The life and times of the red flour beetle

A dynamic thermal death kinetics model for insect pests

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- Food microbiology and thermal death kinetics

Bigelow, W.D. 1921. The logarithmic nature of thermal death time curves. J. Infect. Dis. 29: 528.

Stumbo, C.R. 1973. Thermobacteriology in food processing. Academic Press, New York.

- D and z values – thermal death kinetics parameters

Near-Universal Observation

Under constant temperature conditions, mortality of microbial populations is a logarithmic function of time

$$\log\left(\frac{N}{N_0}\right) = \frac{-t}{D}$$

N_0 is the initial number of bacteria,
N is the number of bacteria at time of exposure t ,
D is the logarithmic rate constant or D-value (in minutes or hours).

D-value (min) - the time required to obtain one log (tenfold reduction) in the population at a given treatment temperature.

z-value - temperature dependence of D-value

$$\log\left(\frac{D_{T_1}}{D_{T_2}}\right) = \frac{T_2 - T_1}{z}$$

T_1 and T_2 are two temperatures (°C) within an established range,
z is the logarithmic constant (°C), also known as the z-value.

z-value (°C) - increase in temperature required for a tenfold reduction in the D-value; measures the temperature sensitivity of bacterial inactivation kinetics.

Static versus dynamic temperature thermal inactivation models

- Real-life heat treatment situations involve dynamic time-temperature profiles
- Heat tolerance of organism to varying heating rates

Baranyi, et al. 1996. A combined model for growth and subsequent thermal inactivation of Brochothrix thermospacta. Applied and Environmental Microbiology. 62(3): 1029-1035.

Van Impe, et al. 1992. Dynamic mathematical model to predict microbial growth and inactivation during food processing. Applied and Environmental Microbiology. 60: 204-213.

Dynamic insect thermal inactivation model

Tang, et al. 2000. High-temperature-short-time thermal quarantine methods. Postharvest Biology and Technology. 21: 129-145.

Dynamic insect thermal inactivation model

Insect population undergoing heat treatment in a dynamic temperature environment, T(t)

$$\log\left(\frac{N'}{N}\right) = \frac{dt}{D}$$

N = instantaneous insect population N at any time t
dt = infinitesimal small increment in time
N' = population at time t-dt

$$D = D_{ref}\ 10^{-\left(\frac{T(t)-T_{ref}}{z}\right)}$$

D_{ref} = D-value at a reference temperature T_{ref}

$$\log\left(\frac{N'}{N}\right) = \frac{dt}{D_{ref}\,10^{-\left(\frac{T(t)-T_{ref}}{z}\right)}}$$

$$\log\left(\frac{N_0}{N}\right)=\int_0^t \frac{dt}{D_{ref}10^{-\left(\frac{T(t)-T_{ref}}{z}\right)}}$$

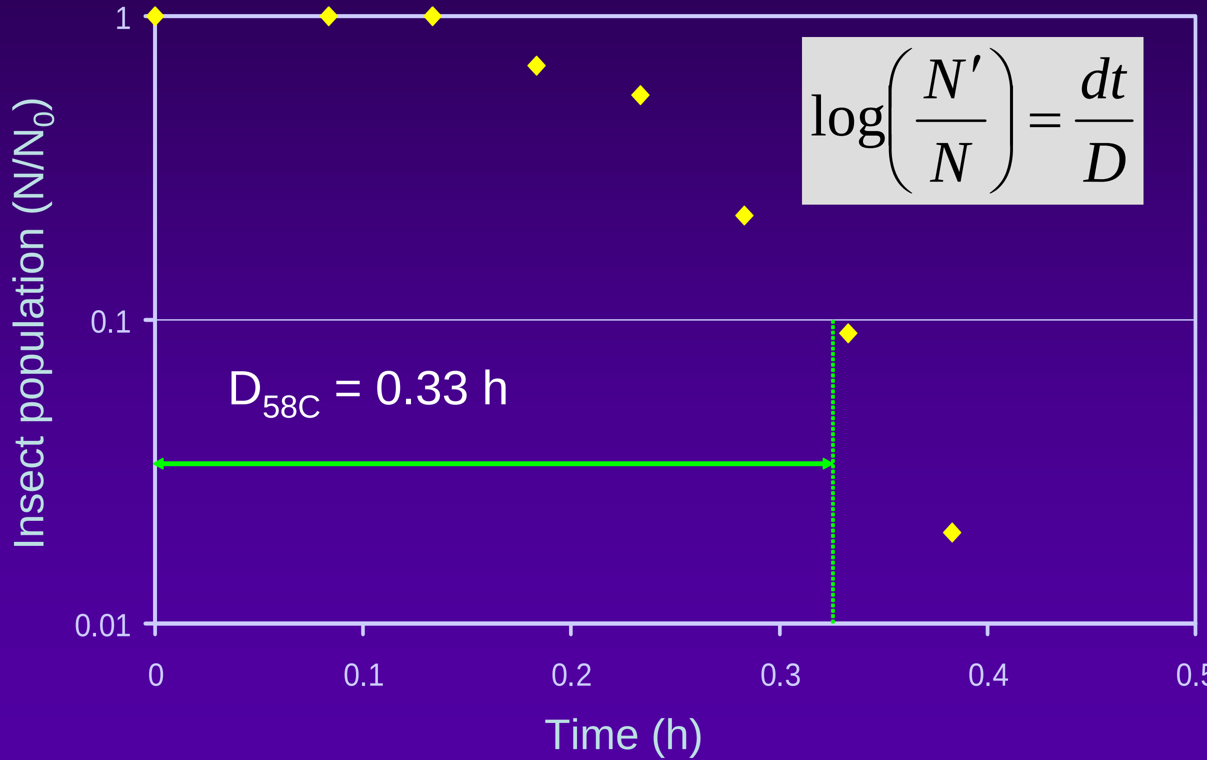
$$\log\left(\frac{N_0}{N}\right)=\frac{1}{D_{ref}}\int_0^t 10^{\left(\frac{T(t)-T_{ref}}{z}\right)}dt$$

Shift factor (T_{shift}) – for quantification of thermal tolerance of insects during heat treatment

$$\log\left(\frac{N_0}{N}\right)=\frac{1}{D_{ref}}\sum 10^{\left(\frac{T(t)-T_{ref}-T_{shift}}{z}\right)}\Delta t$$

Development of dynamic model for red flour beetle

- adult stage (most heat tolerant stage) of red flour beetle (RFB)
- insect population versus time data (mortality data) at 42, 46, 50, 54 and 58°C
- D-value for each temperature from the time taken for reduction of population from 20 to 2 (one log cycle reduction).



$$\log\left(\frac{N'}{N}\right) = \frac{dt}{D}$$

N/No versus time plot for RFB adult stage exposed to heat treatment at 58°C

Estimated D-values for adult RFB

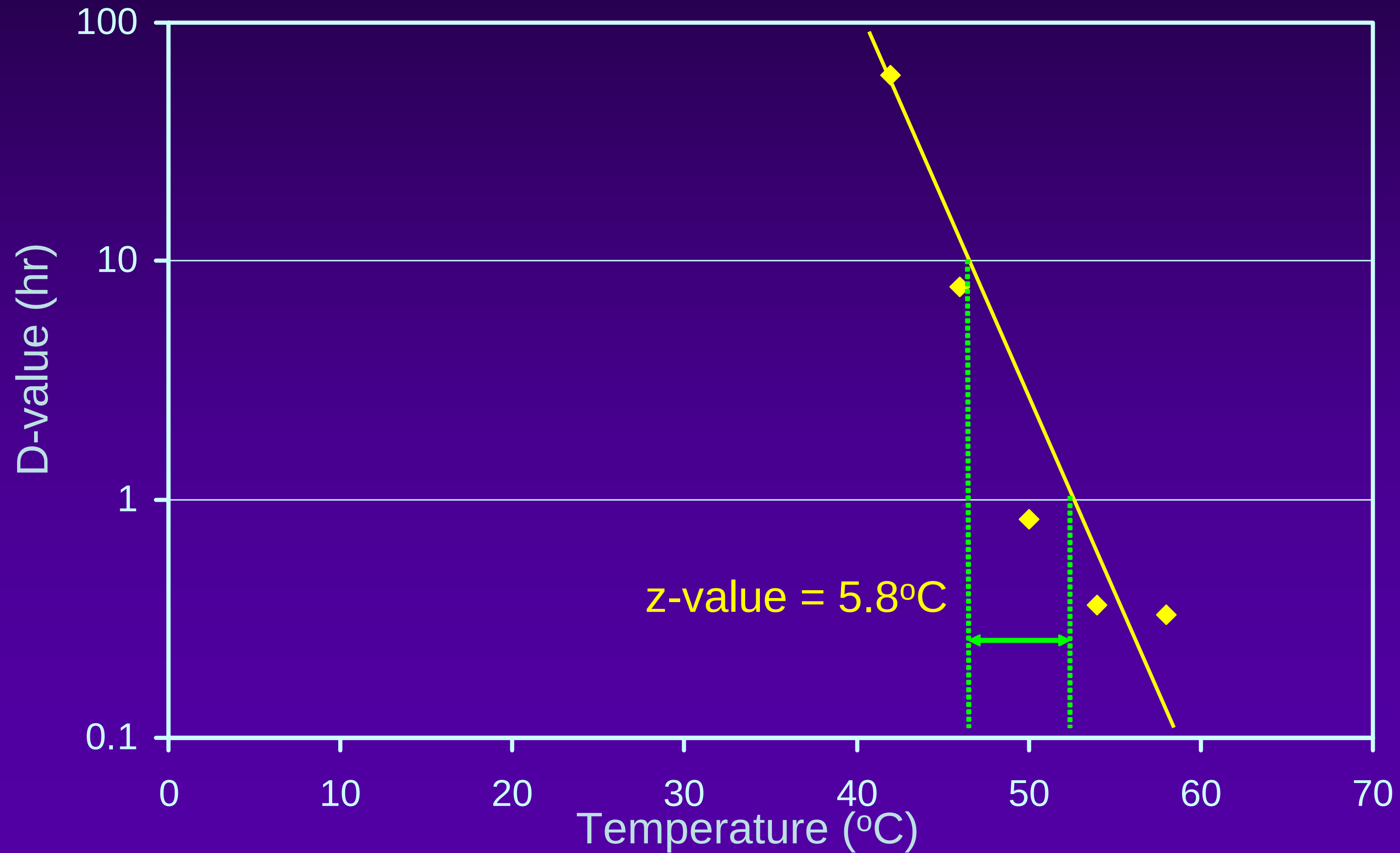
Temperature, T (ºC)	D-value (h)
42	60.00
46	7.75
50	0.83
54	0.36
58	0.33

Mahroof, R., Subramanyam, B., and Eustace, D. **2003**. Temperature and relative humidity profiles during heat treatment of mills and its efficacy against *Tribolium castaneum* (Herbst) life stages. Journal of Stored Products Research. **39: 555-569.**

- calculation of z-value

$$D = D_{ref}\ 10^{-\left(\frac{T(t)-T_{ref}}{z}\right)}$$

Calculation of z-value from estimated D-value vs. temperature data for RFB adult stage.



- dynamic thermal death model incorporated into Excel™ spreadsheet

$$\log\left(\frac{N_0}{N}\right) = \frac{1}{D_{ref}} \sum 10^{\left(\frac{T(t) - T_{ref} - T_{shift}}{z}\right)} \Delta t$$

Input –

- initial insect population, N_0
- reference D-value (D_{ref}) at any arbitrary temperature, T_{ref}
- time – temperature profile of the heat treatment, T(t)
- z-value for insect species
- temperature shift factor, T_{shift}

Output –

- surviving insect population at any time, N(t)

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Thank You !