Mortality of Adult Stored-Product Insects in an Atmosphere Produced by an Exothermic Inert Atmosphere Generator[1,2]

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ABSTRACT

The order of tolerance to low O_2 atmospheres produced by an exothermic inert atmosphere generator was *Sitophilus oryzae* (L.) = *S. granarius* (L.) > *Rhyzopertha dominica* (F.) > *Tribolium castaneum* (Herbst) > *Oryzaephilus surinamensis* (L.). Time periods required to kill 50 and 95% of the adults of each species (LT) were computed from mortality data obtained in 1- to 240-h exposures at temperatures from 15 to 32°C. As the temperature increased from 15 to 32°C, the time required to obtain 50 and 95% mortality of the insects decreased ca. 90%. The highest LT_{95} was 296.7 h for *S. oryzae* at 15°C and the lowest 3.8 h for *O. surinamensis* at 32°C.

Three factors are essential if inert atmospheres are to be used to control insects in stored grain: the atmosphere must be easily obtained in sufficient volume to displace existing atmosphere in large bulk storage; the atmosphere must be lethal to storage pests within a reasonable time; and the atmosphere must have no harmful effects on the quality of the treated commodity. Field studies by Storey (1973) demonstrated that it was practical to use exothermic inert atmosphere generators for displacing the normal atmosphere with an oxygen-deficient atmosphere in large elevator tanks containing wheat. Studies were therefore initiated to establish the treatment that would be required for the control of stored product insects. Data are reported here concerning the toxicity of low-oxygen atmospheres produced by an exothermic inert atmosphere generator to adult stages of 5 stored product insect species.

MATERIALS AND METHODS.—The pilot inert atmosphere treatment system consisted of a laboratory-scale generator, a series of five 20-bu metal cylindrical silos, 2 incubators modified to permit treatment of the insects at selected temperatures, and pneumatic grain handling equipment for loading and unloading silos. The generator was built by Gas Atmospheres, Inc., Strongville, Ohio, and produces ca. 100 ft^3/h of an inert atmosphere composed of less than 1% O_2, and 8.5–11.5% CO_2; the balance was principally N_2.

During operation, natural gas and air are ignited under controlled pressure at a ratio of ca. 1 part gas to 10 parts air. Combustion takes place in a water-cooled, refractory-lined combustion chamber. The exhaust gas from the chamber passes through a water-cooled plate-coil and into a condensate separator. Water removed from the gas leaves the separator through a seal leg located beneath the separator. The RH of the inert atmosphere was maintained at 50±5% by passing the inert atmosphere through a self-draining manifold immersed in a refrigerated constant temperature water bath to lower the temperature of the inert atmosphere below the dewpoint and then reheating the gas to room temperature before release into the incubators.

Oxygen levels in the inert atmosphere were measured daily throughout the test period by using a Servomex® paramagnetic oxygen analyzer. Although some minor variation occurred during day-to-day operations, the concentration of O_2 was generally between 0.1 and 0.25% and rarely exceeded 0.5%. Concentrations of CO_2 ranged from 9 to 9.5% during the test period.

Test insects were exposed to the inert atmosphere in quart jars placed in the modified incubators. Each jar was equipped with a lid seal fitted with a rubber stopper. Plastic lines placed through the stoppers served as inlet and outlet tubes for the inert atmosphere. The rate of gas flow through the jars was 50 cc/min. Airflow rates were controlled by purge meters which adjusted and monitored the air movement through each jar. Twenty-five adult insects of each species, together with a suitable food material, were placed in separate screen cages, 6.5 cm long by 2 cm diam, and exposed to the inert atmosphere flowing through the jars. Tests were conducted at 15, 21, 27, and 32±2°C for the following periods: from 1 to 240 h (1-h intervals from 1 to 4 h, 2-h intervals from 4 to 12 h, 4-h intervals from 12 to 24 h, 12-h intervals from 24 to 72 h, and 24-h intervals from 72 to 240 h).

Test insects were 2-wk-old adults of the rice weevil, *Sitophilus oryzae* (L.), granary weevil, *S. granarius* (L.), lesser grain borer, *Rhyzopertha dominica* (F.), red flour beetle, *Tribolium castaneum* (Herbst), and sawtoothed grain beetle, *Oryzaephilus surinamensis* (L.). After exposure, the insects were transferred to small plastic boxes and stored at 27°C and 60±5% RH for 2 wk until posttreatment mortality observations were completed. Treatments were replicated 3 times for each species and temperature tested. Parallel tests with controls were conducted in atmospheric air for each combination of insect species, exposure, and temperature; however, unsealed jars were used for these insects because preliminary tests showed no differences between the effects of flowing air drawn from within the incubators and static air in unsealed jars.

The time required to kill 50 and 95% of each species 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).

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[2] Mention of a proprietary product does not imply endorsement by the USDA.
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Table 1.—Time required (h) to obtain 50 and 95% mortality of adult stored-product insects exposed to an atmosphere[a] produced by an expothermic inert-atmosphere generator.

°C	LT_{50}	(95% confidence interval)	LT_{95}	(95% confidence interval)
		Rice weevil		
15	209.3	(170.7–247.9)	296.7	(252.9–340.4)
21	139.8	(107.3–172.3)	200.5	(167.0–233.9)
27	29.8	(21.7– 38.0)	48.0	(39.6– 56.3)
32	14.4	(10.7– 18.1)	19.3	(15.3– 23.2)
		Granary weevil		
15	174.1	(150.8–197.4)	227.9	(203.8–252.0)
21	80.3	(48.9–111.8)	145.2	(112.9–177.5)
27	27.9	(17.3– 38.5)	55.4	(44.3– 66.5)
32	11.7	(8.9– 14.5)	20.1	(17.3– 23.0)
		Lesser grain borer		
15	125.6	(99.2–152.0)	175.1	(147.8–202.3)
21	52.2	(35.4– 69.0)	79.3	(62.0– 96.6)
27	21.6	(17.5– 25.7)	31.0	(26.8– 35.3)
32	11.8	(9.4– 14.2)	17.0	(14.6– 19.5)
		Red flour beetle		
15	50.0	(39.3– 60.8)	67.0	(55.8– 78.2)
21	25.7	(23.8– 27.6)	32.2	(30.2– 34.2)
27	12.6	(10.3– 15.0)	16.8	(14.4– 19.3)
32	6.3	(4.5– 8.2)	8.5	(6.7– 10.4)
		Sawtoothed grain beetle		
15	17.3	(0.6– 34.0)	46.8	(29.0– 64.7)
21	9.6	(4.3– 14.7)	18.1	(12.7– 23.4)
27	7.5	(5.1– 9.8)	11.2	(8.8– 13.6)
32	1.7	(0.0– 3.6)	3.8	(1.9– 5.7)

[a] Composition of the inert atmosphere, <1.0% O_2 and 9–9.5% CO_2; the balance principally N_2.

RESULTS AND DISCUSSION.—Table 1 gives LT_{50} and LT_{95} for each species and temperature. The order of tolerance to the generated atmosphere was rice weevil = granary weevil > lesser grain borer > red flour beetle > sawtoothed grain beetle. Rice weevils were more tolerant than granary weevils at 15° and 21°C; granary weevils were more tolerant at 27° and 32°C. As the temperature increased, the time required to obtain the LT_{50} and LT_{95} of all insects decreased, and the overall increase from 15° to 32°C reduced the time by ca. 90%. The greatest decrease in the number of hours required to obtain 95% mortality of the lesser grain borer, red flour beetle, and sawtoothed grain beetle occurred with the increase from 15 to 21°C. The greatest decrease for the 2 weevils occurred with the increase from 21 to 27°C. Further reductions in the LT_{95} were obtained among the 5 species when the temperature was increased from 27 to 32°C; however, the time involved in this reduction represented only 9–17% of the total decrease in LT_{95} values from 15 to 32°C.

The variability between both species and individual insects within each species in their response to the O_2-deficient atmosphere was reflected in the relationship between the LT_{50} and LT_{95} values. An increase from 15 to 21°C reduced the time required to kill 50% of the granary weevil by nearly 54%; however, the time required to kill 95% was reduced only 36%. In contrast, each increase from 15 to 27°C reduced the LT_{95} significantly more than the LT_{50} of the highly susceptible sawtoothed grain beetle; this trend was reversed with the increase to 32°C when the LT_{50} was reduced proportionately more than the LT_{95}. On the other hand, successively higher temperatures did not materially affect the relationship between the LT_{50} and LT_{95} for the lesser grain borer and red flour beetle. Each value was reduced ca. 50% from the preceding value with each increase in temperature. Similar results were obtained with the rice weevil except that the major reduction for both LT values occurred with the increase from 21 to 27°C.

The results obtained with the generated atmosphere compare favorably with results reported for other combinations of N_2 and CO_2. Lindgren and Vincent (1970) reported LT_{95} values of 96 and 86.4 h for adult rice and granary weevils exposed at 27°C to 100% atmospheres of N_2 under static conditions. Person and Sorenson (1970), using a flowing (20–30 cc/min) atmosphere composed of 0.5% O_2 and 99.5% N_2 at 27°C, obtained 90% mortality of adult rice weevils in 60 h and 100% mortality in ca. 80 h. LT_{95} values at 27°C in our present test were 48 h for the rice weevil and 55.4 h for the granary weevil. AliNiazee (1971) exposed adult red flour beetles at 27°C to static atmospheres of CO_2, N_2, and He with amounts of O_2 ranging from 2 to 20%. Atmospheres that contained 95% or more of CO_2 gave complete control in 24 h but an atmosphere of 98% N_2 and 2% O_2 required 96 h to produce 100% mortality. In contrast, the LT_{95} for the red flour beetle exposed to the generated atmosphere at 27°C was only 16.8 h, and complete control was obtained in 20 h.

The acute susceptibility of the adult sawtoothed grain beetle to the generated atmosphere (LT_{95} in less than 12 h at 27°C) contrasted favorably with the toxicity of some fumigants to the weevils. In tests with the sawtoothed grain beetle at 27°C, 24-h exposure, Harein and Soles (1964) reported an LD_{95} of 62 mg/liter for carbon tetrachloride, a major component of several liquid fumigant mixtures; and Lindgren and Vincent (1966) reported an LC_{99} of 0.04 mg/liter (29 ppm) for hydrogen phosphide.

Although death was the principal criterion for evaluating effectiveness of the generated atmosphere, other responses were observed. Immobilization of the adult insects occurred rapidly (generally in less than 60 s) after exposure to the atmosphere and continued throughout the entire exposure. The influence of this suspension of activity on potential population growth, other than simply delaying the normal developmental period, is unknown. Partial paralysis, particularly in the posterior segments, was clearly evident among many of the surviving adults but paralysis was less evident among surviving adults treated at 15°C.

The high level of mortality achieved with the generated atmosphere provides additional stimulus for developing the use of inert atmosphere generators as an alternative to chemical fumigation. Although decreased temperatures significantly increased the time required to obtain effective control, the maximum LT_{95} obtained in the study was ca. 300 h for the rice weevil at 15°C. Depending on the volume of grain to be treated and the output capacity of the generator, this period can be maintained easily in commercial grain silos with operational cost comparable to that of chemical fumigation (Storey 1974).

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