Fresh Produce Safety During Hydrocooling: an Engineering Model

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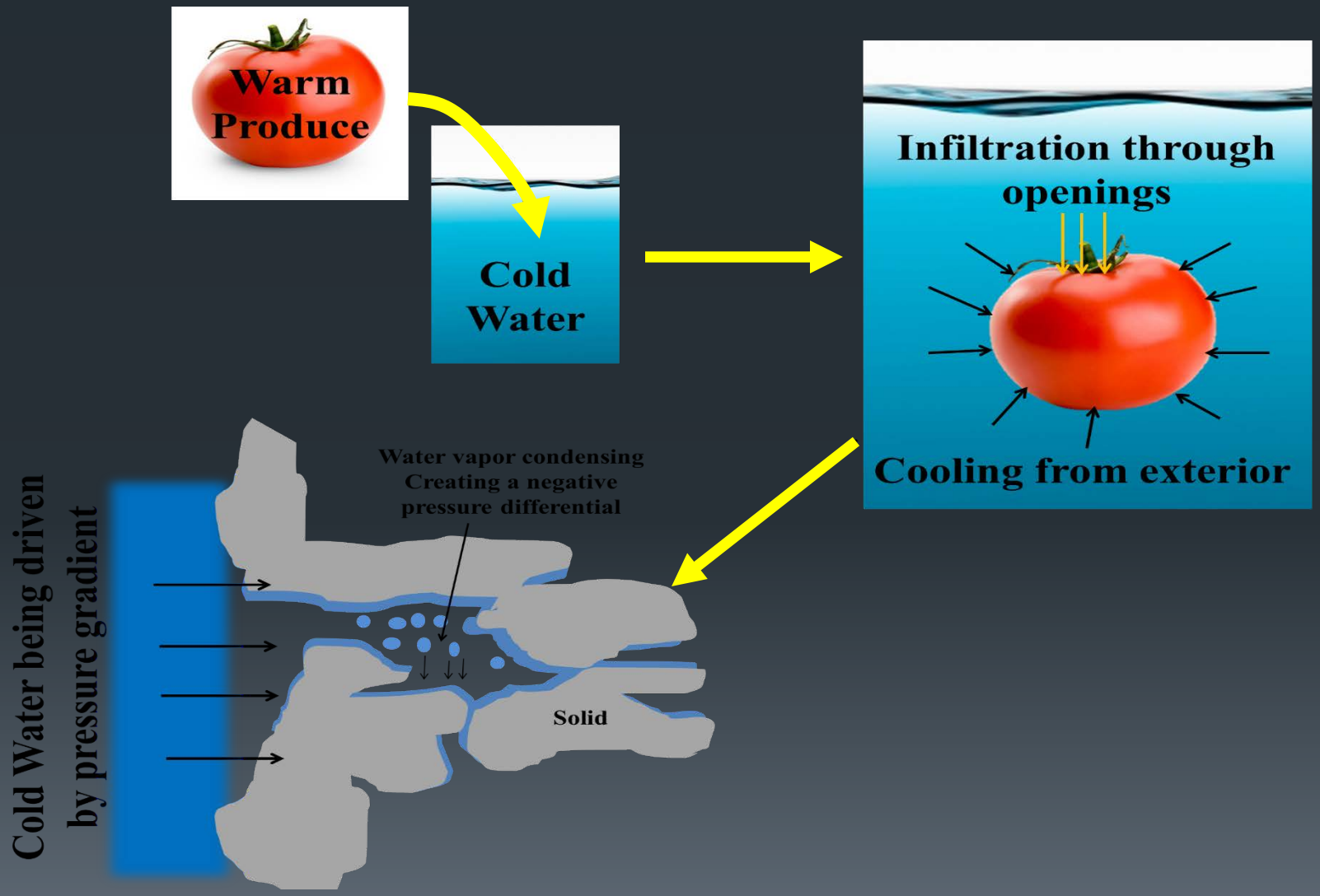
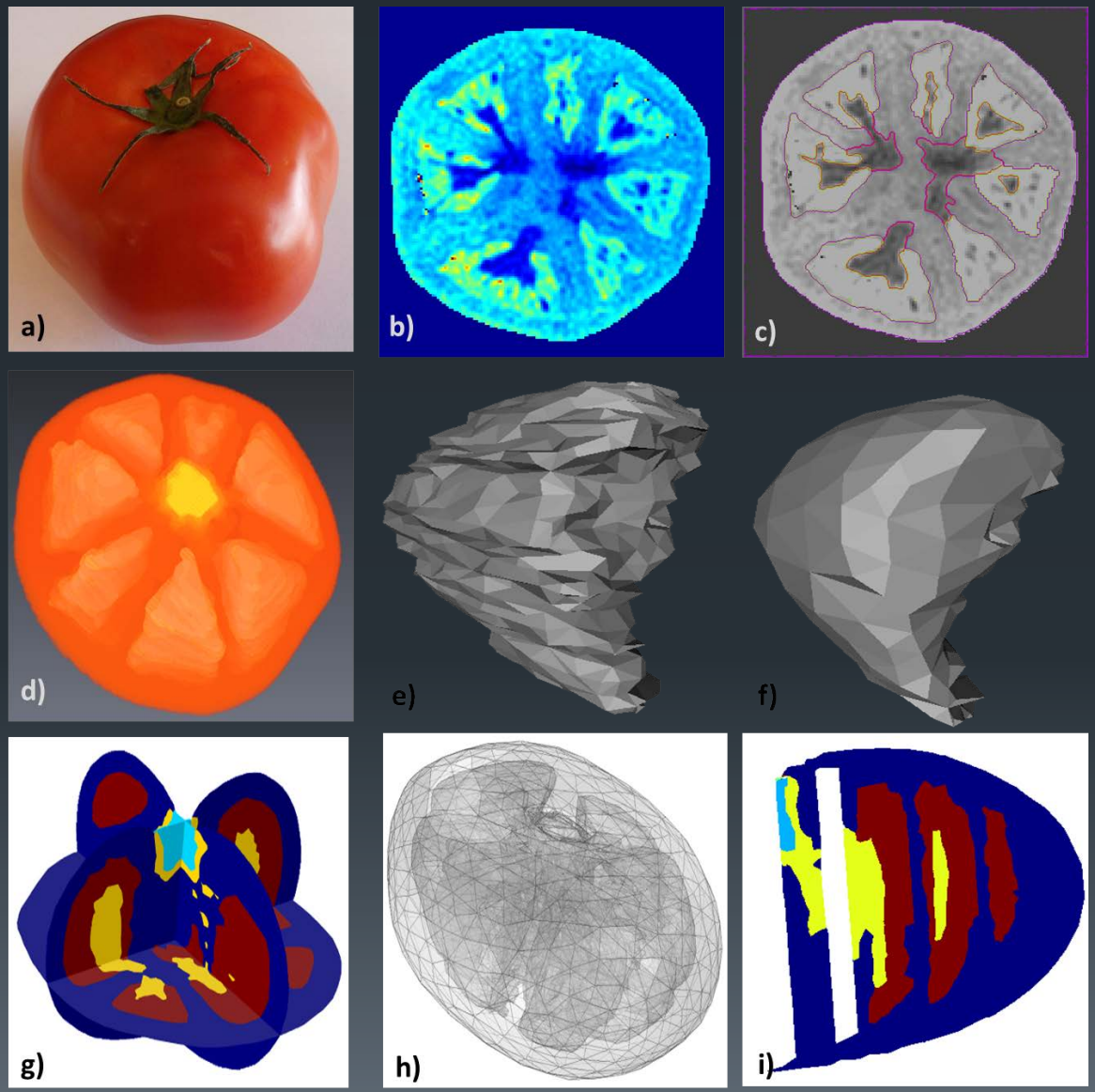
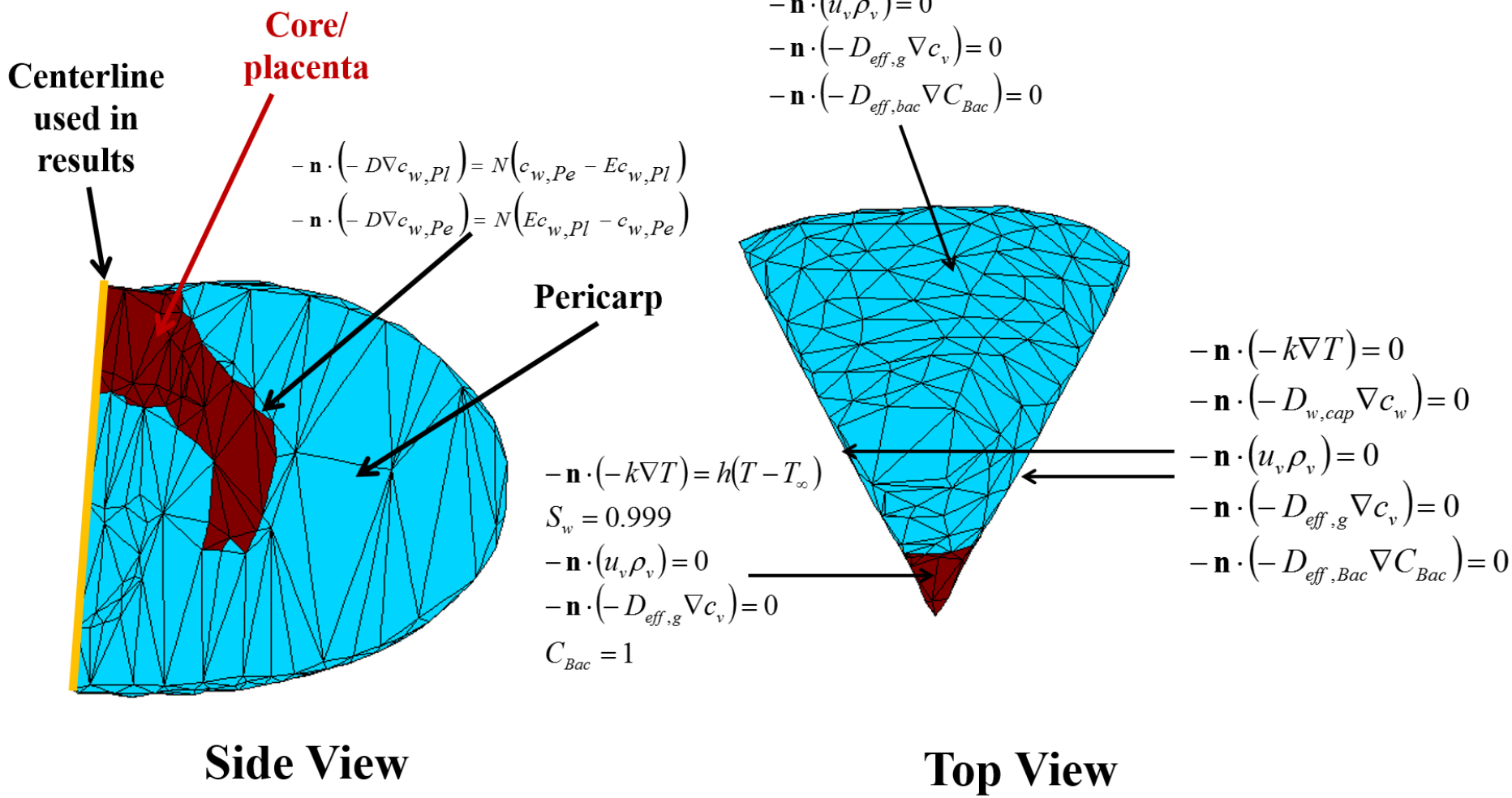
Hydrocooling Background



Geometry Acquisition from MRI



Model Schematic



Governing Equations

Moisture Transport

$$\frac{\partial}{\partial t}(\phi \rho_w S_w) + \nabla \cdot (\mathbf{u}_w \rho_w) = \nabla \cdot (D_{w,cap} \nabla (\phi \rho_w S_w)) - \dot{I}$$

Vapor Fraction Transport

$$\frac{\partial}{\partial t}(\rho_g S_g \phi \omega_v) + \nabla \cdot (\mathbf{u}_g \rho_g \omega_v) = \nabla \cdot \left(\phi S_g \frac{C_g^2}{\rho_g} m_a m_v D_{eff,g} \nabla x_v \right) + \dot{I}$$

Energy Equation

$$\rho_{eff} Cp_{eff} \frac{\partial T}{\partial t} + (\rho Cp \mathbf{u})_{fluid} \cdot \nabla T = \nabla \cdot (k_{eff} \nabla T) - \lambda \dot{I}$$

Darcy's Equation (Pressure)

$$\frac{\partial (\phi S_g \rho_g)}{\partial t} + \nabla \cdot \left(-\frac{\rho_g \kappa_g}{\mu_g} \nabla P \right) = \dot{I}$$

Bacteria Transport

$$\frac{\partial}{\partial t}(C_b \phi S_w) + \nabla \cdot (\mathbf{u}_w C_b) = \nabla \cdot (D_{b,eff} \nabla (C_b \phi S_w))$$

Governing Equations

Non-equilibrium Evaporation

$$\dot{I} = K\left(p_w - P\right)\frac{m_w \phi S_g}{RT}$$

Capillary Diffusivity

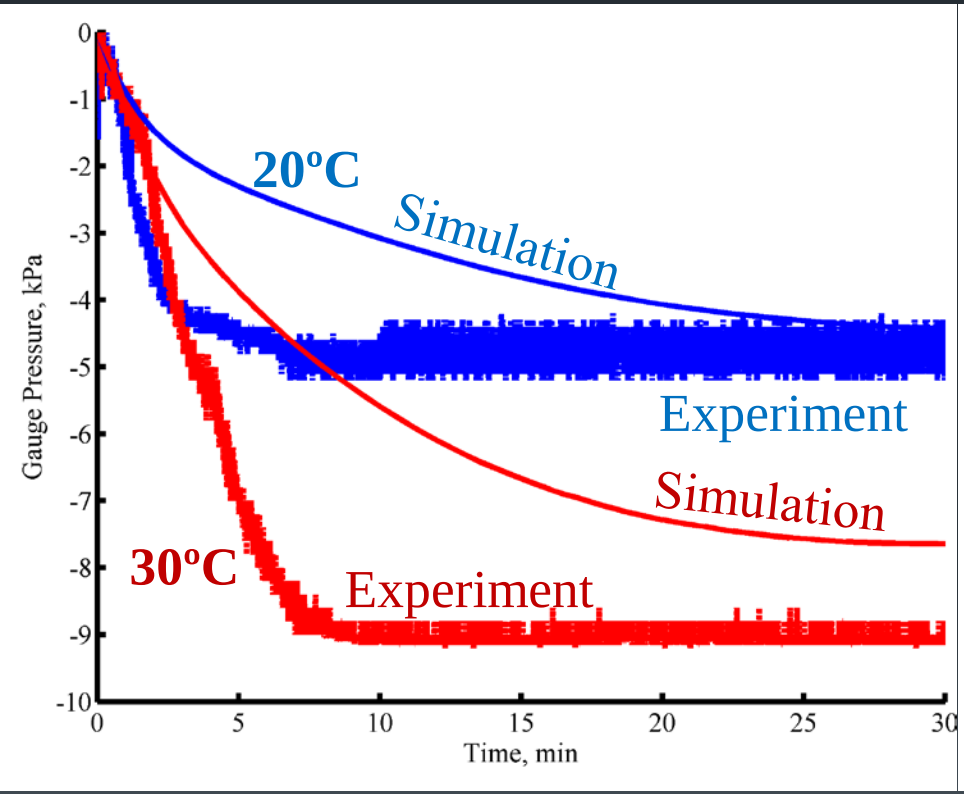
$$D_{w,cap} = -\frac{\kappa_{in,w} k_{r,w} RT}{V_w a_w \phi \mu_w}\frac{\partial a_w}{\partial M_w}\frac{\partial M_w}{\partial S_w}$$

Intrinsic Permeability

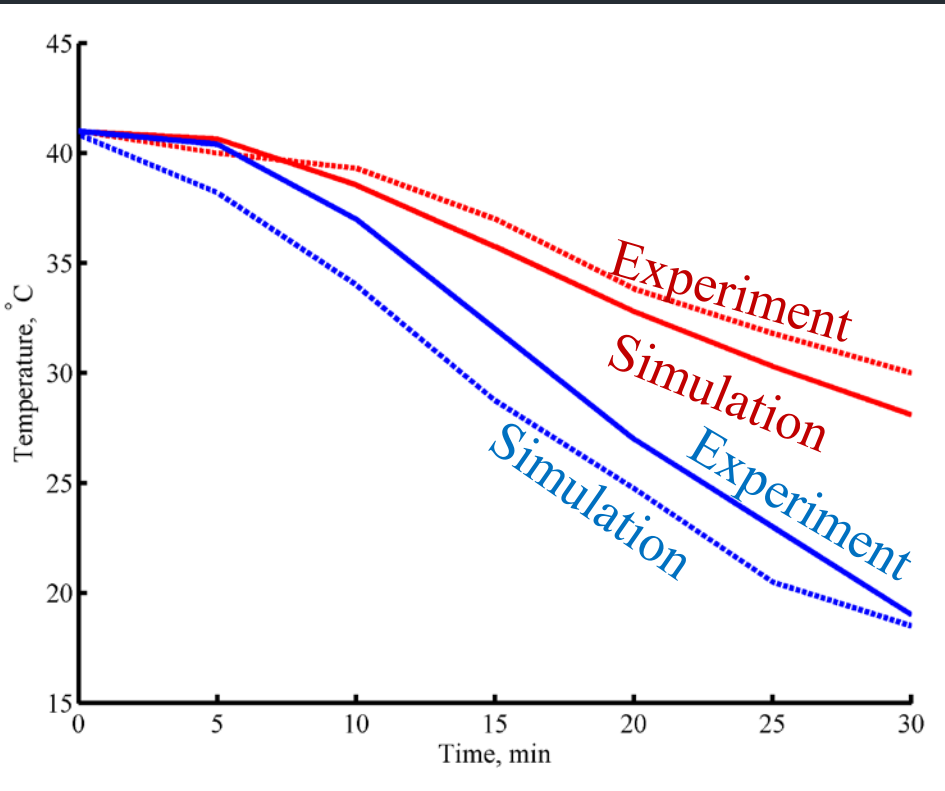
$$\kappa_{in,0} = \frac{n_t \pi R_t^4}{24\tau}$$

Validation

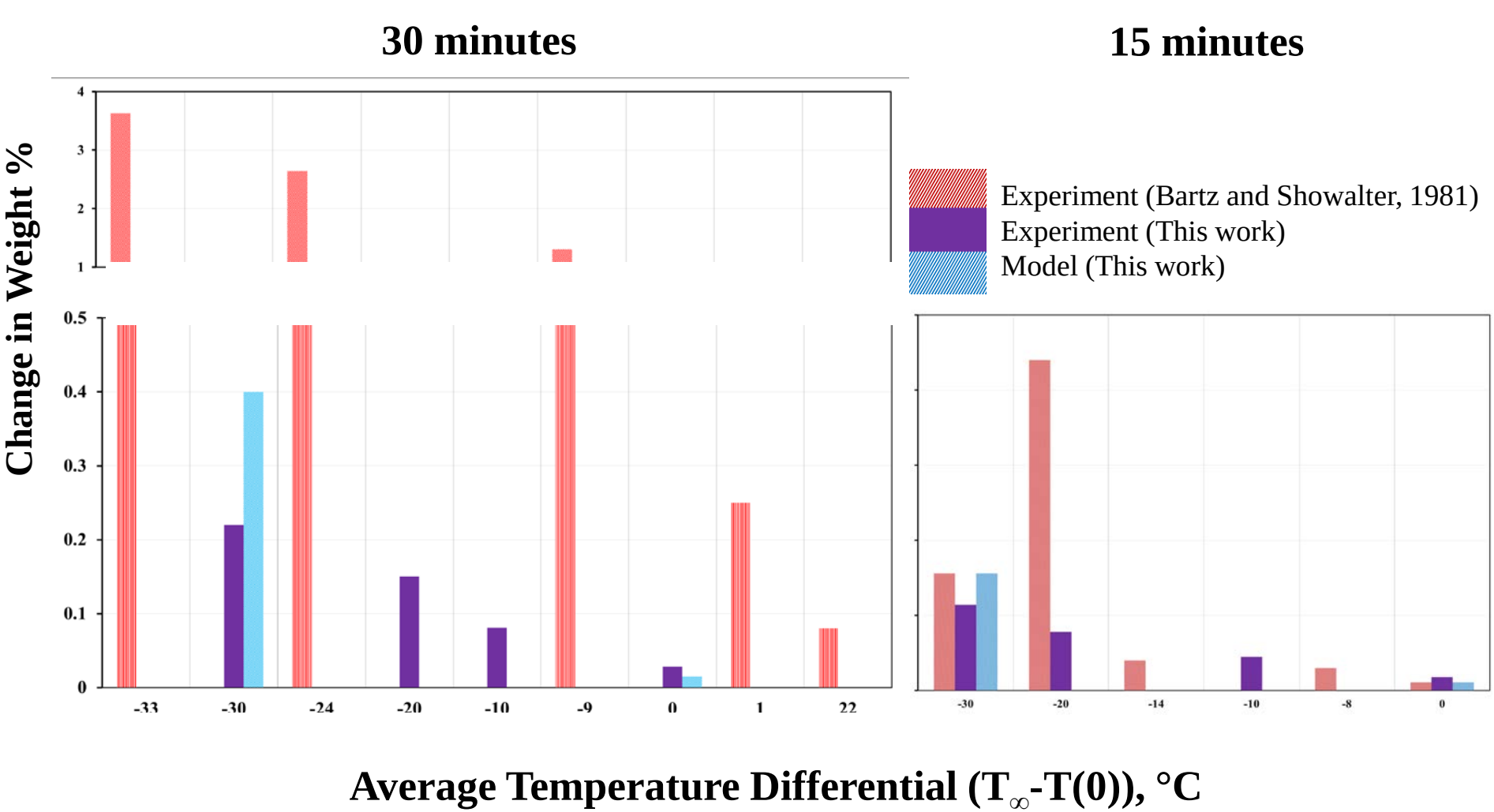
Core Gauge Pressure



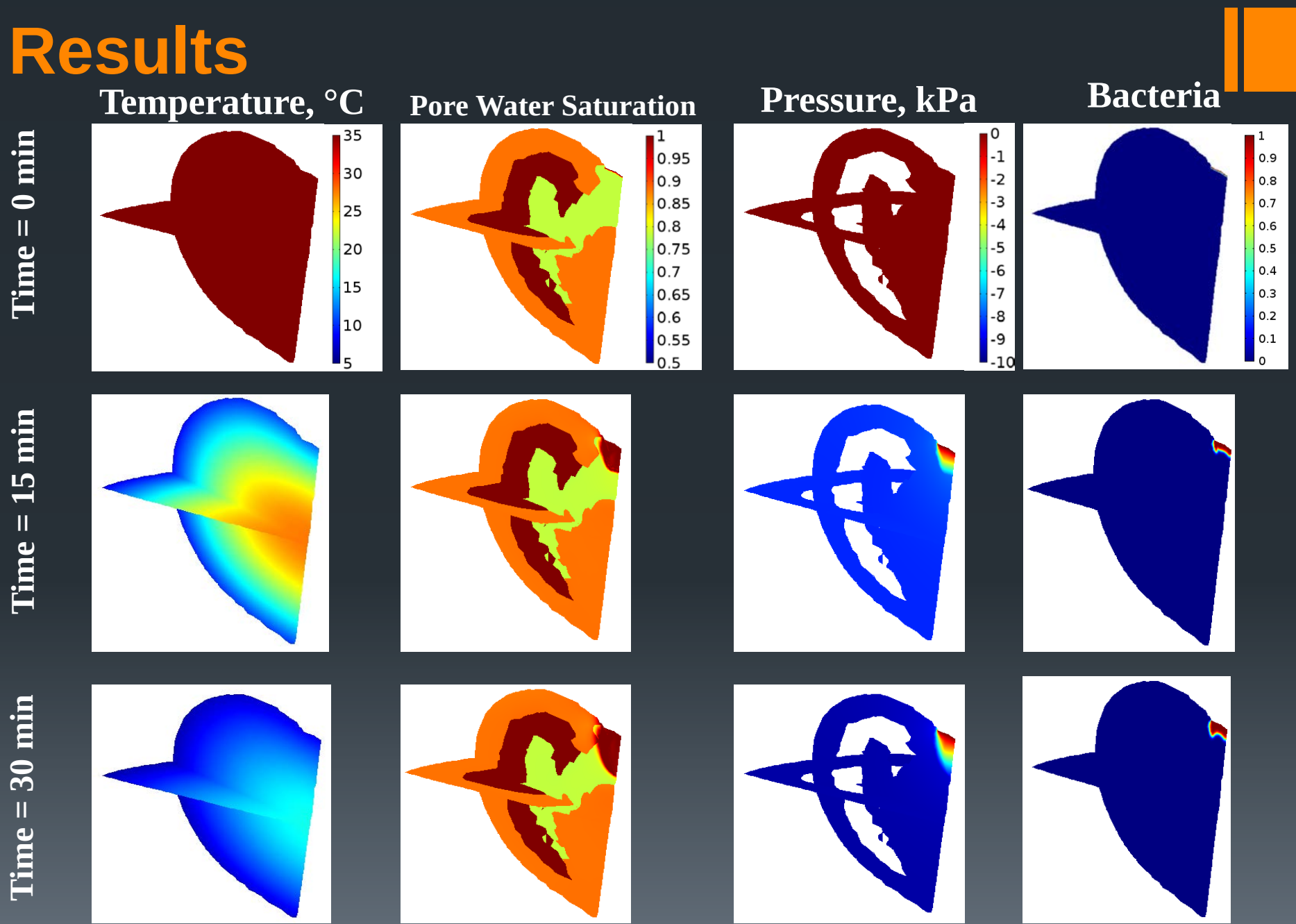
Core Temperature



Validation

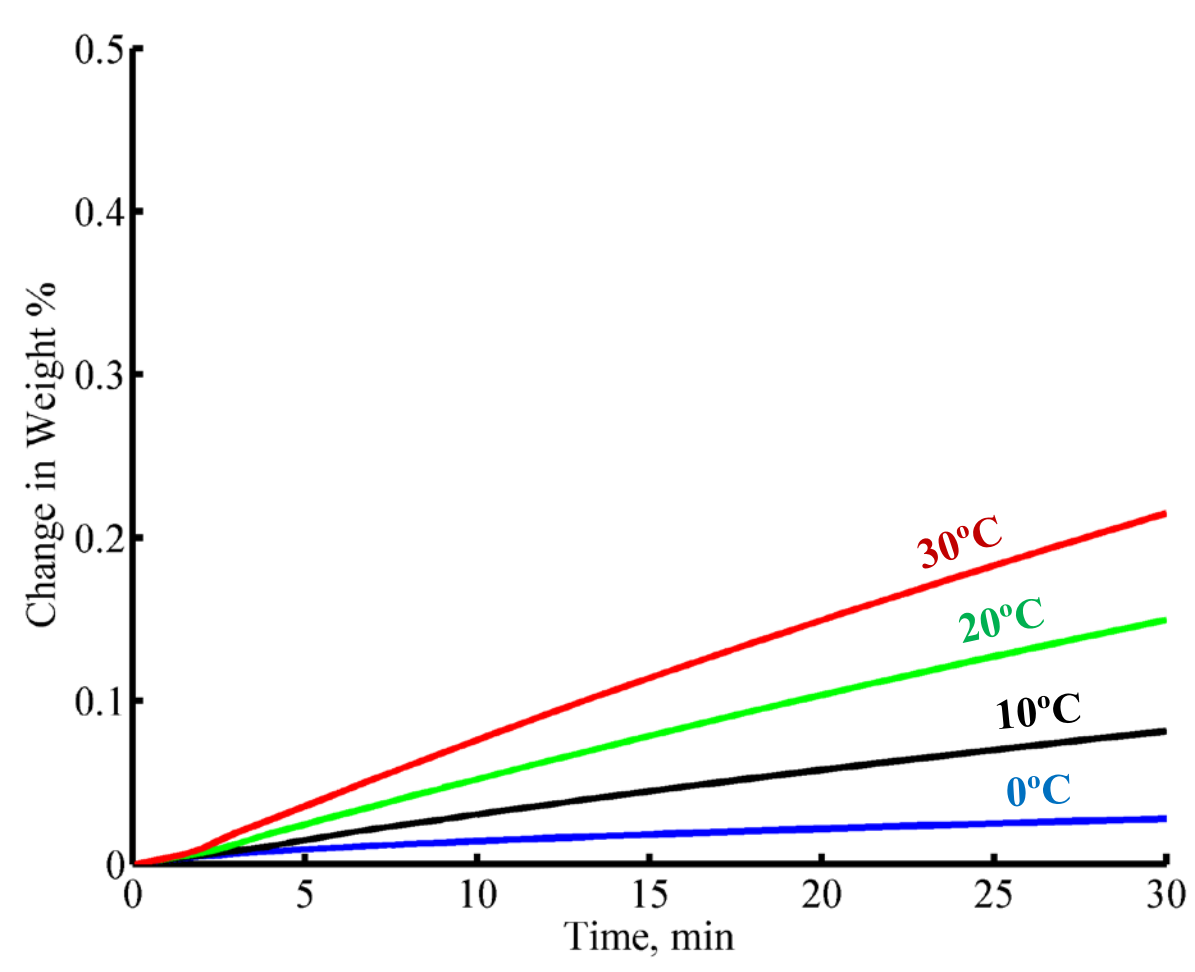

30 minutes
15 minutes
Change in Weight %
Experiment (Bartz and Showalter, 1981)
Experiment (This work)
Model (This work)
4
3
2
1
0.5
0.4
0.3
0.2
0.1
0
-33
-30
-24
-20
-10
-9
0
1
22
-30
-20
-14
-10
-8
0
Average Temperature Differential (T∞-T(0)), °C

Results

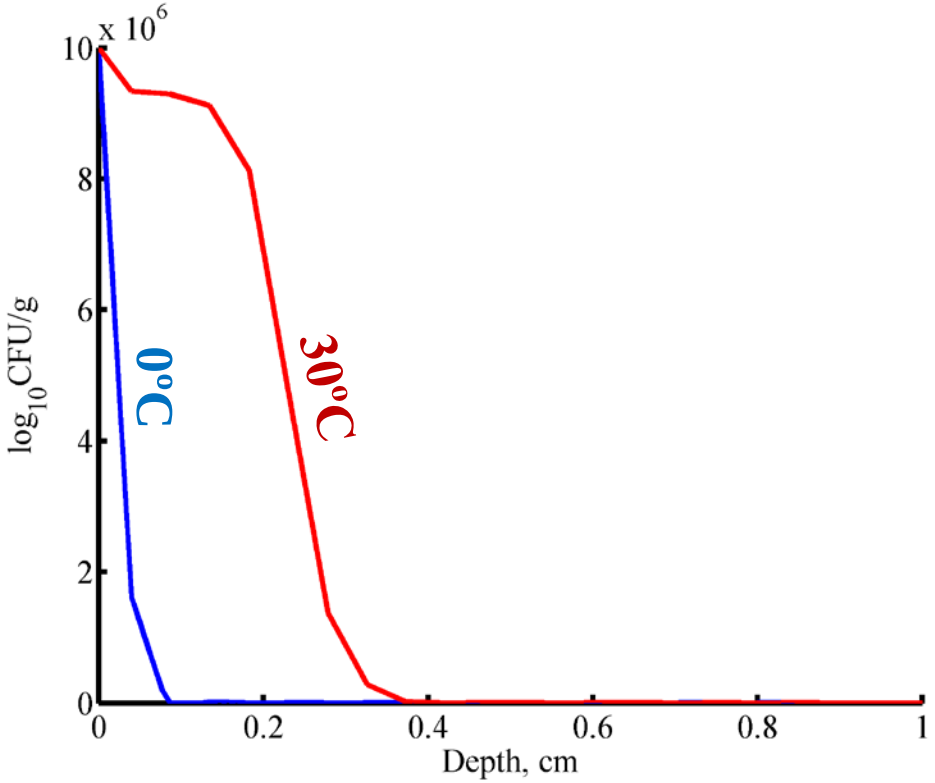

Temperature, °C
Pore Water Saturation
Pressure, kPa
Bacteria
Time = 0 min
Time = 15 min
Time = 30 min
35
30
25
20
15
10
5
1
0.95
0.9
0.85
0.8
0.75
0.7
0.65
0.6
0.55
0.5
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0

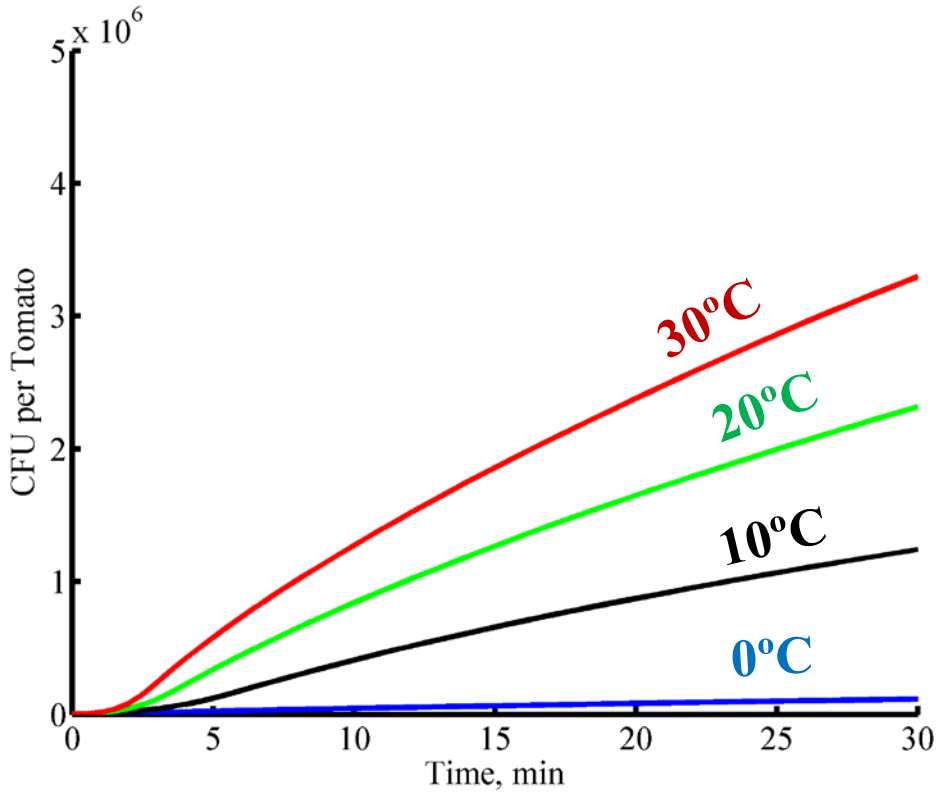
Results, contd.

Temperature differential



Results, contd.



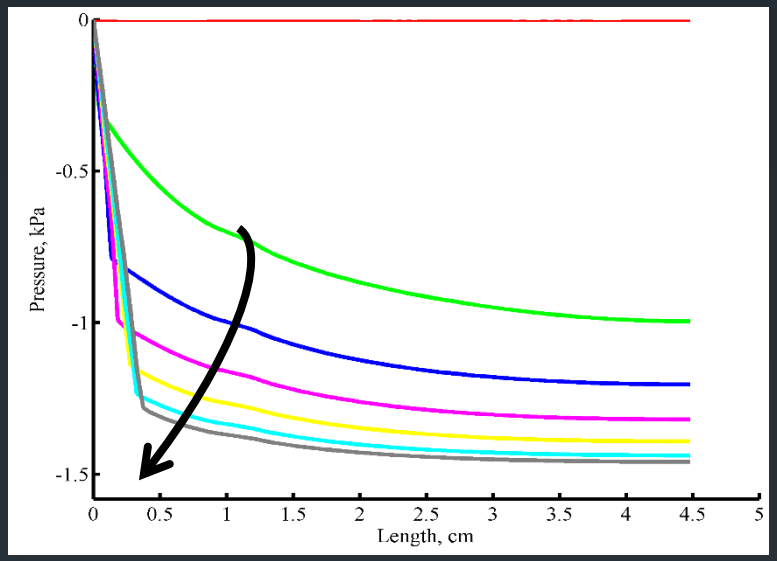


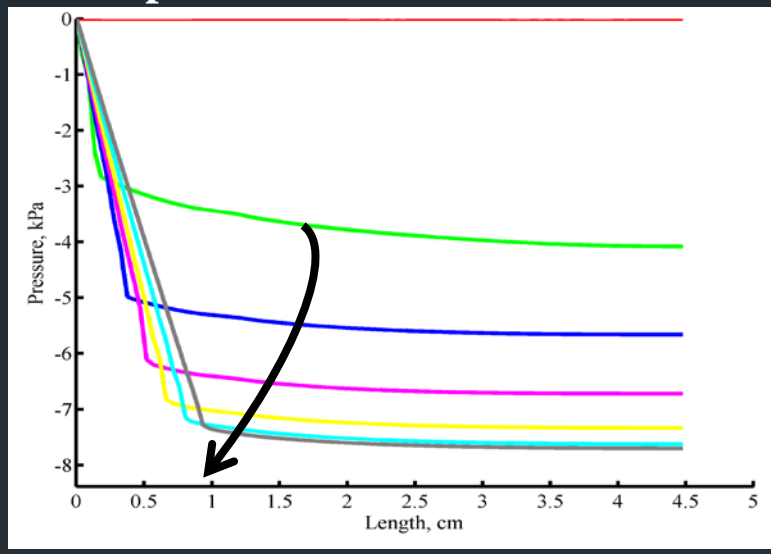
Results, contd.

Temperature differential = 10°C

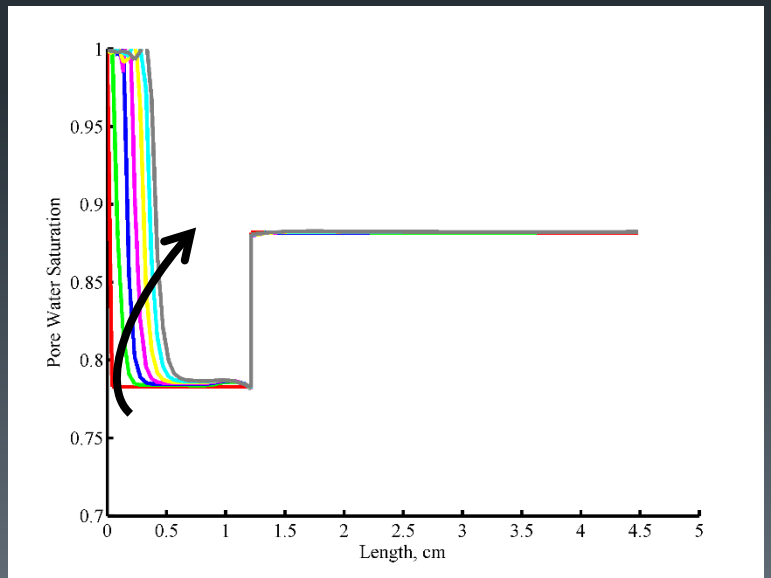
Temperature differential = 30°C

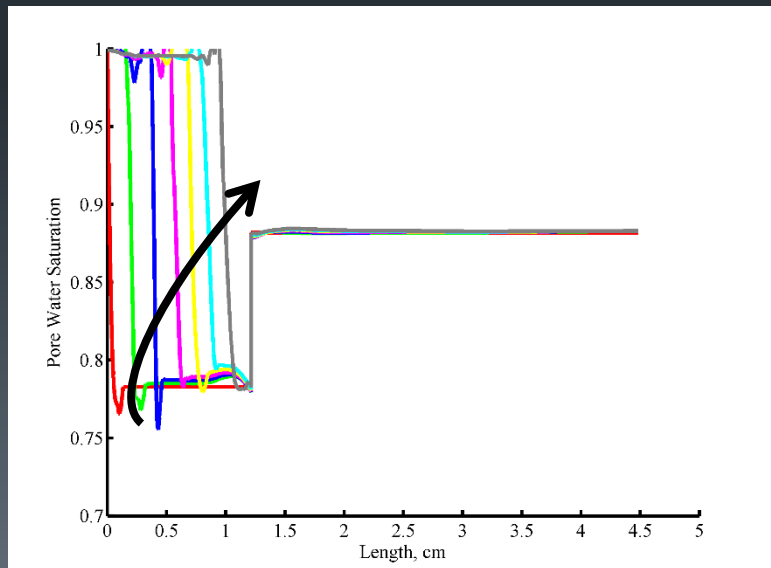
Pressure





Moisture





Conclusions/Challenges

- Geometry reconstruction with multiple interlocking parts is a significant challenge in COMSOL

- Spatial validation of moisture and pressure in a heterogenous structure

- Modeling is an excellent approach to mechanistically explaining food safety problems

- Use of 3D geometries from imaging creates a greater tangible connection between computer and experiment

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References

- Bartz, Jerry A., and R. K. Showalter. "Infiltration of tomatoes by aqueous bacterial suspensions." *Phytopathology* 71.5 (1981): 515-8.
- Bartz, Jerry A. "Infiltration of tomatoes immersed at different temperatures to different depths in suspensions of Erwinia carotovora subsp. carotovora." *Plant disease* 66.4 (1983): 302-306.

Questions?