show that a synergistic effect is observed when gamma radiation and cold treatments are used in tandem. The data show that infested navel oranges stored for 14–21 days at 5.5°C required a radiation dose of 0.30 kGy or less to result in very low, or no, hatch of mature medfly eggs. Furthermore, identical treatment of mature medfly larvae resulted in no adult eclosion from pupae. Shorter durations of cold storage, however, require considerably higher dosages to observe similar mortality rates and may not be desirable as fruit quality may be affected at these higher dosages.

Calfame lemons require higher dosages than oranges to observe similar mortality rates at the same cold treatment durations due to the higher temperature (11.1°C) at which they are stored. The data show that irradiation at 0.30 kGy with cold storage of 21 days or irradiation at 0.50 kGy with cold storage of 14 days is sufficient to cause nearly total egg mortality.

THE CONTINUAL INVASION of the Mediterranean fruit fly, *Ceratitis capitata* (Wiedemann), into California and the ban by the Environmental Protection Agency of the use of ethylene dibromide (EDB) as a chemical fumigant have renewed interest in alternative methods for the disinfestation of export fruit and vegetable commodities. Low-dose gamma radiation and cold treatments are two alternative methods of disinfestation that leave no harmful residues as do some chemical fumigants. In addition, cold and radiation treatments may delay ripening in many fruits, thereby increasing the shelf life of the commodity.

Research has already shown gamma radiation (Balock et al. 1963, 1966; Benschoter and Telich 1964; Bughio et al. 1969; Burditt et al. 1971; MacFarlane 1966; Seo et al. 1973, 1974; Shipp and Osborn 1968; Thomas and Rahalkar 1975) and cold (Back and Pemberton 1916; Mason and McBride 1934; Rivnay 1941; Shoukry and Hafez 1979; Sproul 1976) to be effective treatments for fruit fly disinfestation in some export fruit commodities. However, none of these studies have reported on the effectiveness of a combination of gamma radiation and cold treatments.

We report here the results of studies on the effectiveness of gamma radiation and cold treatments in the disinfestation of the Mediterranean fruit fly (medfly) from California-grown navel oranges and Calfame lemons. The effects of low temperatures (5.5°C for oranges and 11.1°C for lemons) were investigated both

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independent of and in tandem with gamma radiation to simulate postharvest storage and/or shipment durations and temperatures. Other studies on the effectiveness of gamma radiation alone on several varieties of stone and pome fruits are reported by Moy et al. (1983) and Kaneshiro et al. (1983, 1985).

MATERIALS AND METHODS

The flies used in this study were obtained as pupae from the U.S. Department of Agriculture (USDA)/Agricultural Research Service (ARS) Tropical Fruit and Vegetable Laboratory in Hawaii. Approximately 2000 pupae were obtained, placed in a cage (122 × 61 × 61 cm) enclosed on four sides by fine-mesh screen (see Kaneshiro et al. 1983 for details), and maintained for 8 weeks. One cage was started every 2 weeks, and four cages rotated to provide a constant supply of mature gravid females.

The navel oranges and Calfame lemons were obtained directly from the California Department of Food and Agriculture in cartons flown to Hawaii. The fruits were kept in a refrigerator at 4°C until used for experimentation.

A cobalt-60 gamma radiation source (the Hawaii Research Irradiator) located at the University of Hawaii at Manoa was used to irradiate the medfly eggs and larvae. The dosage rates for the period of this study ranged from 0.049 to 0.047 kGy/min.

Egg Hatchability Studies

Oranges and lemons used for egg hatchability studies were placed in a cage containing the medflies for 4 hr to allow oviposition. Following infestation, the fruits were placed in a 46 × 30 × 15-cm rearing box with an organdy cloth cover and held at 20°C for 76 hr before treatment. Eggs approximately 76 hr old were used because older eggs have been shown to be more resistant to irradiation than younger eggs (Balock et al. 1963, Kaneshiro et al. 1983).

Fruits thus infested and incubated were immediately treated and the eggs carefully dissected out of the fruits following treatment. The eggs were removed from the fruit and placed on a 5-cm-square piece of green blotting paper, moistened with distilled water, and placed in a covered petri dish to prevent desiccation. The eggs were then arranged on the paper with a fine-tipped camel-hair brush to facilitate tabulation.

Two studies of the effects of cold treatment alone on medfly egg hatchability were carried out. The first study was conducted to determine whether any difference in egg hatchability could be observed between eggs incubated outside the fruit (in petri dishes) and eggs incubated within the fruit. Whole oranges infested with medfly eggs, as well as eggs that were dissected out of infested oranges, were incubated at 5.5°C for 7, 14, or 21 days. A control group of eggs that were also dissected out of oranges was held at 20°C. Immediately after the incubation period the eggs in the oranges were dissected out, and daily egg hatch counts were made of all eggs.

The second study of the effects of cold treatment alone on medfly egg hatchability was conducted to investigate the time required for egg hatch to occur following removal of the mature eggs from incubation at 5.5°C. At the time cold treatments were first initiated, it was noted that incubation at 5.5°C appeared to cease further development of the eggs (no egg hatch was observed during incubation at 5.5°C) and that following removal from the cold, development resumed at its normal rate. In order to confirm our observations, eggs were obtained from the USDA/ARS medfly stock using plastic egging devices similar to those described by Hart and Miyabara (1968). Eggs thus obtained were placed on moistened blotting paper in 22 petri dishes, 50 eggs per dish. One plate was left out at 20°C while the other 21 dishes were placed at 5.5°C. Each day for 21 days thereafter, one dish was removed from the incubator and the eggs allowed to develop at 20°C; the hatch rate was then recorded daily.

Infested fruits (oranges and lemons) to be tested for the effects of cold and/or radiation were left untreated or irradiated with varying dosages of gamma radiation. Following treatment, the fruits were dissected, and up to 1000

eggs were removed from each fruit. These eggs were then equally divided between two petri dishes to form two identical sets of eggs. One set was placed in cold storage (5.5°C for oranges and 11.1°C for lemons) for 7, 14, or 21 days while the second set remained at 20°C. Daily egg hatch counts were made, and any first instar larvae that hatched were placed on slices of fruit to observe further development.

Some egg hatch was observed with eggs from lemons while in cold storage at 11.1°C. In this case, the first instar larvae obtained from the eggs were placed in fruit slices and returned to cold storage at 11.1°C for the remainder of the scheduled incubation period.

Larval Survival Studies

We used similar procedures for the larval survival studies. Only the incubation temperatures for cold treatments differed between the fruit types (5.5°C for oranges and 11.1°C for lemons). Eggs obtained from plastic egging vials, previously described, were placed on moistened blotting paper in petri dishes and maintained at 20°C until hatching. The resulting first instar larvae were then carefully removed from the paper using a fine camel-hair brush and placed into holes made in the fruit with a fine dissecting needle. Fifty larvae were implanted per fruit, and these "infested" fruits were maintained at 20°C for 8 days. One fruit was then dissected, and if the majority of the larvae in the fruit were found to be in the third instar (mature) stage of development, the remaining fruit were then treated with gamma radiation and/or cold. All treatments were carried out using mature larvae because this stage was found to be the most resistant to radiation treatment (Kaneshiro et al. 1983).

All fruits were placed in rearing boxes on 1/4-in.-mesh hardware cloth, which held the fruits suspended above the bottom of the box. Vermiculite was spread on the bottom of the box to provide a dry medium in which the larvae could pupate. The vermiculite in the boxes of "infested" fruit held at 20°C was sifted after 2–3 weeks to extract any pupae that had developed in them. Boxes that had been incubated in the cold were sifted once immediately after removal from the cold and again 2–3 weeks later. During the final sifting of all boxes, the fruits were broken open and checked for live larvae. If any live larvae were found, the fruits were placed back into the rearing box and held for a few additional days. Any pupae sifted from the rearing boxes were counted and placed into 1-pt paper cartons and held for 6 weeks, by which time all adults should have eclosed.

RESULTS

Egg Hatchability Studies

Table 1 presents data showing the effects of cold treatment (5.5°C) for varying time intervals on medfly eggs treated outside and within California navel oranges. These data show

TABLE 1

EFFECT OF COLD TREATMENT ALONE ON MEDFLY EGG HATCHABILITY IN CALIFORNIA NAVEL ORANGES

TREATMENT	INCUBATION PERIOD AT 5.5°C			
	7 DAYS	14 DAYS	18 DAYS	21 DAYS
Control, 20°C*	1187/1359 (87.34)	1337/1723 (77.60)	803/1000 (80.30)	283/364 (77.75)
Petri dish, 5.5°C	568/968 (58.68)	119/2304 (5.16)	0/833 (0.00)	0/745 (0.00)
Infested fruit, 5.5°C	633/1313 (48.21)	73/1852 (3.94)	9/1077 (0.84)	0/683 (0.00)

NOTE: Numbers shown are no. eggs hatched/total no. eggs obtained. Percent hatch is shown in parentheses.

* This treatment was not incubated at 5.5°C, and the data sets for 7, 14, 18, and 21 days may be combined. They are reported separately here because they were run simultaneously with those incubated at 5.5°C as controls.

TABLE 2

EFFECT OF RADIATION AND COLD TREATMENTS ON EGG HATCHABILITY OF THE MEDFLY IN CALIFORNIA NAVEL ORANGES

TREATMENT	INCUBATION PERIOD AT 5.5°C		
	7 DAYS	14 DAYS	21 DAYS
Control, 20°C*	1323/1730 (76.47)	712/918 (77.56)	2108/2500 (84.32)
Control, 5.5°C	1224/1728 (70.83)	43/1178 (3.65)	5/2500 (0.20)
0.30 kGy, 20°C*	563/1841 (30.58)	380/762 (49.87)	1584/2234 (70.90)
0.30 kGy, 5.5°C	4/1741 (0.23)	1/2761 (0.04)	0/3733 (0.00)
0.40 kGy, 20°C*	13/1000 (1.30)	—	—
0.40 kGy, 5.5°C	4/2000 (0.20)	—	—
0.50 kGy, 20°C*	3/1441 (0.21)	1/1060 (0.09)	310/1880 (16.49)
0.50 kGy, 5.5°C	0/2649 (0.00)	0/1040 (0.00)	0/1880 (0.00)

NOTE: Numbers shown are no. eggs hatched/total no. eggs obtained. Percent hatch is shown in parentheses.

* These treatments were not incubated at 5.5°C, and the data sets for 7, 14, and 21 days may be combined. They are reported separately here because they were run simultaneously with those incubated at 5.5°C as controls.

that no apparent difference in egg hatchability was observed between eggs incubated outside and eggs incubated inside the fruit. Therefore, in subsequent experiments, eggs were dissected out of the fruits immediately after radiation treatment and placed in petri dishes containing moistened blotting paper for cold treatment. Table 1 also shows that cold treatment alone appears to cause total, or nearly total, egg mortality when the eggs are incubated at 5.5°C for approximately 21 days. This finding was consistent with that of Mason and McBride (1934), Rivnay (1941), and Back and Pemberton (1916).

Data of the separate and combined effects of cold storage and radiation treatment on medfly egg hatchability in navel oranges are reported in Table 2. The data from this table indicate that a synergistic effect is observed at all incubation intervals and radiation dosages when cold and radiation treatments are combined. For example, note that irradiation at 0.30 kGy followed by incubation at 5.5°C for only 7 days results in approximately 99% mortality. However, irradiation at 0.30 kGy without cold treatment results in approximately 30% egg hatch after 7 days, and cold treatment alone for 7 days results in 70% egg hatch.

The higher incubation temperature (11.1°C) used for lemons (as compared to 5.5°C used for oranges) made it necessary to use higher radiation dosages and/or longer incubation intervals to obtain egg mortality levels similar to those observed in oranges. Nevertheless, egg hatchability studies of medfly eggs in California Calfame lemons also revealed a synergistic effect in egg mortality when cold and radiation treatments were combined (Table 3).

Some inconsistencies were observed in the data presented in Tables 2 and 3, however, as shown in the experiments in which the eggs remained at 20°C. All eggs kept at 20°C after treatment were never subjected to cold treatment intervals of 7, 14, or 21 days but are reported in these intervals because they were run simultaneously with the cold-treated eggs. Thus, the percent hatch should be consistent among the 7-, 14-, and 21-day-interval experiments of eggs subjected to the same dosages and maintained at 20°C. Some of these experiments, however, produced inconsistent results (e.g., at the 0.50 kGy dosage, a range of 0–45% hatch was observed). This type of in-

TABLE 3

EFFECT OF RADIATION AND COLD TREATMENTS ON EGG HATCHABILITY OF THE MEDFLY IN CALIFORNIA CALFAME LEMONS

TREATMENT	INCUBATION PERIOD AT 11.1°C		
	7 DAYS	14 DAYS	21 DAYS
Control, 20°C*	1415/1697 (83.38)	1139/1551 (73.44)	1513/1762 (85.87)
Control, 11.1°C	1013/1683 (60.19)	1487/2551 (58.29)	392/1752 (22.37)
0.30 kGy, 20°C*	—	—	0/579 (0.00)
0.30 kGy, 11.1°C	—	—	0/578 (0.00)
0.50 kGy, 20°C*	814/1831 (44.46)	28/1760 (1.59)	0/718 (0.00)
0.50 kGy, 11.1°C	365/1833 (19.91)	0/1778 (0.00)	0/708 (0.00)
0.60 kGy, 20°C*	0/786 (0.00)	4/1404 (0.28)	0/575 (0.00)
0.60 kGy, 11.1°C	0/785 (0.00)	0/1373 (0.00)	0/575 (0.00)
0.75 kGy, 20°C*	0/1000 (0.00)	—	—
0.75 kGy, 11.1°C	0/1000 (0.00)	—	—

NOTE: Numbers shown are no. eggs hatched/total no. eggs obtained. Percent hatch is shown in parentheses.

*These treatments were not incubated at 11.1°C, and the data sets for 7, 14, and 21 days may be combined. They are reported separately here because they were run simultaneously with those incubated at 11.1°C as controls.

consistency in controls occurred to lesser and greater degrees in similar studies with other fruit types (Kaneshiro et al. 1983, 1985).

It appears that some critical parameter(s) was not controlled properly, and this caused the observed inconsistencies to appear. Kaneshiro et al. (1983) attribute inconsistencies in egg hatchability in stone fruits to the condition and type of fruit used. They show that eggs submerged in liquid were much less susceptible to radiation treatment; therefore, overripeness, bruised areas, and high water content of fruits may contribute to the extremely high hatch observed in some of their experiments. This does not seem to be true for citrus, however, as eggs are found in the rind, which is relatively dry and does not bruise or liquefy easily. The large variance observed in hatchability between equally treated eggs was probably due, in this case, to a difference in the developmental age of the eggs. Although all the infested fruits were maintained for approximately 76 hr at 20°C before treatment, the developmental stage of the eggs may have varied substantially due to temperature variations. Our incubation period was primarily over weekends and, at times, the air conditioning system malfunctioned. At these times the temperature rose by as much as 5°C by Monday morning. Temperature increases in this range cause medfly development to proceed faster (Back and Pemberton 1916) and may have caused variances in the developmental, but not temporal, age of the eggs. Thus, some experiments may have had more resistant eggs than others of the same chronological age because of the difference in developmental ages of the eggs at the time of treatment.

All the first instar larvae (from both oranges and lemons), which were placed on fruit slices after developing from treated eggs, died before pupation was achieved. Indeed, in all cases, development was not observed beyond the second larval instar stage.

The results presented in Table 4 show that incubation at 5.5°C for up to 2 days does not appear to have any effect on egg hatch or

TABLE 4

NUMBER OF EGGS HATCHING 1–7 DAYS FOLLOWING INCUBATION AT 5.5°C FOR 0–22 DAYS

DAYS INCUBATED AT 5.5°C	DAYS AFTER REMOVAL FROM 5.5°C							HATCH (%)
	1	2	3	4	5	6	7	
0	44	2	0	0	0	0	0	92.0
1	43	3	0	0	0	0	0	92.0
2	36	8	0	0	0	0	0	88.0
3	18	28	0	0	0	0	0	92.0
4	21	21	1	0	0	0	0	86.0
5	12	35	0	0	0	0	0	94.0
6	0	39	2	0	0	0	0	82.0
7	3	30	3	1	0	0	0	74.0
8	0	27	8	0	0	0	1	72.0
9	0	33	5	0	0	0	0	76.0
10	1	25	2	0	0	0	0	56.0
11	0	9	4	0	1	0	0	28.0
12	0	0	2	0	0	0	0	4.0
13	0	2	0	1	0	0	0	6.0
14	0	1	2	0	0	0	0	6.0
15	0	0	0	0	0	0	0	0.0
16	0	0	0	0	0	0	0	0.0
17	0	0	0	0	0	0	0	0.0
18	0	0	0	0	0	0	0	0.0
19	0	0	0	0	0	0	0	0.0
20	0	0	0	0	0	0	0	0.0
21	0	0	0	0	0	0	0	0.0

TABLE 5

EFFECT OF COLD TREATMENT ALONE ON MEDFLY LARVAL SURVIVAL IN CALIFORNIA NAVEL ORANGES

TREATMENT	NUMBER OF LARVAE IMPLANTED	NUMBER PUPATED	% PUPATED	NUMBER ECLOSED
Control, 20°C*	400	142	35.50	127
5.5°C for 7 days	500	125	25.00	112
Control, 20°C*	500	88	17.60	74
5.5°C for 14 days	600	31	5.17	20
Control, 20°C*	500	65	13.00	58
5.5°C for 21 days	650	4	0.62	3

* These treatments were not incubated at 5.5°C, and the data sets for 7, 14, and 21 days may be combined. They are reported separately here because they were run simultaneously with those incubated at 5.5°C as controls.

development other than the cessation of development during the incubation period. However, incubation for 3–5 days delays egg hatch by 1 day following removal from the cold with no adverse affects on egg hatchability. Incubation for 6–10 days results in virtually no hatch 1 day after removal from the cold with a lowering of egg hatchability. Eggs incubated in the cold for 11–14 days showed a continued decline in egg hatchability and an increase in the time required to obtain hatch after removal from the cold. No hatch was obtained from eggs incubated for 15 days or longer at 5.5°C.

Larval Survival Studies

The results of larval survival studies in California navel oranges are reported in Tables 5 and 6 and for California Calfame lemons in Table 7. Table 5 shows the effects of cold treatment alone on medfly larval survival.

TABLE 6

EFFECT OF RADIATION AND COLD TREATMENTS ON MEDFLY LARVAL SURVIVAL IN CALIFORNIA NAVEL ORANGES

	7 DAYS				14 DAYS				21 DAYS			
TREATMENT	NUMBER OF LARVAE IMPLANTED	NUMBER PUPATED	% PUPATED	NUMBER ECLOSED	NUMBER OF LARVAE IMPLANTED	NUMBER PUPATED	% PUPATED	NUMBER ECLOSED	NUMBER OF LARVAE IMPLANTED	NUMBER PUPATED	% PUPATED	NUMBER ECLOSED
Control, 20°C*	450	100	22.22	98	450	83	18.44	74	450	87	19.33	85
Control, 5.5°C	450	77	17.11	51	450	4	0.89	0	350	1	0.29	0
0.30 kGy, 20°C*	100	12	12.00	0	100	49	49.00	0	—	—	—	—
0.30 kGy, 5.5°C	100	12	12.00	0	100	11	11.00	0	—	—	—	—
0.50 kGy, 20°C*	200	42	21.00	0	200	61	30.50	0	100	5	5.00	0
0.50 kGy, 5.5°C	200	6	6.00	0	200	5	2.50	0	100	0	0.00	—
0.60 kGy, 20°C*	1000	66	6.60	0	1000	66	6.60	0	1000	66	6.60	0
0.60 kGy, 5.5°C	1000	1	0.10	0	1000	0	0.00	—	1000	0	0.00	—
0.75 kGy, 20°C*	100	26	26.00	0	100	4	4.00	0	200	23	11.50	—
0.75 kGy, 5.5°C	100	7	7.00	0	100	0	0.00	—	250	0	0.00	—

*These treatments were not incubated at 5.5°C, and the data sets for 7, 14, and 21 days may be combined. They are reported separately here because they were run simultaneously with those incubated at 5.5°C as controls.

TABLE 7

EFFECT OF RADIATION AND COLD TREATMENTS ON MEDFLY LARVAL SURVIVAL IN CALFAME LEMONS

	7 DAYS				14 DAYS				21 DAYS			
TREATMENT	NUMBER OF LARVAE IMPLANTED	NUMBER PUPATED	% PUPATED	NUMBER ECLOSED	NUMBER OF LARVAE IMPLANTED	NUMBER PUPATED	% PUPATED	NUMBER ECLOSED	NUMBER OF LARVAE IMPLANTED	NUMBER PUPATED	% PUPATED	NUMBER ECLOSED
Control, 20°C*	100	20	20.00	13	100	10	10.00	0	100	8	8.00	8
Control, 11.1°C	150	4	2.67	3	200	2	1.00	0	200	3	3.00	1
0.50 kGy, 20°C*	200	0	0.00	—	200	0	0.00	—	200	0	0.00	—
0.50 kGy, 11.1°C	200	0	0.00	—	200	0	0.00	—	200	0	0.00	—
0.75 kGy, 20°C*	200	1	0.50	0	200	0	0.00	—	200	0	0.00	—
0.75 kGy, 11.1°C	200	0	0.00	—	200	0	0.00	—	200	0	0.00	—

*These treatments were not incubated at 11.1.°C, and the data sets for 7, 14, and 21 days may be combined. They are reported separately here because they were run simultaneously with those incubated at 11.1°C as controls.

These data show that only a very low percentage of treated larvae survive to pupate and eclose as adults. This generally supports the findings of Back and Pemberton (1915) that citrus is a relatively poor host for medfly. Table 6 presents data on the effects of radiation and cold treatment on mature medfly larvae in oranges. These data show that a synergistic effect is obtained when radiation and cold treatments are used in tandem. Although no adults eclosed from any of the radiation dosages used, a much lower percentage of the larvae pupated when subjected to cold treatment following irradiation. The larval survival data from lemons (Table 7) show that no pupation was observed from any of the dosages used in this study.

DISCUSSION

Previous studies of gamma radiation as a possible treatment for disinfestation of the Mediterranean fruit fly from fruit commodities (see references at the beginning of this paper) have reported procedures designed to enable the calculation of the probit 9 quarantine security level. This security level (developed by Baker 1939) requires that a given treatment result in 99.9968% mortality of the target organism in an estimated population of 100,000 treated individuals. Burditt and Seo (1971) determined that 26 krad (0.26 kGy) was the minimum absorbed dose necessary to prevent adult emergence from pupae at the probit 9 security level for the three species of fruit flies in Hawaii [i.e., *Dacus dorsalis* Hendel, *D. cucurbitae* Coquillett, and *Ceratitis capitata* (Weidemann)] in tropical fruit.

The procedures used in our studies differed considerably from those used previously for reasons given in detail by Ohta et al. (1985). Briefly, our methods differed from those previously used because we observed relatively high levels of egg hatch at the 0.26-kGy dosage level, with the larvae developing into the third instar (mature) stage. This would certainly lower the marketability of the fruits and may even cause importing countries to reject such shipments containing live larvae. In addition, we felt that treatment should be completed with the eggs in situ (i.e., inside the fruit) to observe any effects the fruits may have on the eggs before and during treatment.

The procedures described above make it evident that only a relatively small sample size can be obtained per treatment for any given fruit variety. These relatively small sample sizes make any extrapolation to the probit 9 security level meaningless. However, we felt the amount of additional information gained by using the procedures described above justified sacrificing the probit 9 analysis.

The use of irradiation for the disinfestation of California navel oranges and Calfame lemons is certainly a viable alternative from our standpoint. Citrus fruits have been shown to be poor hosts for medfly even without treatment of any kind (Back and Pemberton 1915). Furthermore, Keck (1934) has shown that oviposition punctures from fruit flies on citrus causes premature dropping of the fruit as well as promoting mold formation. Therefore, aside from the natural defenses of the fruits, an alert crew of pickers and inspectors should be able to cull much of the infested fruit before treatment is applied.

Our data show that if oranges are stored for 14–21 days at 5.5°C, only a relatively low dose of radiation (0.30 kGy) is necessary to satisfy quarantine requirements in oranges. At these treatment levels, very low, or no, hatch was observed when mature medfly eggs were irradiated (Table 2), and no adult eclosion was observed when mature larvae were irradiated (Table 6). Unfortunately, time did not allow us to study the effects of dosages lower than 0.30 kGy; therefore, it may be possible to further lower the radiation dose required to disinfest oranges.

Shorter durations of cold storage for navel oranges require considerably higher dosages of radiation to obtain high egg mortality. As much as 0.50–0.60 kGy is required for fruits incubated at 5.5°C for 7 days. These higher dosages may not be desirable, however, as dosages above 0.30 kGy may significantly affect the quality of navel oranges (MacFarlane and Roberts 1968).

California Calfame lemons may require higher dosages due to the higher temperature (11.1°C) at which they are stored. Our data

show that no hatch was obtained when lemons were irradiated at 0.30 kGy and incubated for 21 days. For the 14-day incubation period, a 0.50-kGy radiation dosage appears sufficient to cause a very high, if not total, egg mortality. Lower dosages were not completed with lemons; therefore, we were not able to predict the lowest dosage at which similar results would be obtained. It is possible, however, that a 0.30-kGy dose and an incubation period of 14–21 days also is adequate for the disinfestation of medfly from lemons.

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