Damage to Raisins, Almonds, and Walnuts by Irradiated Indianmeal Moth and Navel Orangeworm Larvae (Lepidoptera: Pyralidae)

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ABSTRACT Damage to raisins, almonds, and walnuts due to feeding by irradiated larvae of the Indianmeal moth, *Plodia interpunctella* (Hübner), and the navel orangeworm, *Amyelois transitella* (Walker), was determined. Larvae of both species were reared on bran diet. Age of the larvae when irradiated was 8 d for Indianmeal moth and 13 d for navel orangeworm. Larvae were irradiated with doses ranging from 337 to 497 Gy (gray) before transfer to almonds, walnuts, and raisins. Adult emergence was prevented by all doses. In products containing irradiated larvae, damage was consistently reduced. The percentage of weight losses of almonds infested with untreated Indianmeal moth and navel orangeworm larvae and of walnuts infested with untreated navel orangeworm larvae was significantly higher than the percentage of weight loss of those infested with irradiated larvae. Radiation also improved the overall appearance of the product by reducing webbing and frass. These results indicate that although radiation-induced mortality may be delayed, damage to product quality due to infestation by larvae would be significantly reduced.

KEY WORDS Insecta, gamma radiation, *Plodia interpunctella, Amyelois transitella*

MOST OF THE U.S. DRIED FRUIT and nut crop is produced in California (USDA 1985). A major problem in the production and processing of these products is the presence of postharvest insect infestations. Particularly important are two pyralid moths, the Indianmeal moth, *Plodia interpunctella* (Hübner), and the navel orangeworm, *Amyelois transitella* (Walker). The Indianmeal moth is capable of repeated infestation of and reproduction in the product during storage. Infestations by the navel orangeworm commonly originate in the field and are carried into storage; adults do not reproduce under storage conditions (Simmons & Nelson 1975). Larvae of both insects not only reduce the quality of products by their presence and production of webbing and frass, but they also inflict direct damage by feeding.

The dried fruit and nut industry relies on chemical fumigants such as methyl bromide and hydrogen phosphide for control of postharvest insect infestations. Concern over dependence on these chemicals has prompted research into alternative methods. The U.S. Food and Drug Administration recently approved the use of low doses ($\leq$1.0 kGy)[1] of ionizing radiation in foods (Young & Bowen 1986). The use of radiation as a substitute for fumigation of dried fruit and nuts is being considered. Short treatment times and the lack of chemical residues are advantages of disinfestation by radiation.

Low doses of gamma radiation applied to lepidopterous pupae and adults reduce or prevent their reproduction (Brower & Tilton 1970, 1971, 1972; Tilton et al. 1978; Johnson & Vail 1987). Similar doses applied to larvae prevent pupation or adult emergence (Husseiny & Madsen 1964, Cogburn et al. 1966, Brower 1980, Johnson & Vail 1988). Because irradiation does not produce immediate mortality, the extent of feeding damage sustained by the product after treatment must be evaluated to determine the efficacy of the method. Here we report the results of a 1985 study designed to evaluate posttreatment feeding damage by irradiated Indianmeal moth and navel orangeworm larvae on raisins, almonds, and walnuts.

Materials and Methods

Test insects were reared in plastic cups (30 ml) containing 10 g of wheat bran diet modified from Finney & Brinkman (1967) and Tebbets et al. (1978). The cups were infested with eggs obtained from Indianmeal moth and navel orangeworm colonies reared in our laboratory. Either a standard weight of Indianmeal moth eggs known to approximate 100 eggs or a paper strip carrying 100

[1] The Systeme Internationale (SI) unit for expressing absorbed radiation is the gray (Gy), which replaces the older, more familiar rad. One kilorad (krad) = 10 Gy.

navel orangeworm eggs cut from oviposition paper was added to the diet in each cup. All cups were covered with snap-on lids and held at 27°C, 60% RH, and a 12:12 (L:D) photoperiod until irradiation. The Indianmeal moths and navel orangeworms were irradiated when larvae were about 8 and 13 d old, respectively.

Irradiation was done at the Sandia National Laboratories in Albuquerque, N. Mex. The day before treatment, cups with diet and larvae were placed in racks made by cutting holes in Styrofoam blocks. The racks were packed in insulated plastic ice chests for overnight shipment by air freight to Albuquerque. All treatment cups were irradiated in a cesium-137 chamber irradiator with a dose rate of approximately 12.5 Gy/min. Applied doses were monitored by dosimeters (TLD-400 [LiF]). For each combination of insect and product, five cups were used at each of three doses, including unirradiated controls. Average applied doses used in the almond evaluations were 337 ± 30.5 and 497 ± 49.5 Gy, and 338 ± 17.3 and 486 ± 37.6 Gy in the walnut and raisin evaluations ($\bar{x}$ ± SD). After treatment, all cups were immediately repacked and return to Fresno, Calif.

The products tested were shelled 'nonpareil' almonds, 'Hartley' walnut meats and sun-dried 'Thompson seedless' raisins. Damage by Indianmeal moths was evaluated on all three products; navel orangeworm damage was evaluated on the nuts only. Approximately 24 h after irradiation, test larvae were transferred to Mason jars (0.47 liter) containing 125 g of the selected product. A group of 50 Indianmeal moth or 40 navel orangeworm larvae from a single cup were placed in each jar. The infested products were held at 27°C and ambient RH (22–30%) and examined daily for adult emergence. Adults were collected and their numbers recorded daily. Based on earlier observations on the survival of irradiated larvae (Johnson & Vail 1988), all jars were held for 50 d after irradiation and then were frozen before evaluation.

All of the nuts in each jar were evaluated individually. From each jar of raisins, 150 raisins (approximately 50% of the total) were randomly selected for evaluation. Damage to each nut or raisin was evaluated using a 0–3 rating scale in which 0 is no damage or negligible damage, including nicks that could be machine damage; 1 is slight damage, including one or two small pinholes; 2 is moderate damage, in which up to one-third of the nut or raisin was consumed; and 3 is severe damage, in which one-third or more of the nut or raisin was consumed. The product in each jar was then brushed to remove any frass and weighed.

Commodities were statistically analyzed separately. A damage rating for each replicate was calculated by averaging the ratings of individual nuts or raisins. Untransformed data were subjected to analysis of variance, and significant differences in treatment means ($P \leq 0.05$) were separated by Duncan's (1955) multiple range test.

Table 1. Damage to almonds, walnuts, and raisins caused by irradiated Indianmeal moth (IMM) and navel orangeworm (NOW) larvae

Commodity	Dose, Gy	IMM		NOW	
		Mean damage[a]	% Weight loss[b]	Mean damage[a]	% Weight loss[b]
Almonds	0	1.17a	5.3a	1.49a	8.4a
	337	0.68b	4.2b	0.61b	4.0b
	497	0.55b	4.0b	0.41b	4.0b
Walnuts	0	1.24a	4.2a	2.04a	10.6a
	338	0.23b	1.8b	0.43b	2.3b
	486	0.12b	4.0a	0.13c	2.8b
Raisins	0	1.61a	9.4a	—	—
	338	1.16b	7.8a	—	—
	486	1.20b	8.6a	—	—

For each commodity, means within columns followed by the same letter are not significantly different ($P < 0.05$ level; Duncan's [1955] multiple range test).

[a] Values are based on a damage rating scale of 0–3, with 0, negligible damage and 3, severe damage.

[b] Initial product weight = 125 g.

Results and Discussion

No adults were recovered from any of the products infested with irradiated larvae. Adult emergence from untreated Indianmeal moth and navel orangeworm larvae infesting almonds was 90.8 ± 10.1% and 84.5 ± 8.5%, respectively ($\bar{x}$ ± SD). Adult emergence from untreated larvae reared on walnuts was slightly lower (79.6 ± 6.7%, Indianmeal moth and 62.5 ± 9.8%, navel orangeworm). Emergence of adults from untreated Indianmeal moth larvae infesting raisins was only 33.2 ± 8.3%, suggesting that raisins are a poor diet for development of Indianmeal moth. These results are consistent with earlier studies in which relatively low doses of radiation prevented pupation and adult emergence of Indianmeal moth and navel orangeworm larvae (Husseiny & Madsen 1964, Cogburn et al. 1966, Brower 1980, Johnson & Vail 1988).

Product damage due to feeding by irradiated larvae was reduced when compared with damage caused by untreated larvae (Table 1). In all cases, products infested with untreated larvae showed significantly higher damage ratings than those infested with irradiated larvae.

The percentage of weight loss of nuts infested with untreated navel orangeworm larvae was significantly higher than the percentage of weight loss of nuts infested with irradiated navel orangeworm. Larvae of the Indianmeal moth, which are smaller than navel orangeworm larvae, consumed less of the product; thus, differences in weight loss were harder to detect. Untreated Indianmeal moth larvae caused significantly greater weight loss in almonds than did Indianmeal moth larvae irradiated at either dose, but the weight loss of walnuts with untreated Indianmeal moths was not significantly different from that of walnuts infested with Indianmeal moths irradiated at 486 Gy. The reason for this anomaly is unknown, but it may be due to the difficulty in cleaning the walnuts of frass without losing small fragments of walnuts. No significant differences in percentage of weight loss were detected in any of the raisins infested with Indianmeal moths, even though there were significant differences in damage to raisins examined individually. Because the raisins were held at relatively low humidity for 50 d and then frozen, moisture levels dropped considerably, causing most of the weight change observed in all three treatments.

During evaluations of products infested with irradiated larvae, no pupae and very few prepupae were found. Most irradiated insects were recovered as larvae. Although there was no way to determine how long larvae survived after irradiation, previous work showed that mortality is not immediate. Larvae may live for weeks after treatment and larvae most often died as they attempted to molt to the next stadium or stage (Johnson & Vail 1988).

Radiation improved overall product quality, estimated by visual observation, by reducing webbing and frass production. Although the degree of damage caused by irradiated larvae may seem unacceptable, this derives from the unnaturally high infestation levels used in the test. The densities of larvae used, 50 Indianmeal moth and 40 navel orangeworm larvae per 125 g of product, are much higher than would be found in commercial storage situations. At normal infestation levels, the damage caused by irradiated larvae should be negligible.

Previous research established that the population growth of Indianmeal moth within stored products could be controlled by treatment with 200 to 500 Gy of ionizing radiation (Brower & Tilton 1970, 1971, 1972; Tilton et al. 1978; Johnson & Vail 1987). Although the navel orangeworm is not known to reproduce under storage conditions, its presence is a concern for packers, who fear some reproduction might be possible. Radiation doses capable of controlling Indianmeal moths should be adequate to control navel orangeworms, either by preventing pupation (Johnson & Vail 1988) or by reducing the number of viable adults (Husseiny & Madsen 1964). Unfortunately, these doses do not immediately kill treated insects and may lengthen the normal duration of the larval stage (Brower 1980, Johnson & Vail 1988). To obtain quick mortality of larvae, much higher doses are needed (Papadopoulou 1964). Because of the high cost of radiation and regulations restricting doses to ≤ 1 kGy, a more realistic control criterion would be adult sterility, provided that product damage from feeding larvae is not increased significantly.

Tissue sensitivity to radiation is dependent on the degree of cellular reproductive activity and differentiation (Bergonie & Tribondeau 1959). In feeding insects, cells of the midgut epithelium are continually replaced by groups of undifferentiated regenerative cells. Radiation commonly causes destruction of these regenerative cells and results in histolysis of the midgut epithelium (Ashraf et al. 1971). Reduction in feeding by stored-product beetles has been observed after radiation treatments, with a corresponding decrease in feeding damage (Cornwell 1964, Watters & MacQueen 1967, Brower & Tilton 1973). Our earlier studies with Indianmeal moth and navel orangeworm feeding on artificial diet showed that irradiated larvae ate less and eventually stopped feeding altogether (Johnson & Vail 1988). Results of the present study corroborate those of earlier workers by showing that low doses of radiation reduced damage by Indianmeal moth and navel orangeworm larvae, even though larval mortality may be delayed several weeks.

The biggest disadvantage to the efficacy of radiation treatments for dried fruits and nuts is delayed mortality and the possibility of inspection problems or consumer reaction to living larvae encountered in the product. Careful timing of marketing to provide for delayed mortality, and combining irradiation with alternative treatments, could help to avoid this problem.

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