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Mortality of Three Stored Product Moths in Atmospheres Produced by an Exothermic Inert Atmosphere Generator[1,2]

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ABSTRACT

The order of tolerance to an atmosphere of less than 1% O_2 (27°C and 50% RH) produced by an exothermic inert atmosphere generator was: the Angoumois grain moth, *Sitotroga cerealella* (Olivier) —larvae-pupae > eggs > adults; the almond moth, *Cadra cautella* (Walker) — eggs > pupae > larvae > adults; and the Indian meal moth, *Plodia interpunctella* (Hübner) —pupae > eggs > adults > larvae. All stages of the Indian meal moth and all except the eggs of the almond moth were killed by 24-h exposures; eggs of the almond moth required a 48-h exposure. The tolerance of Angoumois grain moth larvae to the inert atmosphere increased with each successive week of growth after the eggs hatched and the larvae entered the wheat kernels. An exposure of 120 h was required to cause 100% mortality of fully grown larvae and pupae.

Oxygen deficient atmospheres produced by exothermic inert atmosphere generators have been found effective for controlling insects in large concrete silos of wheat (Storey 1973) and the lethal exposure times for the adults of 5 stored product beetles and the immature stages of two of these insects have been determined (Storey 1975a, b). Data are given here on the response of all stages of 3 species of stored product moths, the Indian meal moth, *Plodia interpunctella* (Hübner), the almond moth, *Cadra cautella* (Walker), and the Angoumois grain moth, *Sitotroga cerealella* (Olivier) to the oxygen deficient atmosphere.

MATERIALS AND METHODS.—The inert atmosphere (oxygen < 1%, (O_2 9–9.5% and the balance principally N_2) was produced in a pilot inert atmosphere treatment system, and the insects were exposed to it at a flow rate of 25 cc/min in 1 pt jars as previously described (Storey 1975a). Oxygen levels in the inert atmosphere were measured daily by using a Servomex® paramagnetic oxygen analyzer. Although some minor variation occurred during day-to-day operations, the O_2 concn was generally between 0.1 and 0.25% and rarely exceeded 0.5%.

Twenty-five eggs (0–1, and 1–3-days old) each of the Indian meal moth and the almond moth from a laboratory colony were placed in the 1-pt jars with 25 g of a larval medium composed of 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 food material was ca. 19–21 days from oviposition to adult. The eggs of the Angoumois grain moth were collected on double strips of black paper suspended in jars containing adult moths. Twenty-five of these eggs (0–1, and 1–3-days old) still attached to the black paper were placed in the stoppered 1-pt jars with 50 g of hard red winter wheat (moisture content 13%). Development time in wheat was ca. 42 days from oviposition to adult. The jars containing the 1–3-day-old eggs of the 3 species were exposed immediately after the eggs were placed in the food medium. Larvae of Indian meal moth and almond moth from the 0–1 day eggs were exposed 2–3, 6–7, and 10–11 days after hatch and larvae of the Angoumois grain moth 14, 21, and 28 days after hatch.

Pupae of the Indian meal moth and almond moth were collected in small rolls of corrugated paper ca. 3 cm diam and 2 cm thick placed on the surface of larvae medium for 24 h. The rolls were placed in ½ pt jars for treatment and 1 roll of each species was exposed when in the early and in the late pupal stage. The average number of Indian meal moth pupae was 66/roll; the average for the almond moth pupae was 56/roll. In the case of the Angoumois grain moth, wheat samples containing the developing immature insects were exposed to the inert atmosphere 35 days after hatching when the insects were assumed to be pupae.

Twenty five adults of each of the 3 species were exposed in pt jars to the inert atmosphere 1 day after emergence.

Exposures were from 2 to 120 h at 27° ± 1°C and 50 ± 5% RH. After exposure, jar lids were replaced with screened caps, and the jars stored at 27° ± 1°C and 65 ± 5% RH. Counts of adult moths emerging from treated and untreated food material or wheat began when the 1st emergence was observed in the untreated control and ended 30 days later. Counts of the pupal stage of the Indian meal moth and almond moth were based on the actual number of pupal cases exposed vs. the number of adults that emerged from each roll. Percentage mortality was calculated by using Abbott's formula.

All treatments (species, ages, and exposure times) were replicated 3 times. Parallel jars of controls were held in atmospheric air.

RESULTS AND DISCUSSION.—Table 1 shows mortalities resulting from the exposure of the 3 species to the generated inert atmosphere.

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[2] Mention of a proprietary product does not imply endorsement by the USDA.
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Table 1.—Toxicity of an atmosphere[a] produced by an exothermic inert atmosphere generator to 3 stored product moths.

Stage	Age	Avg % mortality[b] after exposure of:								
		2 h	4 h	8 h	12 h	24 h	48 h	72 h	96 h	120 h
				Indian meal moth						
Eggs	1–3 days	42	67	72	88	100	100	100	100	—
Larvae	2–3 days	13	96	100	100	100	100	100	100	—
	6–7 days	6	90	100	100	100	100	100	100	—
	10–11 days	14	96	100	100	100	100	100	100	—
Pupae	Early period	0	22	58	82	100	100	100	100	—
	Late period	1	4	27	84	100	100	100	100	—
Adults	1-day	0	22	100	100	100	100	100	100	—
				Almond moth						
Eggs	1–3 days	6	10	11	38	71	100	100	100	—
Larvae	2–3 days	4	57	100	100	100	100	100	100	—
	6–7 days	0	52	100	100	100	100	100	100	—
	10–11 days	7	13	100	100	100	100	100	100	—
Pupae	Early period	5	8	16	36	100	100	100	100	—
	Late period	0	18	24	50	100	100	100	100	—
Adults	1-day	6	75	100	100	100	100	100	100	—
				Angoumois grain moth						
Eggs	1–3 days	—	16	27	47	70	100	100	100	—
Larvae	14-days	—	3	6	32	52	86	100	100	—
	21-days	—	14	23	28	41	63	91	100	100
	28-days	—	8	31	37	44	58	68	85	100
Pupae	35-days	—	3	18	19	33	54	70	94	100
Adults	1-day	0	8	55	72	100	100	100	100	—

[a] Composition, 1.0% O_2 and 9–9.5% CO_2; the balance principally N_2.
[b] Avg of 3 replicates.

The most susceptible species-age was Indian meal moth larvae, and the most tolerant were the fully grown larvae and pupae of the Angoumois grain moth that developed within the wheat kernel. Almond moth larvae and pupae were more tolerant of the low-O_2 atmosphere than larvae and pupae of the Indian meal moth in the short exposures, but the minimum times to 100% mortality of each age group of these moths were the same, except for the egg stage. Eggs of the Indian meal moth were killed by 24-h exposures, but the more tolerant almond moth eggs required a 48-h exposure.

Among pupal and larval stages of the 3 moths, the order of tolerance was Angoumois grain moth > almond moth > Indian meal moth. Only relatively short exposures were required to control the Indian meal moth and almond moth, but an exposure of 120 h was required to cause 100% mortality of last-instars and pupae of Angoumois grain moths. Indeed, the tolerance of Angoumois grain moths to the inert atmosphere increased with each successive week of larval development once the eggs hatched and larvae entered the wheat kernels. The high tolerance of fully grown larvae of the Angoumois grain moth was similar to that found during a similar period of development of rice and granary weevils (Storey 1975b). The period of high tolerance among the weevils appeared to correspond with the cessation of feeding in the 4th instar and ended midway through pupal development.

Larvae of the Indian meal moth and almond moth that survived exposure to the inert atmosphere were examined periodically during their development to the pupal stage. Partial paralysis, particularly in the posterior segments, was clearly evident among several surviving larvae. Paralyzed larvae appeared incapable of defecation, and dried fecal material was observed protruding from the abdomen; none survived to the pupal stage. Adults from immature stages of the Indian meal moth and almond moth that did survive exposure to the inert atmosphere emerged about the same time as the untreated controls, but adults from immature stages of the Angoumois grain moth that survived exposures of 72 and 96 h emerged 1–2 weeks later than the controls.

Control of the various stages of the 3 months in the inert atmosphere compared favorably with that obtained with fumigants. Lindgren and Vincent (1966) reported an LC_{99} of 0.078 mg/liter (56 ppm) for hydrogen phosphide in 24-h exposures of Indian meal moth larvae at 27°C. Storey and Davidson (1973) reported only 40% mortality of Indian meal moth pupae in 24-h exposures to hydrogen phosphide at 0.083 mg/liter (60 ppm), and a 2nd generation of moths was obtained from eggs exposed for 24 h to 0.7 mg/liter (500 ppm); in addition, eggs, larvae, and pupae survived 24-h exposures of CCL_4-CS_2 (80:20 mixture) at 12.5 mg/liter, and a 2nd generation was produced from eggs exposed for 24-h at 25 mg/liter. In contrast, in the present test, none of the life stages of Indian meal moths exposed to the generated inert atmosphere survived exposures of 24 h at 27°C. Likewise, Rout et al. (1969) reported 76% mortality of Angoumois grain moth eggs in 24-h exposures to hydrogen phosphide at 1.16 mg/liter (834 ppm) and 30°–32°C, whereas 70% mortality was obtained with the inert atmosphere in 24-h exposure at 27°C, and eggs failed to hatch after 48-h exposures.

The present study, therefore, demonstrated the lethality of the low-O_2 atmosphere produced by the exothermic inert atmosphere generator to all life stages of the 3 stored product moths tested. Except for the larval-pupal period of the Angoumois grain moth, tolerance to the inert atmosphere was low. The method of treatment is thus a possible alternative to conventional chemical fumigation for storage facilities where the existing atmosphere can be displaced with the generated inert atmosphere.

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