TEMPERATURE PROFILES DURING HEAT TREATMENT OF MILLS, AND EFFICACY AGAINST INSECTS

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Heat disinfestation of mills involves increasing the ambient mill temperature to ≥50°C for at least 24–36 hours. However, stratification of temperatures during heat treatment results in non-uniform distribution of temperatures within and across mill floors. It is in areas where temperatures do not reach 50°C that insects typically survive.

During August 4-8, 2001, the pilot flour at Kansas State University was subjected to heat treatment using 2 portable steam heaters. The heaters were turned on August 4 at 6:30 p.m., and were turned off between 7:30 a.m. and 4:30 p.m. on August 6. All steam heaters were turned off at 7:30 a.m. on August 8. The feed mill was heat-treated using 5 portable gas heaters, which were turned on at 8:00 p.m. on August 6, and turned off at 9:30 a.m. on August 8.

Temperatures were monitored in 10 locations each in the flour and feed mills. Previous experience with heat treatments has shown that it is difficult to attain proper heat distribution in these locations. Eggs (0-2-d-old), younger instars (0.24 mg/larva), older instars (7.1 mg/larva), pupae (26-d-old from egg laying), and adults (≤2 wk-old) of the red flour beetle, *Tribolium castaneum* (Herbst) (Tenebrionidae: Coleoptera), were placed in the same 10 locations in each mill to determine the effectiveness of the heat treatment.

The outdoor average ambient temperature and relative humidity, at the street level, during the heat treatment was 24.5°C and 63.2%, respectively. The outdoor roof (outside 4th floor cleaning house) temperature and relative humidity was 36.2°C and 50.1%, respectively. The ambient temperature across all flour mill floors was 34°C, while the feed mill temperature averaged 36°C. Relative humidity of mills was ≤44% before heat treatments, and decreased to about ≤20% during the heat treatment.

The time from the ambient to 50°C or the rate of temperature increase up to 50°C, time above 50°C, and the maximum temperature varied within and among the mill floors (Tables 1 and 2). In general, the rate of increase in temperature was faster in the feed than the flour mill. This is due to more heaters and fans being used in the feed mill when compared with the flour mill. In the flour mill, the portable steam heaters were inadequate to heat the mill floors rapidly, and therefore, the heaters had to be kept running for 4 days. Despite faster and better heat distribution in the feed mill, the southwest corner of first floor (location 2) never reached 50°C.

The egg and younger instars in flour have not developed into adults yet. Therefore, in this abstract, the mortality data of older instars, pupae, and adults were presented. Except for location 2, where the temperature never reached 50°C (maximum, 46°C), adults placed in all other locations of the feed mill were dead at the end of the heat treatment (Table 3). In location 2, all adults survived the heat treatment. The mortality of older instars and pupae was <23% in location 2, and ≤50% in locations 9 and 10 of the feed mill. The adults that emerged from older instars and pupae had a morphological aberration in the form of separated wings (inverted "V" shape). In locations 9 and 10, the temperatures reached 50°C and were above 50°C for more than 20 hours. However, these temperatures were insufficient to kill older instars and pupae. In the flour mill, all exposed adults and older instars were killed (Table 3). All pupae were killed in location 10, whereas in the other locations, the mortality ranged from 78-98%. In the laboratory, at 54, 58, and 60°C, all exposed pupae died at 32, 18, 15 minutes, respectively (R. Mahroof, unpublished data). Based on these results, we should have expected 100% mortality of pupae in most of the locations of the feed and flour mills. In the laboratory, the pupae were taken from 28°C and immediately placed at higher temperatures, whereas during a heat treatment, pupae are exposed to gradually increasing temperatures. We believe that thermal acclimation of pupae may have resulted in their ability to withstand temperatures well above 50°C for extended periods during the heat treatment.

In summary, pupae of *T. castaneum* were more tolerant to heat treatment, followed by the older instars. Older instars and pupae that emerged into adults had a morphological aberration. The biological significance of this aberration warrants further study. Thermal acclimation in insects to gradually increasing temperatures, temperature distributions in the presence or absence of forced air circulation, and rate of increase in temperature, may all determine the degree of insect susceptibility. Our past and present data suggest that it is not always easy to predict mortality of insects exposed to high temperatures.

Table 1. Temperature profiles in the 10 feed mill locations, August 6-8, 2001.

Location	Starting Temp, °C	Time to 50°C, h	Rate of increase, (°C/h)[a]	Time above 50°C, h	Maximum temp, °C
1	33.5	6.0	2.74	31.3	62.7
2	29.9	0.0	0.00	0.0	45.9
3	30.7	14.3	1.35	22.5	53.5
4	35.3	15.0	0.98	21.8	56.0
5	34.4	10.3	1.52	26.8	61.7
6	34.8	11.3	1.35	26.3	59.2
7	35.3	19.3	0.77	18.3	56.0
8	34.8	10.3	1.48	27.3	60.6
9	35.7	11.0	1.30	24.0	59.2
10	36.1	14.2	0.97	20.8	55.7

[a](50°C - Starting temp, °C)/Time to 50°C.

Table 2. Temperature profiles in the 10 flour mill locations, August 4-8, 2001.

Location	Starting Temp, °C	Time to 50°C, h	Rate of increase, (°C/h)[a]	Time above 50°C, h	Maximum temp, °C
1	33.8	22.00	0.74	17.75	59.92
2	35.7	18.25	0.78	71.25	61.29
3	42.0	4.50	1.78	63.00	69.12
4	34.8	20.75	0.73	68.50	59.22
5	35.3	15.50	0.95	74.00	62.74
6	37.4	14.25	0.88	27.25	62.01
7	33.2	47.00	0.36	42.25	56.29
8	35.3	32.75	0.45	9.00	54.44
9	37.9	22.00	0.55	65.00	58.22
10	37.9	20.50	0.59	68.75	58.55

[a](50°C - Starting temp, °C)/Time to 50°C.

Table 3. Mortality of older instars, pupae, and adults of *T. castaneum* in the 10 locations of the feed and flour mills.

Location	Average mortality (%)[a]					
	Feed mill			Flour mill		
	Older instars	Pupae	Adults	Older instars	Pupae	Adults
1	100	100	100	100	78	100
2	7.5	22.5	0	100	93	100
3	100	100	100	100	98	100
4	100	100	100	100	90	100
5	100	100	100	100	95	100
6	100	100	100	100	85	100
7	100	100	100	100	90	100
8	100	100	100	100	80	100
9	50	50	100	100	88	100
10	30	30	100	100	100	100
Control[b]	5	0	0	0	2.5	0

[a]Each average is based on 2 samples at each location.
[b]Growth chamber set at 28°C and 42 % RH.

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