Fresh Produce Safety During Hydrocooling: An Engineering Model

A. Warning[1], A. K. Datta[1]
1. Biological & Environmental Engineering, Cornell University, Ithaca, NY, USA

Introduction:

Hydrocooling (**Fig. 1**) is the process by which warm produce is cooled in cold water after harvesting. The cooling of the produce creates a pressure differential that increases water infiltration. But if the water is contaminated with pathogens, literature[1,2] hypothesized that hydrocooling will exacerbate the problem of bacteria infiltrating into fresh produce. We use a tomato (**Fig. 2**) as a case study and use the realistic geometry acquired from MRI (from symmetry, we only use a wedge **Fig. 3**).

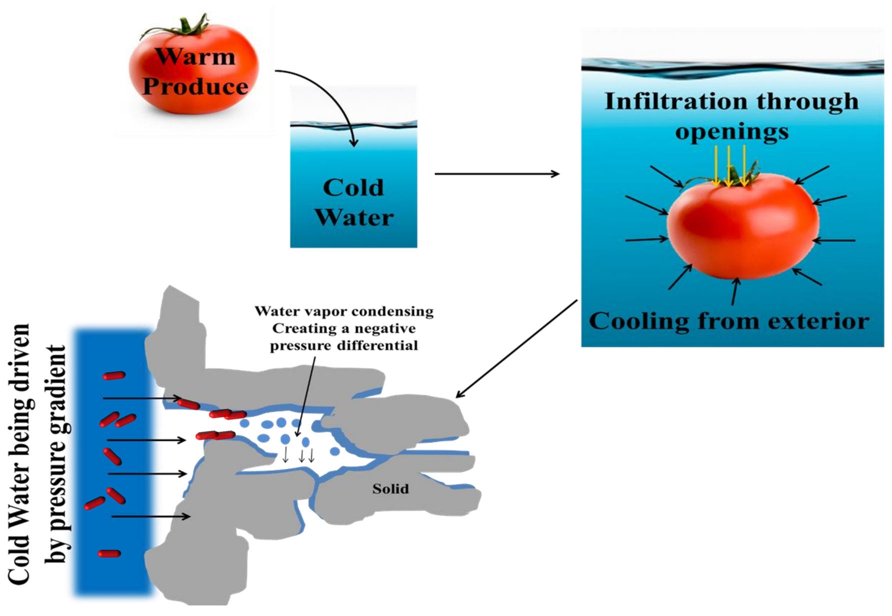

Figure 1. Hydrocooling of a tomato. The condensing gas creates suction.

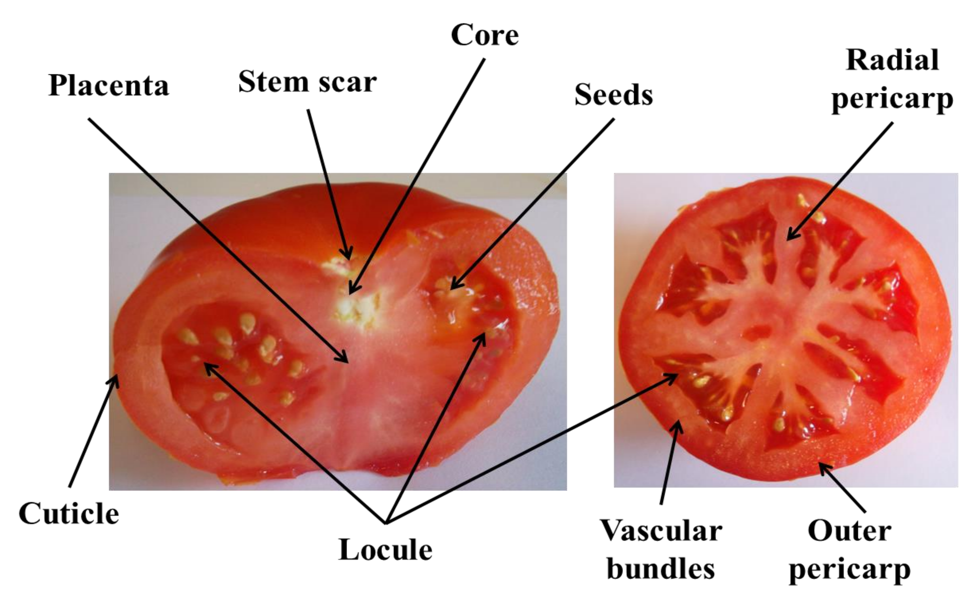

Figure 2. Anatomy of tomato

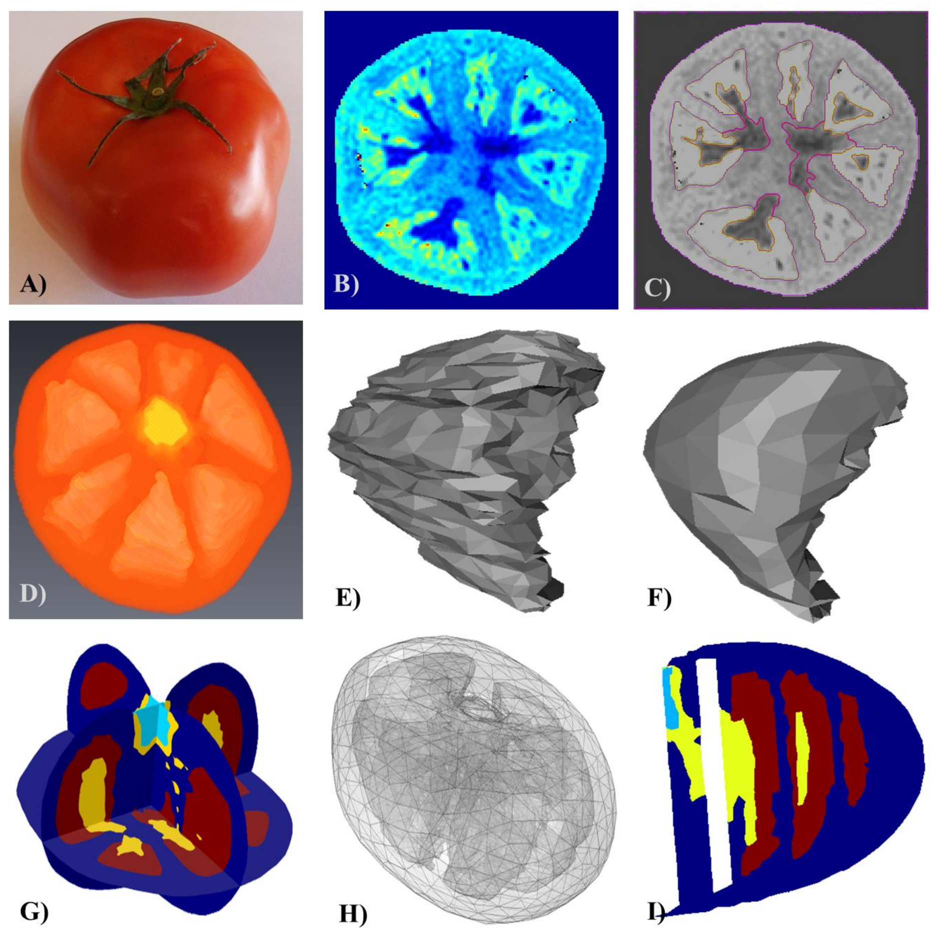

Figure 3.
A) Tomato
B) T2 map of tomato
C) Segregated slice
D) Segregated slices combined to form whole tomato
E) Example locular tissue after whole geometry has been reduced to 18000 faces
F) Smoothed and reduced number of faces of locular tissue
G) Planes cutting final geometry, where each color represents a different region
H) Complete geometry in COMSOL
I) Scaled tomato wedge used in simulations

Model:

Moisture Transport

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

Energy Transport

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

Pressure (Darcy's Eq)

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

Concentrated Species (Binary Gas Mass Transport)

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

Bacteria Transport

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

Evaporation

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

Capillary Diffusivity

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

Permeability

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

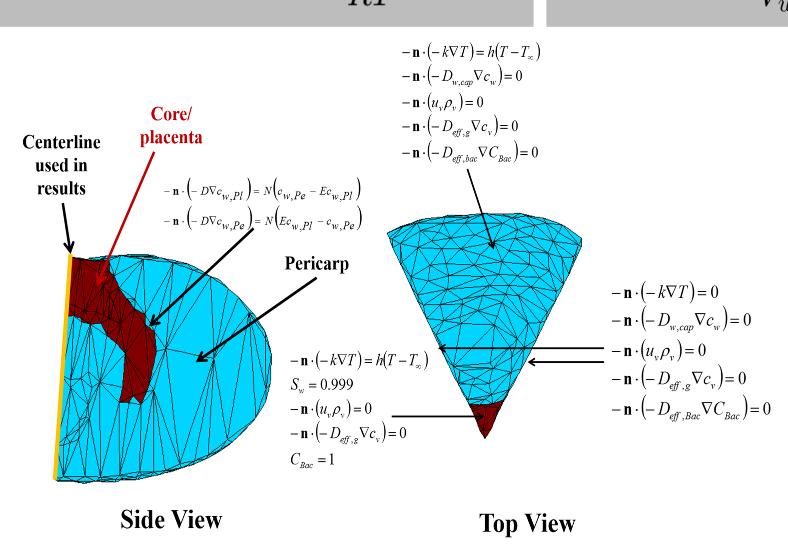

Figure 4. Model schematic. The locular tissue is not shown.

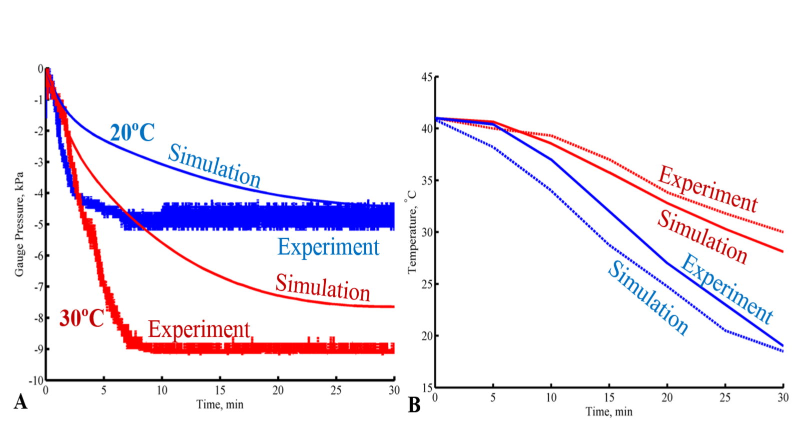

Figure 5. Model Validation: A) Core gauge pressure; B) Core Temperature

Results:

Surface Plots

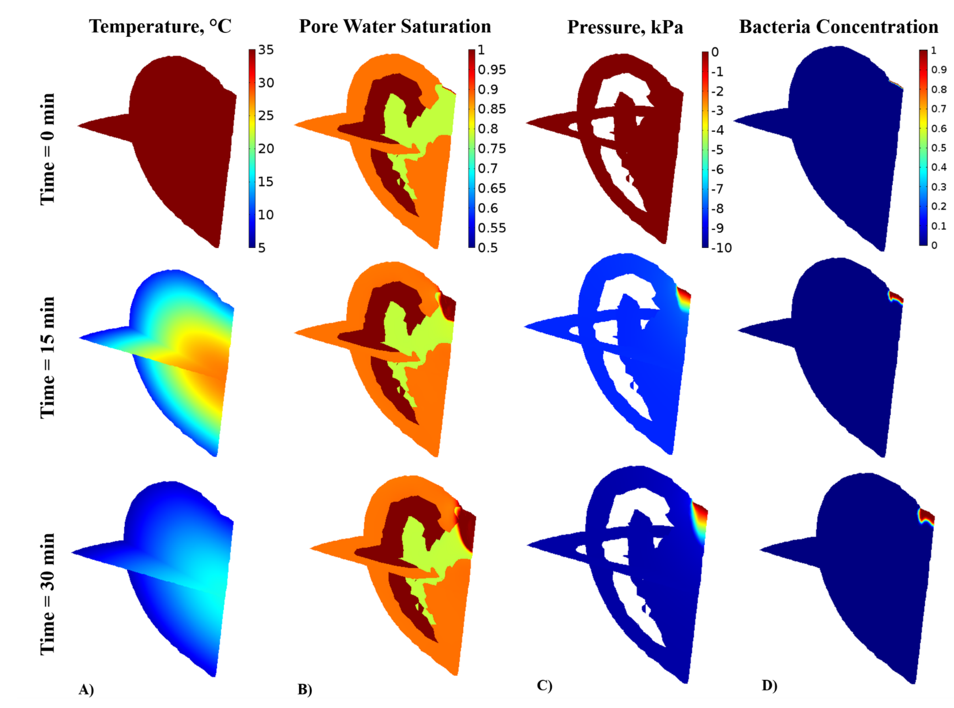

Figure 6. A) Spatial variation in tomato wedge of temperature, B) pore water saturation, C) gauge pressure and D) bacteria concentration at three times. The initial temperature is 35° C and the water temperature is 5° C.

Temperature

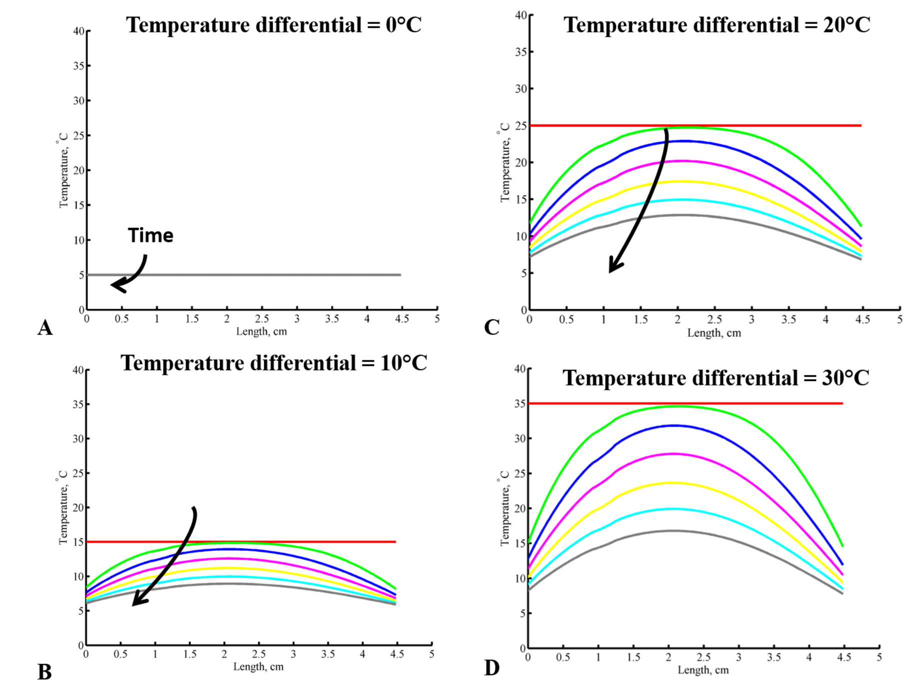

Figure 7. Temperature from stem scar to opposite end of tomato along the centerline for four temperature differentials. Each line represents five minutes.

Water

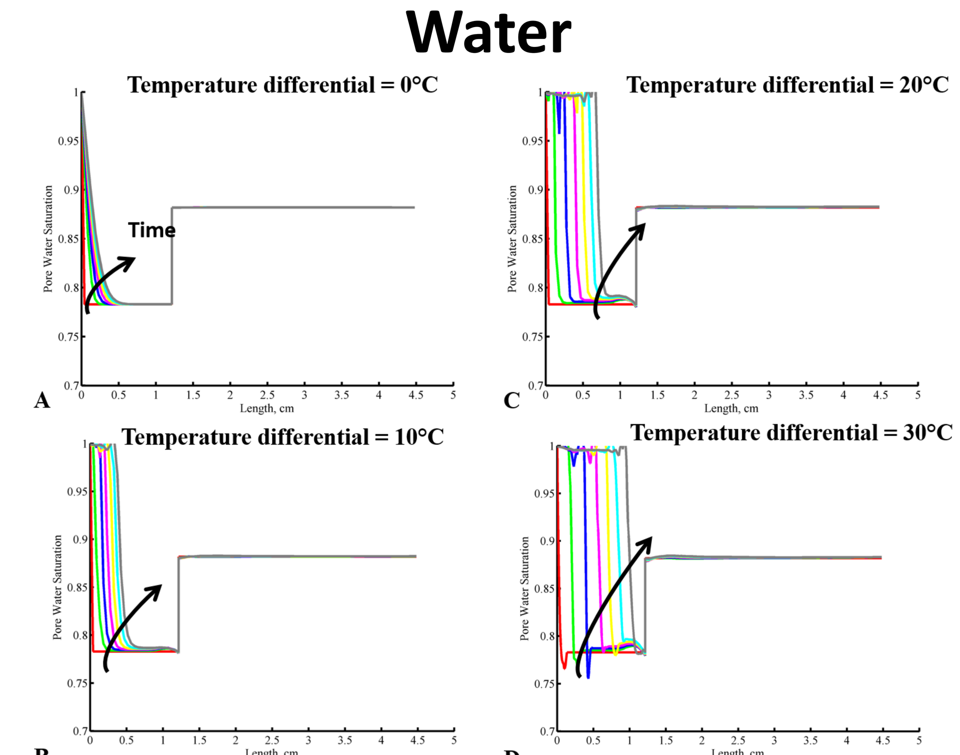

Figure 8. Pore water saturation from stem scar to opposite end of tomato along the centerline for four temperature differentials. Each line represents five minutes.

Pressure

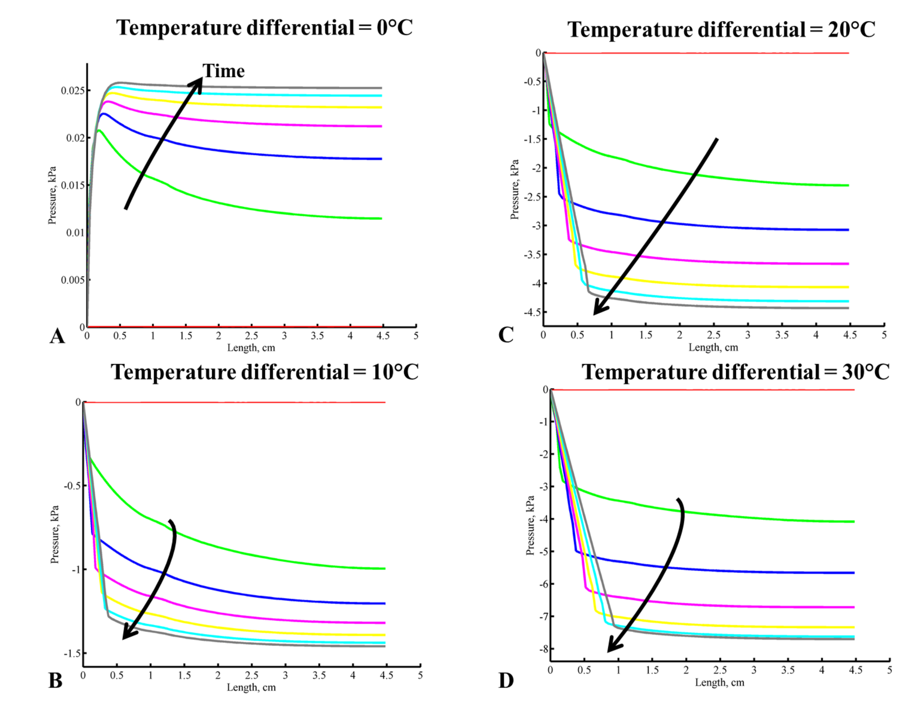

Figure 9. Gauge pressurefrom stem scar to opposite end of tomato along the centerline for four temperature differentials. Each line represents five minutes.

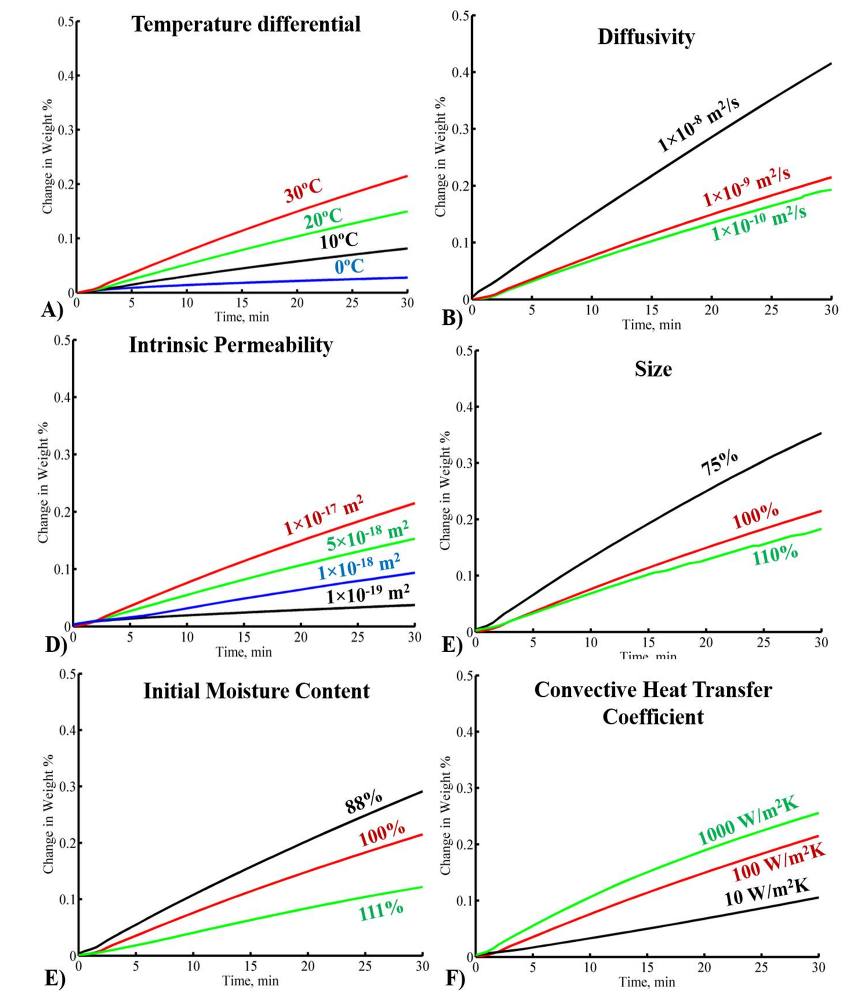

Figure 10. Model Parameter Sensitivity

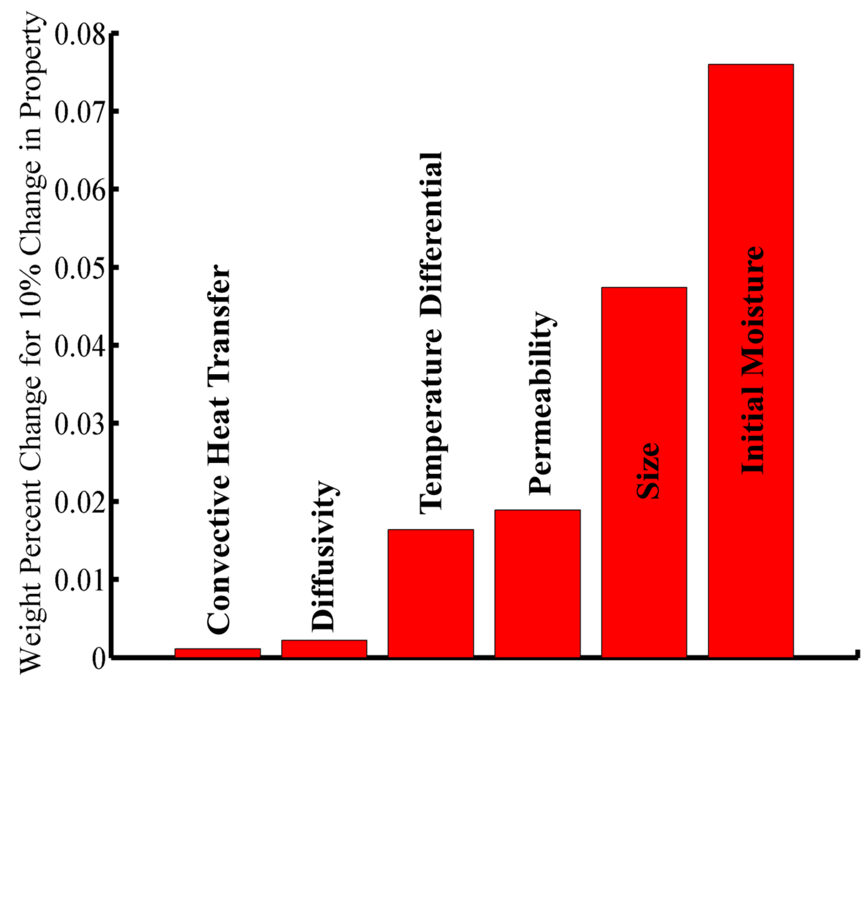

Figure 11. Effect of Each parameter on water absorption

Conclusions:

The temperature differential significantly affected change in weight but overall was very small compared to the weight of the tomato. The highest pressure gradient was near the stem scar. The temperature profile was primarily conduction driven. Initial moisture, produce size, permeability and temperature gradient all play important roles in dictating the amount of water absorbed. The rate of heating and diffusivity did not affect weight change significantly.

References:

- 1. Bartz, Jerry A., and R. K. Showalter. "Infiltration of tomatoes by aqueous bacterial suspensions." *Phytopathology* 71.5 (1981): 515-8.
- 2. 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.