Comparison of heat and sulfuryl fluoride for management of stored-product insects

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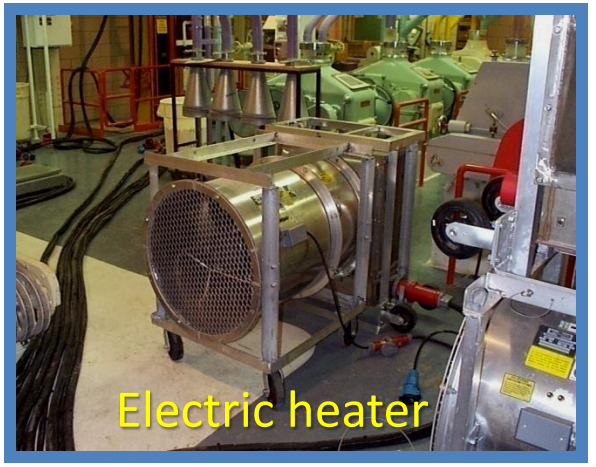
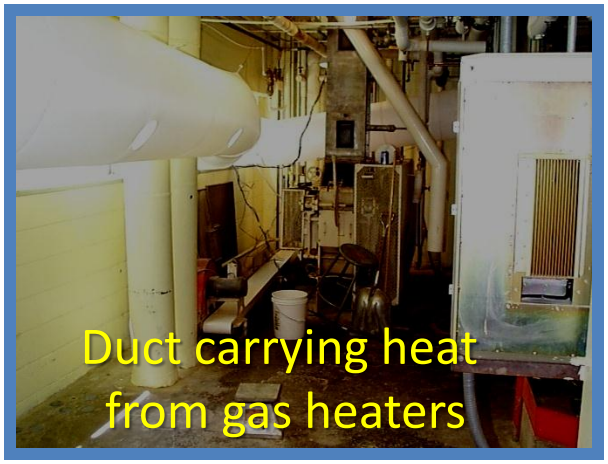
Heat treatment concept: Raising the ambient air temperature of the complete facility, or a part of it, to 122-140°F (50-60°C), and maintaining these temperatures for at least 24 hours.


Gas heaters


Steam heater


Electric heater


Duct carrying heat from gas heaters


Fan

Stored product insect responses at different temperature ranges*

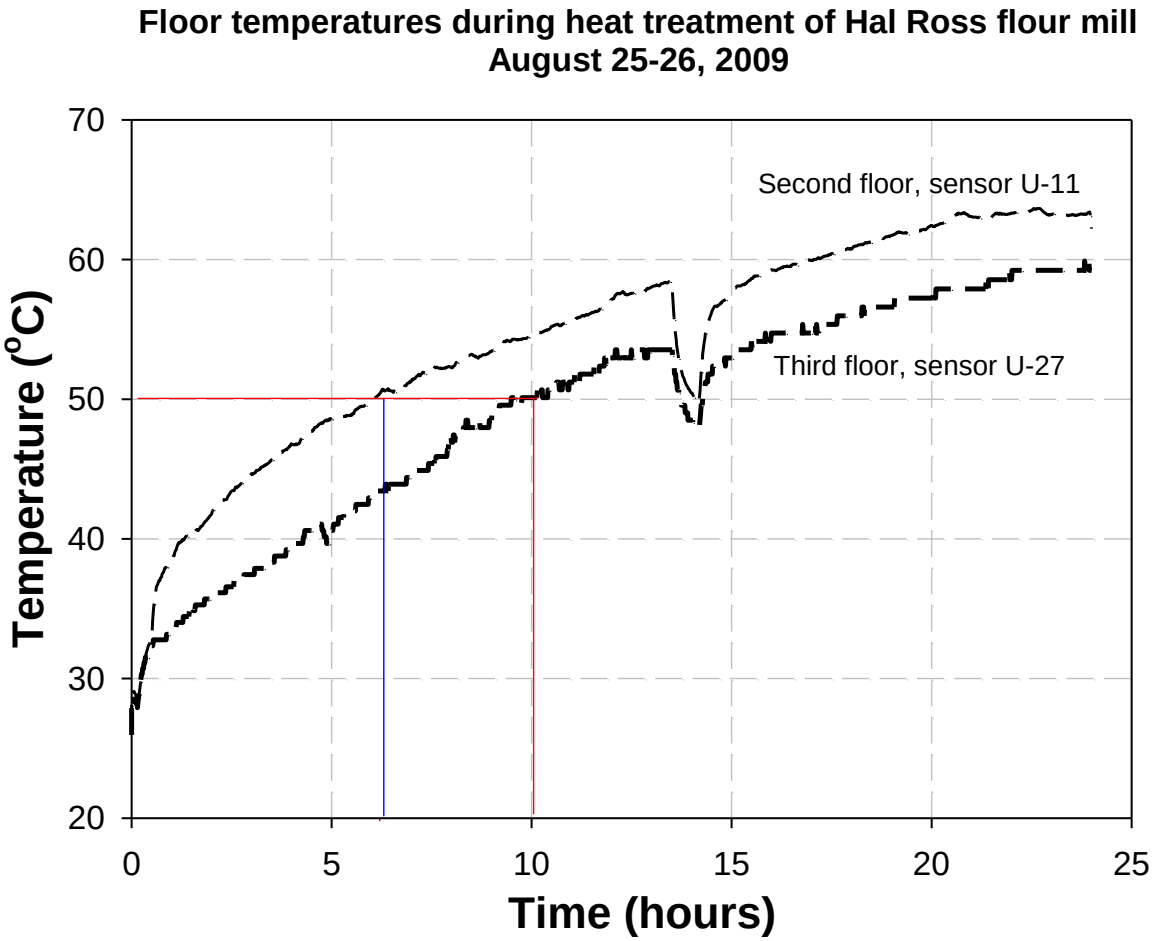
Temp. ºC (ºF)	Response
25 – 32 (77 - 89.6)	Optimum for development
33 – 35 (91.4 – 95)	Upper limit for reproduction for most stored-product insects
36 – 42 (96.8 – 107.6)	Populations die out, mobile insects seek cooler zones
45 – 49 (113 – 120.2)	Death within a day
50 – 60 (122 – 140)	Death within hours to minutes
Above 62 (> 143.6)	Death within a minute

*After Banks and Fields, 1995.

Air circulation is important

Photos: Courtesy, P. G. Fields

Typical temperature profile

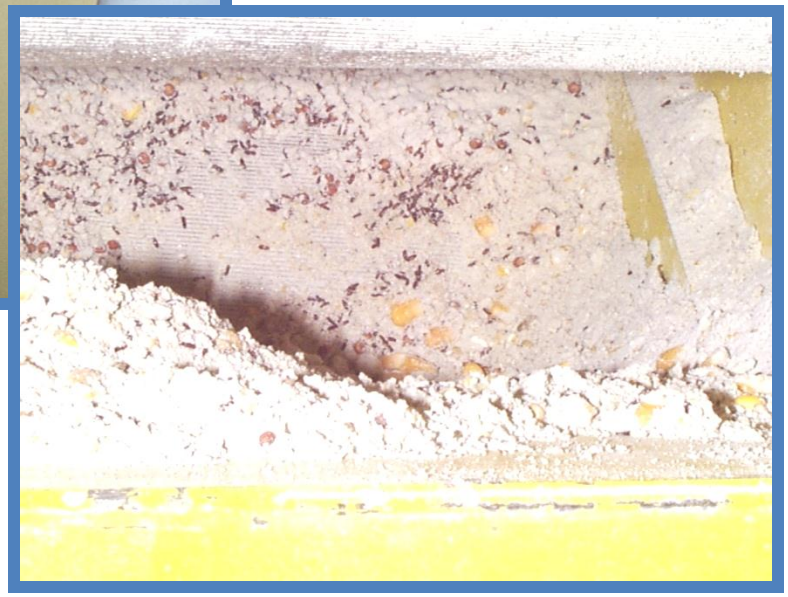


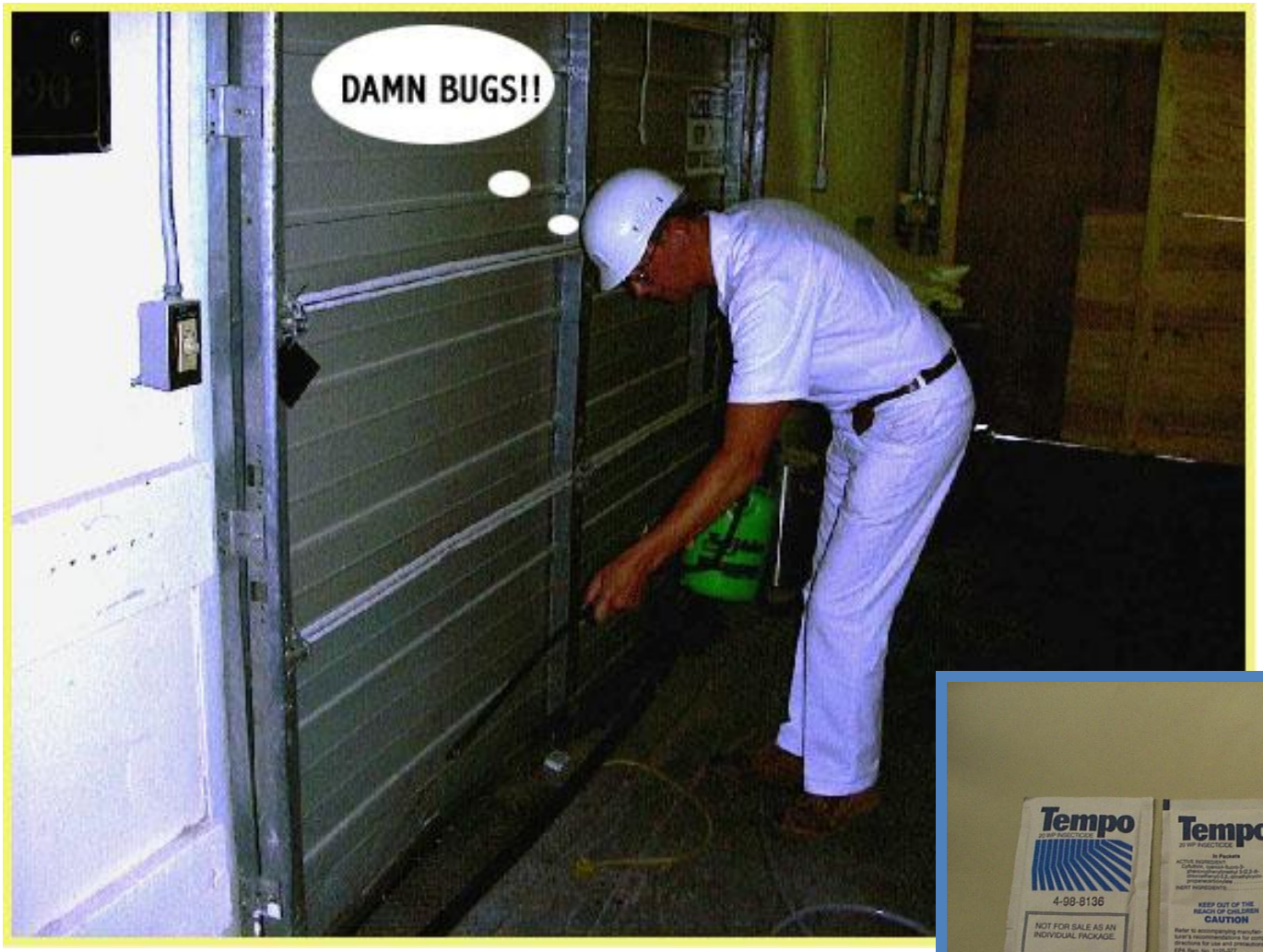
Locations where heat can be used

- Bins/silos
- Whole-facility treatment
- Specific rooms
- Specific pieces of equipment

Sanitation is the key

Important as heat does not penetrate products well.





Apply a residual pesticide such as cyfluthrin (Tempo) or diatomaceous earth

Determine heat energy requirements

- Calculate heat loss from all surfaces to determine the amount of heat required to raise the temperature of a room or an area

Total energy required

- $Q_{total} = Q_{ES}+Q_{I}+Q_{SS}$
- Q_{ES} = heat loss due to exposed surfaces
- Q_{I} = heat loss due to infiltration
- Q_{SS} = heat loss due to steel surfaces
- Involve an engineer to make these calculations
- Heat Treatment Calculator (2.0)

- Rule of thumb
  - Heat treatment companies: 10-15 BTU/cubic feet/hour or 0.10-0.15 kW/cubic meter/hour

Total heat energy

A = 0.10-0.15 kW/cubic meter/hour

B = Volume of building in cubic meters

C = Duration of treatment in hours

Total hat energy = A x B x C

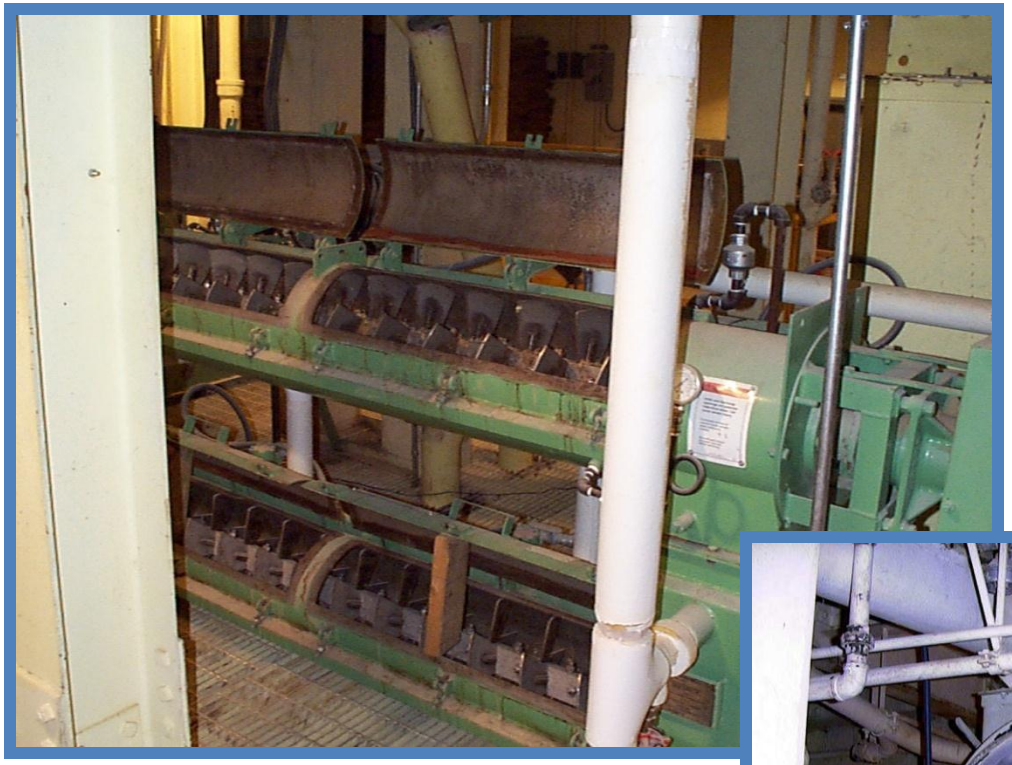
Based on this determine what heat equipment you need

Indirect method for determining if you have adequate heat energy

- Need to reach 50°C (122°F) within 6-12 hours

- Rate of temperature increase from ambient to 50°C should be between 3 and 5°C/hour

Should equipment be opened or closed?



- Open, clean, and then close
- In open equipment, heat penetration is 20 minutes faster than in unopened equipment

Characterizing temperature profiles

Data logger

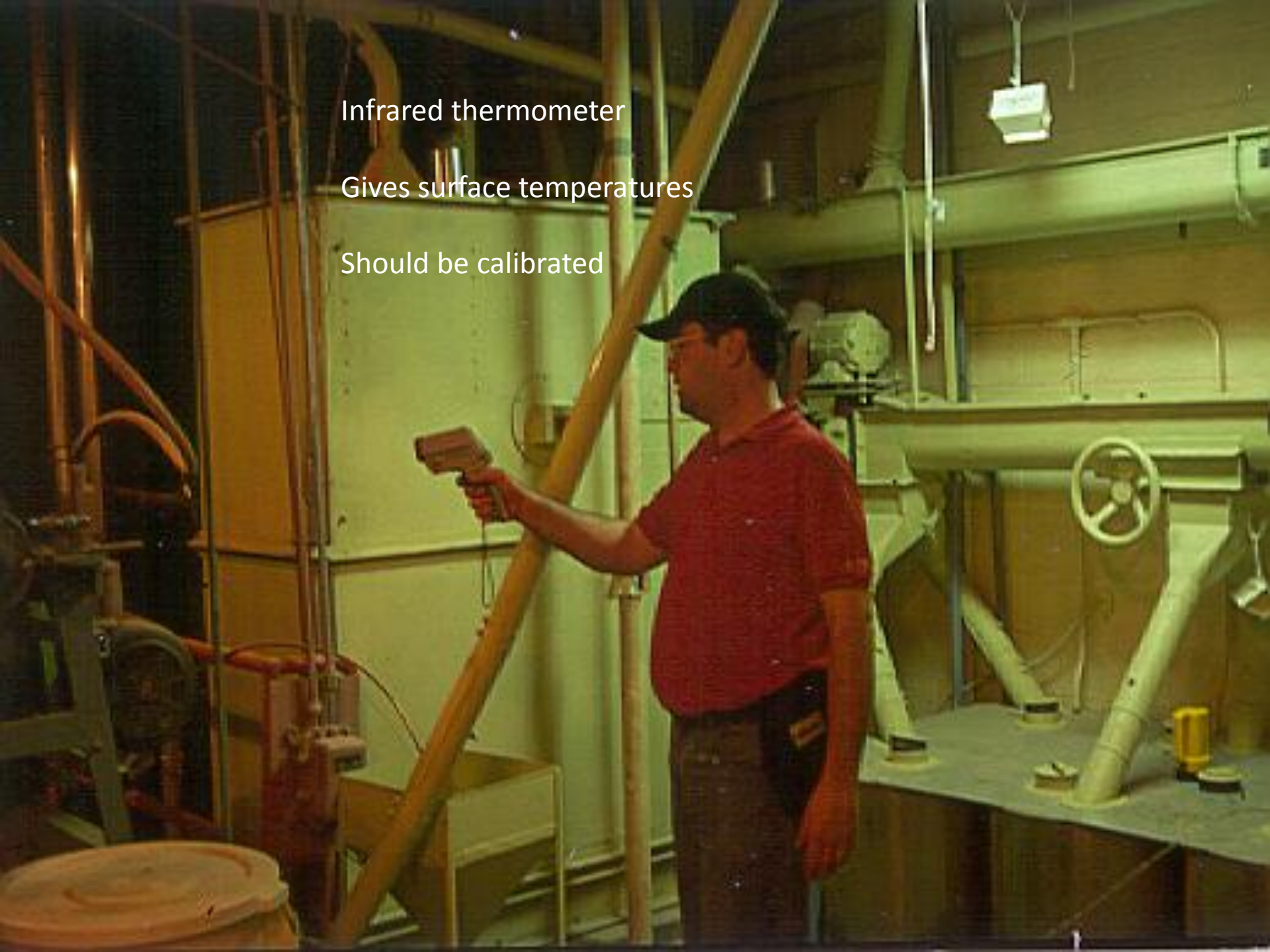
Gives real-time reading

Microprocessor-based data logger

Records temperature and relative humidity

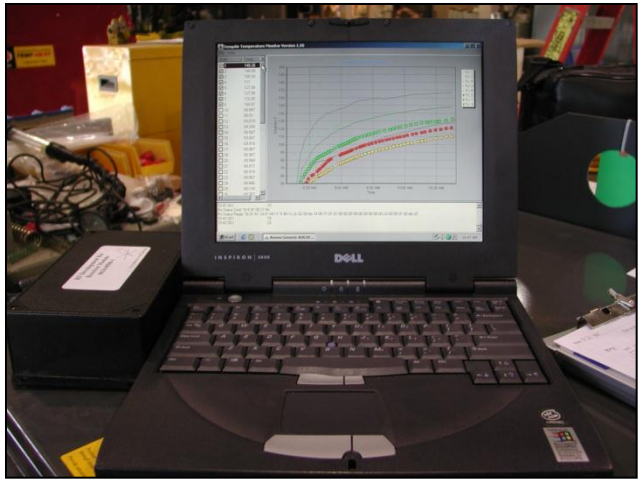
Launched and read by computer

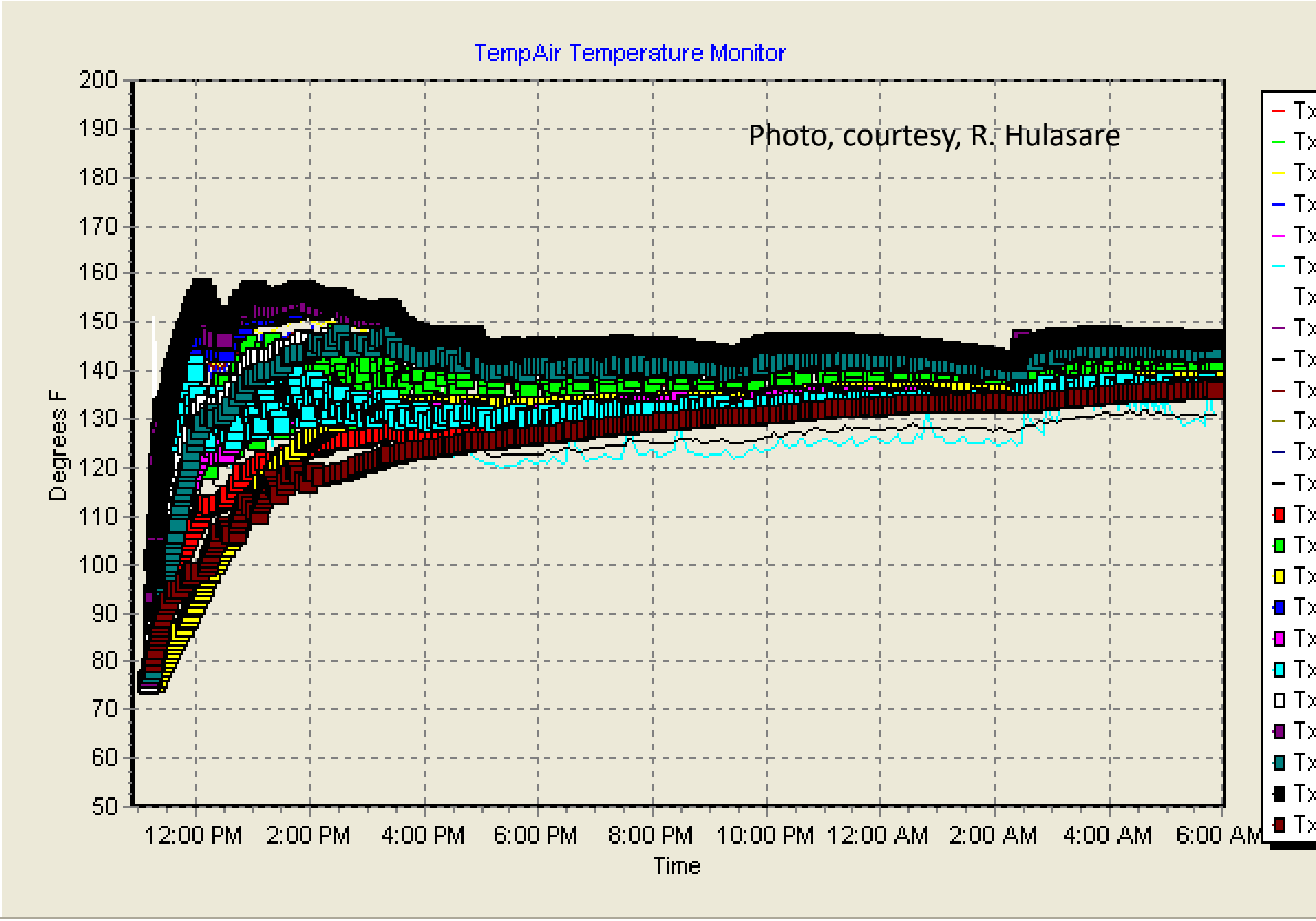
Gives readings after heat treatment


Infrared thermometer
Gives surface temperatures
Should be calibrated

Wireless devices

- Radio frequency
- Transmitter
- Receiver
- Gives real-time reading




TempAir Temperature Monitor
Photo, courtesy, R. Hulasare
Degrees F
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
12:00 PM
2:00 PM
4:00 PM
6:00 PM
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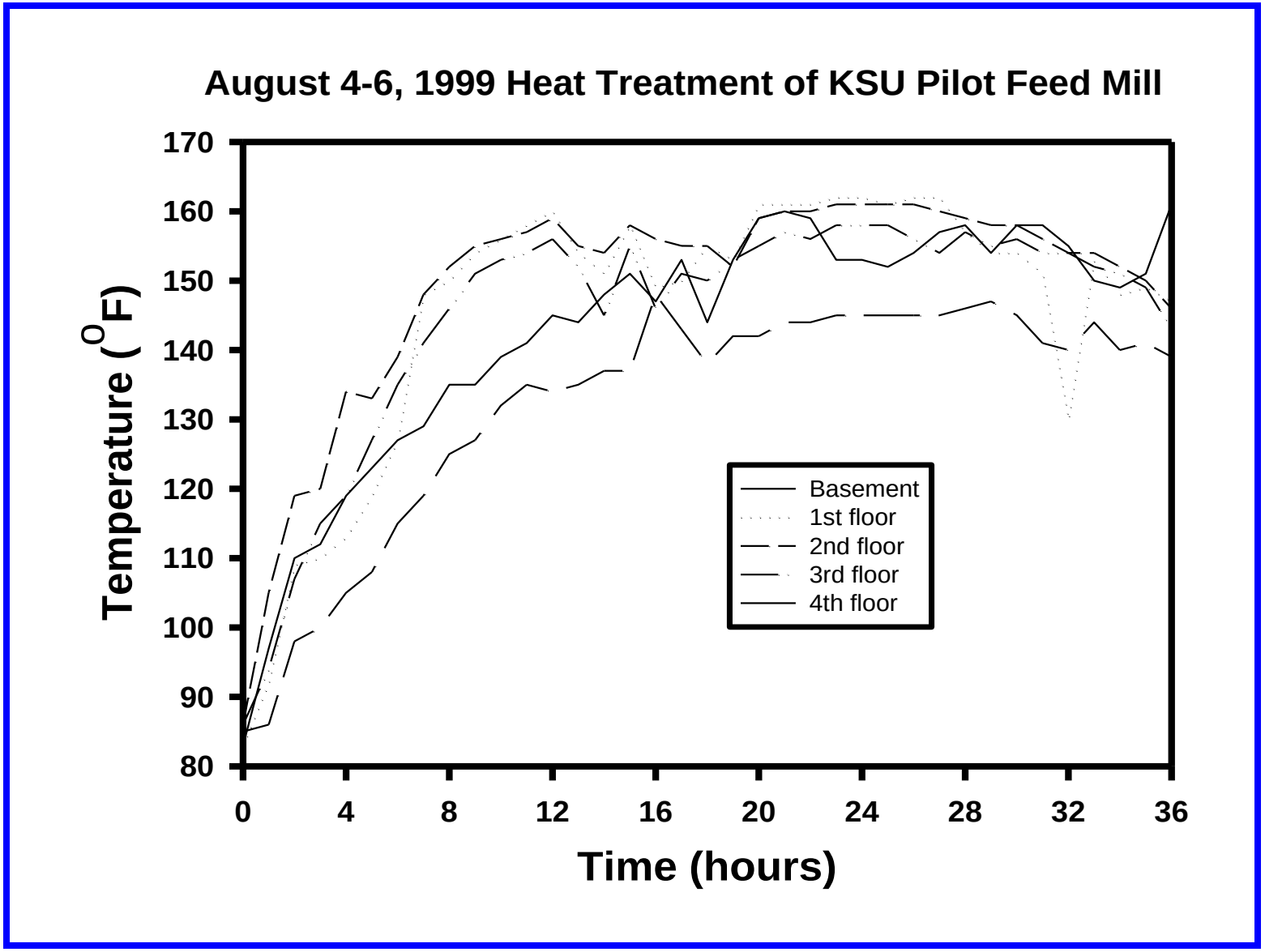
12:00 AM
2:00 AM
4:00 AM
6:00 AM
Time


August 4-6, 1999 Heat Treatment of KSU Pilot Feed Mill
Temperature (°F)
170
160
150
140
130
120
110
100
90
80
0
4
8
12
16
20
24
28
32
36
Time (hours)
Basement
1st floor
2nd floor
3rd floor
4th floor

Gas heat treatment, August 4-6, 1999
Feed mill, KSU

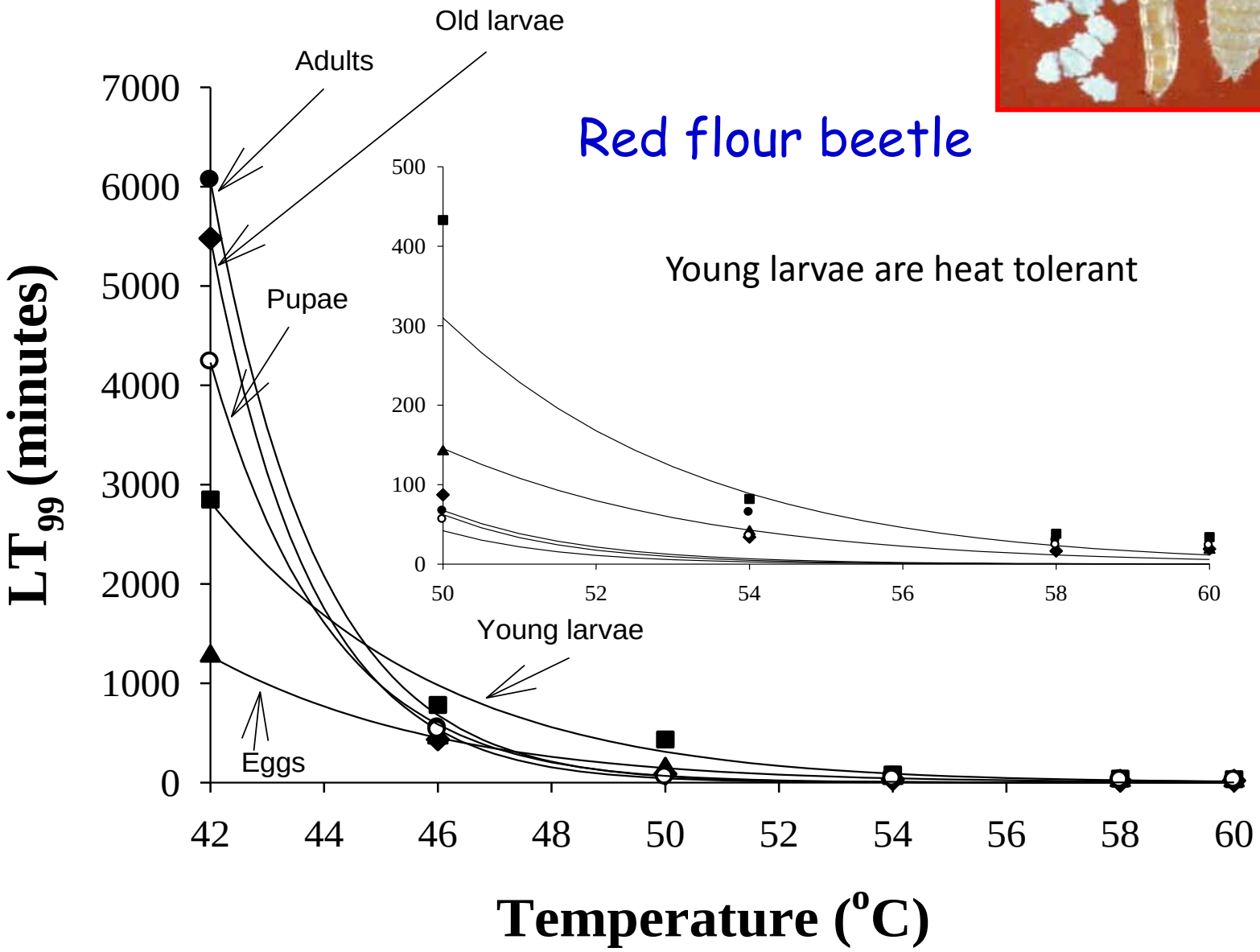
Location	Hours to reach 50°C	Hours above 50°C	Maximum temperature (°C)
Basement	4-4.3	31.7-32	71.7
1st floor	1.5-3.2	32.8-34.5	63.9
2nd floor	2.1-2.4	33.6-33.9	70.7
3rd floor	3.1-3.4	32.6-32.9	70
4th floor	7.2-8	28-28.8	64.4
Warehouse	1.3-2.3	33.7-34.7	65.6

Heater discharge: 62.8-104.4°C. Outside: 22.2-24.4°C. Mill: 28.3-30.6°C.

Susceptibility differences among life stages and insect species

Red flour beetle

Young larvae are heat tolerant



Comparison of heat tolerant stages of four species (LT_{99} in minutes (95% CL))

Species	Stage	46°C	50°C	54°C
Cigarette beetle	Eggs	598.1 (571.21-633.10)	165.45 (152.62-182.84)	37.87 (35.14-41.56)
Red flour beetle	Young larvae	430.7 (364.3-573.6)	432.8 (365.3-572.6)	81.9 (60.4-207.7)
Confused flour beetle	Mature larvae	299.46 (281.81-324.88)	90.05 (81.80-102.26)	55.71 (48.75-67.25)
Indianmeal moth	Mature larvae	69 (62-80)	34 (29-43)	Not tested

A successful heat treatment depends on.....

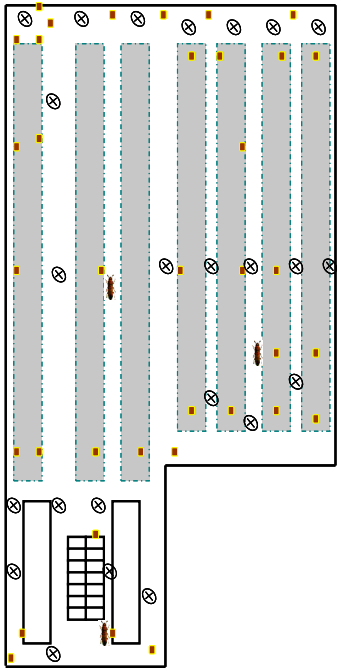
- Estimating the amount of heat required (through heat-loss calculations)
  - KSU Heat Treatment Calculator 2.0 [VisualBasic.NET]
- Improving pest management efficacy
  - Eliminating cool spots through uniform heat distribution (use of fans)
  - Assessing pre- and post-heat treatment insect counts
  - Following good exclusion and sanitation practices

Facilities subjected to heat treatment

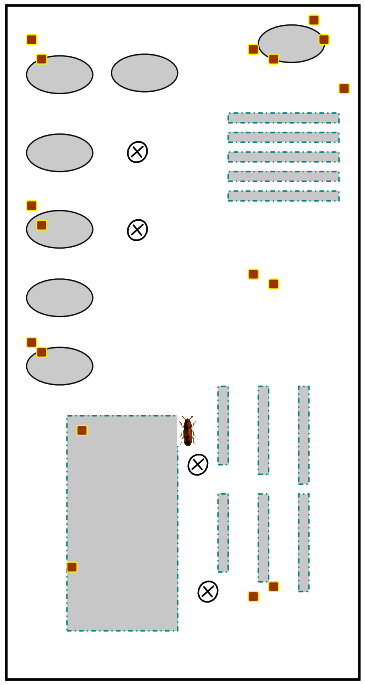
Facility	Product	Area Treated	Heat Source	Heat Treatment Dates
A	New World Pasta	Press room Flour room	Gas	Jul 1-2, 2006
B	GPC	Processing and packaging rooms	Steam (new)	Jan 25-26, 2007
C	Quaker Oats (PepsiCo)	Corn mill room 8	Steam (old)	Aug 31-Sep 2, 2007

Layout of facilities

NW Pasta

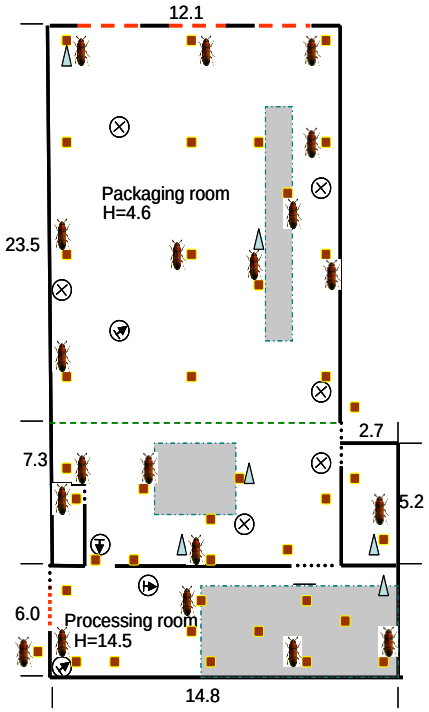


Facility A
Press room



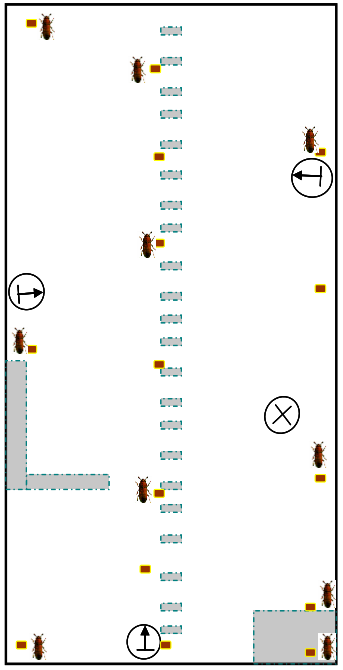
Facility A
Flour room

GPC



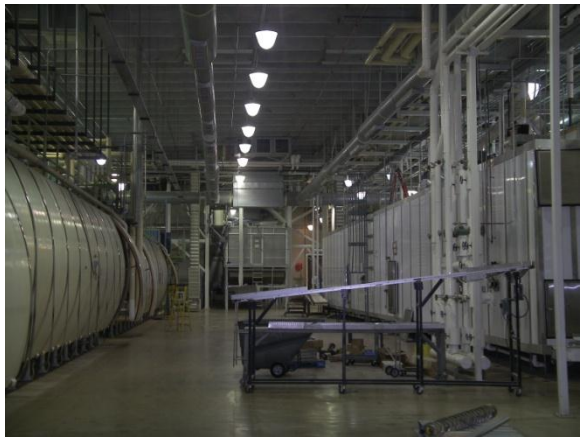
Facility B

Quaker Oats



Facility C

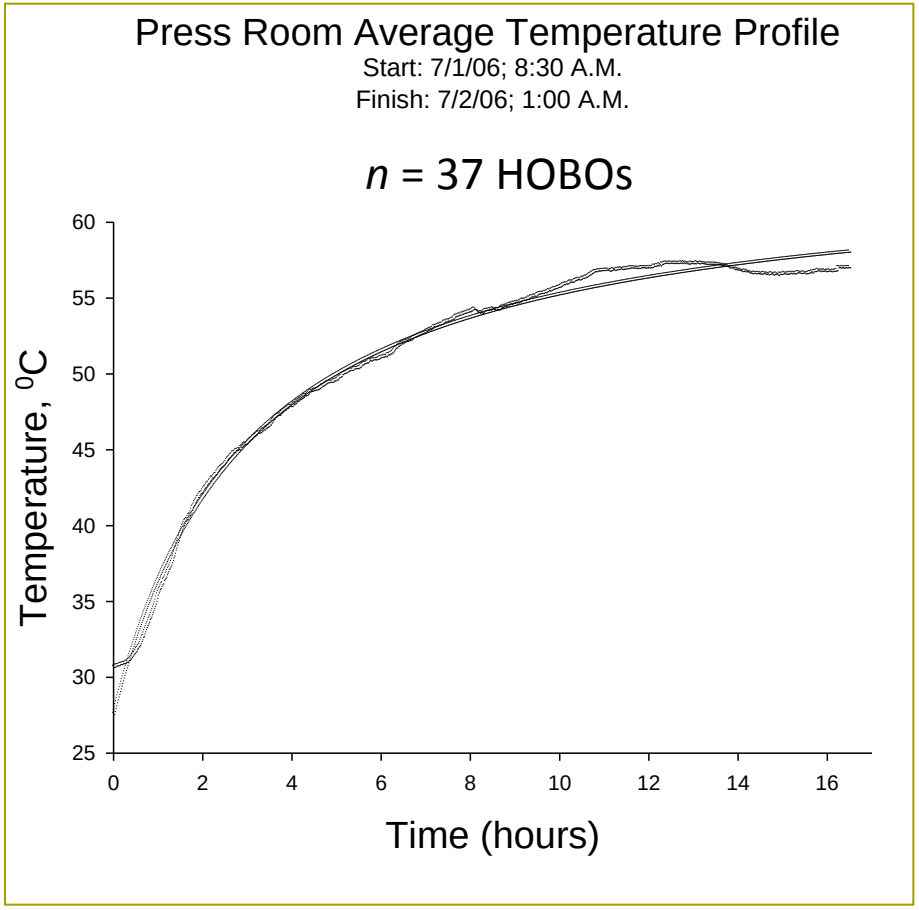
Pasta facility (A)

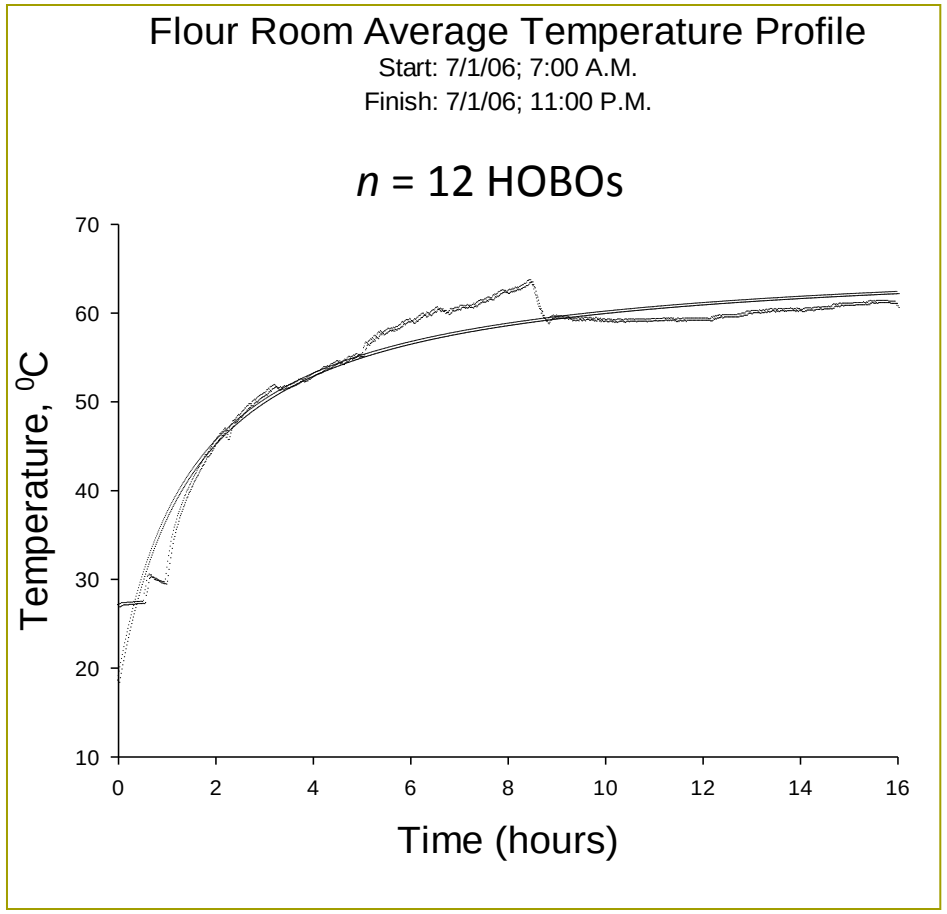


- Press area:
- Volume: 1.55 million cu ft
- Surface area: 46,750 sq ft
- Wt of steel: 9,710,00 lb

- Flour room:
- Volume: 120,000 cu ft
- Surface area: 3,600 sq ft
- Wt of steel: 750,000 lb

Facility A – Temperature Profiles





Heat energy requirements based on KSU Heat Treatment Calculator

Area	Heat requirements (in million BTU)			BTU/cubic foot/hour			Natural gas usage (in Therms)		
	Hourly		Total	Rise	Hold	Total	Hourly		Total
	Rise	Hold					Rise	Hold	
Flour Room	1.6	0.7	18.24	13.4	5.8	9.6	21.5	9.8	250.4
Press Room	11.53	4.9	142.6	6.3	2.7	4.6	165	70	2041

Total estimated heat required: 160.8 million BTU. Estimated fuel cost: $ 2498

Heat generated at 70% efficiency: 155 million BTU
Natural gas used during heat treatment: 2212 Therms
Cost of fuel used during heat treatment: $ 2411

Use traps before and after heat treatment

Food and pheromone-baited trap for crawling insects

Sticky trap for moths/beetles

Captures of red flour beetles (*Tribolium castaneum*)

Mean number of adults/trap/week

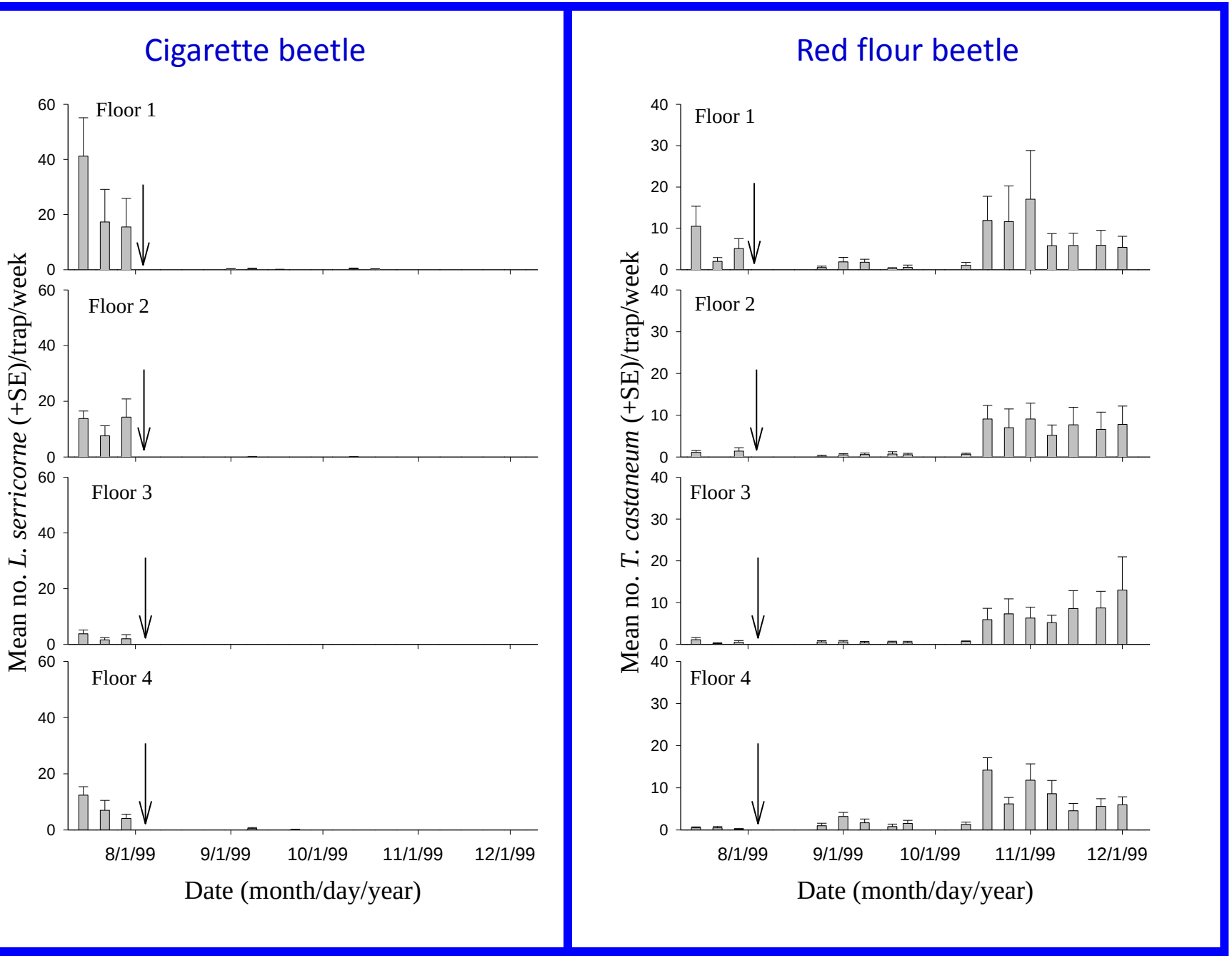
Date	Press room (*n*=35)	Flour room (*n*=10)	Outside (*n*=5)
5/30/2006	0.46	0.40	0.50
6/14/2006	0.20	0.42	0.65
6/28/2006	0.32	0.65	0
7/11/2006	0 (100%)	0.09 (86%)	0
7/25/2006	0.03	0.10	0.38
8/8/2006	0	0.05	0.50
8/23/2006	0.01	0.05	0.20

Good sanitation and exclusion kept numbers low after heat treatment

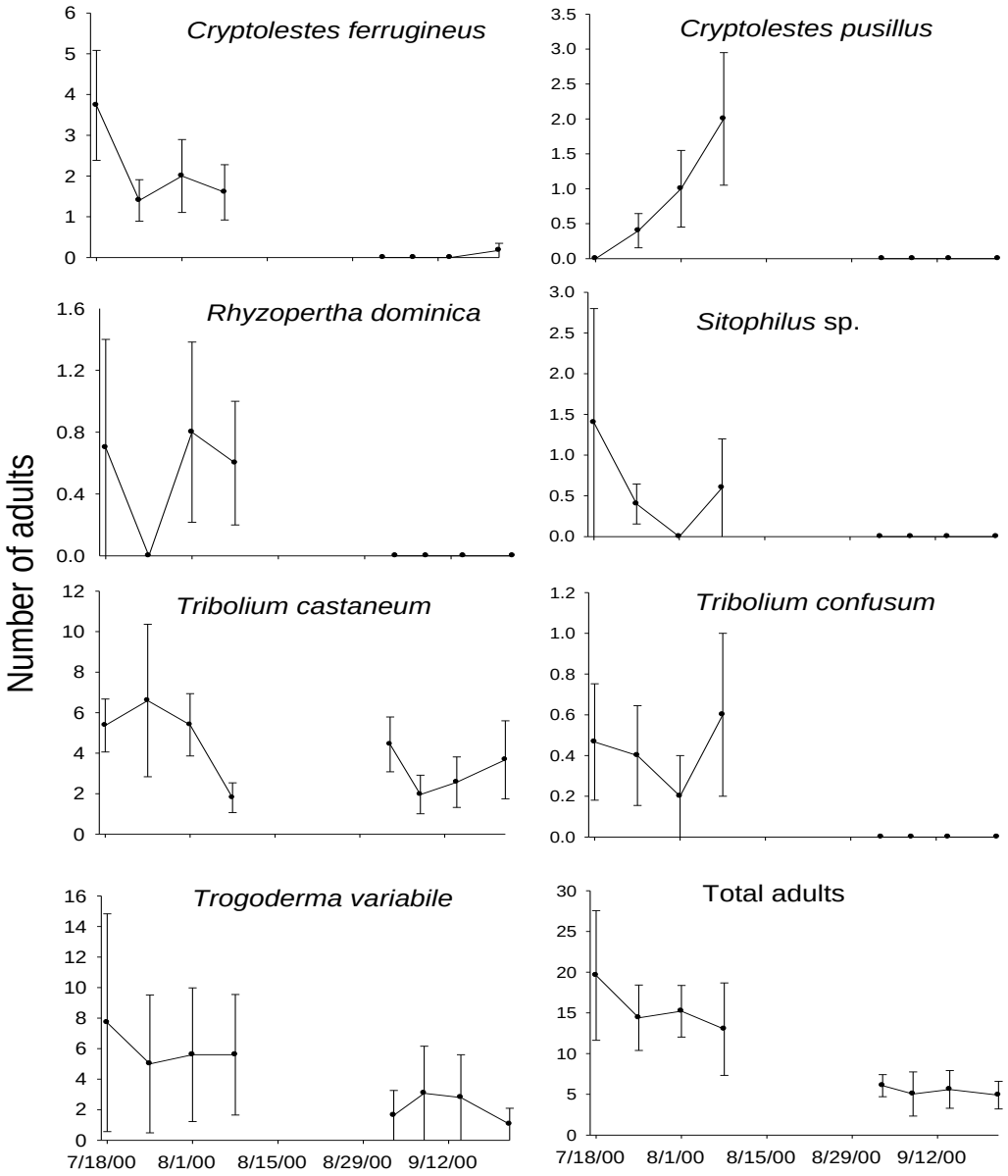
Captures of warehouse beetles (*Trogoderma variabile)*

Mean number of adults/trap/week

Date	Press room (*n*=35)	Flour room (*n*=10)	Outside (*n*=5)
5/30/2006	0.40	0.05	26.90
6/14/2006	0.47	1.40	35.00
6/28/2006	0.34	1.62	39.74
7/11/2006	0.03 (91%)	0 (100%)	53.90
7/25/2006	0.12	0.15	69.88
8/8/2006	0.10	0.20	18.90
8/23/2006	0.06	0.00	36.00



Roesli et al. (2003)



Trap catch of beetles in 1st floor of feed mill (2000 data)

Monitoring very important to determine degree and duration of insect suppression

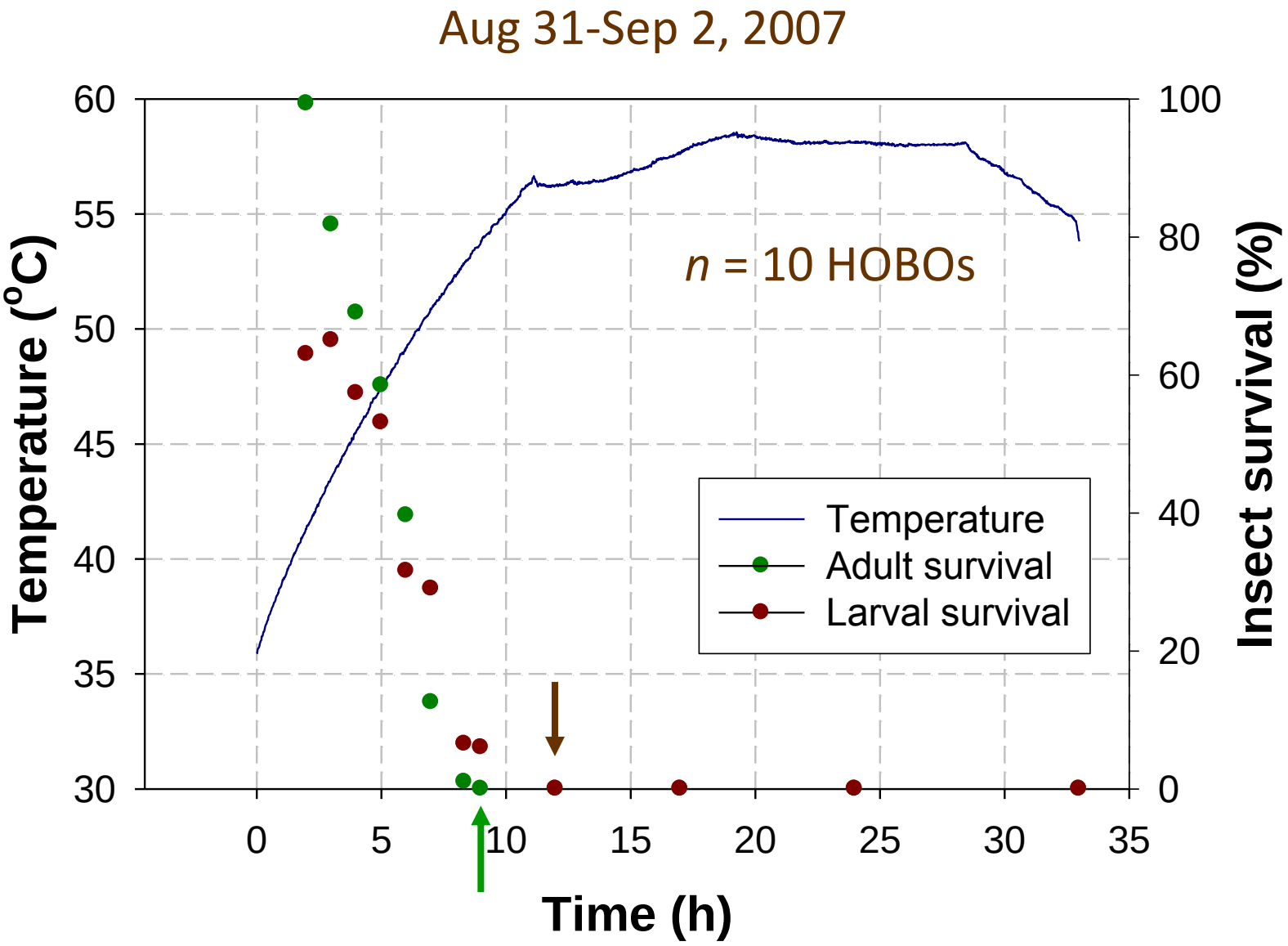
Understand reasons for insect rebound

Do we need a 24-36 h exposure time?


C-30230
LO 02146
DANGER
CONFINED SPACE
ENTER BY
PERMIT ONLY


23.3
24
23

Facility C, Quaker Oats



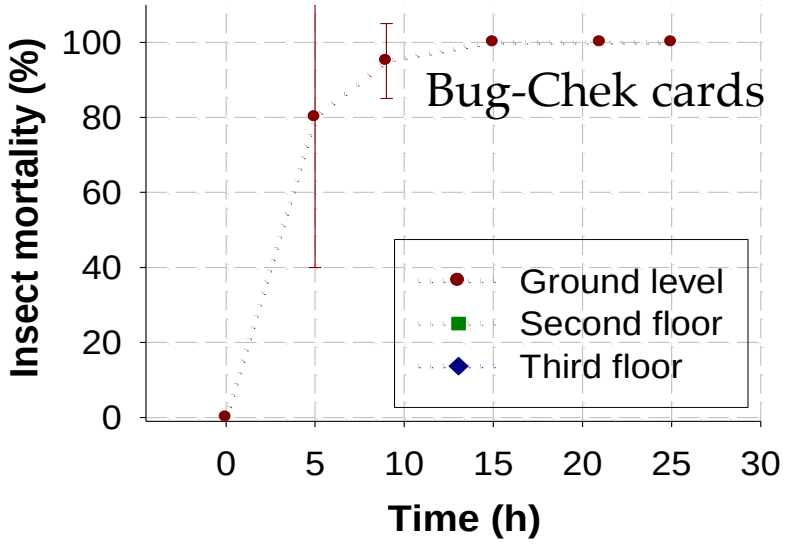
Quaker Oats (PepsiCo)

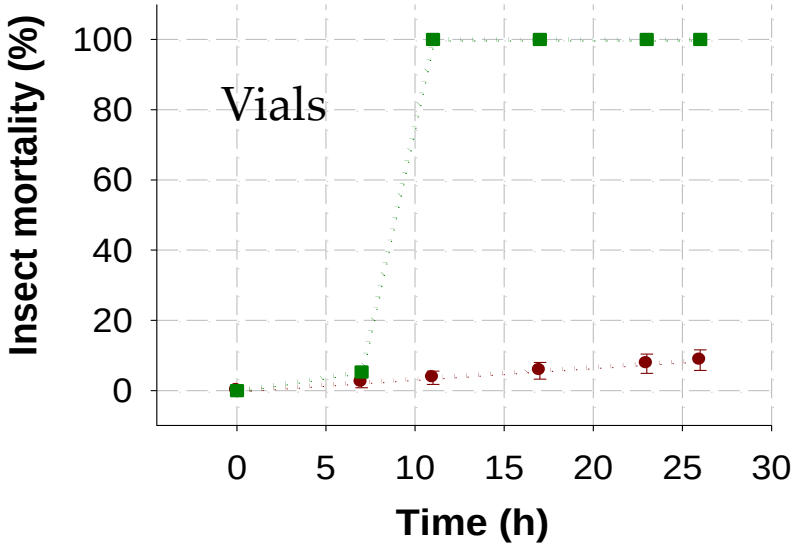
- Heat treat for 24 h instead of 32-34 hours
- Annual savings are, $25,000
- Email, November 25, 2009

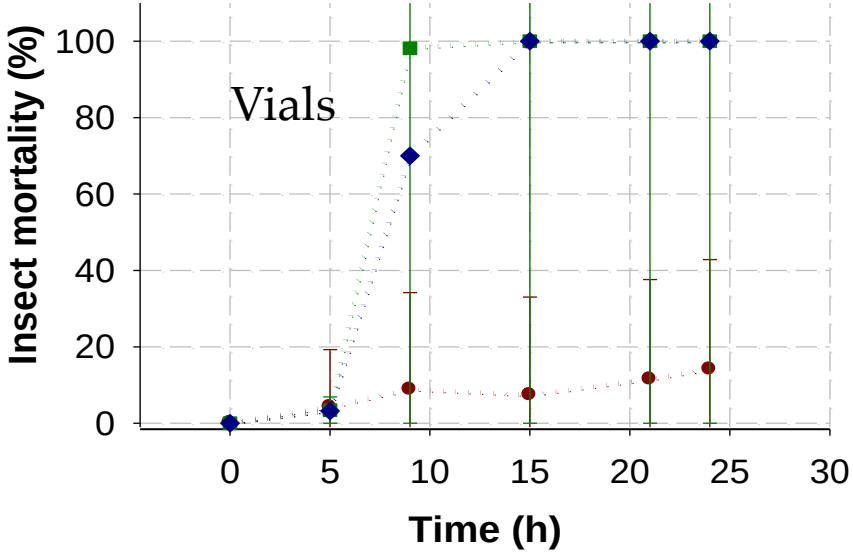
- Are Bug-Chek cards good indicators of treatment effectiveness?

Mortality of red flour beetles (*Tribolium castaneum*) in vials and commercial Bug-Chek cards

Facility (B)







Can mortality of heat tolerant stages of an insect species be predicted during heat treatment?

Thermal death kinetic model for the most heat tolerant stage

$$\log_{10}\left(\frac{N_{t-dt}}{N_t}\right) = \frac{dt}{D(T_t)}$$

where $N_{t\text{-}dt}$ is the survival at *t-dt* time interval N_t is survival at time *t* upon integration equation becomes

$$\int_0^t \log_{10}\left(\frac{N_{t-dt}}{N_t}\right) = \int_0^t \frac{dt}{D(T_t)}$$

$$\log_{10}\frac{N_o}{N_t} = \int_0^t \frac{dt}{D(T_t)}$$

Boina, Subramanyam, & Alavi (2008)

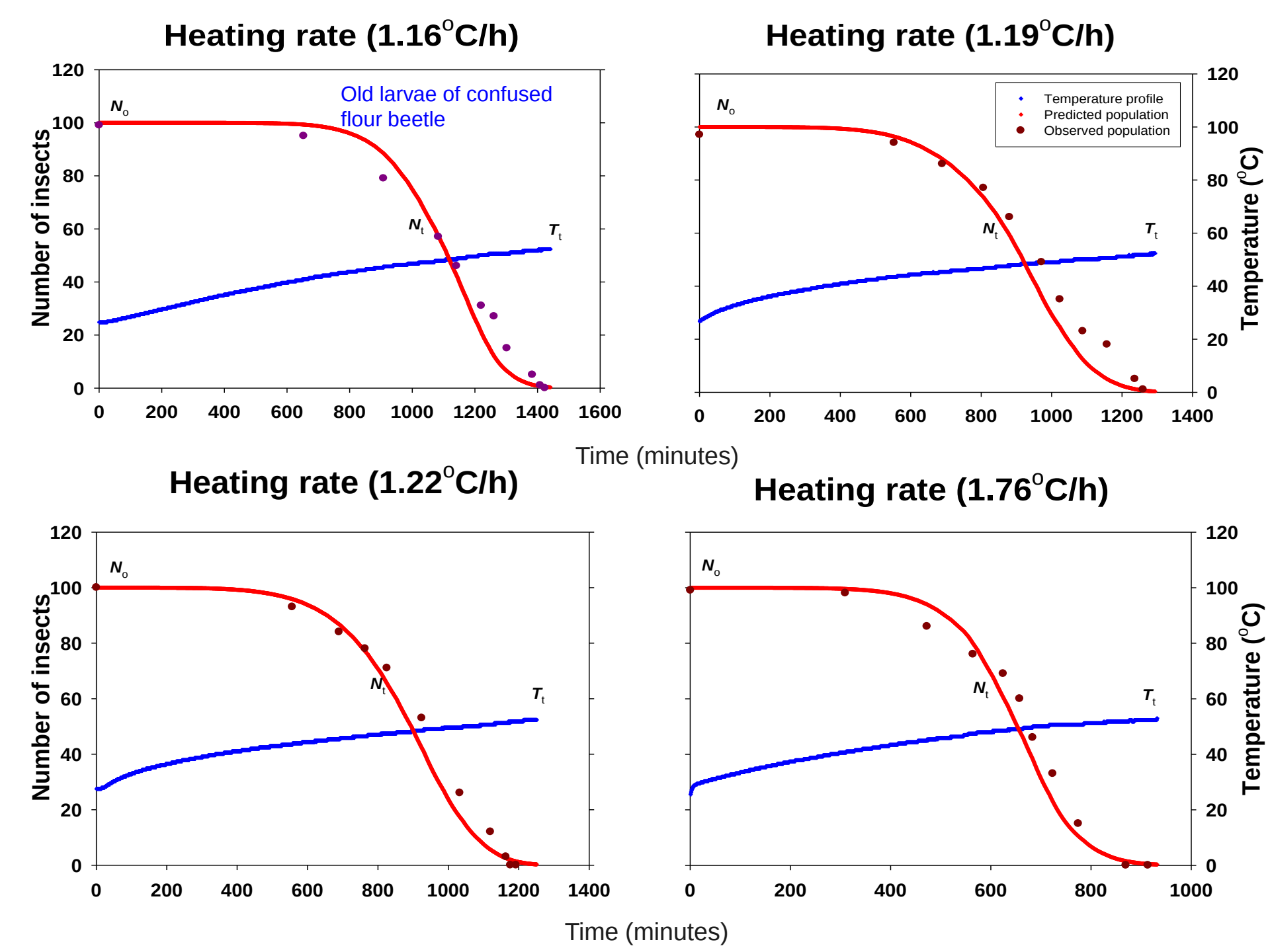
$$\log_{10}\frac{N_t}{N_0} = -\sum_0^t \frac{dt}{D(T_t)}$$

$$N_t = \frac{N_0}{10^{\sum_0^t \frac{\Delta t}{D(T_t)}}}$$

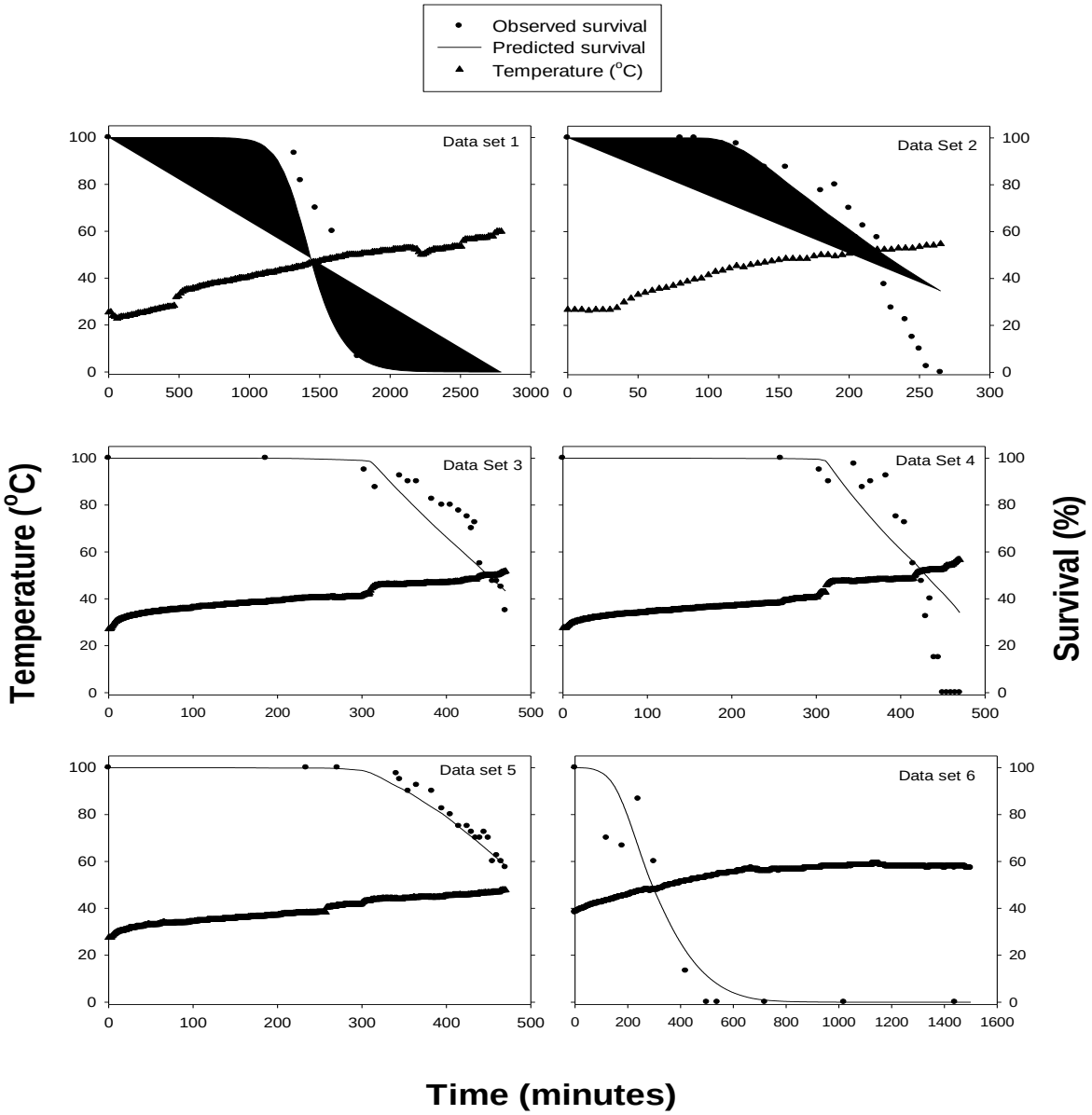
where N_o is the original number of insects; N_t is number of larvae at time *t*; Δt is the incremental exposure time (1-min), *D* is the mean instantaneous *D*-value as a function of temperature (T_t), and T_t is time- dependent temperature profile

Survival of old larvae of *Tribolium confusum* as a function of temperature

Comparison of model predictions to actual
Insect survival


Heating rate (1.16°C/h)
Old larvae of confused flour beetle
Heating rate (1.19°C/h)
Temperature profile
Predicted population
Observed population
Heating rate (1.22°C/h)
Heating rate (1.76°C/h)
Number of insects
Temperature (°C)
Time (minutes)
Time (minutes)

Observed and predicted survival of red flour beetle young larvae (Subramanyam & Mahroof, unpublished)



Supernova (C-Sharp)

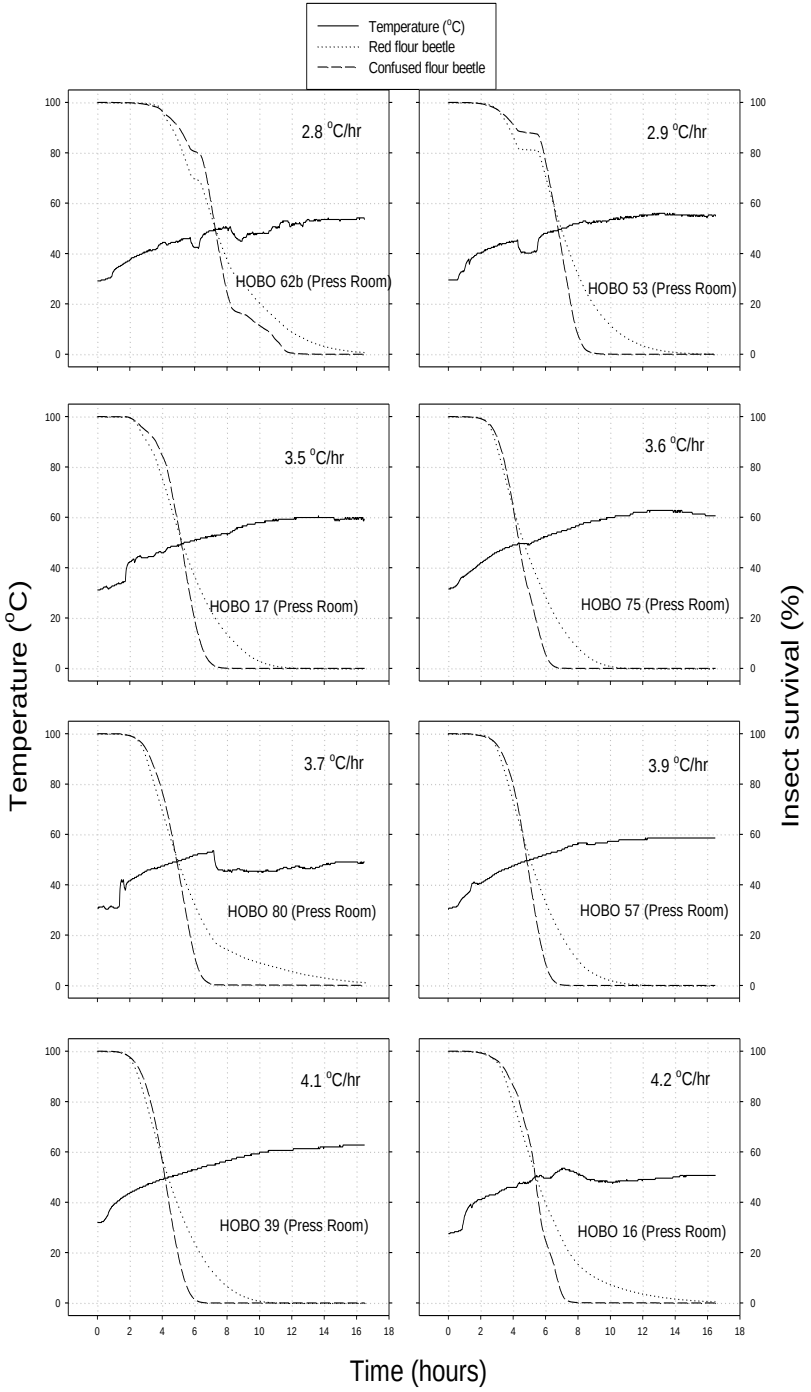
- A software program (requires data in Excel format)
- Predicts survival of young larvae of *T. castaneum* and old larvae of *T. confusum* based on time-dependent temperature profile
- Gives information on heating rate (^{o}C/h)
- Gives information on 90, 95, and 99% mortality
- Saves output data in an Excel file for graphing purposes

An example: Quaker Oats

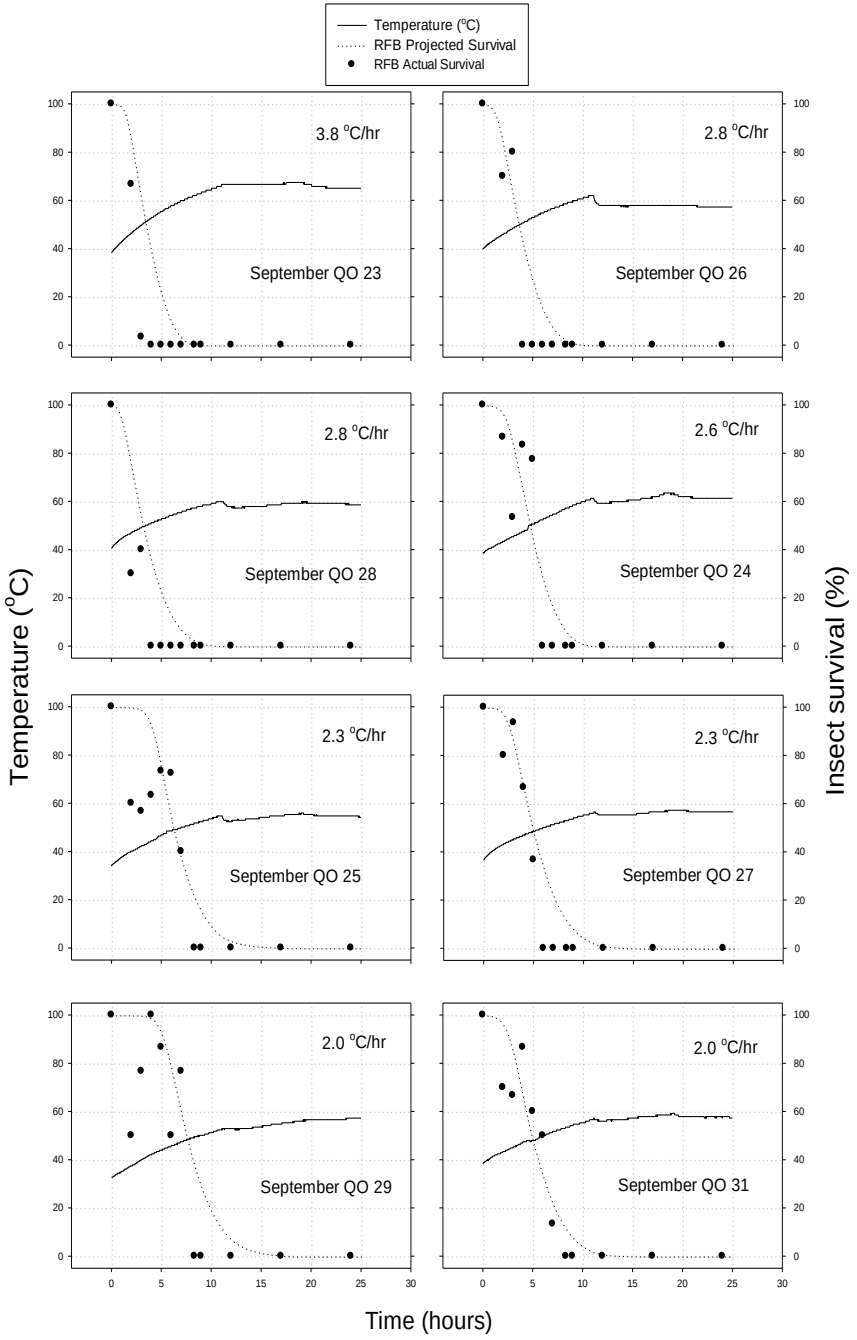
	Temp 22	Temp 23	Temp 24
Heating Rate	1.6 °C/hr	3.8 °C/hr	2.6 °C/hr
RFB 99%	16.07 Hr	7.72 Hr	10.00 Hr
RFB 95%	13.58 Hr	6.65 Hr	8.60 Hr
RFB 90%	12.33 Hr	5.98 Hr	7.75 Hr
CFB 99%	11.52 Hr	4.52 Hr	6.42 Hr
CFB 95%	11.27 Hr	4.17 Hr	5.97 Hr
CFB 90%	11.13 Hr	3.97 Hr	5.73 Hr

If ≥90% is not reached the end point mortality is given

	11T	12T	13T	14T
Heating Rate (°C/hr)	*	*	3.5	4.24
RFB 99%	23.58 %	0.00 %	21.30 Hr	13.33 Hr
RFB 95%	23.58 %	0.00 %	17.27 Hr	11.53 Hr
RFB 90%	23.58 %	0.00 %	15.40 Hr	10.70 Hr
CFB 99%	23.74 %	0.30 %	13.77 Hr	8.97 Hr
CFB 95%	23.74 %	0.30 %	12.30 Hr	8.70 Hr
CFB 90%	23.74 %	0.30 %	11.70 Hr	8.57 Hr



Predicted survival of young larvae of *T. castaneum* and old arvae *of T. confusum* in a pasta plant (Facility A)



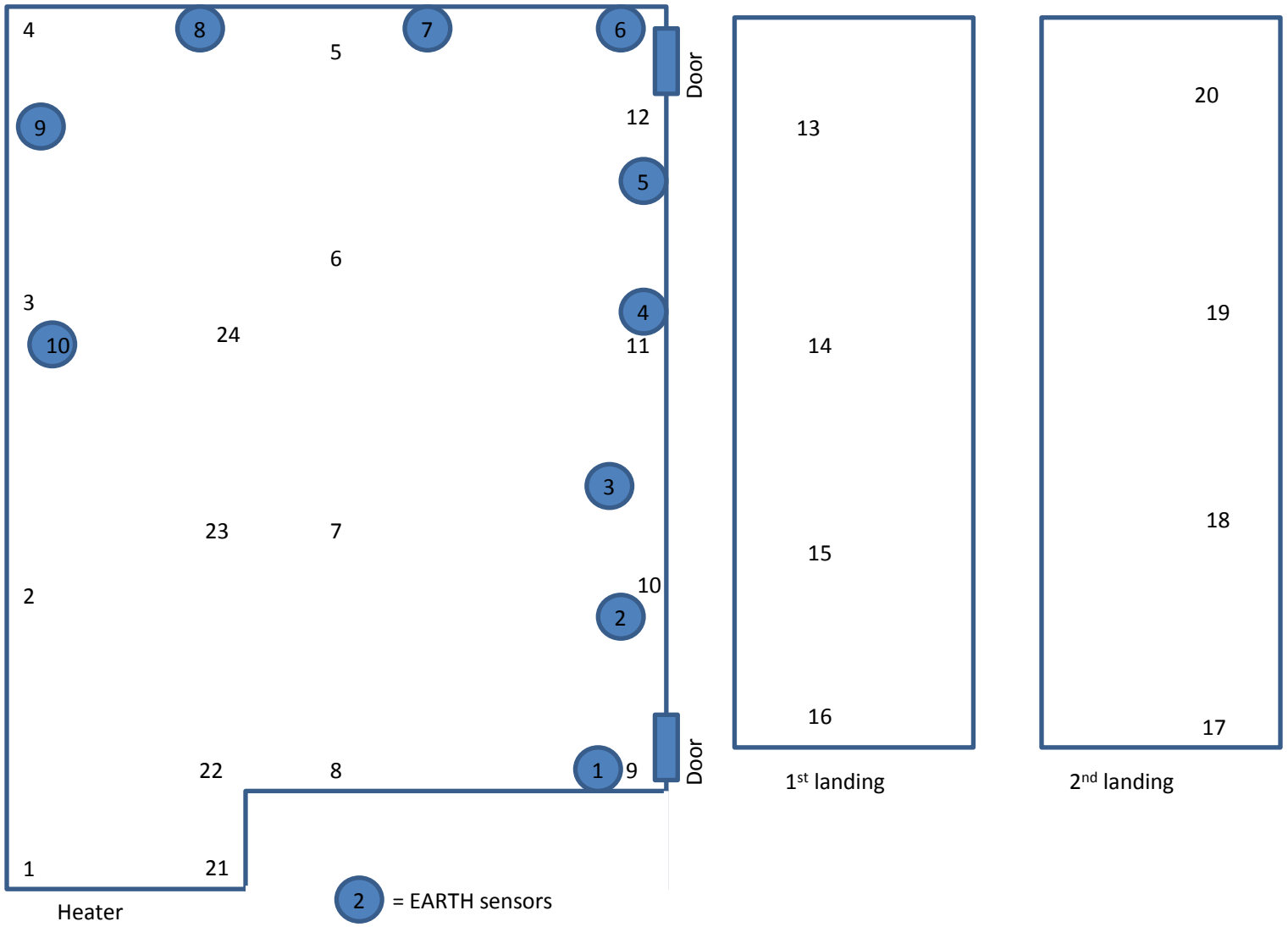
Observed and predicted survival of young larvae of *T. castaneum* in a breakfast cereal plant (Facility C)

Recent data from commercial facilities

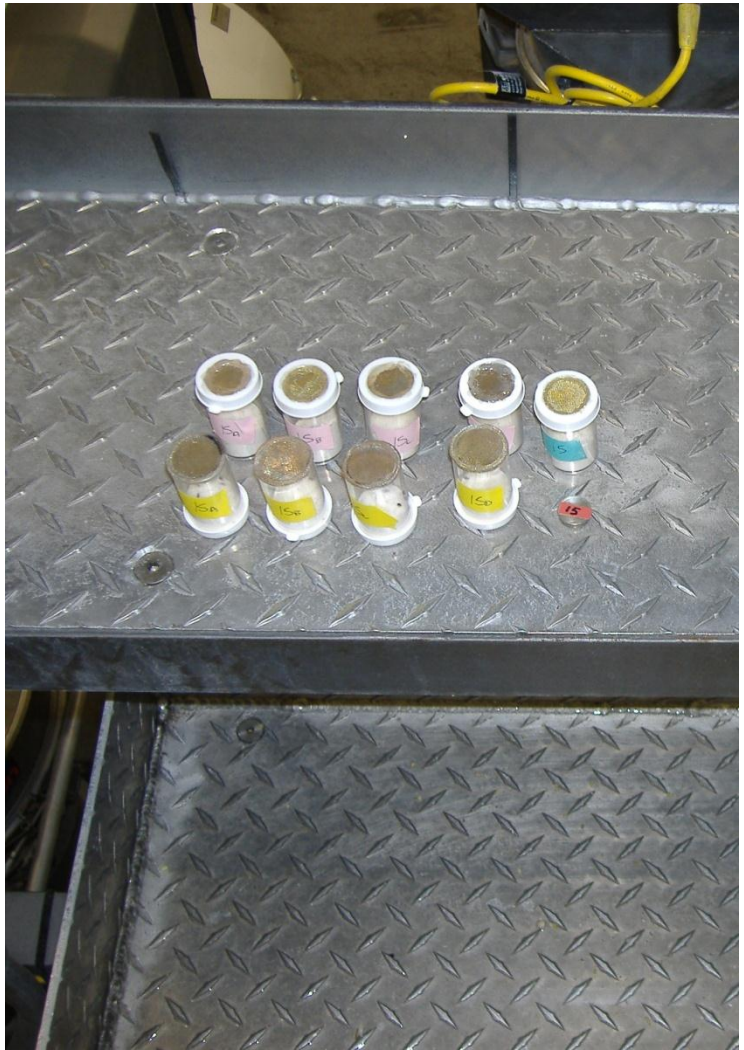

FLAMMABLE GAS
1075
2

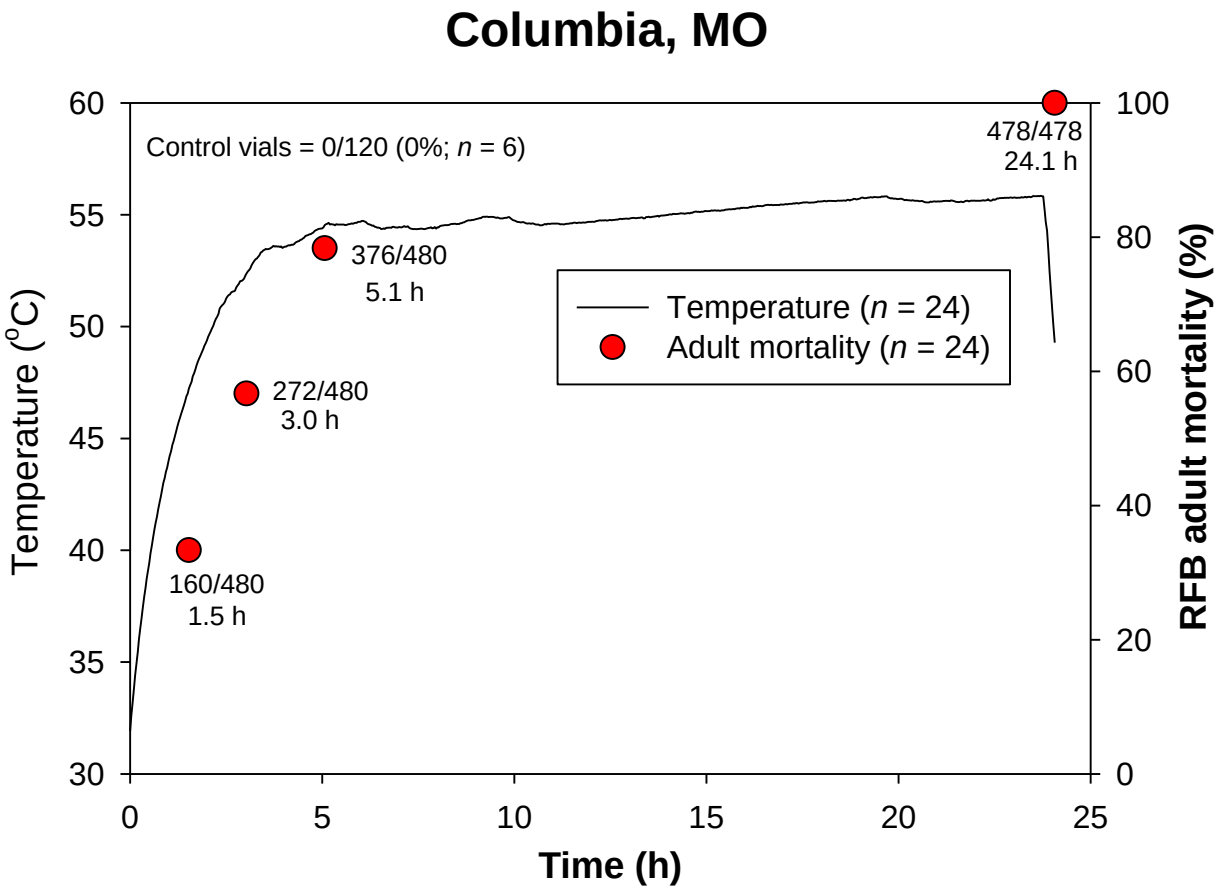

070W

Columbia, MO Facility



Red flour beetle bioassays

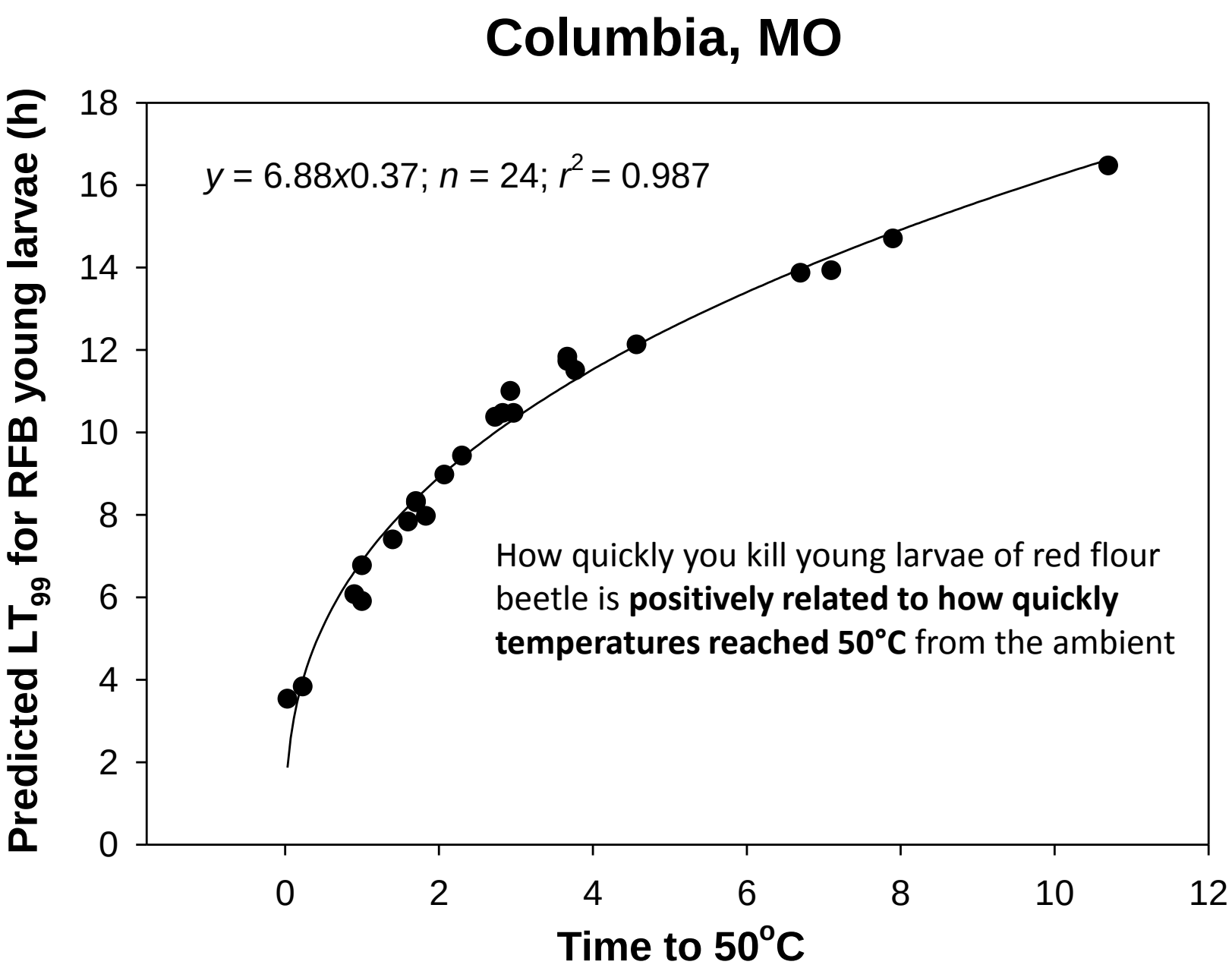


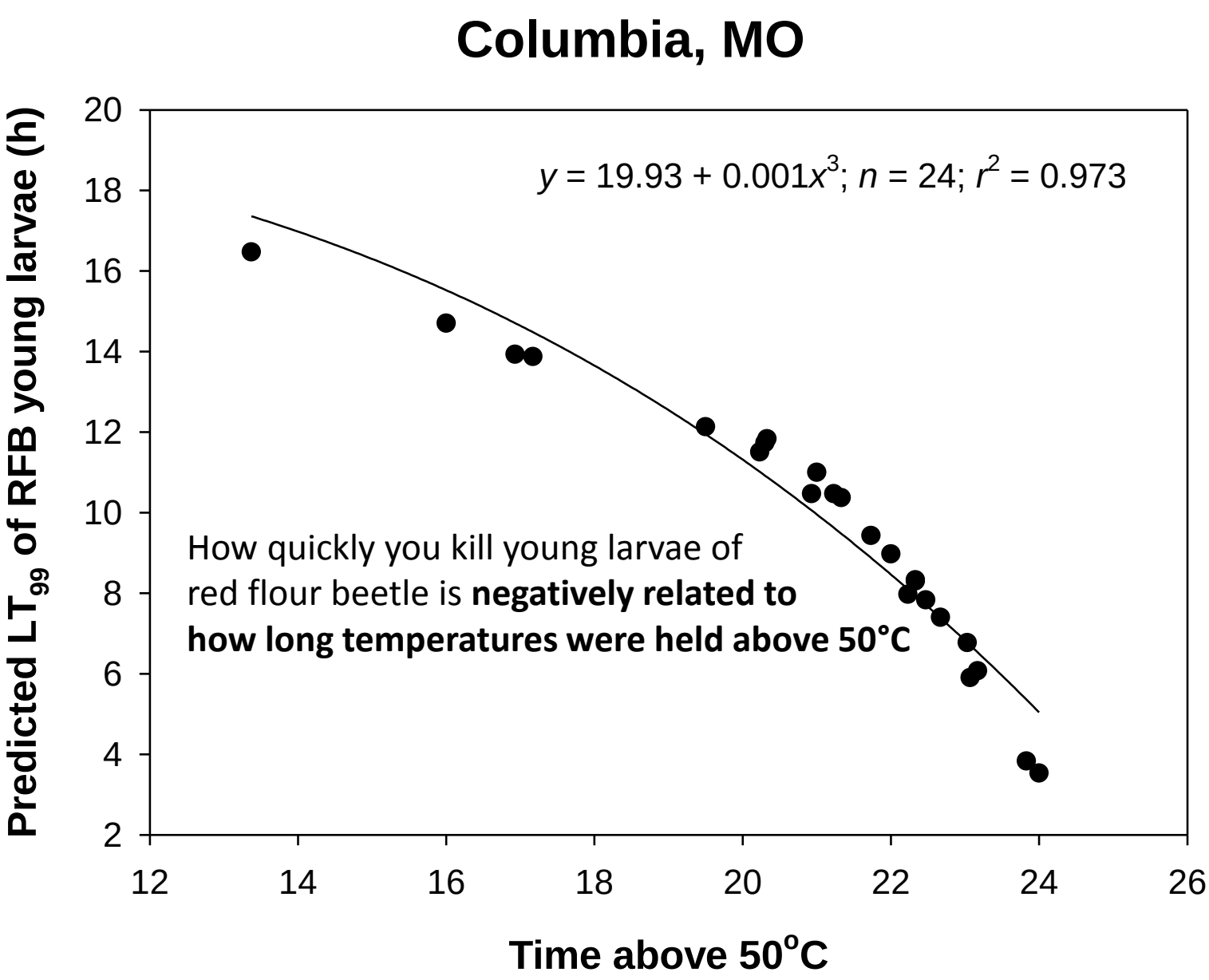


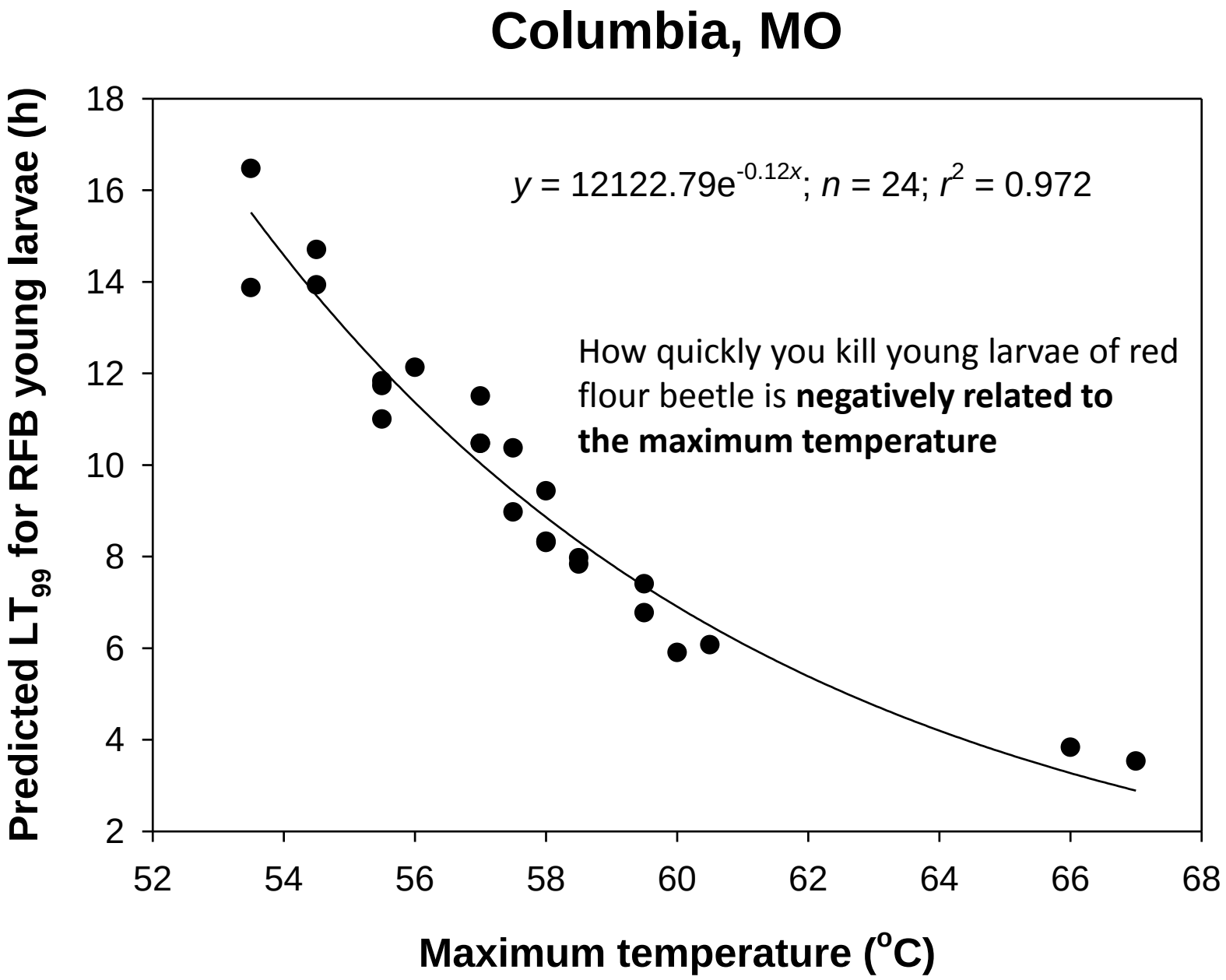
Egg –to-adult survival

Time (h)	Control (*n*=6 vials)	Heat exposed (*n* = 24 vials)
1.5	81/120	84/480
3.0	79/120	0/480
5.1	84/120	0/480
24.1	80/120	0/480

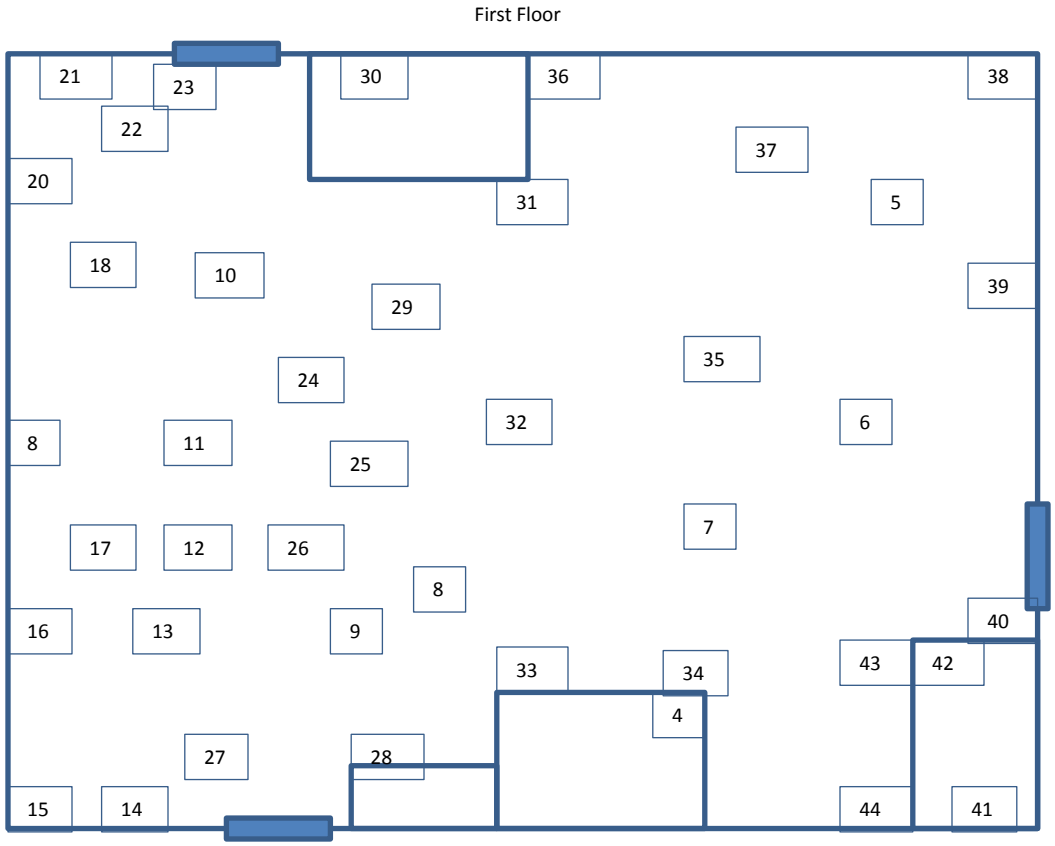
Each via has 20 eggs.

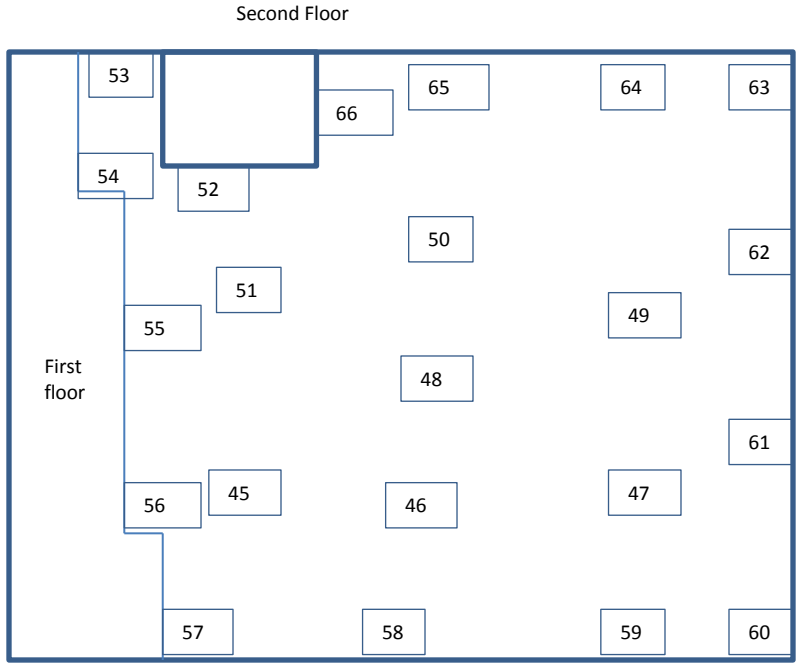

Columbia, MO
Predicted LT99 for RFB young larvae (h)
Time to 50°C
y = 6.88x0.37; n = 24; r2 = 0.987
How quickly you kill young larvae of red flour beetle is positively related to how quickly temperatures reached 50°C from the ambient
0
2
4
6
8
10
12
14
16
18
0
2
4
6
8
10
12

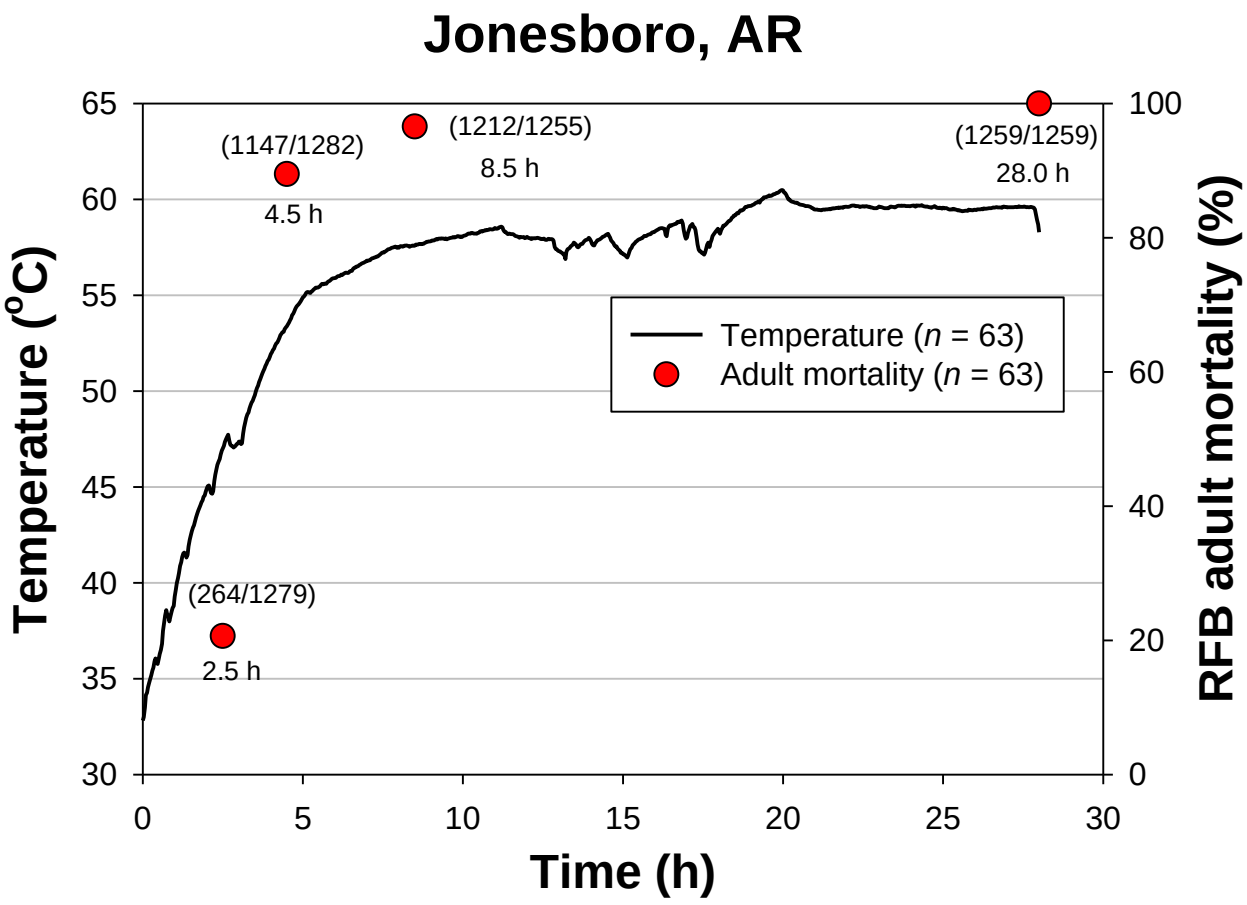

Columbia, MO
$y = 19.93 + 0.001x^3$; $n = 24$; $r^2 = 0.973$
How quickly you kill young larvae of red flour beetle is **negatively related to how long temperatures were held above 50°C**
Predicted LT_{99} of RFB young larvae (h)
Time above 50°C
20
18
16
14
12
10
8
6
4
2
12
14
16
18
20
22
24
26


Columbia, MO
$y = 12122.79e^{-0.12x}$; $n = 24$; $r^2 = 0.972$
How quickly you kill young larvae of red flour beetle is **negatively related to the maximum temperature**
Predicted LT_{99} for RFB young larvae (h)
Maximum temperature (°C)
18
16
14
12
10
8
6
4
2
52
54
56
58
60
62
64
66
68

Jonesboro, AK Facility







Egg-to-adult survival

Time (h)	Control (*n*=4 vials)	Heat exposed (*n* = 64 vials)
2.5	58/80	397/1280
4.5	64/80	0/1280
8.5	44/80	0/1280
28.0	48/80	0/1280

Each vial had 20 eggs

Commercial facilities

- New World Pasta, VA
- Quaker Oats (PepsiCo-Oats & Corn Milling), IA
- Grain Processing Corporation, IA
- Hills Pet Foods, IN
- ConAgra (David Sunflower Seeds), MO
- Gerber Foods, MI
- Anheuser Busch, AR
- Quaker Oats (PepsiCo-Rice Cakes Facility), MO
- PepsiCo (Rice-O-Roni facility), IL
- Loulis Flour Mill, Volos, Greece

Optimizing heat treatments

- Using the right amount of heat energy (0.1 kW/h/m^3)
- Eliminate cool spots (Temp. <50^oC)-fans/heaters
- Determining when to stop a heat treatment
  - Achieving 100% kill of insects without adverse effects on structure or equipment
- Making it cost-competitive with other responsive tactics
- Delaying population rebounds
- Use K-State software programs☺

Comparison of heat, methyl bromide, and sulfuryl fluoride in flour mills

Whole facility treatments for mills

Methyl bromide

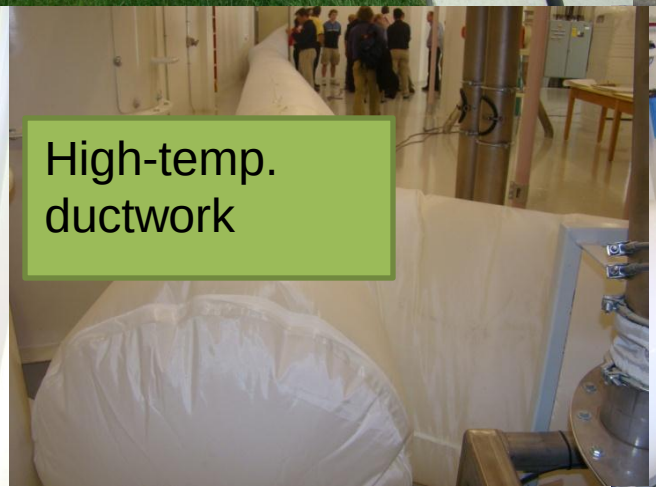
Heat treatment

Sulfuryl fluoride

Experimental Setup

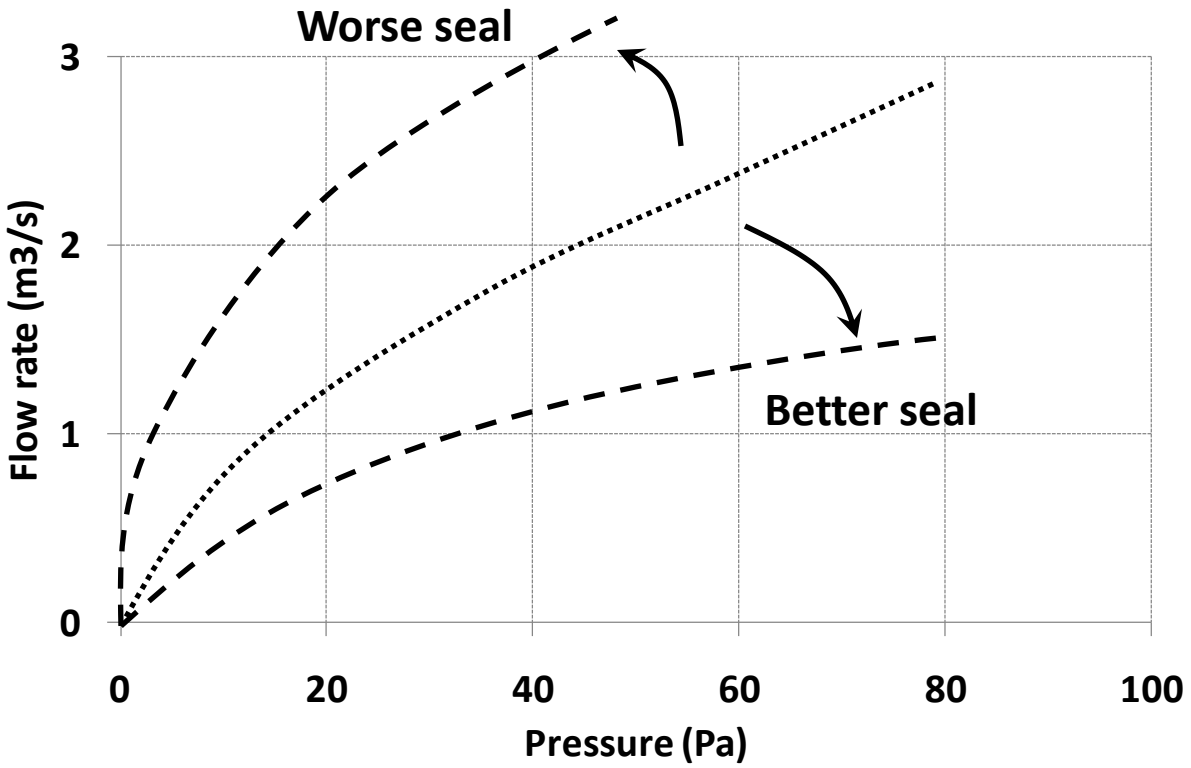
- Weather station (temperature, RH, wind, solar radiation, barometric pressure)
- Temp/RH logger (one point on each floor)

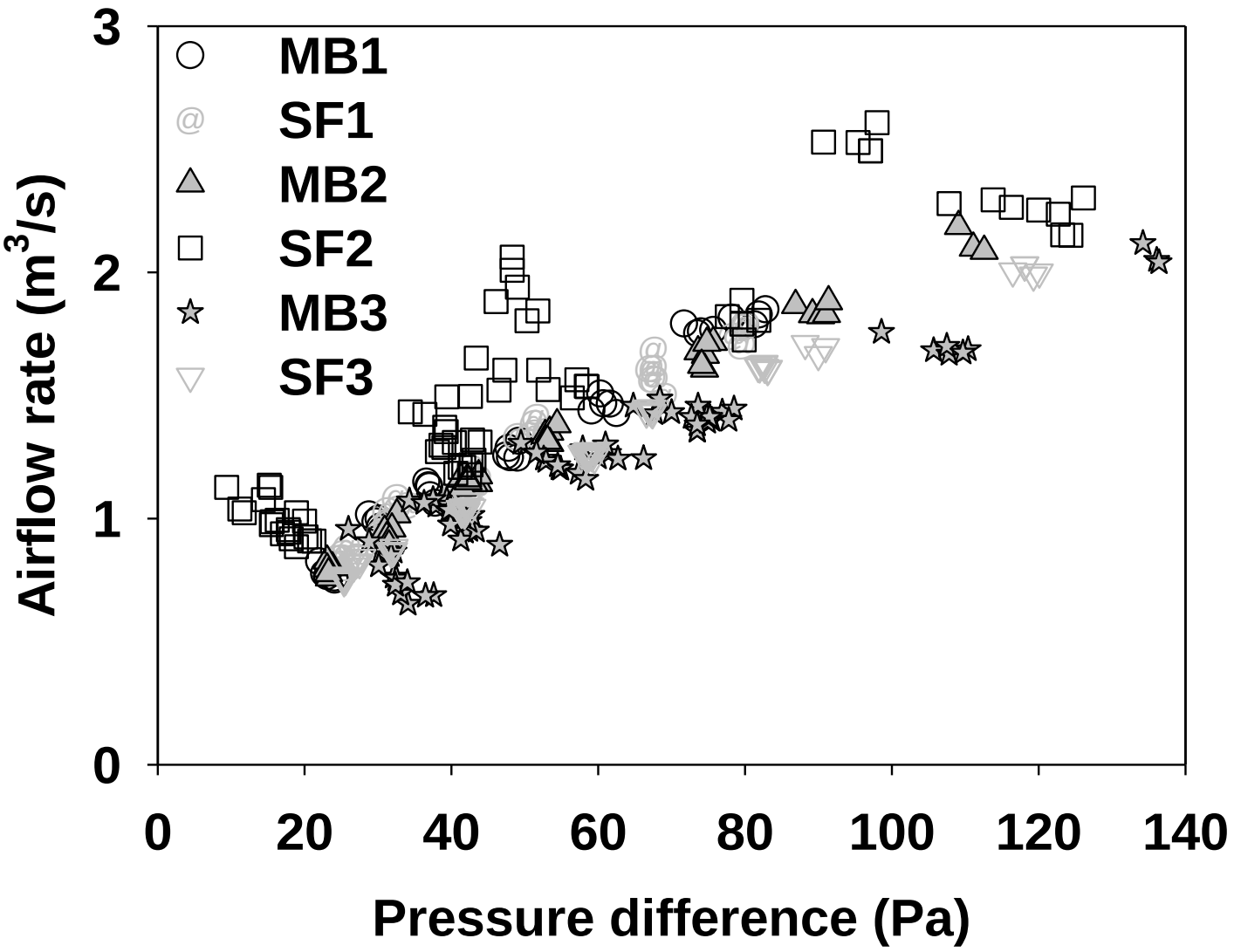
KSU Hal Ross flour mill



Pressurization Test

- Flow rate VS Pressure
  - Good seal → Lower flow rate at any given pressure




MB1
SF1
MB2
SF2
MB3
SF3
Airflow rate (m3/s)
Pressure difference (Pa)
0
1
2
3
0
20
40
60
80
100
120
140

Fumigation details

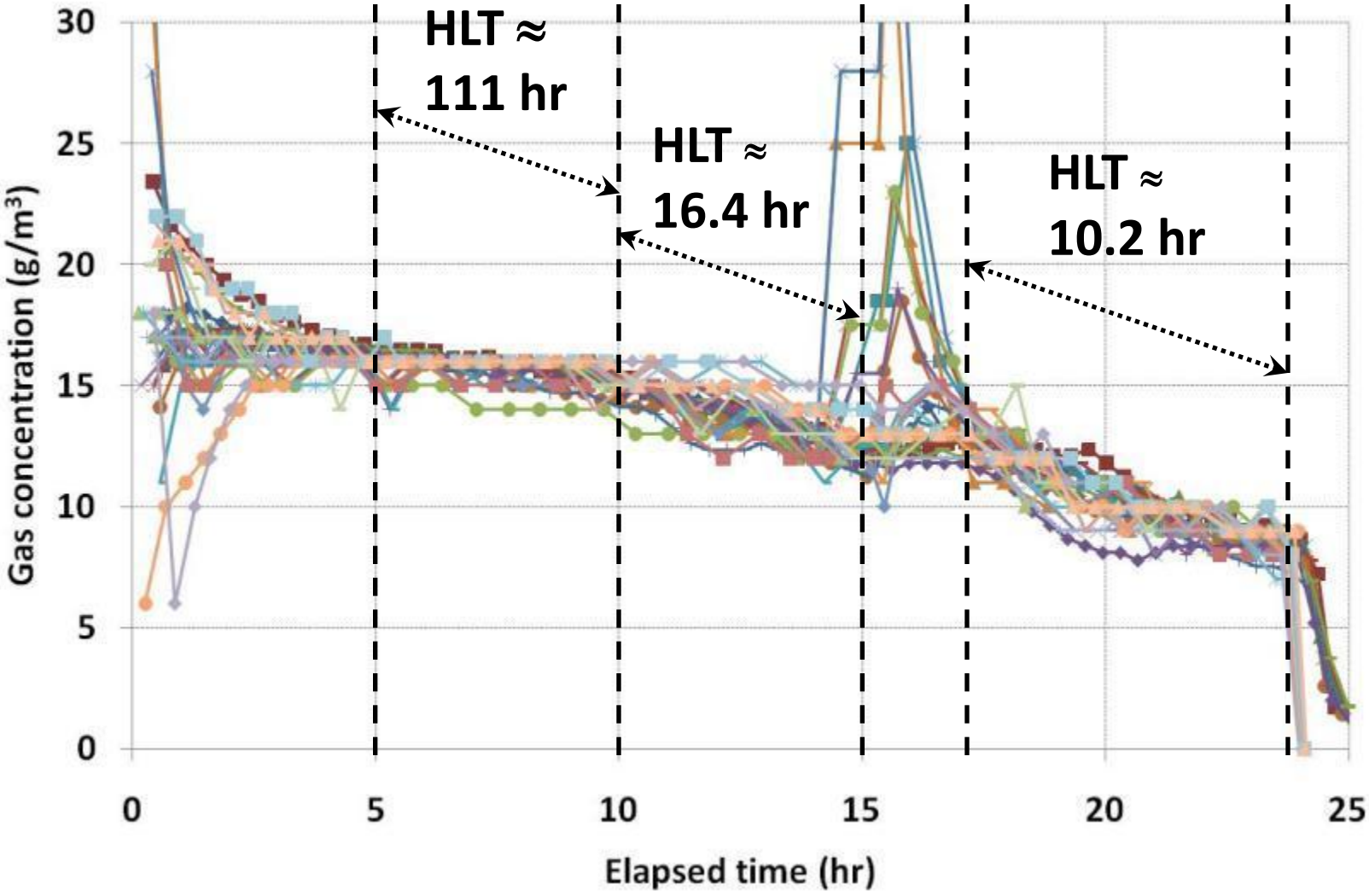
Fumigation	Fumigant introduction		Exposure period (h)	Introduced amount (kg) on mill floor					
	Date	Time		First	Second	Third	Fourth	Fifth	Total
MB1	6 May 2009	6:40 pm	24	22.7 +22.7[a]	22.7	22.7	45.4	45.4	181.6
SF1	27 May 2009	6:00 pm	24.5	113.6	113.6	113.6	113.6	113.6	568.0
MB2	11 Aug 2009	2:50 pm	24	22.7	22.7	22.7	45.4	45.4	158.9
SF2	19 Aug 2009	2:45 pm	24	113.6	56.8	113.6	113.6	113.6	511.2
MB3	11 May 2010	5:00 pm	24.3	+22.7[b] +18.1[c]	22.7	22.7	45.4	45.4	199.6
SF3	25 May 2010	5:10 pm	25	113.6	113.6	113.6	113.6 +28.3[d]	113.6 +28.3[d]	623.7

[a]Top-up (additional gas) release at 9:50 am on 7 May 2009.
[b]Top-up release at 8:15 am on 12 May 2010.
[c]Top-up release at 9:45 am on 12 May 2010.
[d]Top-up release at 7:50 am on 26 May 2010.

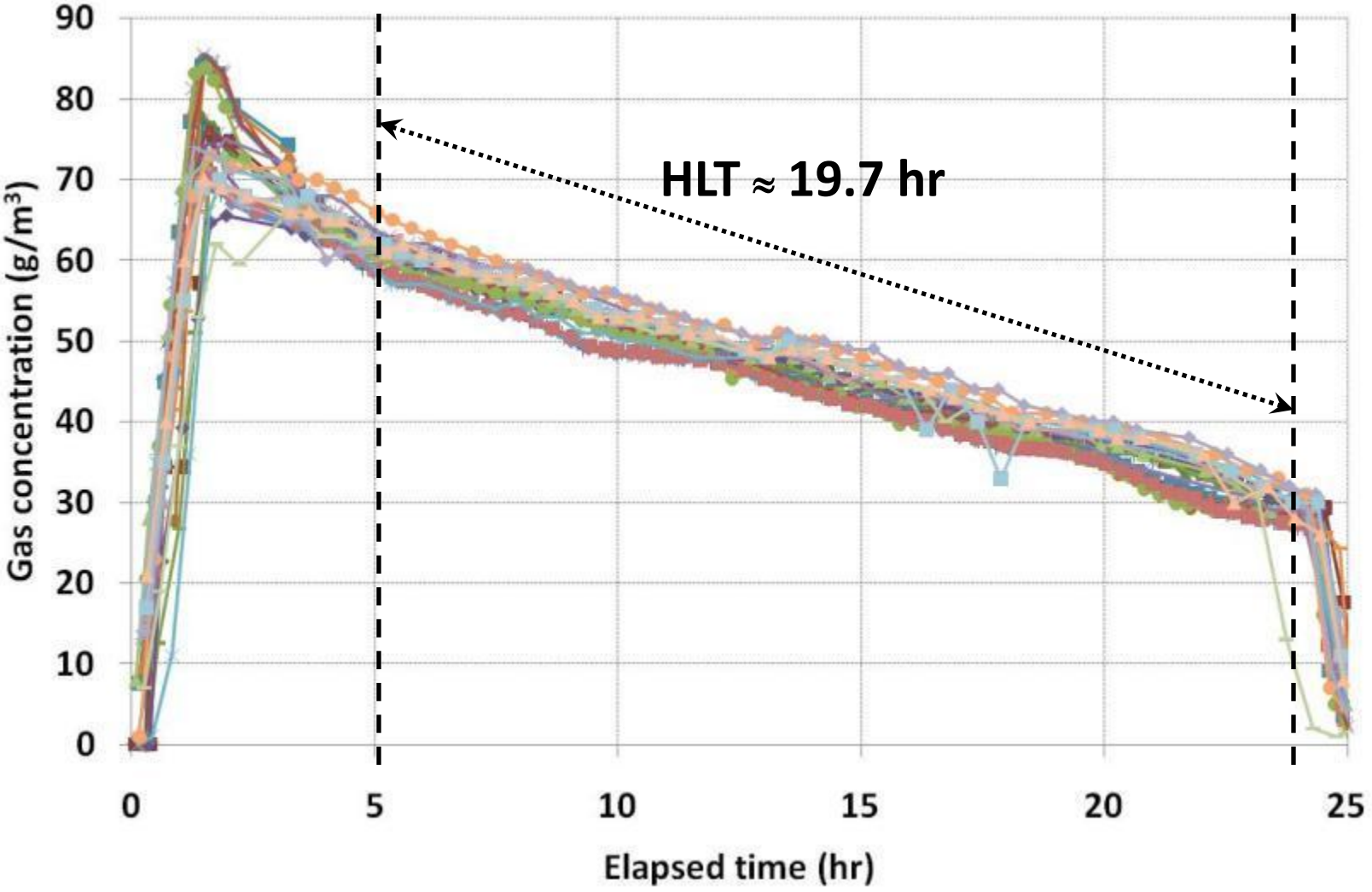
Temperature and relative humidity inside

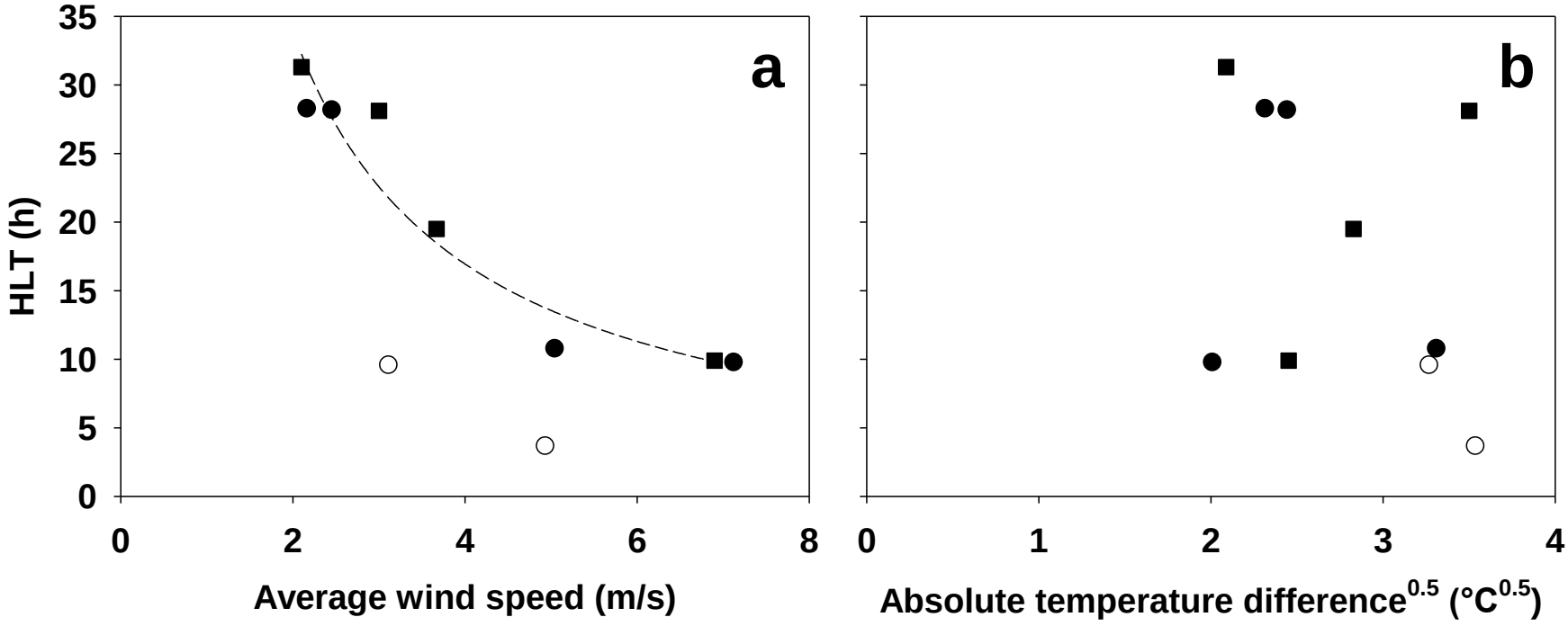
Fumigation	Floor				
	First	Second	Third	Fourth	Fifth
	Temperature (°C)				
MB1	21.9 ± 0.009	22.2 ± 0.010	22.3 ± 0.014	23.0 ± 0.014	23.0 ± 0.008
SF1	23.3 ± 0.006	24.4 ± 0.004	25.2 ± 0.003	25.7 ± 0.009	25.6 ± 0.000
MB2	26.7 ± 0.013	28.6 ± 0.011	30.0 ± 0.010	30.9 ± 0.010	31.1 ± 0.005
SF2	27.9 ± 0.005	29.7 ± 0.009	31.1 ± 0.002	31.9 ± 0.001	31.1 ± 0.000
MB3	23.6 ± 0.007	23.8 ± 0.008	24.4 ± 0.000	24.7 ± 0.007	25.4 ± 0.009
SF3	27.6 ± 0.009	28.3 ± 0.010	28.4 ± 0.015	28.9 ± 0.014	29.3 ± 0.009
	Relative humidity (%)				
MB1	46.3 ± 0.097	45.2 ± 0.088	44.3 ± 0.056	42.7 ± 0.064	40.9 ± 0.080
SF1	43.2 ± 0.030	40.1 ± 0.028	37.6 ± 0.025	36.7 ± 0.025	34.8 ± 0.028
MB2	57.6 ± 0.049	50.6 ± 0.043	46.0 ± 0.031	43.5 ± 0.029	41.3 ± 0.018
SF2	54.2 ± 0.027	46.5 ± 0.064	43.0 ± 0.023	41.1 ± 0.031	41.1 ± 0.031
MB3	34.7 ± 0.043	33.4 ± 0.035	32.1 ± 0.026	31.1 ± 0.021	29.2 ± 0.022
SF3	49.8 ± 0.122	46.5 ± 0.047	46.0 ± 0.036	43.1 ± 0.037	42.1 ± 0.066

Gas Concentration: MB1



Gas Concentration: SF1



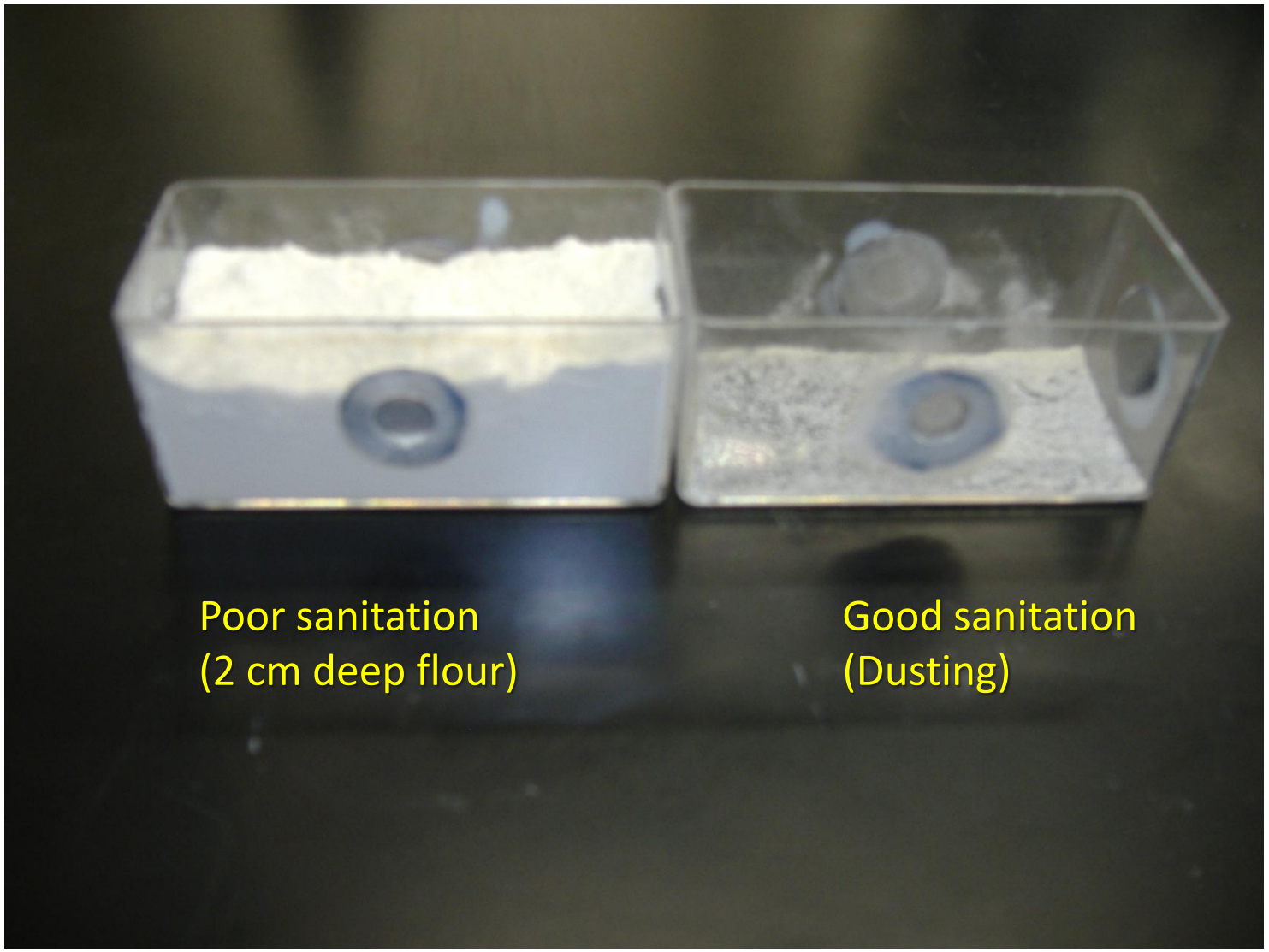

a
b
HLT (h)
35
30
25
20
15
10
5
0
0
2
4
6
8
0
1
2
3
4
Average wind speed (m/s)
Absolute temperature difference0.5 (°C0.5)

Effectiveness against red flour beetle life stages

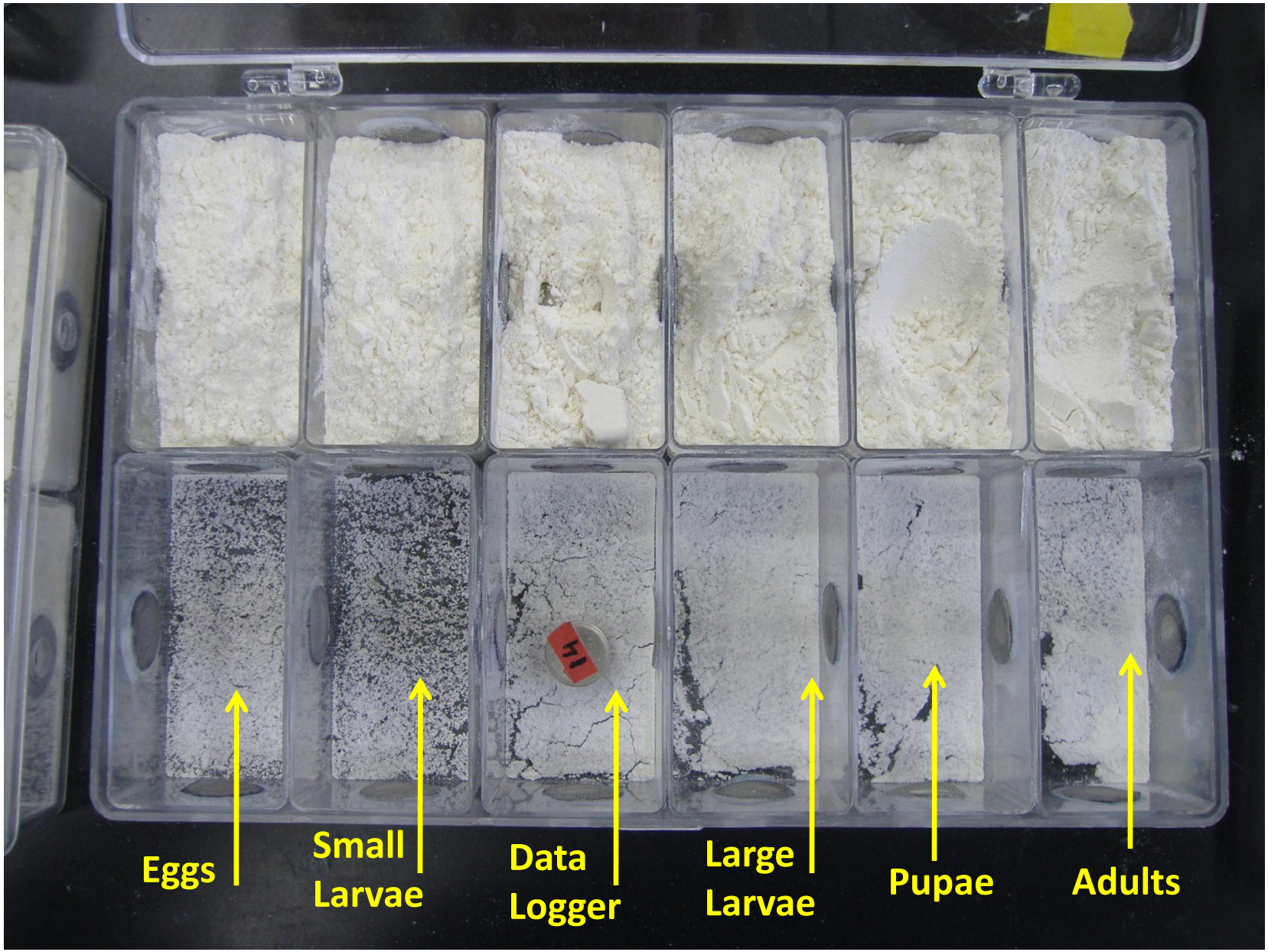
Insect bioassays

Bioassay box

Sanitation levels simulated



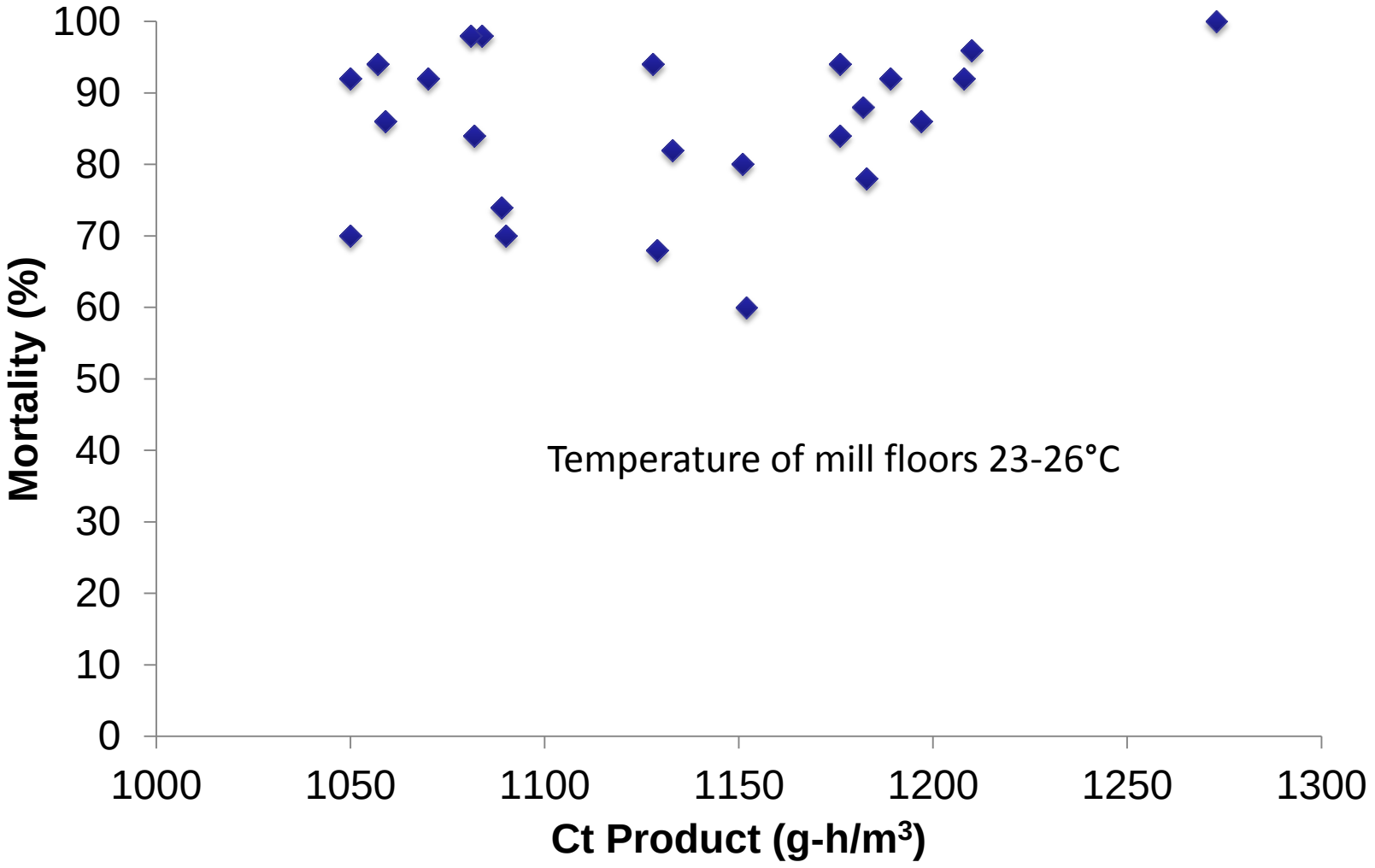
The whole bioassay



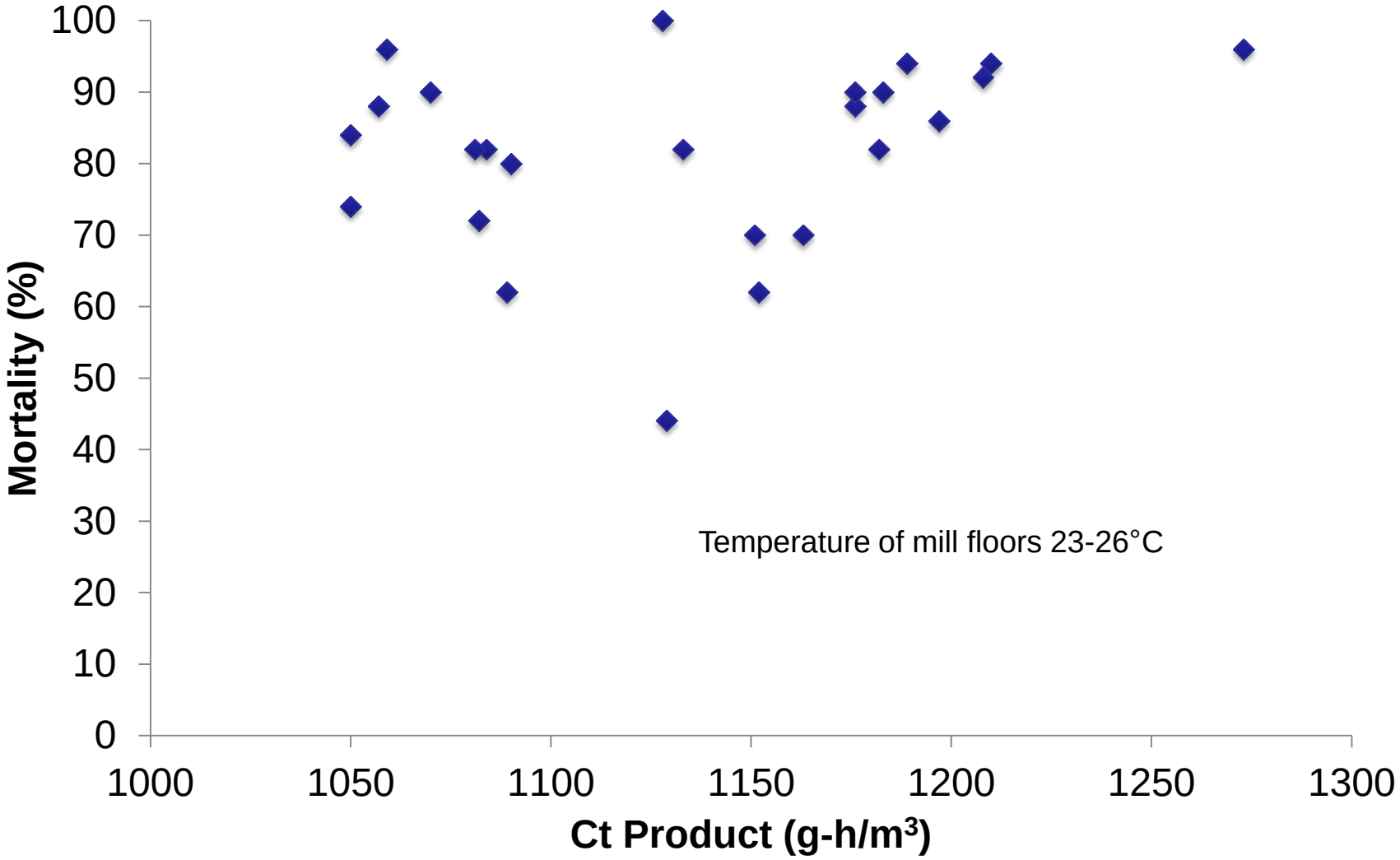
Mill interior

25 boxes in the mill
1 control box in lab

Scatter plot showing variation in egg mortality in compartments with **flour dusting** as a function of the concentration x time (Ct) product during May 6-7, 2009 fumigation with sulfuryl fluoride



Scatter plot showing variation in egg mortality in compartments with **2 cm deep flour** as a function of the concentration x time (Ct) product during May 6-7, 2009 fumigation with sulfuryl fluoride

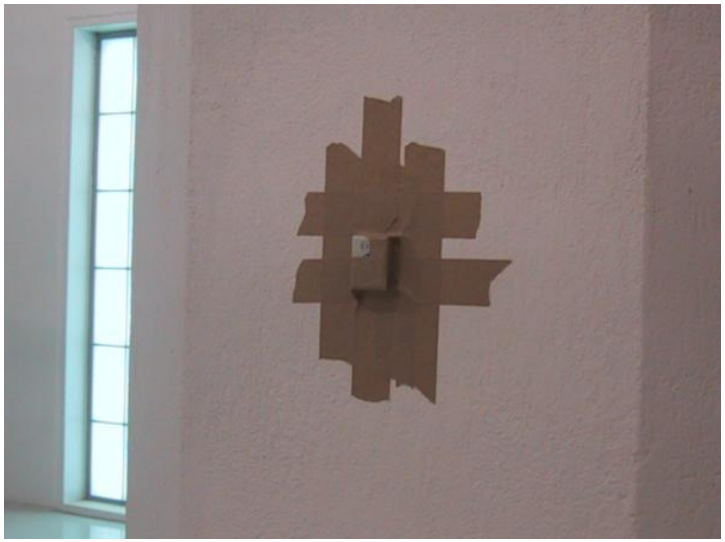


Efficacy of sulfuryl fluoride against eggs and adults of *Tribolium castaneum* in commercial flour mills

- Five SF fumigations in three commercial mills
  - Mill volumes 8,495–28,317 m^3
  - 4-7 floors/mill
- Monitored inside and outside air temperatures
- Monitored temperature in bioassays
- Monitored gas concentrations hourly
  - One monitoring location per floor
- Bioassays: *Tribolium castaneum*
  - Vials (25 ml; 2.6 cm diam x 4.9 cm high)
  - Adults
  - Eggs

	Fumigation trial				
	1	2	3	4	5
Mill	1	2	3	3	4
Mill volume (m^3)	8,495	9,911	28,317	28,317	13,592
Number of floors	5	4	6	6	7
Exposure time (h)	23	23	24	23.5	23.5
Initial release (kg)	624	510	907	907	567
Top-up (kg)	397	284	113	113	0
Gas monitoring points	5	4	6	4	7

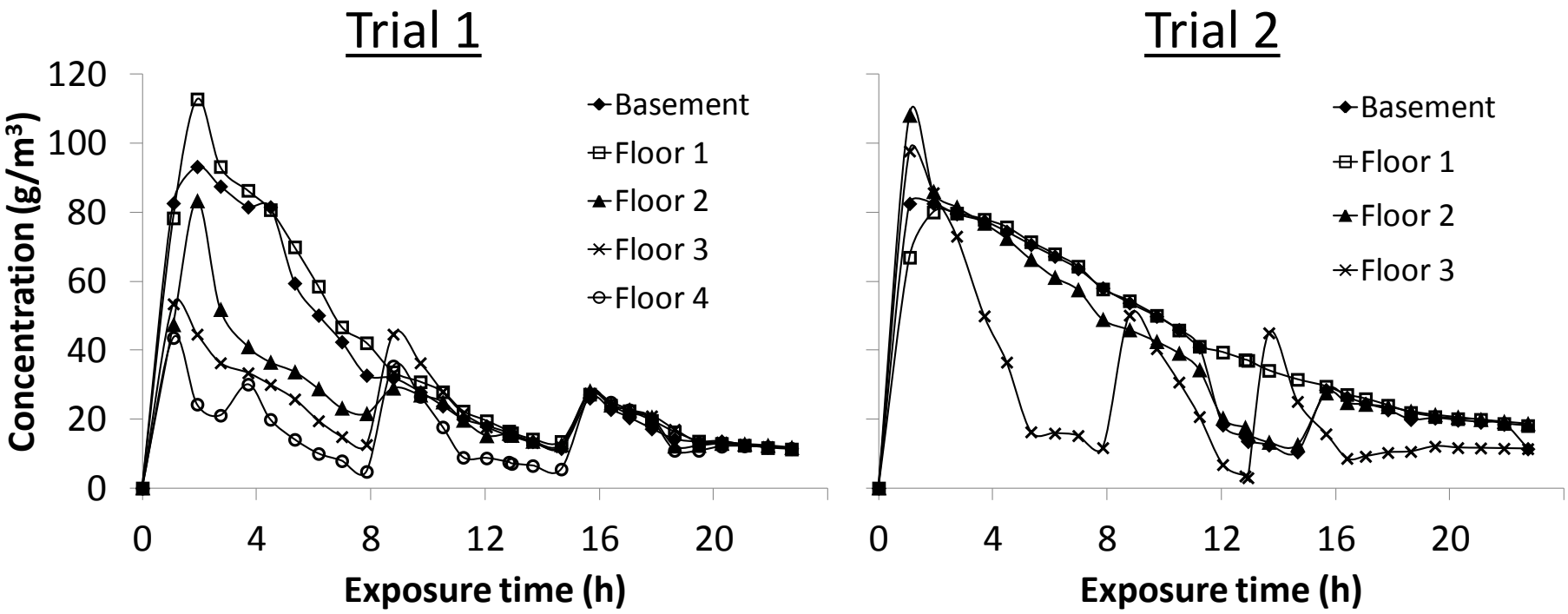
- Weather station (temperature, relative humidity, wind, solar radiation, barometric pressure)
- Temperature logger (one point on each floor)



- Gas concentrations manually recorded every hour at 1 point on each floor

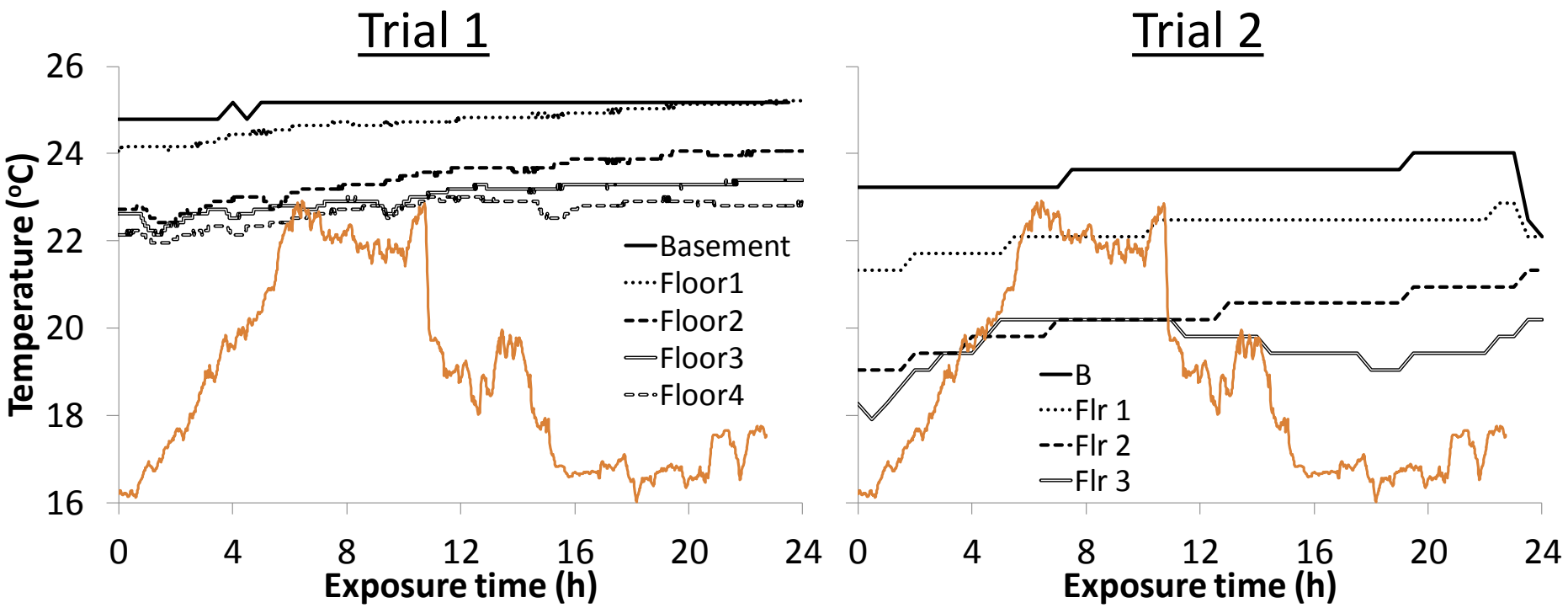
- 25 ml plastic vial with 5 g of wheat flour
- Trials 1 and 2
  - 50 adults and 50 eggs put in separate vials
  - One adult vial and one egg vial placed at 20 locations on each mill floor
- Trials 3 – 5
  - 20 adults left in a vial for 3 d to lay eggs before fumigation
  - 52.9 $\pm$ 3.3 eggs/vial (*n* = 20)
  - 15 vials placed on each mill floor
- Vials were kept at 28°C and 65% r.h. for 42 d for progeny production
  - 36.7 $\pm$ 1.4 F_1 adults/vial (*n* = 15)

- Two adjacent mills (8495 and 9911 m^3)
  - April 22-23, 2011
- Old mills → gas leaked quickly
- HLT = 2.88 – 9.19 h



- Maximum temp difference between floors ≈ 5°C
- Within each floor, air temp varied within ±1°C of average value
- Effect of outside temp on inside temp could not be seen

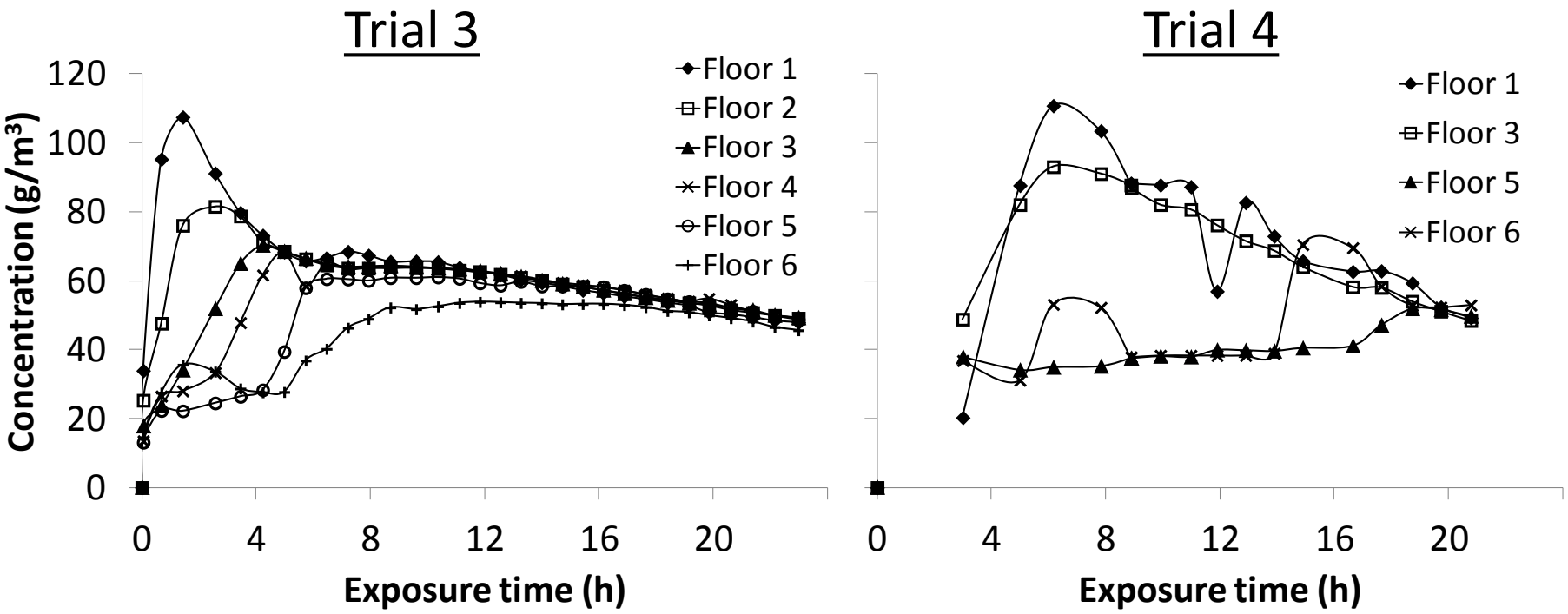
→ Temp data of all other trials indicated the same trend



- Ct ≤ 1,000 g-h/m^3 and temp ≤ 25°C
- 100% adult mortality; Less than 70% egg mortality

Trial	Floor	Ct (g-h/m^3)	Mean temp (°C)	Mortality (%)	
				Adult	Egg
1	B	808.2	25.1	___	___
	1	875.8	24.8	100	62.0
	2	592.4	23.5	100	19.5
	3	545.1	23.0	100	19.1
	4	395.1	22.7	100	9.7
2	B	955.1	23.5	100	69.4
	1	1,026.2	22.2	100	54.0
	2	953.1	20.3	100	38.5
	3	646.3	19.6	100	29.0

- Same mill at different times of year (28317 m^3)
  - May 28-29 and September 3-4, 2011
- Trial 3 had a recirculation pump
  - More even gas distribution only in Trial 3
- For Trial 3, HLT = 47 h
- For Trial 4, HLT = 19.42 – 23.66 h

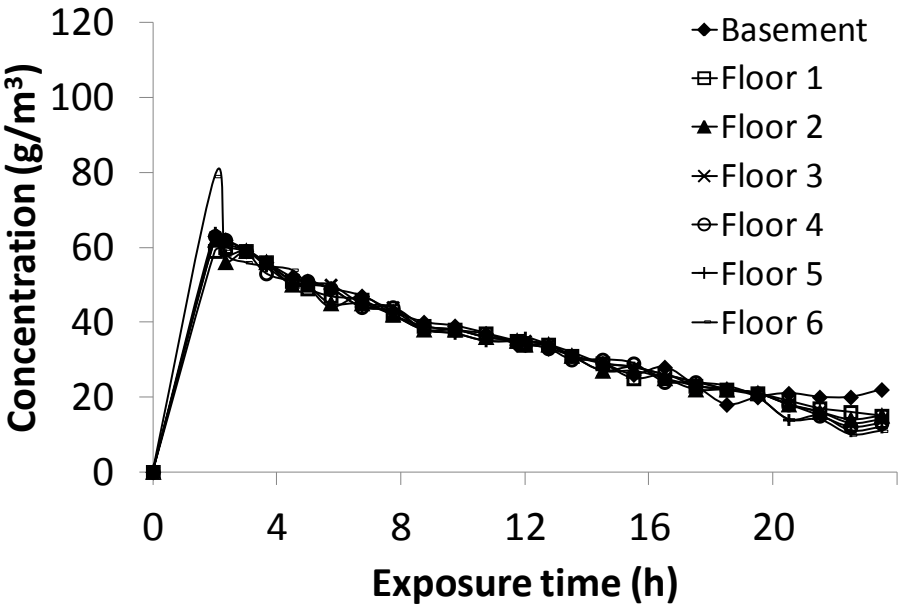


- 100% adult mortality
- Mostly, Ct > 1,000 g-h/m^3 and temp > 30°C → Egg mortality > 90%
- When temp was close to 25°C, egg mortality dropped to 80% even though Ct was 1,521 g-h/m^3

Trial	Floor	Ct (g-h/m^3)	Mean temp (°C)	Mortality (%)	
				Adult	Egg
3	1	1,521.1	25.7	100	80.4
	2	1,435.6	29.3	100	99.8
	3	1,332.7	29.8	100	100
	4	1,285.4	30.1	100	94.7
	5	1,175.3	30.7	100	99.8
	6	1,069.1	30.2	100	93.3
4	1	1,603.7	33.5	100	99.5
	2	1,616.9 (est)	36.9	100	100
	3	1,630.1	37.9	100	100
	4	1,283.9 (est)	38.1	100	100
	5	937.7	38.1	100	99.5
	6	1,073.0	36.9	100	100

- 13592 m^3
- September 4-5, 2011
- HLT = 10.15 h
- Ct products were all slightly over 800 g-h/m^3
- Temp were mostly over 30°C
- Egg mortality > 98%

Trial 5



Floor	Ct (g-h/m^3)	Mean temp (°C)	Mortality (%)	
			Adult	Egg
B	851.5	33.3	100	99.3
1	823.2	32.8	100	98.3
2	817.1	32.1	100	98.9
3	825.6	34.0	100	100
4	825.0	32.4	100	99.3
5	816.6	31.4	100	99.7
6	845.0	28.7	100	98.9

- Maximum temp difference between floors ≈ 5°C
- Within each floor, air temp varied within ±1°C of average value
  - Check temp on each floor to determine gas dosage
  - Temp measurement at beginning of fumigation could be accurate up to ±2°C
- Achieved Ct products were 395.1 – 1,630.1 g-h/m^3
- Adults were all 100% killed even at relatively low Ct and temp
- Confirms many other previous studies
  - For effective kill of *T. castaneum* eggs, always aim for temperature > 30°C and Ct product > 1,000 g-h/m^3

Insect stage	Sanitation level	Treatment	% Mean (SE) mortality	*F (df=2,7)*	*P*
Adults	2 cm	MB	100a	69.90	<0.0001
		SF	100a		
		Heat	90.1 (1.2)b		
	dusting	SF	100	1.00	0.4219
		MB	100		
		Heat	98.7 (1.3)		
Pupae	2 cm	MB	100	2.56	0.1568
		SF	100		
		Heat	95.4 (2.9)		
	dusting	MB	100	0.60	0.5787
		SF	98.7 (1.3)		
		Heat	97.3 (2.7)		
Large larvae	2 cm	MB	99.8 (0.1)a	8.62	0.0172
		SF	100 (0.0)a		
		Heat	96.1 (1.3)b		
	dusting	MB	99.9 (0.1)	1.73	0.2552
		SF	100		
		Heat	98.2 (1.3)		
Small larvae	2 cm	MB	100a	5.39	0.0457
		SF	100a		
		Heat	93.5 (2.8)b		
	dusting	MB	100	3.69	0.0901
		SF	100		
		Heat	99.4 (0.3)		
Eggs	2 cm	MB	99.9 (0.1)	1.02	0.4145
		SF	92.3 (7.3)		
		Heat	99.3 (0.3)		
	dusting	MB	99.9 (0.1)	1.25	0.3523
		SF	88.7 (10.0)		
		Heat	99.8 (0.1)		

K-State Study (2009-2010)

n = 3/trt

Trt time=24 h for all

Cost (MB, SF, HT)-Based on treatments at K-State

Month	Treatment	Amount used (kg or L)	Total cost	Cost per m^3 (based on 9628 m^3)
May 2009	HT	5300	38005	3.95
	MB	182	16977	1.76
	SF	568	36263	3.77
August 2009	HT	4883	27005	2.8
	MB	159	16552	1.72
	SF	511	35450	3.68
May 2010	HT	5500	25605	2.66
	MB	200	17314	1.8
	SF	624	37062	3.85
Average	**HT**	**5228**	**30205**	**3.14**
	MB	**180**	**16948**	**1.76**
	SF	**568**	**36258**	**3.77**

Workshops and presentations

- May 13-15, 2009
  - Hands-on workshop on heat treatment
  - Weblink: http://www.ksre.ksu.edu/grsc_subi/Heat_Workshop_09_slides.htm
  - Plus additional workshop proceedings (1999-2008)
- August 19-21, 2009 & May 13-15, 2010
  - Hands-on workshops on sulfuryl fluoride & methyl bromide fumigations
  - Weblink: http://www.ksre.ksu.edu/grsc_subi/Conference/Workshop_SF_2009/index_old.htm


Thank You