Evaluation of a heat treatment based on temperature profiles attained, trapping data, and bioassays

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Abstract

The flour and pasta press rooms of a pasta manufacturing facility were subjected to a steam heat treatment during July 1-2, 2006. The steam was generated by a natural gas-fired boiler. Temperatures attained were measured at 49 total locations in both rooms. The flour room was heated up for 16 h and the press room for 17 h. Temperatures reached 50°C in 3.5-5 h in most locations and stayed above 50°C for 12.5-14 h. In addition, 10 and 35 commercial food and pheromone baited pitfall traps were placed in the flour and press room, respectively, to determine captures of adults of the red flour beetle, *Tribolium castaneum* (Herbst). Five traps were also placed outside the facility to monitor numbers of *T. castaneum* adults. Captures of *T. castaneum* adults outdoors were generally higher than those captured inside the facility. There was 100% reduction in trap captures of *T. castaneum* adults in the press room immediately after the heat treatment, and an 86% reduction in captures in the flour room. Numbers of adults were kept low for two more months after heat treatment by following good sanitation and exclusion practices. Bioassays of adults of *T. castaneum* were placed in the heat treated rooms at four different locations. There was 100% mortality of *T. castaneum* adults within 5.7 h in the flour room. In the press room time to 100% mortality varied by location and ranged from 5.9-17 h. These results suggest that heat treatment is a viable alternative to structural fumigants, and an effective heat treatment can be conducted in 16-17 h.

Keywords: heat treatment, stored-product insects, efficacy assessment

1. Introduction

The use of elevated temperatures or heat treatments to manage stored-product pests associated with grain-processing facilities is an effective alternative method to using fumigants such as methyl bromide and sulfuryl fluoride (Brijwani et al., 2012). Methyl bromide, an ozone-depleting fumigant was phased out in the United States in 2005. Sulfuryl fluoride, a non-ozone depleting fumigant registered by United States Environmental Protection Agency in 2004, is not effective against eggs of stored-product insects, especially at temperatures below 27ºC (Lawrence et al., 2012). Heat treatment involves raising the ambient temperature of clean, empty grain-processing facilities to 50-60ºC and holding these temperatures for 24 h or less. Insects exposed to 50ºC will die within minutes to an hour (Fields, 1992). Heat treatments are environmentally sensitive and safe for workers. The effectiveness of heat treatments against stored-product pests depends on how quickly temperatures reach 50ºC from the ambient, how long temperatures are held above 50ºC, and the maximum temperature (Subramanyam et al., 2011, 2012). The predicted time to kill 99% of young larvae of the red flour beetle, *Tribolium castaneum* (Herbst), which is the most heat tolerant stage when compared with eggs, old larvae, pupae, and adults at 50-60°C, was positively related to time to 50ºC and negatively related to time above 50ºC and the maximum temperature, based on

tests conducted in commercial facilities (Subramanyam et al., 2012). In the present investigation the effectiveness of a heat treatment of a pasta manufacturing facility was evaluated by examining temperatures attained, number of adults of *T. castaneum* captured several weeks before and after the heat treatment intervention, and mortality of insects in bioassay boxes. The heat treatment was conducted in-house during July 1-2, 2006 using steam heat generated by a boiler fueled by natural gas. Two rooms, a smaller flour room that had metal bins for raw materials and a larger press room for making pasta, were subjected to heat treatment for 16 and 17 h, respectively.

2. Materials and Methods

2.1. Heat treatment

The press room had a volume of 43,891 m^3 with a floor area of 4,343 m^2. The flour room volume was 3,398 m^3 with a floor area of 335 m^2. To uniformly circulate hot air within the heated rooms, five drum fans were placed throughout the flour room, and seven drum fans, 10 pedestal fans, and four heat buster fans (TempAir, Burnsville, MN, USA) were placed throughout the larger press room. Room schematics and placement of bioassays are shown in Fig. 1.

2.2. Temperature measurements

Temperatures were recorded at one minute intervals using HOBO® data loggers (Onset Computers Corporation, Bourne, MA, USA). There were 37 data loggers placed in the Press Room, and 12 data loggers in the flour room. A data logger was placed with the insect bioassays (see below) in each of the three locations in the press room and in one location in the flour room so that temperature, time, and mortality data could be correlated.

2.3. Bioassays

Cultures of *T. castaneum* from the Stored-Product Insect Research and Education Laboratory, Department of Grain Science and Industry, Kansas State University were reared on organic whole wheat flour plus 5% by weight brewer's yeast diet. All cultures were reared in a growth chamber at 28°C and 65% r.h. Unsexed adults (50) of mixed ages of *T. castaneum* were placed in plastic bioassay boxes (4.5 cm x 1.5 cm high) containing 5 g of flour. Plastic boxes were placed in three locations in the press room (A, B, and C) to get a representative sampling of temperature differences within the room. In the flour room one location (D) had insect bioassays which consisted of 50 *T. castaneum* adults in each 0.45-L glass jars with 50 g of flour. In the press room, bioassay boxes with *T. castaneum* were collected at the following times after heat treatment started: 1.2, 2.8, 4.1, 5.8, 6.6, 7.5, 8.0, 8.3, 8.7, 8.8, 9.1, 9.5 and 12.4 h. In the flour room, bioassay boxes were collected after 2.6, 3.4, 4.1, 4.7, 5.2, 5.7, 6.2, 6.7, 7.5, and 8.3 h into the heat treatment because of temperatures reaching lethal levels (≥50°C) quickly. Counts were taken of live and dead insects on July 2, 2006 on site, and the percent survival was calculated. Control insects were held in an unheated room with an average temperature of 20ºC. None of the control insects died during the heat treatment period.

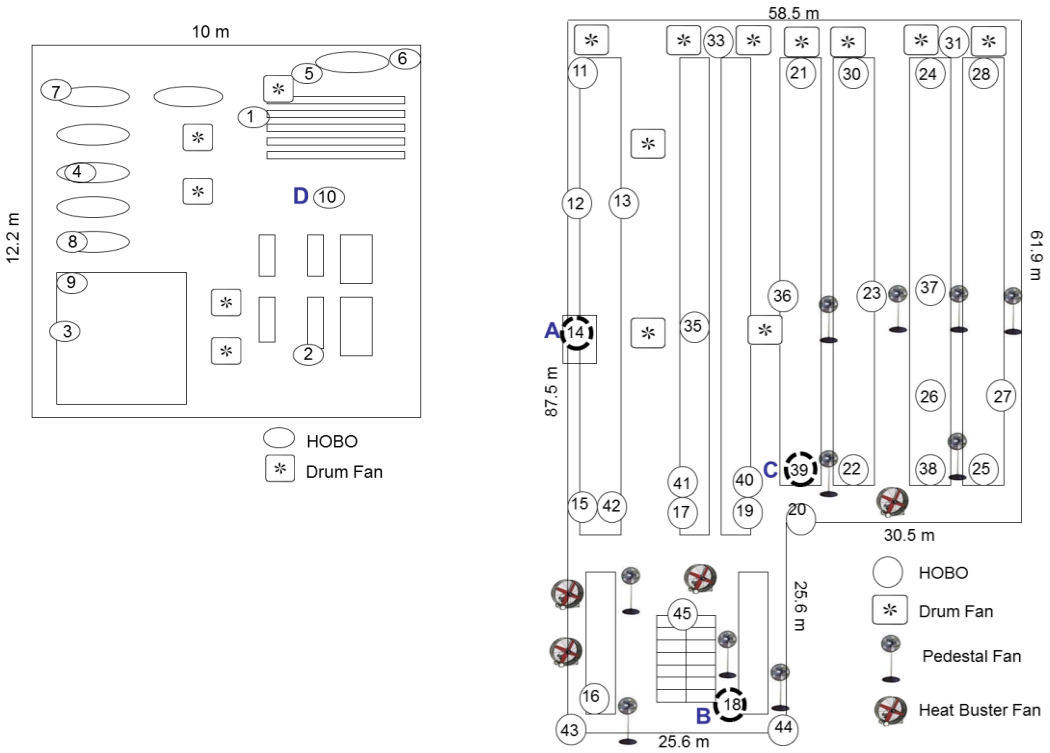

Figure 1 A schematic of the flour and press rooms showing locations of fans, HOBO® temperature loggers, and insect bioassays.

2.4. Trapping

Commercial food- and pheromone-baited pitfall traps (Trécé, Enid, OK, USA) were used to sample adults of *T. castaneum* in 35 locations in the press room, 10 locations in the flour room, and in five locations outside the facility. The receptacle of the bottom portion of the trap was fitted a filter paper and 15 drops of a food attractant oil was added. The lid for the trap on the inside was fitted with an aggregation pheromone (4,8-dimethyldecanol) lure to capture red flour beetles, *Tribolium castaneum* (Herbst). Traps were placed on the floor of each room in a grid-like fashion (Campbell et al., 2002). Trapping was conducted for approximately six weeks prior to the heat treatment (May 16 through June 28, 2006) and for an additional seven weeks after (July 3 through August 23, 2006). Trap captures were counted at approximately biweekly intervals. New traps and lures were placed after the heat treatment. Trap capture of adult insects before and after heat treatment intervention were used to determine the degree of suppression of resident populations and duration of effectiveness of a single heat treatment.

2.5. Data analysis

The time-dependent temperature data from each location was used to determine the starting ambient temperature, time required to reach 50ºC and rate of heating to 50ºC, time temperature was held above 50ºC, and the maximum temperature attained. Trap capture data immediately before and immediately after a heat treatment in each of the two rooms were subjected to a two-sample *t*-test (SAS Institute, 2008), and means were considered significant at $\alpha = 0.05$. Trapped insect data was transformed to log(x+1) scale (Roesli et al., 2003) for SAS analysis. Percent reduction in *T. castaneum* adults was calculated using non-transformed data as:

$$\%\,\boldsymbol{reduction} = \left(\mathbf{1} - \frac{\boldsymbol{A}}{\boldsymbol{B}}\right) * \mathbf{100} \quad (1)$$

where *A* is the mean number of *T. castaneum*/trap/week immediately after heat treatment, and *B* is the mean number of *T. castaneum*/trap/week immediately before heat treatment (Roesli et al., 2003).

3. Results and Discussion

3.1. Temperature measurements

Temperatures in both the flour room (Table 1) and press room (Table 2) at the start of the heat treatment ranged from 23.2-39.7°C. The time to reach 50°C varied from 1.1 to 12.2 h. The rate of increase varied from location to location. Therefore, time above 50°C also varied by location. Three locations in the press room did not reach 50°C due to inadequate heat flow to these areas. However, in other locations (1, 4, 6-12, 14, 16-18, 20, 23, 26-28, 30-33, 35, 42-45, and 47-49) temperatures attained were greater than 60°C. Temperature control should be implemented so that temperatures do not exceed 60°C for extended periods of time which may cause structural damage. On average, temperatures in the press and flour rooms reached 50ºC within 4-5 h, and temperatures were held above 50ºC for 12-14 h, and the average maximum temperatures were 61-65°C.

Table 1 Temperatures measured in the flour room during heat treatment.

Location	Initial temp. (°C)	Time to 50°C (h)	Rate of increase (°C/h)[a]	Time above 50°C (h)	Max. temp. (°C)
1	26.73	4.90	4.75	4.07	61.29
2	26.34	1.78	13.29	15.08	59.90
3	26.34	5.33	4.44	11.77	57.89
4	27.52	5.18	4.34	11.28	73.70
5	27.52	6.82	3.30	9.60	53.53
6	27.12	2.55	8.97	13.95	65.01
7	27.52	1.13	19.89	15.53	83.75
8	26.73	3.53	6.59	13.47	62.74
9	27.52	2.98	7.54	13.90	62.74
10	23.24	2.90	9.23	13.57	67.42
11	23.63	3.62	7.28	13.32	66.60
12	23.63	2.97	8.88	13.47	66.60
Average	26.15	3.64	8.21	12.42	65.10

[a](50°C – initial temperature, °C)/Time to 50°C (h).

Table 2 Temperatures measured in the press room during heat treatment.

Location	Initial temp. (ºC)	Time to 50ºC (h)	Rate of increase (ºC/h)[a]	Time above 50ºC (h)	Max. temp. (ºC)
13	28.31	12.17	1.78	4.48	50.66
14	36.13	1.35	10.27	17.88	71.80
16	39.67	1.67	6.19	15.88	66.60
17	30.31	2.23	8.83	15.38	66.60
18	32.76	2.50	6.90	15.15	65.79
19	35.27	5.97	2.47	11.65	59.22
20	30.17	2.00	9.92	15.42	64.24
21	30.71	16.5	1.17	0.25	50.66
22	27.52	5.32	4.23	2.95	51.22
23	31.12	5.35	3.53	12.02	60.59
24	34.01	6.93	2.31	10.65	54.74
25	29.90	10.82	1.86	4.50	52.95
26	29.90	3.40	5.91	14.20	61.29
27	29.90	4.42	4.55	13.65	60.59
28	35.70	2.02	7.08	16.63	70.88
29	29.90	3.60	5.58	13.78	59.22
30	29.90	3.33	6.04	14.38	62.01
31	33.17	1.85	9.10	16.08	68.25
32	29.10	2.60	8.04	15.33	65.79
33	31.93	4.37	4.14	14.82	62.74
34	29.50	7.93	2.59	9.57	57.89
35	32.76	2.15	8.02	11.82	60.59
36	29.50	8.33	2.46	8.68	55.97
37	29.50	7.00	2.93	9.82	55.97
38	30.31	5.03	3.91	12.47	58.55
41	29.10	7.48	2.79	0.53	50.66
42	31.93	3.58	5.05	16.42	67.42
43	31.52	1.43	12.92	19.95	72.74
44	31.52	5.15	3.59	50.11	62.74
45	34.01	1.40	11.42	17.98	73.70
46	30.71	5.22	3.70	2.02	53.53
47	30.71	8.47	2.28	9.00	61.29
48	31.52	3.57	5.18	14.37	65.01
49	29.50	2.50	8.20	50.10	65.79
Average	31.40	4.93	5.44	14.06	61.40

[a](50°C - starting temperature, °C)/Time to 50°C (h).

3.2. Bioassays

Adults of *T. castaneum* died within 12.4 h, 16.5 h, and 5.8 h in locations A, B, and C, respectively, in the press room (Figure 2). In the flour room, 100% mortality was achieved within 5.2 h. The results are consistent with data from other grain-processing facilities where bioassays of adults of *T. castaneum* were placed (Brijwani et al., 2012, Subramanyam et al., 2012).

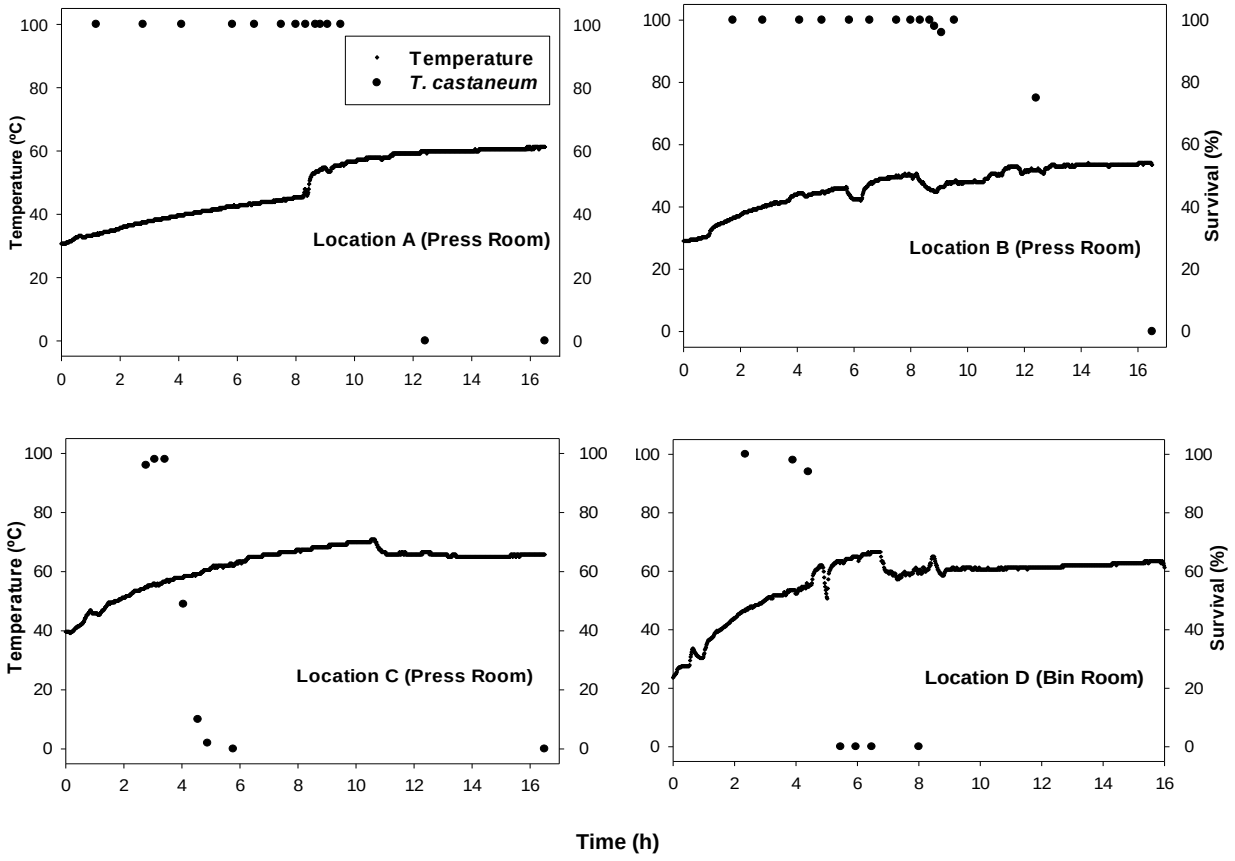

Figure 2 Temperature profiles and percent survival of *T. castaneum* adults as a function of time at locations A, B, and C in the press room, and location D in the flour room.

3.3. Trapping

Trapping results showed 86% reduction immediately after the heat treatment in the flour room and despite this level of reduction the mean number of adults of *T. castaneum* captured after the heat treatment were not signficantly different from those captured prior to the heat treatment (t = 1.66; df = 11.56; P = 0.1233). In the press room, there were no captures (100% reduction) after the heat treatment, and this reduction was significant (t = 2.05; df = 34; P = 0.048) (Table 3). Higher numbers of *T. castaneum* were captured outside the facility. Outside the facility, insects were commonly found at the entryway to the storage area of raw ingredients and the door leading to the area for natural gas service. Inside the facility, adult captures were higher in the flour room compared to the press room. This could be due to the fact that the semolina and durum flour are stored in the flour room. Insect populations were kept at low levels as inferred by trap captures for two months through effective sanitation and exclusion (closing doors) practices by facility sanitarians.

Table 3 Trap captures of *T. castaneum* adults before and after a heat treatment.

Date of collection (2006)	Mean no. adults/trap/week		
	Press room (*n*=35)	Flour room (*n*=10)	Outside (*n*=5)
30 May	0.46	0.40	0.50
14 June	0.20	0.42	0.65
28 June	0.32	0.65	0
1-2 July	Heat treatment		
11 July	0	0.09	0
25 July	0.03	0.10	0.38
8 August	0	0.05	0.50
23 August	0.01	0.05	0.20

4. Conclusions

Our results suggest that heat treatment is an effective tool to manage stored-product insects in grain-processing facilities provided temperatures reach 50ºC and are held above 50ºC for several hours. Heat treatment is a viable alternative to structural fumigants, and an effective heat treatment can be conducted in 16-17 h.

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