Applying a Path-Dependent Model for *Salmonella* Thermal Inactivation in Slow-Cooked Turkey and Beef Products

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Outline

- Pathogen thermal inactivation
- Model development
- Methods
- Model application and Results
- Conclusions and Significance

Objectives

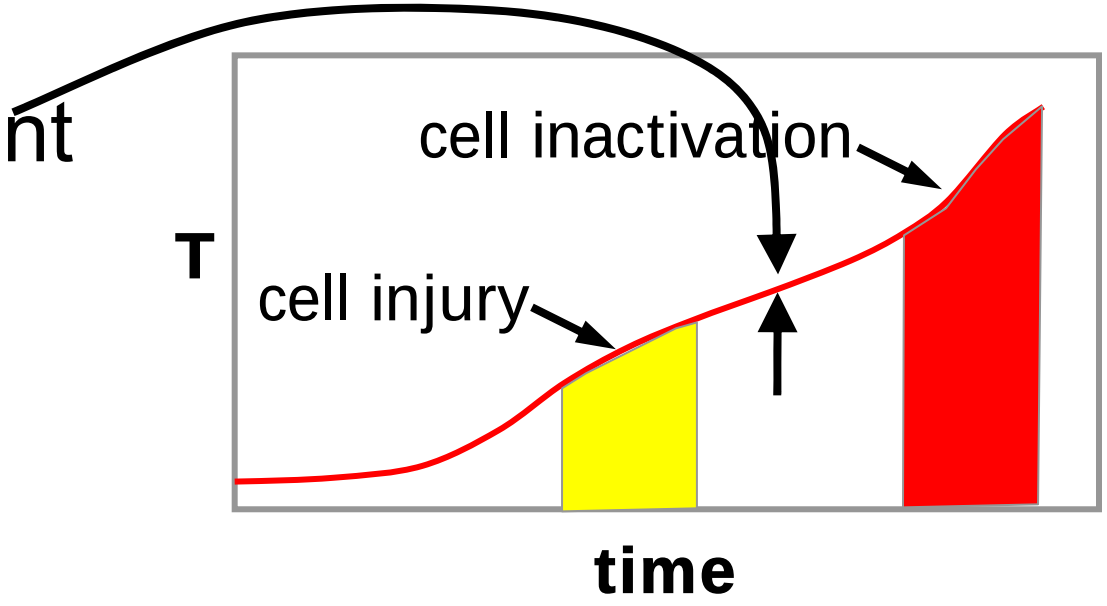
1. To estimate the parameters for a novel, path-dependent model for thermal inactivation of *Salmonella* in meat products.

2. To validate the model against independent data from scaled-up experiments.

Pathogen thermal inactivation

State-dependent models…

b = f(state)



But, bacterial populations can adapt (e.g., synthesis of heat shock proteins), so that in path-dependent models

b = f(state *and* sublethal thermal history)

Model Development

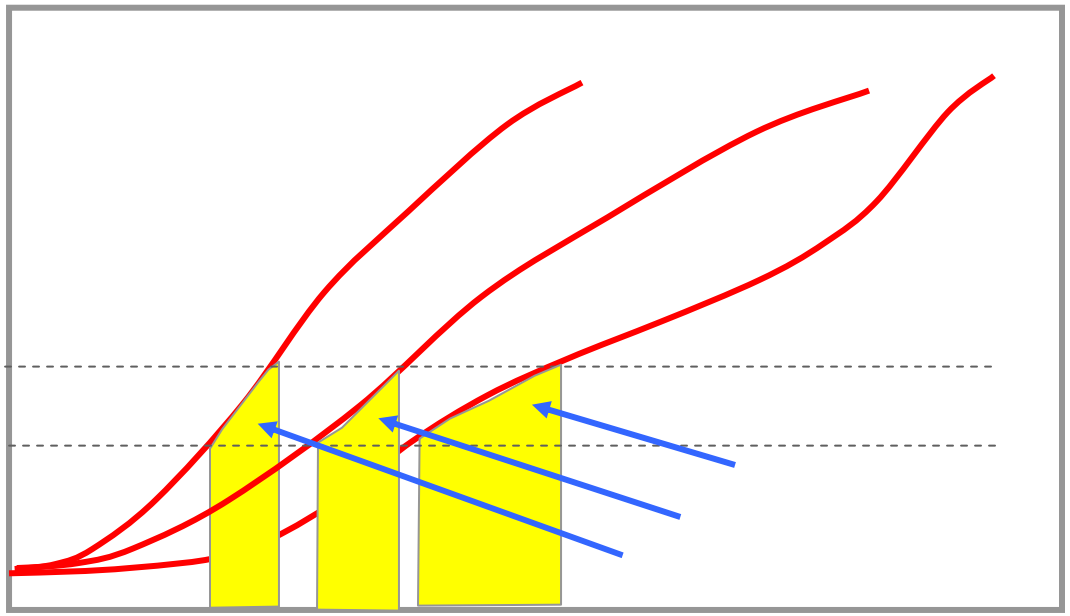
- Current model: *state-dependent*

$$\log S = \log \frac{N}{N_o} = -bt$$

$$b(T) = b_{ref} \exp\left\{-\beta_1\left[\frac{1}{T(t)} - \frac{1}{T_{ref}}\right]\right\}$$

Model Development

- New model: *path-dependent*
- Heat shock region (“memory” effect)
- Sublethal thermal history (τ)

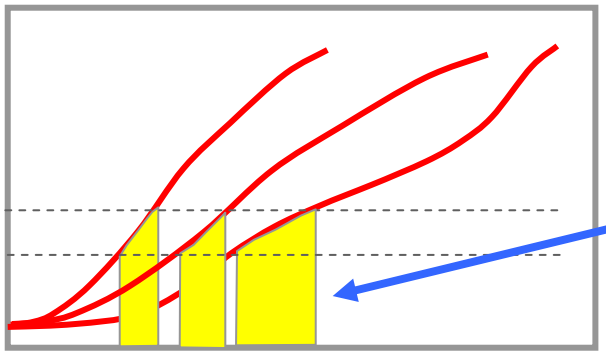


Model Development

- New model: *path-dependent*

$$\log \frac{N}{N_o} = -bt$$

$$b(T) = b_{ref} \exp\left\{-\beta_1\left[\frac{1}{T(t)} - \frac{1}{T_{ref}}\right].....\right\}$$



$$\tau = \int_{t_{38°C}}^{t_{52°C}} \left[T(t) - HS_{lower}\right] dt$$

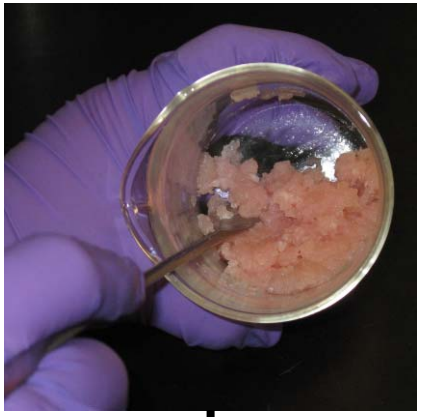
Experimental design, 1 g samples

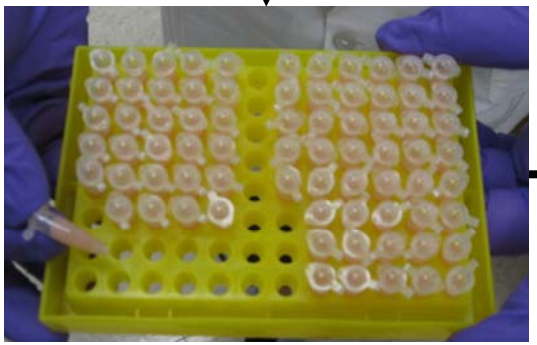
- Ground turkey and beef
  - Calibration (n=30 treatments each)
  - Validation (n=15 treatments each)
- Random combinations (in triplicate) of:
  - Heating rate (1, 2, 3, 4, or 7 K/min)
  - Sublethal holding (none, 40, 45, or 50°C)
  - Final (lethal) holding (55, 58, 61, or 64°C)
  - Sublethal history (τ = 14, 25, 50, 100, 200 K min)
  - Target kill (various)

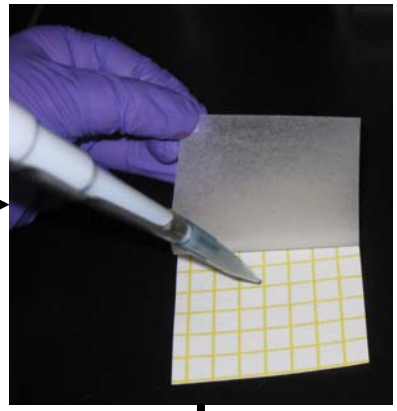
Experimental design, 25 g samples

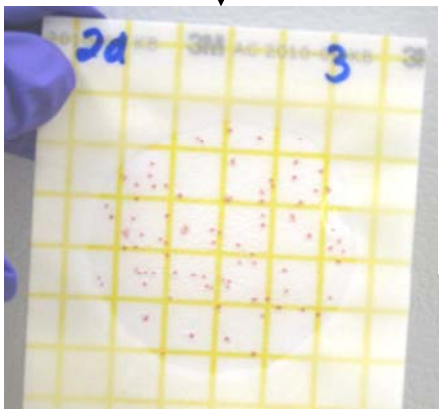
- Substrate:
  - Ground turkey and beef patties (n=9)
- Inoculum:
  - *Salmonella* (8-serovar “cocktail”)
  - Initial concentration in meat: 10^8 CFU/g
- Treatments:
  - Computer-controlled, moist-air convection oven
  - Variable times (30-120 min)
  - Target: 6.5 and 7 log reductions

Methods, 1 g samples









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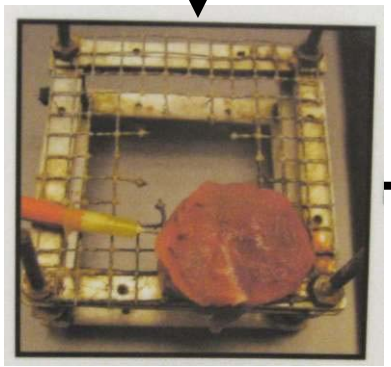
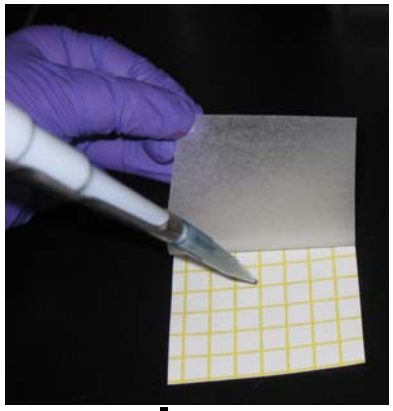
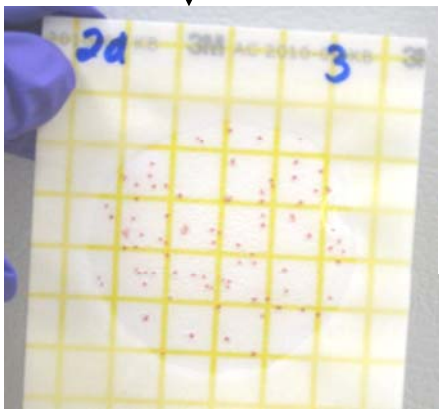
Methods, 25 g samples



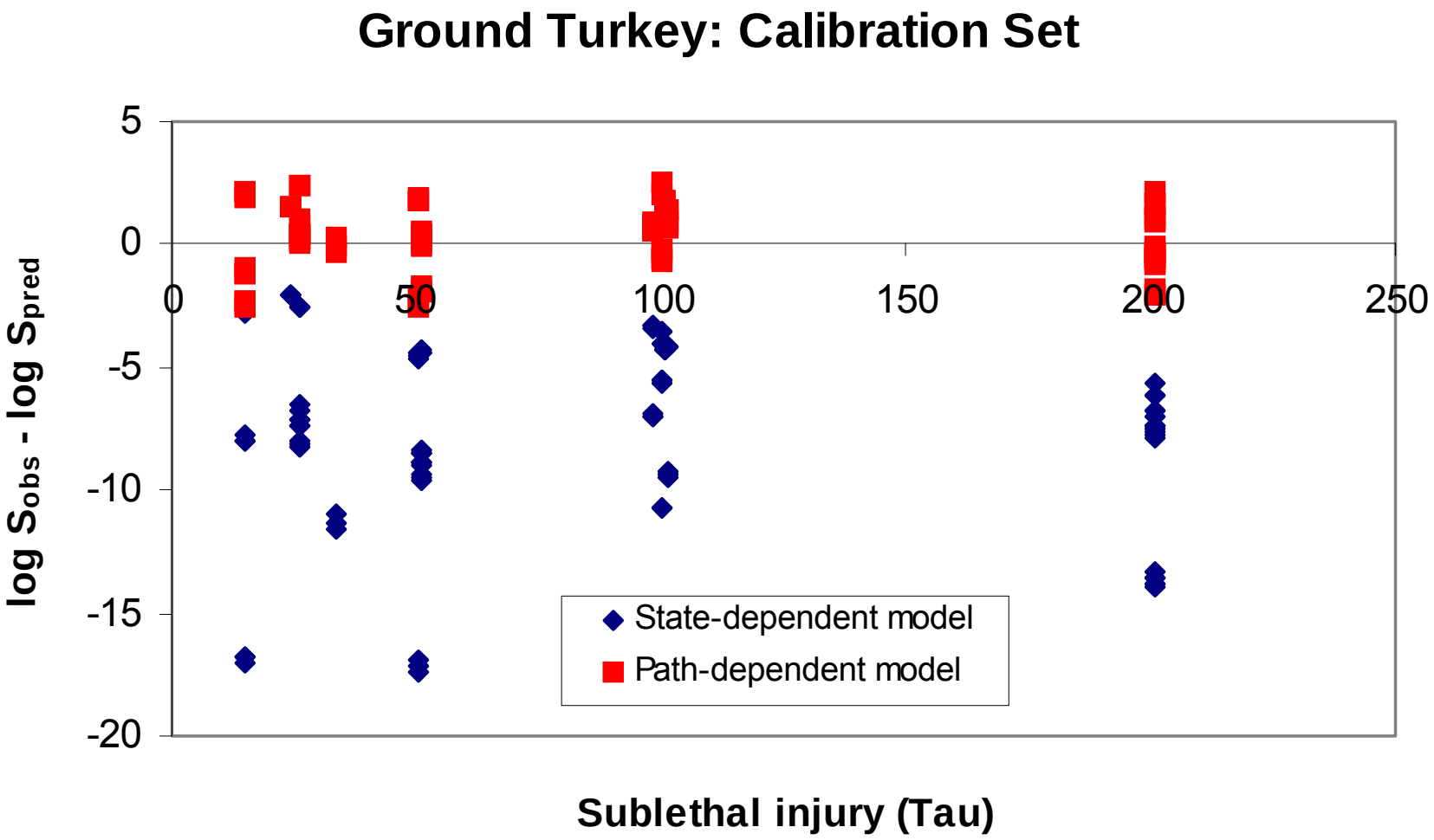




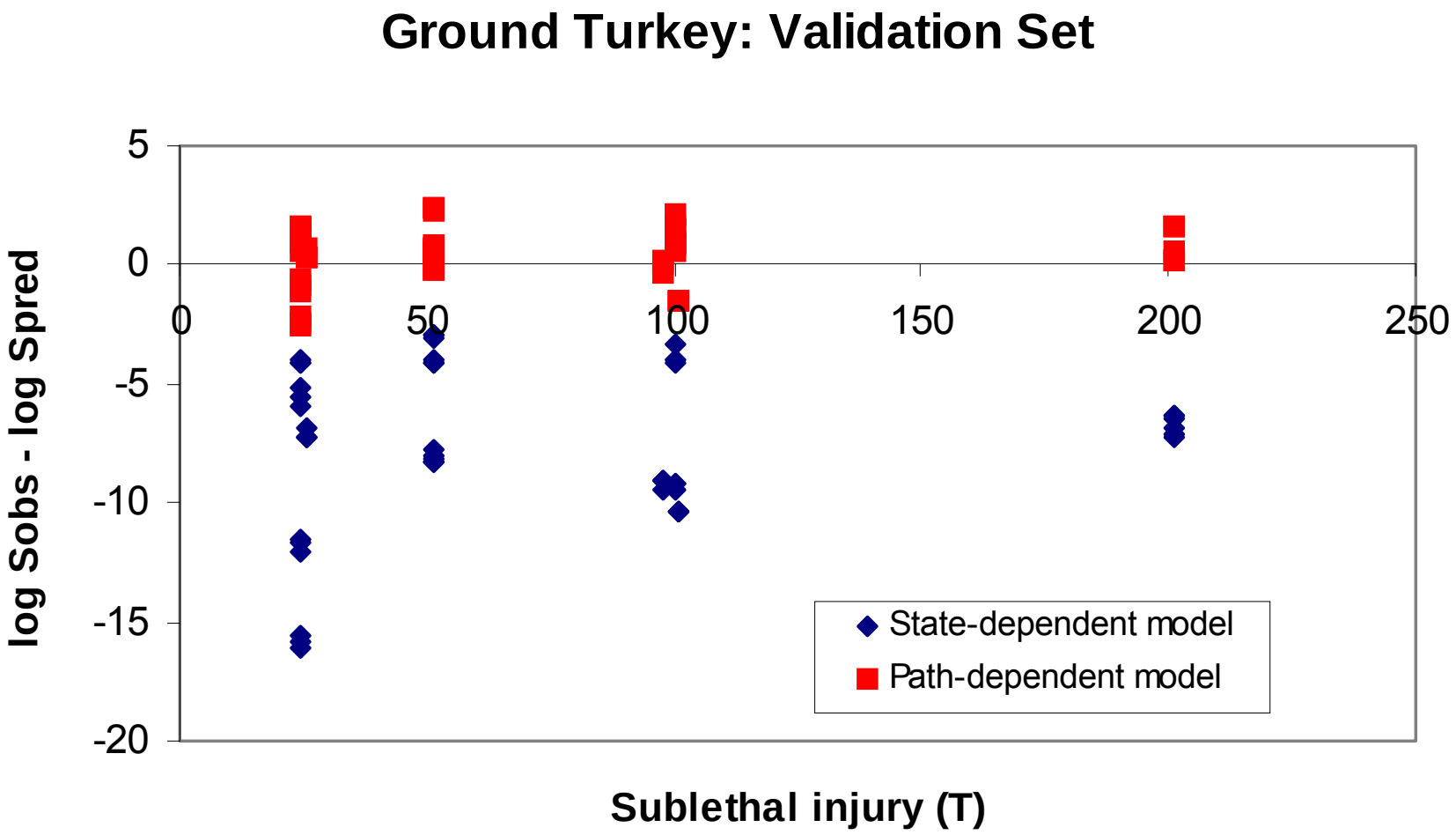
Obtaining new model parameters

- Parameters: b_{ref}, β_1, β_2
- Calculated cumulative lethality (i.e., log reductions) for each treatment (**1 g**)
  - Error = Observed – Predicted
  - Minimize SSE using Excel's solver
- Compared state-dependent to path-dependent model results
- Additionally: obtained β_2 with oven-cooked data (**25 g**), with fixed b_{ref}, β_1.

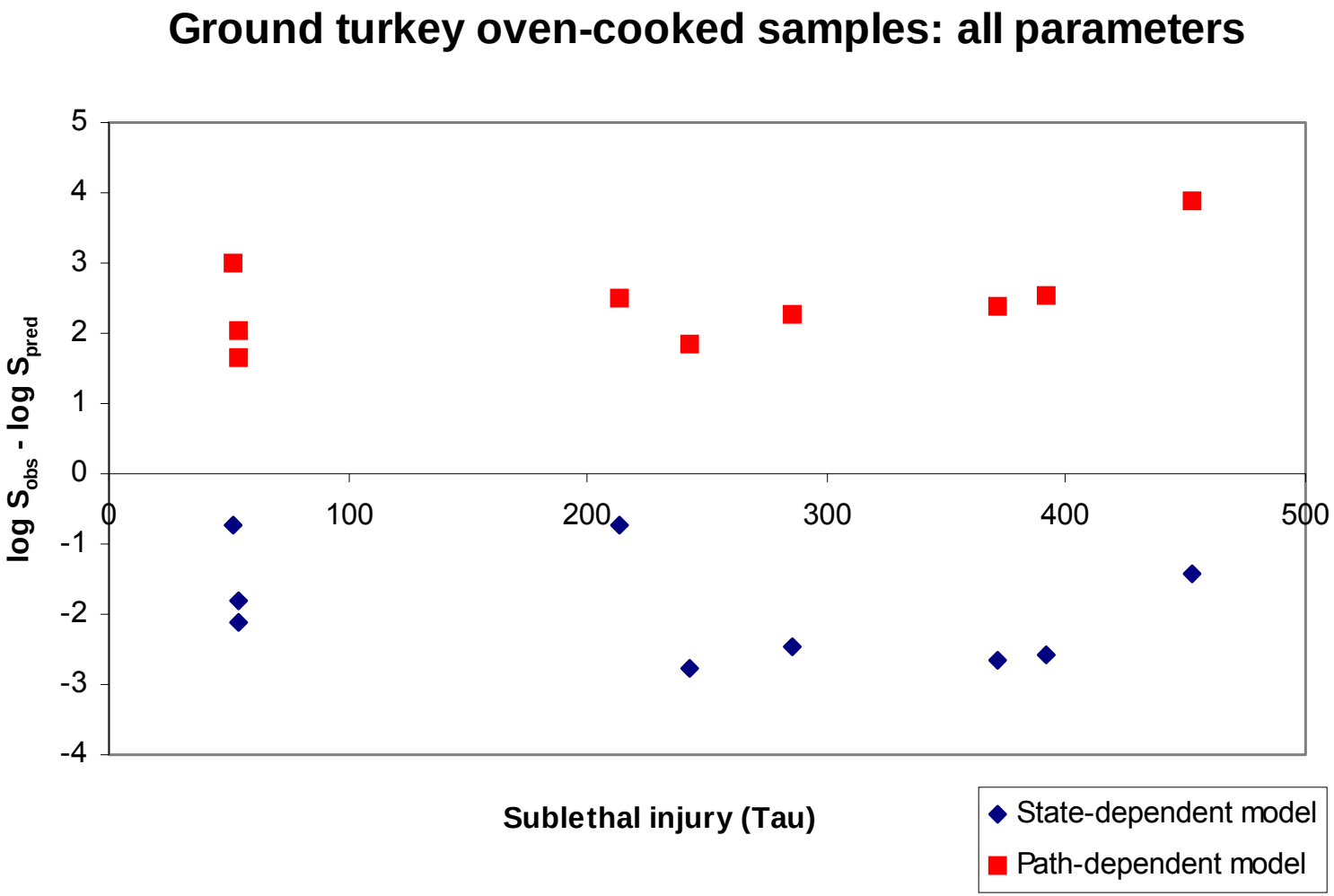
Results, 1 g samples, turkey



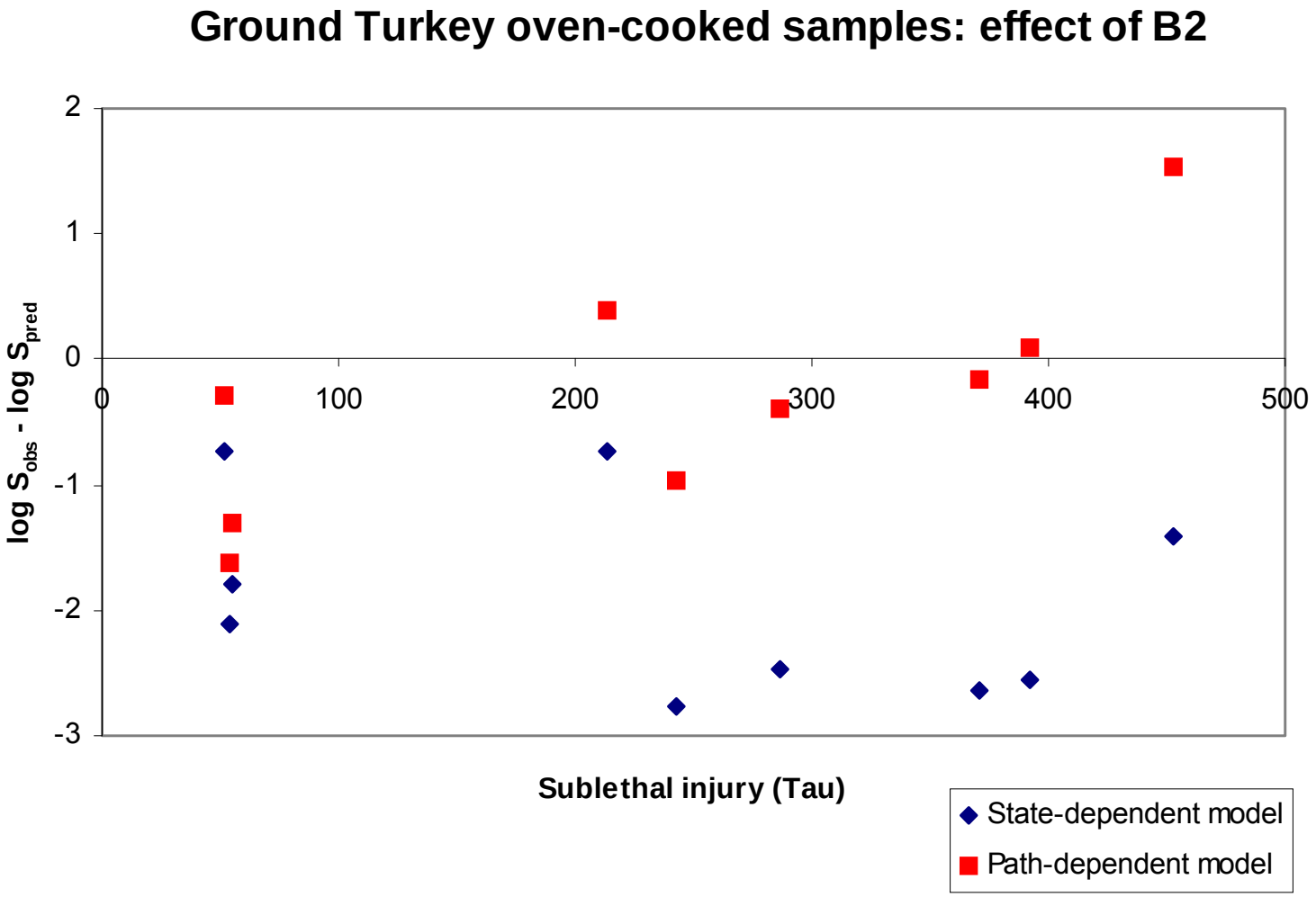
Results, 1 g samples, turkey



Results, 25 g samples, turkey



Results, 25 g samples, turkey



Results, turkey

Parameters	Tested against	Results	RMSE reduction
State-dependent model	Calibration (1 g)	n=90 RMSE=8.5	-
	Validation (1 g)	n=45 RMSE=8.3	-
	Oven-cooked (25 g)	n=9 RMSE=2.1	-
Path-dependent model	Calibration (1 g)	n=90, p=3 RMSE=1.4	84%
	Validation (1 g)	n=45 RMSE=1.3	84%
	Oven-cooked (25 g)	n=9 RMSE=2.5	-20%
State-dependent model with B2	Oven-cooked (25 g)	n=9, p=1 RMSE=1.0	51%

Results, beef

Parameters	Tested against	Results	RMSE reduction
State-dependent model	Calibration (1 g)	n=90 RMSE=8.7	-
	Validation (1 g)	n=45 RMSE=8.8	-
	Oven-cooked (25 g)	n=9 RMSE=3.1	-
Path-dependent model	Calibration (1 g)	n=90, p=3 RMSE=1.1	88 %
	Validation (1 g)	n=45 RMSE=1.1	88%
	Oven-cooked (25 g)	n=9 RMSE=1.6	49 %
State-dependent model with B2	Oven-cooked (25 g)	n=9, p=1 RMSE=1.7	45 %

Results, turkey parameters

Parameters	State-dependent model	Path-dependent model
b_{ref} (min^{-1})	0.9395	0.3775
β_1 (K^{-1})	48,762	45,564
β_2 (K^{-1} min^{-1})	-	6.83×10^{-3}

Results, beef parameters

Parameters	State-dependent model	Path-dependent model
b_{ref} (min^{-1})	1.0100	0.3873
β_1 (K^{-1})	46,573	36,836
β_2 (K^{-1} min^{-1})	-	3.23×10^{-5}

Conclusions

- Model parameters reflect:
  - b = rate of inactivation
  - β_1 = effect of T on rate of inactivation
  - β_2 = effect of sublethal injury on inactivation rates
- State-dependent model biggest deviations:
  - 1 g : -17.3 and -19.5 log reductions (turkey and beef respectively)
  - 25 g : -2.8 and -5.2 log reductions
- Path-dependent model biggest deviations:
  - 1 g : -2.6 and -1.9 log reductions
  - 25 g : 3.9 and 2.7 (-1.0 for “dangerous”) log reductions

Significance

- Estimating inactivation parameters for bacterial food pathogens is…
  - influenced by relatively large variability in the raw data (i.e., biological organisms).
  - influenced by substrate.
- The path-dependent model significantly improved accuracy (and would thereby improve assurance of food safety).
- Reducibility of the path-dependent model was relatively poor, indicating a need to improve the sublethal thermal injury (τ) function.

Questions / Comments ?