HEAT STERILIZATION – CAN IT EFFECTIVELY CONTROL INSECTS?

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With the impending phase out of methyl bromide, there is renewed interest in using heat to control insects in food and feed-handling establishments. During heat sterilization or treatment, the temperature of the mill is slowly increased to 50°C or higher and held at these temperatures for 24-36 hours. In the past, many studies examining the effects of heat on insects were conducted at constant temperatures, using different heat sources, and experimental methods. This makes comparisons across the various studies conducted somewhat difficult. However, during a heat sterilization, insects are exposed over time to increasing temperatures. More data are needed over a range of constant temperature above 44°C to predict effects on insects during heat sterilization. In past research mortality counts of insects were taken immediately after they were exposed to heat. As temperatures reach lethal levels, beetle adults appear to be knocked-down or moribund within a few minutes. However, some of them gradually recover once they are removed from the heated environment. Therefore, it may be worthwhile to take mortality counts ≥24 hours after exposure to high temperatures to avoid over estimating mortality. In this paper, we report on the effects of high temperatures (variable and constant) on the life stages of the red flour beetle, *Tribolium castaneum* (Herbst), a common and important pest associated with flour and feed mills.

Experiments during heat sterilization of flourmill: Eggs, larvae, pupae, and adults of *T. castaneum* were exposed to extreme temperatures (≥50°C) during steam heat treatment (March 17–21, 2000) of the Department of Grain Science and Industry's pilot flourmill, Kansas State University, Manhattan, KS. Temperatures were measured using HOBO data loggers (Onset Computer Corp., Pocasset, MA). The insects were removed at different times during the heat treatment to observe for mortality. Adults were observed for mortality 24 hours after they were removed from the mill. In the case of eggs, larvae and pupae, mortality counts were based on those that did not emerge into adults after incubation at 28°C and 65% RH in the laboratory.

Data from the HOBO units kept near the experimental cages showed that it took about 42 hours to reach the threshold temperature of 50ºC. The highest temperature recorded was 58.6ºC. Temperatures stayed above 50ºC for more than 42 hours.

Table1 shows the mortality of the different life stages at varying temperatures during the steam heat treatment. The effects of heat on life stages increased with increasing exposure time. All adults died when temperatures reached 48ºC. At these temperatures, only 50% of the pupae died. Many adults emerging from heat-treated pupae had separated wings; a few dead pupae had pupal-adult characteristics. The proportion of adults with separated wings increased with increased time of exposure to heat (Figure 1). More adults emerged from older larvae exposed to heat than from younger larvae. Larvae emerging from eggs exposed to heat were smaller (no data on size), and weighed less than those emerging from eggs that were not exposed to heat (Figure 2).

During a recent gas heat treatment (August 14–16, 2000) temperatures reached lethal levels of 50ºC within 7 hours, and the highest temperature achieved was 68.2ºC. Because the HOBO units were set up to record the data every 30 seconds, we were unable to record temperatures beyond 31 hours. The heat was turned off four hours later. Based on the HOBO data, temperatures were maintained above 50ºC for more than 24 hours. All stages of the red flour beetle exposed in cages, with 0.5 grams of whole-wheat flour, were killed at the end of the heat treatment.

Experiments at constant temperatures: All life stages of *T. castaneum* were exposed to 50ºC for varying lengths of time. The degree of heat tolerance (expressed as time to death) was highest in pupae, followed by late instar larvae, adults, early instar larvae, and eggs. For example, for 100% mortality of eggs, younger larvae, older larvae, pupae, and adults, it took 30, 50, 65, 90, and 55 minutes, respectively. These results were somewhat similar to those observed during heat sterilization (see above).

In another experiment *T. castaneum* adults were exposed to 7 different temperatures between 44 and 50ºC, and 20-21% RH. All adults exposed to 50^{o}C were killed in 55 minutes; at 44^{o}C all adults were killed after 26 hours. Table 2 shows the minimum time across the 7 temperatures beyond which *T. castaneum* adults begin to die, and the minimum time for 100% mortality under our experimental conditions.

We are currently using data obtained from experiments conducted during heat treatment of flourmills (K-State mill and other commercial mills) and at constant temperatures, to develop models to predict mortality of *T. castaneum* life stages. The model will be validated with independent field data. The data from the mill and laboratory experiments clearly suggest that less than 50^{o}C may be sufficient to kill *T. castaneum* adults, whereas other life stages may require higher temperatures (>50^{o}C) or longer exposures (>3 hours) at 50^{o}C. Therefore, using a heat tolerant stage, such as pupae may provide valuable information regarding the minimum temperature and exposure time needed for complete control of all other stages of *T. castaneum*.

In summary, our studies show that during thermal disinfestation of flourmills, a temperature of 50^{o}C for a minimum of 3 hours kills all exposed life stages of *T. castaneum*. Sanitation is critical for removing refugia for insects and for effective insect management, because grain and flour residues act as heat insulators. Heat appears to be an appealing and safe alternative to methyl bromide. However, more quantitative information is needed on responses of other stored-product insects to heat and on the economics of using this technology. Such information would make heat more widely accepted and adopted by the food industry.

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Table 1. Mortality of the life stages of *Tribolium castaneum* during steam heat treatment, March 17-21, 2000.

Hours after heat was turned on	Temperature attained, °C (°F)	Mortality (%Mean ± SE)[a]				
		Eggs	Younger larvae	Older larvae	Pupae	Adults
33.0	46.4 (115.5)	55.0 ± 5.0	3.3 ± 3.3	3.3 ± 1.7	5.0 ± 0	0
34.0	46.9 (116.4)	78.0 ± 1.7	20.0 ± 10.4	11.7± 11.7	10.0 ± 2.9	0
35.0	47.4 (117.3)	85.0 ± 2.9	63.3 ± 1.7	8.3 ± 4.4	21.7 ± 11.7	45.0 ± 7.6
35.5	48.0 (118.4)	96.7 ± 1.7	78.3 ± 10.1	18.3 ± 7.3	43.3 ± 4.4	91.7 ± 1.7
36.0	48.0 (118.4)	96.7 ± 1.7	90.0 ± 5.0	63.3 ± 10.1	50.0 ± 5.8	100 ± 0
Control[b]	28.0 (82.4)	0	0	0	0	0

[a]Each mean is based on *n*=3, and 20 insects were used at each *n*.
[b]Growth chamber in the laboratory.

Table 2. Temperatures and associated times required to kill *Tribolium castaneum* adults.

Temperature, °C (°F)	Minimum exposure time beyond which adults begin to die, minutes (hours)[a]	Minimum exposure time to kill 100% of adults, minutes (hours)
44 (111.2)	660 (11.0)	1590 (26.5)
45 (113.0)	500 (8.3)	1260 (21.0)
46 (114.8)	240 (4.0)	540 (9.0)
47 (116.6)	140(2.3)	340 (5.7)
48 (118.0)	60 (1.0)	150 (2.5)
49 (120.2)	60 (1.0)	110 (1.8)
50 (122.0)	25 (0.4)	50 (0.8)

[a]Mortality at the indicated time is 0%.

Figure 1. Adults (% Mean + SE) of *Tribolium castaneum* with separated wings that emerged from pupae surviving the steam heat treatment (*n*=3, and 20 insects were used at each *n*).

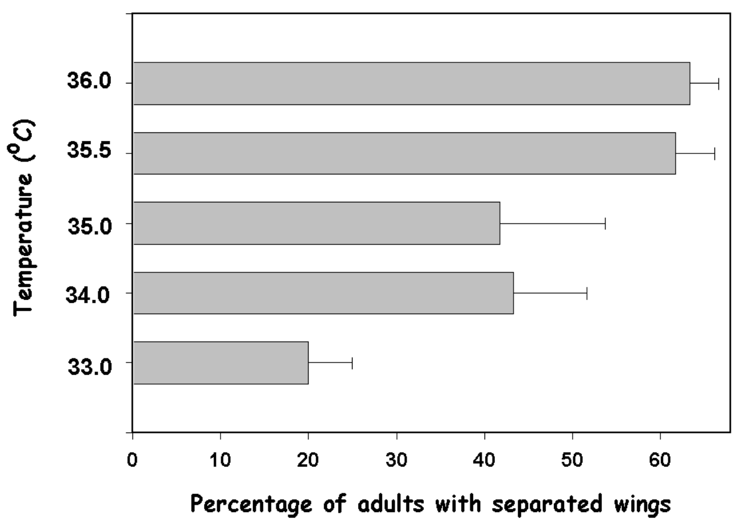

Figure 2. Percentage reduction in weight of *T. castaneum* larvae emerging from eggs that survived the steam heat treatment. The average weight of larvae in control treatment was 2.8 milligrams. *n* within each bar represents the number of larvae weighed.