

Mortality of Navel Orangeworm¹ in a Low Oxygen Atmosphere^{2,3}

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ABSTRACT

Various stages of *Paramyelois transitella* (Walker) were exposed to a modified atmosphere (O₂ < 1%, CO₂ 9–9.5%, balance principally N₂) produced by an exothermic inert atmosphere generator. Exposure times required for 50 or 95% mortality showed that mature larvae, pupae, and 0-, to 1-day-old eggs were more tolerant while young larvae, adults, and eggs ready to hatch were more susceptible. The

generated atmosphere was more toxic at 27° than at 18°C. Pupae, 30 days from the oviposition period, were the most tolerant stage with LT₉₅ values of 38.3 h at 27°C and 145 h at 18°C. Sublethal exposures of adult navel orangeworms to the generated atmosphere significantly reduced the number of progeny produced by surviving adults.

The navel orangeworm, *Paramyelois transitella* (Walker), is found in the southern United States and Mexico but is generally considered a scavenger, except in California. There the insect is a pest of walnuts and almonds, crops that have annual values of \$66 million for walnuts and \$116 million for almonds.⁶

Infestation of almonds by the navel orangeworm starts in the field at the time of "hull crack" and continues through the harvest period and into storage. It has been estimated that during this period there is a \$12 million loss⁷ due to this insect, partly because of the weight loss of the almonds but also because hand labor must be used to remove damaged nuts. Current methods of controlling the navel orangeworm in stored almonds include fumigation with methyl bromide or phosphine and applications of malathion as a protectant. However, methods of control that would not leave residues of insecticide on the almonds would be desirable. One such method that has been effective against other stored product insects in stored grains is controlled atmosphere fumigation (Storey 1975a, b, c). Therefore, such atmospheres were investigated for control of the navel orangeworm in almonds since it is the primary pest at the beginning of storage.

MATERIALS AND METHODS.—The inert atmosphere (oxygen < 1%, CO₂ 9–9.5%, balance principally N₂) was produced in a pilot inert atmosphere treatment system. Oxygen levels in the inert atmosphere were measured daily with a Servomex[®] paramagnetic oxygen analyzer. Although some minor variations occurred during day-to-day operations, the O₂ concn was generally between 0.1 and 0.2% and rarely exceeded 0.5%.

Adult navel orangeworms (ca. 50) were taken from stock cultures the 3rd and 4th day after emergence began and placed in 3.8-liter oviposition jars containing a double layer of filter paper (11 cm diam) placed

diagonally in the jar and another filter paper placed beneath the screened lid. After 24 h, the papers were removed and cut into strips with 25 eggs/strip. Each strip was placed in a 0.47-liter jar containing larval medium (ground wheat, wheat shorts, wheat germ, yeast, sorbic and benzoic acid, honey, glycerin, and water). At 27±1°C and 60±5% RH, development time in this diet was ca. 34–35 days from egg to adult. The development stages and age in days from oviposition at the time of the exposures to the inert atmosphere were: eggs 0–1 and 3–4 days; larvae 7, 14, 21, and 28 days; pupae 30 and 33 days; and adults 38 days.

Treatment temperatures were 27±1° and 18.5±1°C; inert atmosphere was maintained at 50±5% RH. The method of exposure in 0.47-liter jars was that of Storey (1975a). Flow rate through the jars was 25 cc/min. Times of exposure were 8, 12, 24, 36, 48, 72, 96, 120, 144, 168, and 192 h for immature stages and 4, 8, 12, 24, and 48 h for adults. After the exposures, insects were transferred to incubators maintained at 27±1°C and 60±5% RH. Counts of adults emerging from treated and untreated samples began when the 1st emergence was observed in the untreated control (jars held in atmospheric air) and ended 30 days later. Each treatment was replicated 3 times. The time required to kill 50 and 95% of each age group was estimated by transforming mortality data to probits and calculating the regression of probits on time. Lethal times (LT) were then estimated by using the linear calibration technique (Snedecor and Cochran 1967).

The effect of sublethal periods of exposure of adult moths on egg deposition, development, and progeny production also was investigated. Twenty-five unsexed adult moths were collected from adults emerging the 3rd and 4th days after emergence began in stock cultures. (Finney and Brinkman (1967) reported that adults emerging during this time were ca. ½ males and ½ females). When these adults were 2–3 days old, they were exposed to the generated atmosphere at 27±1°C and 50±5% RH in 0.24-liter jars for ½–24 h. Then they were transferred (while still immobilized by the inert atmosphere) to 0.95-liter jars containing 50 g of larval medium and filter papers, 7 cm diam, as ovipositional sites. Each treatment was replicated 3 times. Filter papers were examined daily

¹ Lepidoptera: Pyralidae.

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³ Mention of a proprietary product does not constitute an endorsement by the USDA.

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⁶ Taken from the 1975 Dried Fruit Association of California brochure.

⁷ 1970–1971 California Almond Growers Exchange Annual Report.

Table 1.—Mortality of developing navel orangeworms exposed at 2 temperatures to an atmosphere^a produced by an exothermic inert atmosphere generator.

Stage and Days from Oviposition	LT ₅₀ (h)-(95% Confidence Interval)		LT ₉₅ (h)-(95% Confidence Interval)	
	18°±1°C	27°±1°C	18°±1°C	27°±1°C
Eggs (0-1)	58.1 (31.8-84.3)	10.6 (6.0-15.1)	91.6 (65.5-118.3)	27.6 (23.1-32.2)
Eggs (3-4)	9.7 (0-34.1)	0 (0-11.5)	37.2 (12.3-62.8)	8.4 (0-22.8)
Larvae (7)	13.7 (9.8-17.6)	6.4 (0-13.4)	29.8 (26.0-33.7)	13.6 (6.5-21.0)
Larvae (14)	29.2 (23.4-34.9)	11.9 (4.5-19.4)	52.1 (46.3-58.0)	17.2 (10.0-25.2)
Larvae (21)	97.6 (70.2-125.6)	27.3 (17.1-37.9)	118.4 (91.1-147.4)	37.4 (27.1-48.4)
Larvae (28)	104.5 (97.8-111.3)	26.8 (25.3-28.2)	138.5 (131.7-145.5)	36.9 (35.4-38.4)
Pupae (30)	114.2 (79.6-148.9)	29.2 (27.9-30.5)	145.0 (110.6-180.6)	38.3 (37.0-39.6)
Pupae (33)	66.7 (48.5-85.0)	25.3 (23.6-27.1)	100.1 (81.9-118.7)	34.7 (33.0-36.5)
Adults (38)	18.0 (16.0-20.1)	10.6 (8.6-12.5)	25.1 (23.0-27.3)	16.6 (14.6-18.7)

^a Composition of the inert atmosphere <1% O₂ and 9-9.5% CO₂, balance principally N₂.

for egg deposition, and the jars were observed for evidence of development of progeny. Because the moths were free to deposit eggs on the filter papers and in the medium, no attempt was made to quantify the number or rate of eggs deposited. However, the number of adults that failed to revive or died within 48 h of exposure was recorded, and those that died were removed from the jars. Survivors were left in the jars until they died. The number of adult progeny emerging from each jar was recorded during a 3-week period beginning when with the 1st emergence was observed in the untreated controls.

RESULTS AND DISCUSSION.—Table 1 gives the LT₅₀ and LT₉₅ for each age and stage of the navel orangeworm. Results showed that susceptibility to the generated atmosphere is not the same at each stage and age of development; toxicity to each stage is increased by higher temperatures; and tolerance tends to decrease with increasing age of the egg and pupae but tends to increase with increasing age of the larvae. Adults, 3-, to 4-day-old eggs, and young larvae were the most susceptible at each treatment temperature; mature larvae, pupae, and 1-, to 2-day-old eggs were the most tolerant. An increase in temperature from 18.5-27°C decreased the time required to kill 50 and 95% of a stage, and this decrease was particularly significant among the mature larvae and pupae that were relatively tolerant of the inert atmosphere at the lower temperature.

Somewhat longer exposures to the generated inert atmosphere were required to kill 95% of each stage of the navel orangeworm, particularly the larvae and adult stages, than to kill 100% of each stage of the Indian meal moth, *Plodia interpunctella* (Hübner), and almond moth, *Cadra cautella* (Walker) (Storey 1975b). Thus, a treatment that controlled navel orangeworm also would control Indian meal moths and almond moths.

A sublethal exposure of the adult navel orangeworms to the inert atmosphere reduced the number of progeny produced by the surviving adults (Table 2). Exposures of ½-3 h did not kill any exposed

adults, but the number of 2nd generation adult progeny declined from 123 (ca. the same as the untreated controls) among adults exposed for ½ h to less than 1 progeny from adults exposed for 3 hours. Adults surviving a 4-h exposure deposited viable eggs, but the newly hatched larvae had limited mobility, particularly in the posterior segments, and most died during the 1st week of development. Some eggs were deposited by adults surviving 8-h exposures, but none of the red coloration typical of developing eggs of the navel orangeworm was observed, and none of the eggs hatched. Although more than 1/3 of the adults survived the 12-h exposure, no eggs were found on the filter paper oviposition sites, and no evidence of larval activity was detected in the food medium. Adults in the untreated controls deposited eggs on the filter papers within a few hours after they were placed in the jars, but most of the adults that had been exposed to the generated atmosphere did not deposit eggs until the day after exposure.

The lethality of the low oxygen controlled atmosphere to all life stages of the navel orangeworm

Table 2.—Percent mortality and number of progeny of adult navel orangeworms exposed at 27±1°C to low O₂ atmosphere produced by an exothermic inert atmosphere generator.

Exposure (h)	% Mortality ^a in 48 h	Progeny/25 adults ^a
Control (untreated)	0	122.0
½	0	123.0
1	0	88.0
2	0	1.3
3	0	1.0
4	6	1.0
8	26	0.0
12	64	0.0
24	100	0.0

^a Avg of 3 replicates.

suggests that this method of treatment is a possible alternative to chemical fumigation for the disinfestation of stored almonds.

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