Multiscale Model of Human Pathogen Growth on Fresh Produce

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Introduction:

Outbreaks are not caused from bacteria originating in the produce but from a contaminated animal or water source being used to irrigate or wash plants[1]. As contamination is likely inevitable, an understanding of how pathogens interact with fresh produce is necessary to develop mitigation strategies. Here we study *growth* and *death* under isothermal and transient temperature profiles on a spinach surface. Then, we look at *dispersion and nutrient limitations* on the surface of fresh produce to better under internalization within foods.

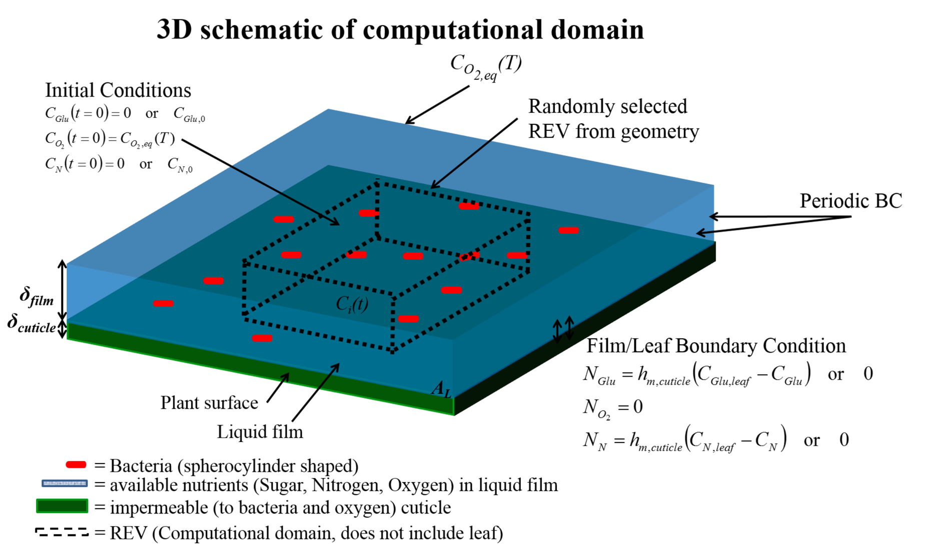


Figure 1. 3D Schematic of computational domain

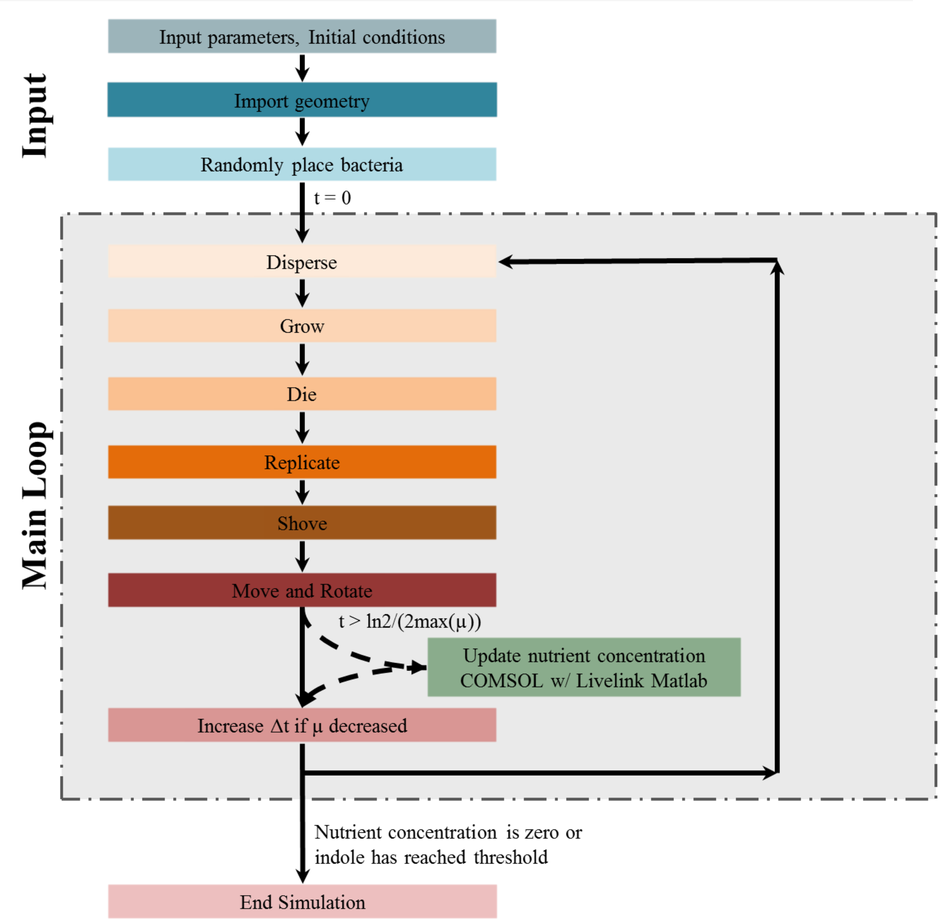


Figure 2. Computation Algorithm

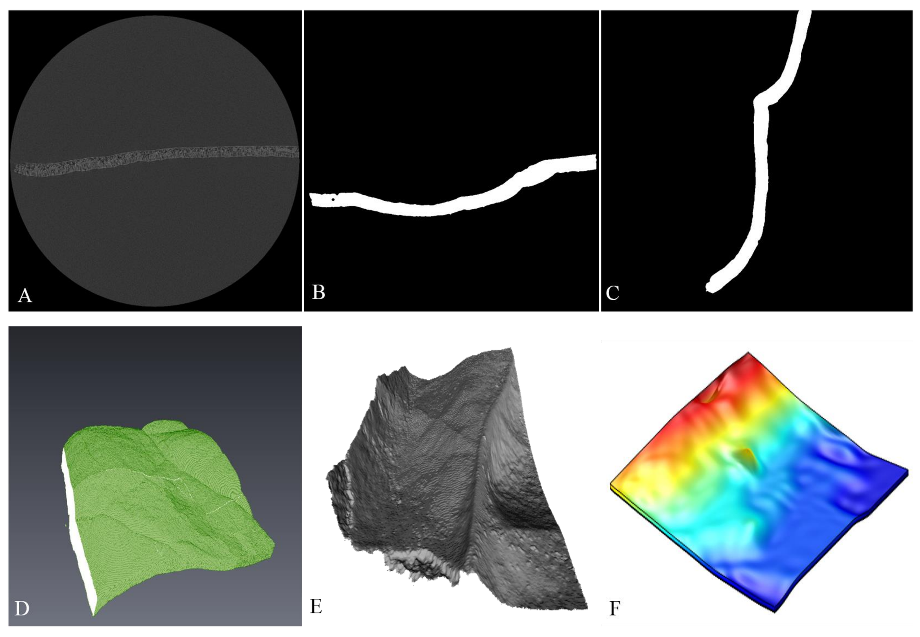


Figure 3. Surface segmentation algorithm:
A) µCT image of spinach
B) ROI of spinach using Matlab
C) Images from the previous step were resliced from left to right using imageJ and then the same algorithm as in the previous step was run
D) The spinach was segmented in Aviso
E) One side of the surface was extracted with Meshlab and borders were cleaned
F) Imported surface into COMSOL for only one REV (color represents surface height)

Model:

Carbon (Glucose), Nitrogen (Ammonium), and Oxygen Transport

$$\frac{\partial C_i}{\partial t} = D_{i,w}(X,T)\nabla^2 C_i + r_{i,X}$$

Nutrient Consumption

$$r_{i,X} = Y_{i/X}\mu X \qquad X = \frac{\sum_{V_{REV}} m^j}{V_{REV}}$$

Growth Rate

$$\mu^j = \mu^j_{max}\prod_i \phi_i \qquad \phi_i = \frac{C_i}{K_i(T) + C_i}$$

Volume Rate of Change

$$\frac{dv^j}{dt} = \mu^j v^j$$

Cell-Cell Signaling

$$\frac{d[C]_{QS}}{dt} = \kappa_{QS}[C]_n$$

Dispersion Velocity

$$\vec{v}_X = \frac{300}{\sqrt{2}}\frac{\nabla C_{Glu}}{C_{Glu}}$$

Dispersion Criterion

$$\frac{\mu^j}{\|\vec{v}_X\|/L^j} < 0.1$$

Isothermal Validation and Results:

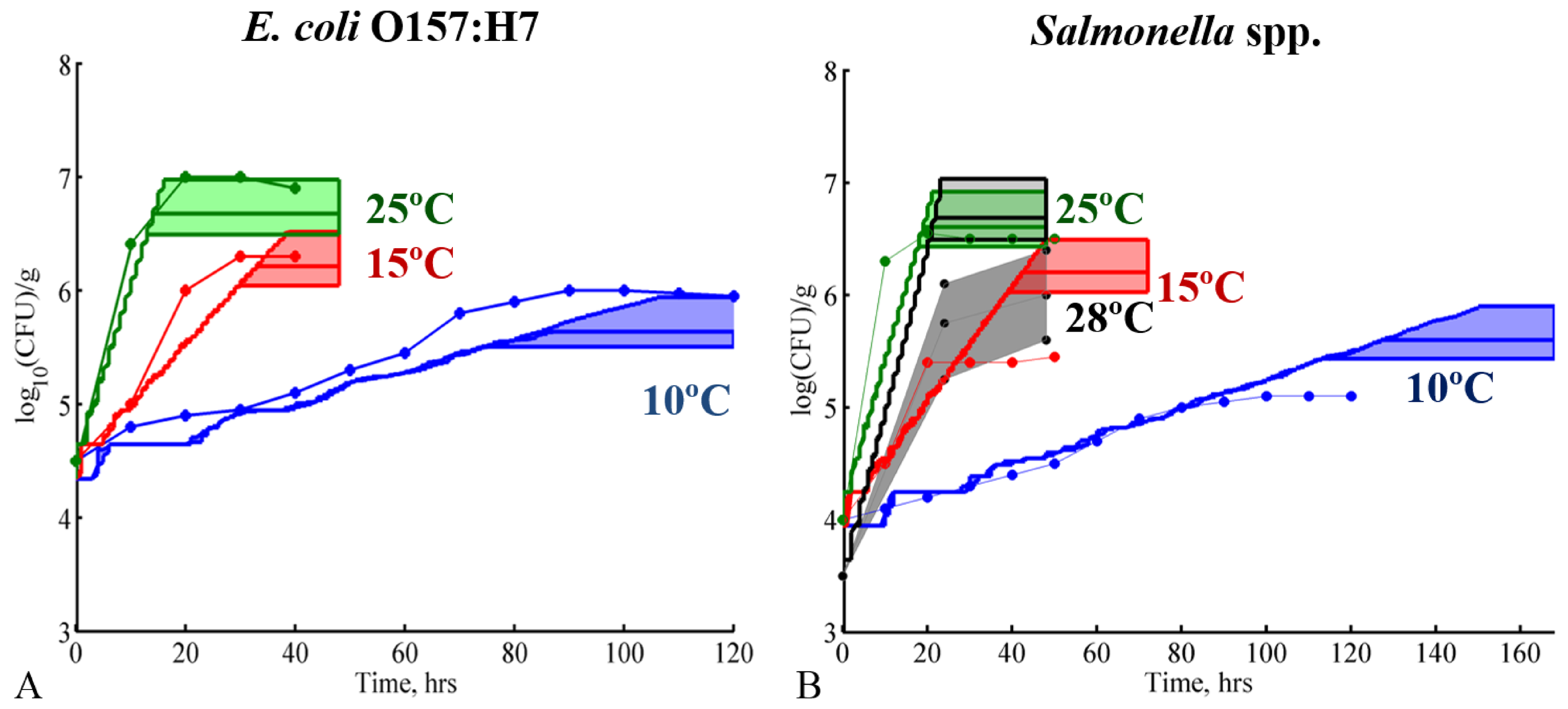


Figure 4: Experimental[2,3] and model growth curves for *E. coli* O157:H7 (A) and *Salmonella* spp. (B)

Dynamic Temperature Validation and Results:

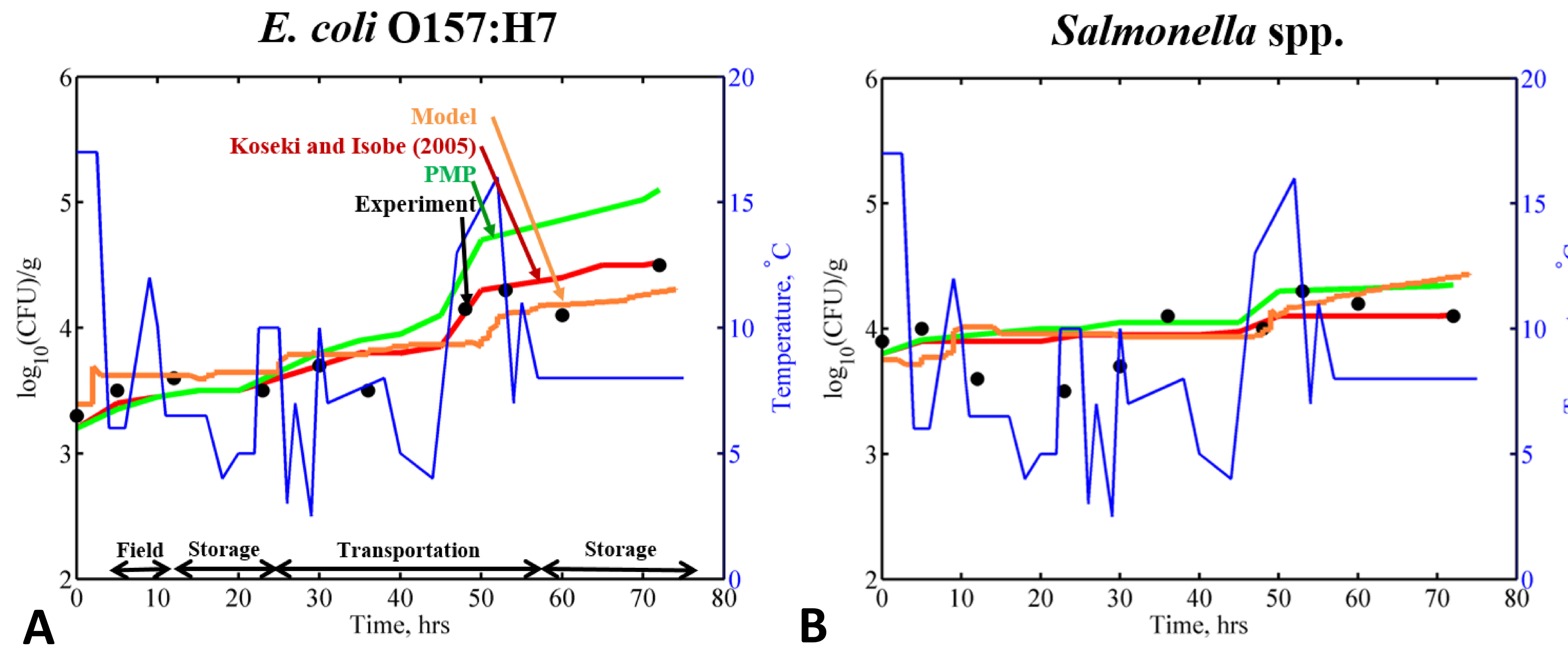


Figure 5. Growth of *E. coli* O157:H7 (A) and Salmonella spp. (B) under actual dynamic temperature conditions[2]

Growth and Nutrient Validation:

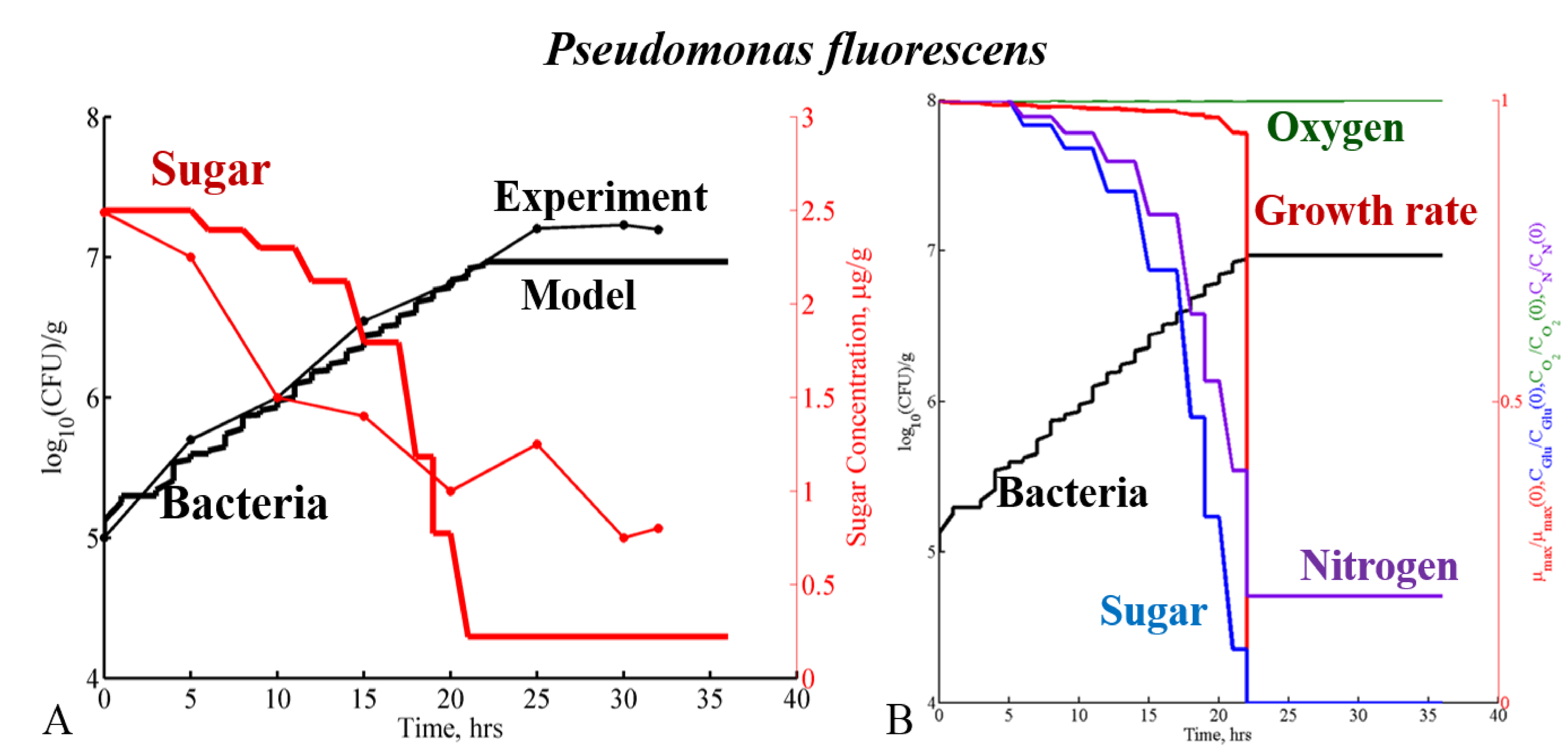
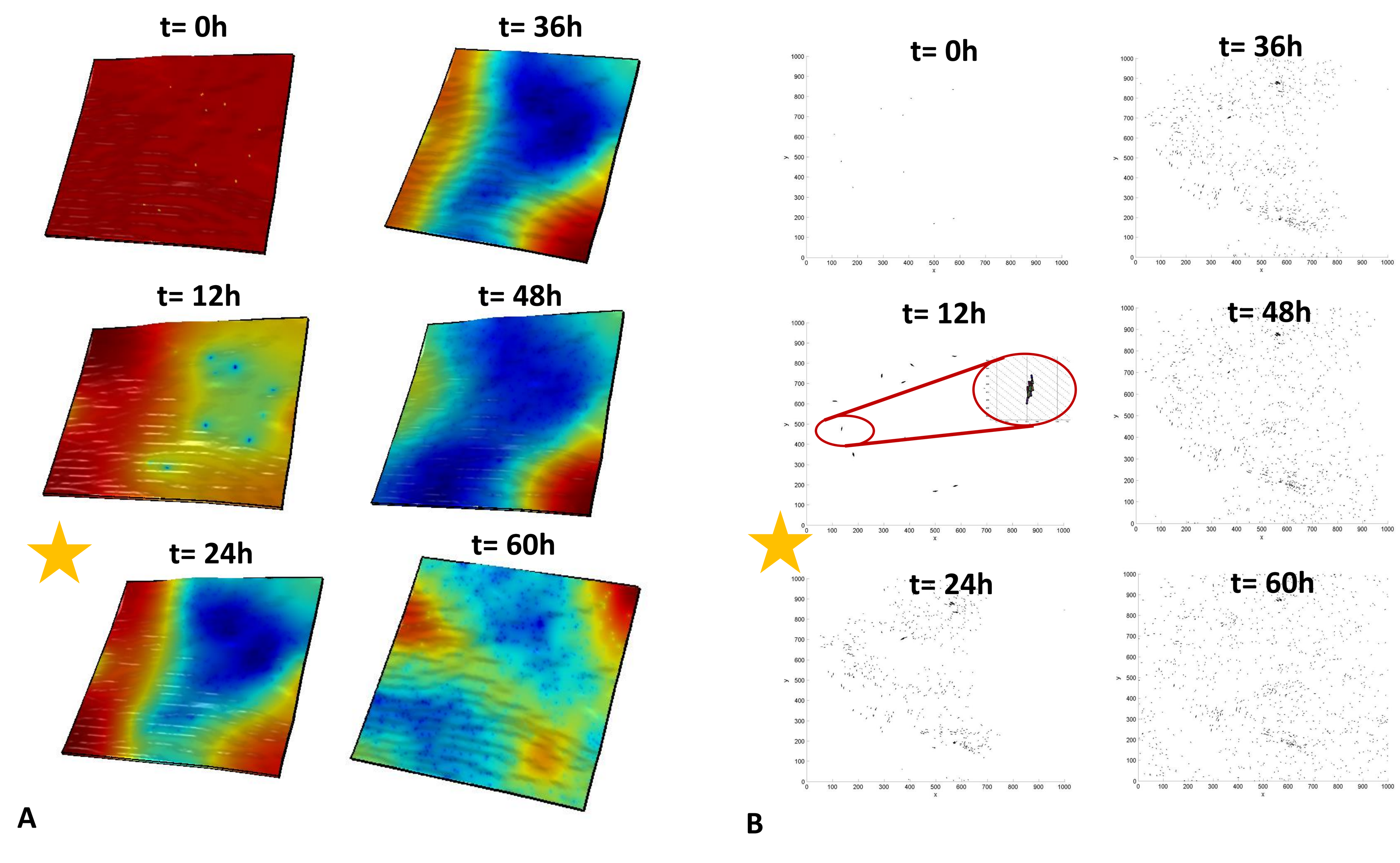


Figure 6. Growth and nutrient concentration results and validation [4]. Assuming zero flux in leaf and no cell signaling.



★ Limited nutrients and high concentration gradient leads to dispersion (12→24h)

Figure 7. Concentration (A) profiles and spatial organization of bacteria (B) over time. Initially only 10 bacteria per mm². At 12 hrs, bacteria disperse due to limited growth

Conclusions:

The model showed good validation for several species in isothermal and dynamic temperature differentials along with nutrient concentration in the film. When bacteria are grown at low initial nutrient concentration, the model shows how nutrient gradients form spurring dispersion and possible infiltration. Future work will involve studying the effect of non-uniform nutrients being secreted from the leaf and how it affects internalization.

References:

- 1. Solomon, Ethan B., Hoan-Jen Pang, and Karl R. Matthews. "Persistence of Escherichia coli O157: H7 on lettuce plants following spray irrigation with contaminated water." *Journal of food protection* 66.12 (2003): 2198-2202.
- 2. Koseki, Shigenobu, and Seiichiro Isobe. "Prediction of pathogen growth on iceberg lettuce under real temperature history during distribution from farm to table." *International Journal of Food Microbiology* 104.3 (2005): 239-248.
- 3. Brandl, M. T., and R. Amundson. "Leaf age as a risk factor in contamination of lettuce with Escherichia coli O157: H7 and Salmonella enterica." *Applied and environmental microbiology* 74.8 (2008): 2298-2306.
- 4. Mercier, Julien, and S. E. Lindow. "Role of leaf surface sugars in colonization of plants by bacterial epiphytes." *Applied and Environmental Microbiology* 66.1 (2000): 369-374.

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