Mechanistic Understanding of Food Microbiological Safety: Multiphase Transport Through a Leaf Stomate During Vacuum Cooling

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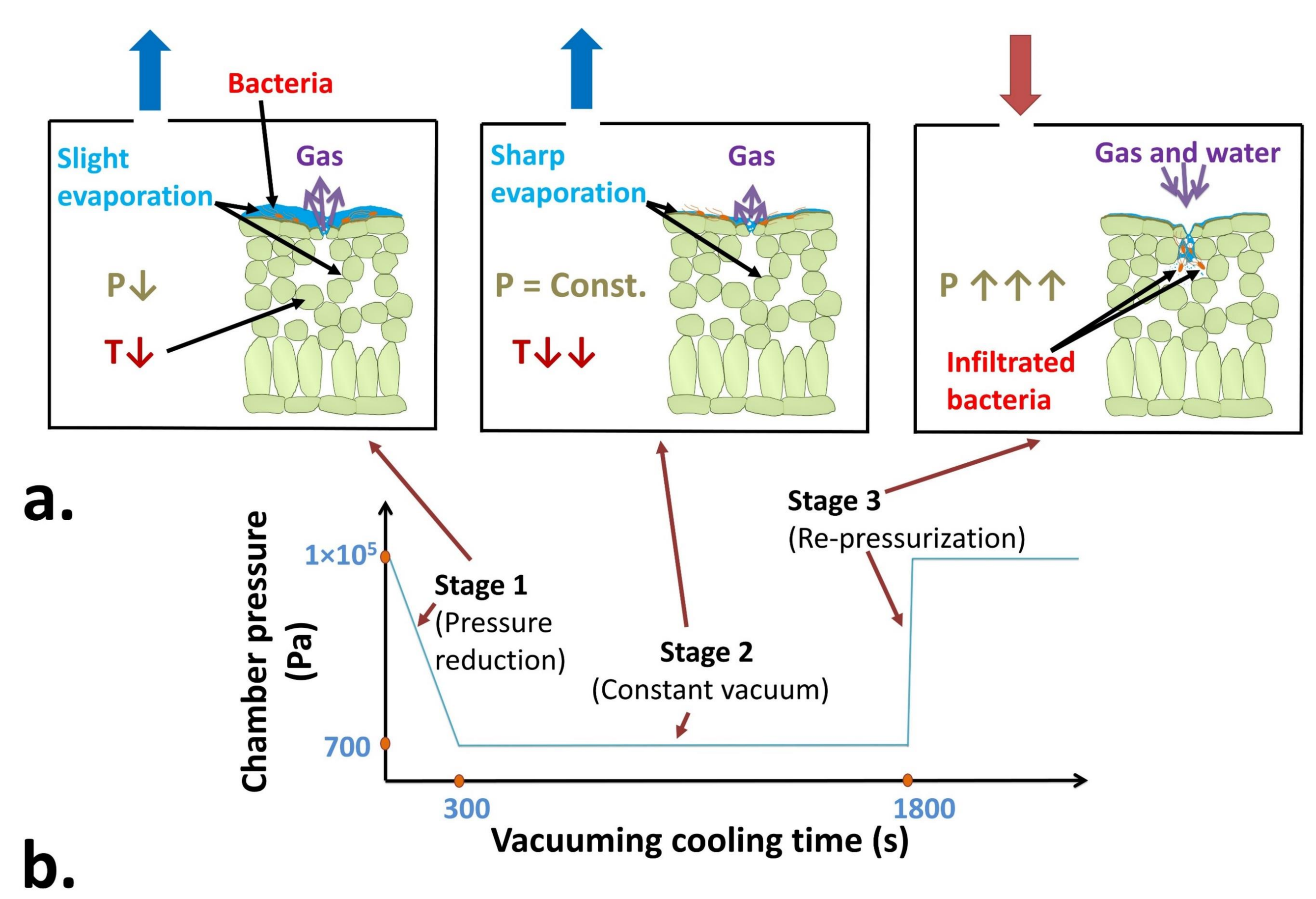
INTRODUCTION: Vacuum cooling is a common unit operation in the leafy greens industry and is considered as an efficient approach to extend shelf-life of the fresh produce. However, during this popular process, bacteria can infiltrate into the produce due to large pressure gradients created at re-pressurization stage.

Problem description



COMPUTATIONAL METHODS: We developed a mechanistic multiphase transport model to simulate passive infiltration of pathogenic bacteria (initially being in a liquid film at the leaf surface) into a spinach leaf through one stomate during the vacuum cooling process.

1. Transport of free water (*fw*) in the mesophyll

$$\frac{\partial}{\partial t}(\phi\rho_w S_{fw}) + \nabla.(u_w\phi\rho_w S_{fw}) = \nabla.(D_{w,cap}\nabla(\phi\rho_w S_{fw})) - \dot{I}_v + \dot{J}_{w,bf}$$

2. Transport of bound water (*bf*) in the mesophyll

$$\frac{\partial}{\partial t}(\phi\rho_w S_{bw}) = \nabla.(D_{w,w}\nabla(\phi\rho_w S_{bw})) - \dot{J}_{w,bf}$$

3. Transport of vapor (*v*) in the mesophyll

$$\frac{\partial}{\partial t}(\phi\rho_g S_g\omega_v) + \nabla.(u_g\phi\rho_g S_g\omega_v) = \nabla.(\phi S_g\frac{C_g^2}{\rho_g}M_a M_v D_{bin}\nabla x_v) + \dot{I}_v$$

4. Gas (*g*) pressure equation

$$\frac{\partial}{\partial t}(\phi\rho_g S_g) + \nabla.(-\rho_g\frac{k_g^m}{\eta_g}\nabla P) = \dot{I}_v$$

5. Transport of bacteria (*b*) in the mesophyll

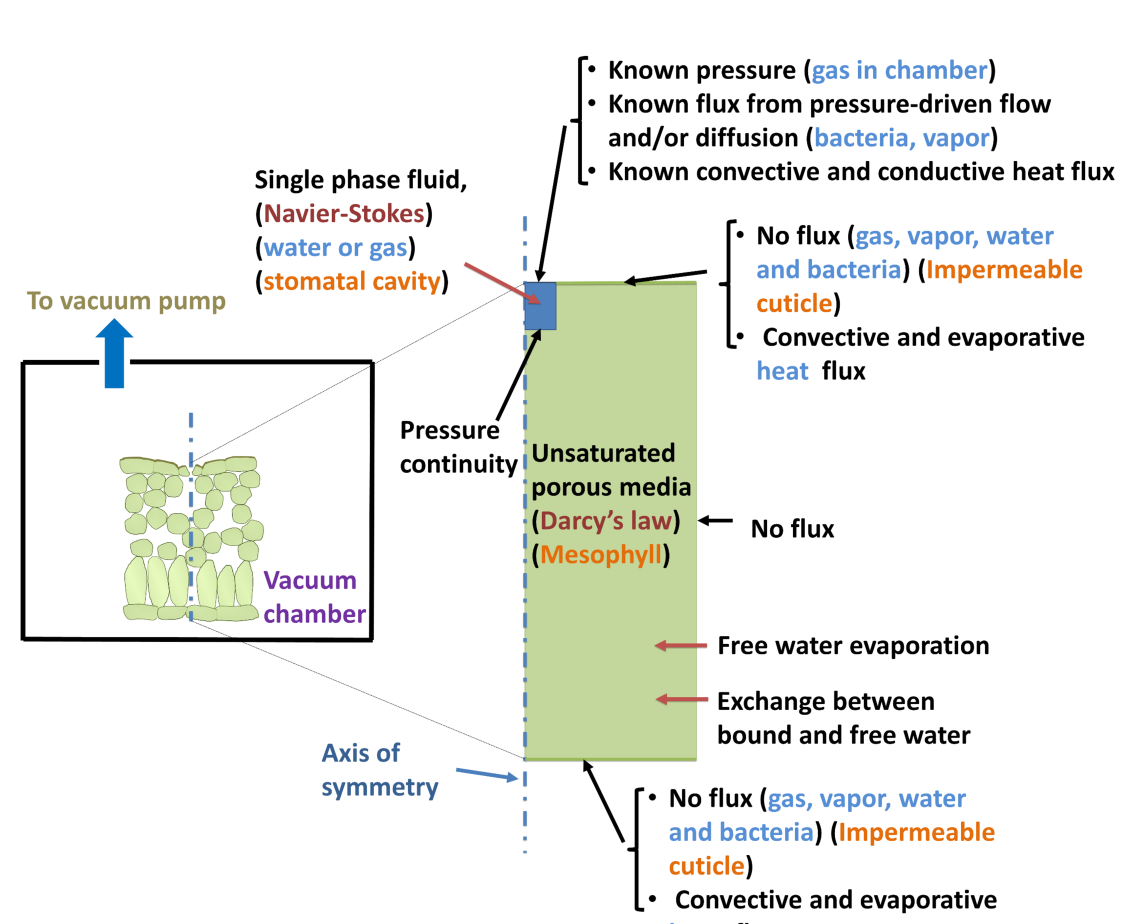
$$\frac{\partial(c_b\phi S_w)}{\partial t} + \nabla.(u_b c_b) = \nabla.(D_{eff,b,w}\nabla(c_b\phi S_w))$$

6. Heat transfer equation

$$\rho_{eff}C_{p_{eff}}\frac{\partial T}{\partial t} + (\rho C_p u)_{fluid}\nabla T = \nabla.(k_{eff}\nabla T) + h_v\dot{I}_v$$

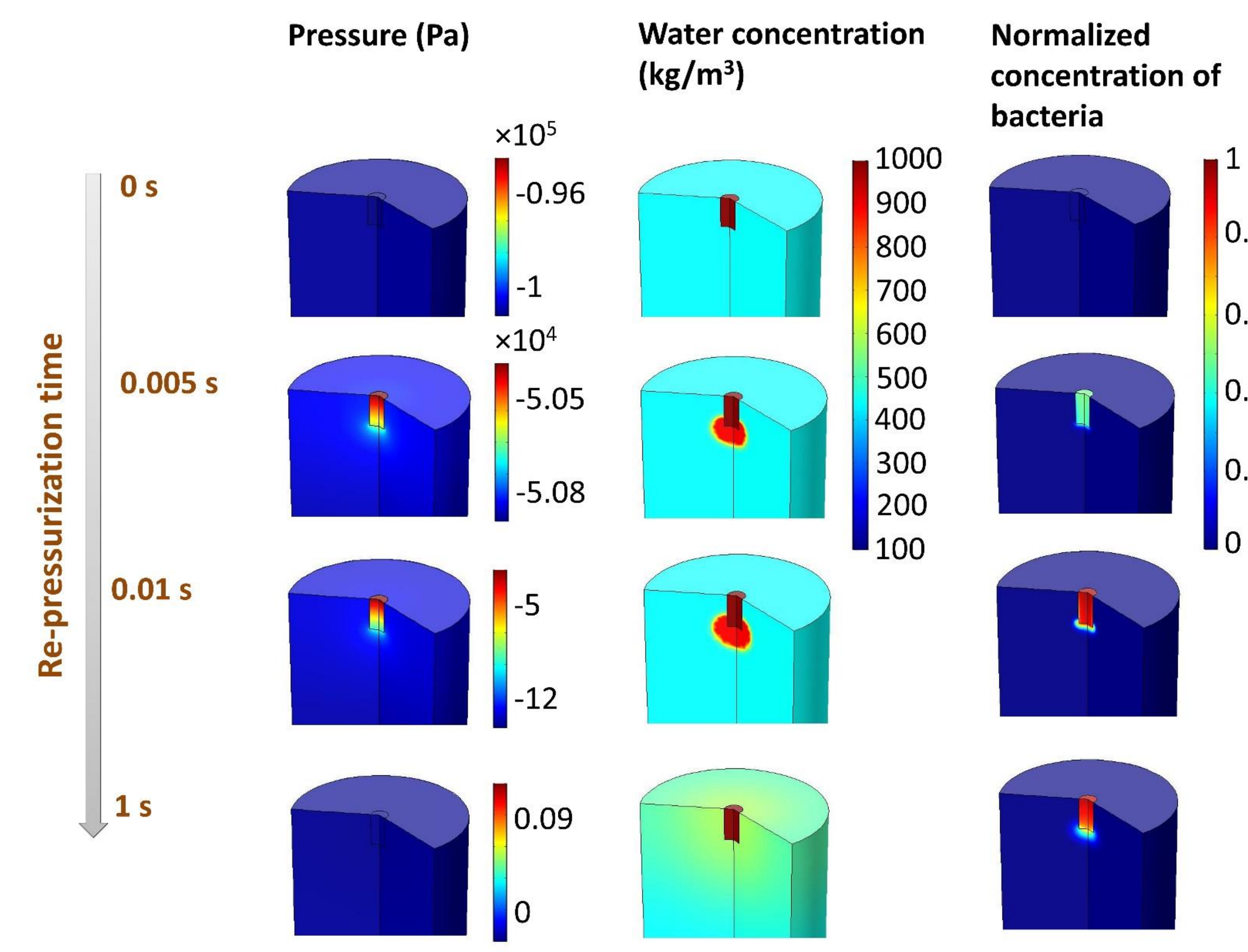
Variable	Description
c	Concentration (kg/m³)
C_p	Specific heat capacity (J/kg.K)
D	Diffusivity (m²/s)
h_v	Latent heat of vaporization of water (J/kg)
$\dot{I}_v$	Rate of evaporation of water (kg/m³.s)
$\dot{J}_{w,bf}$	Rate of water transfer from bound water to free water (kg/m³.s)
k	Thermal conductivity (W/m.K)
M	Molar mass (kg/mol)
P	Pressure (Pa)
S	Saturation (m³/m³)
t	Time (s)
T	Temperature (K)
u	Velocity (m/s)
x	Mole fraction
ϕ	Porosity (m³/m³)
ρ	Density (kg/m³)

Model schematic

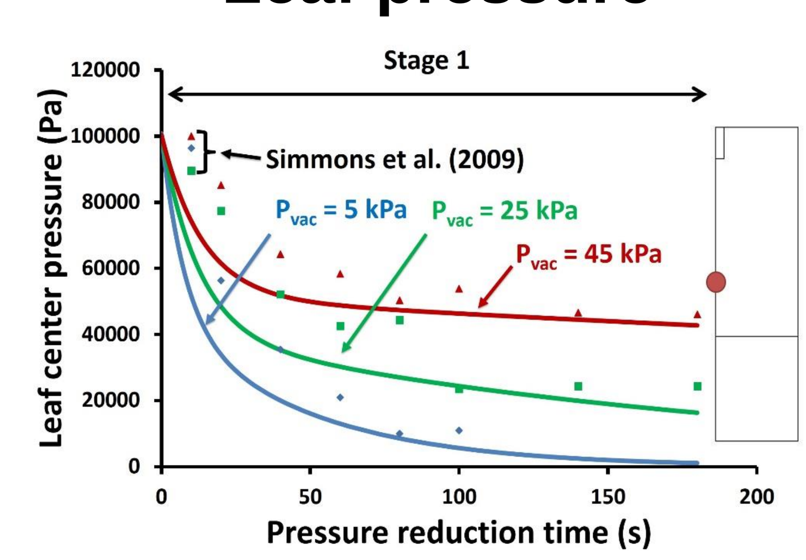


RESULTS:

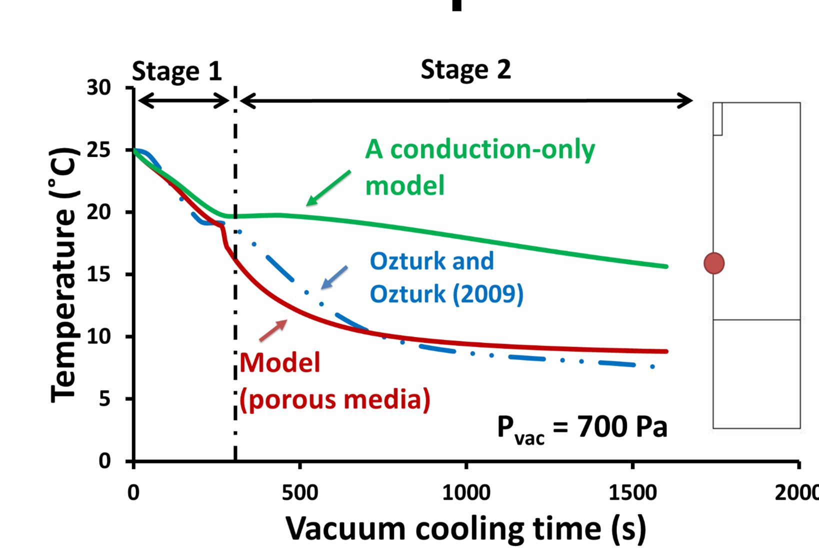
Water and bacteria infiltration during re-pressurization stage



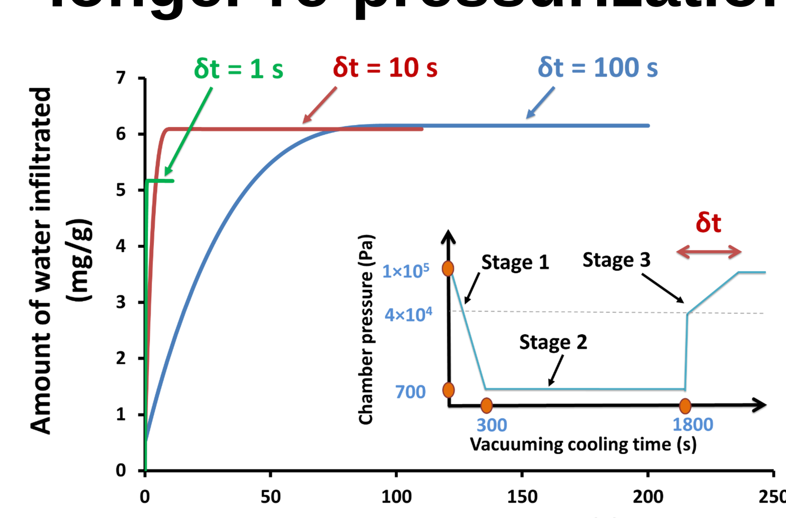
Leaf pressure



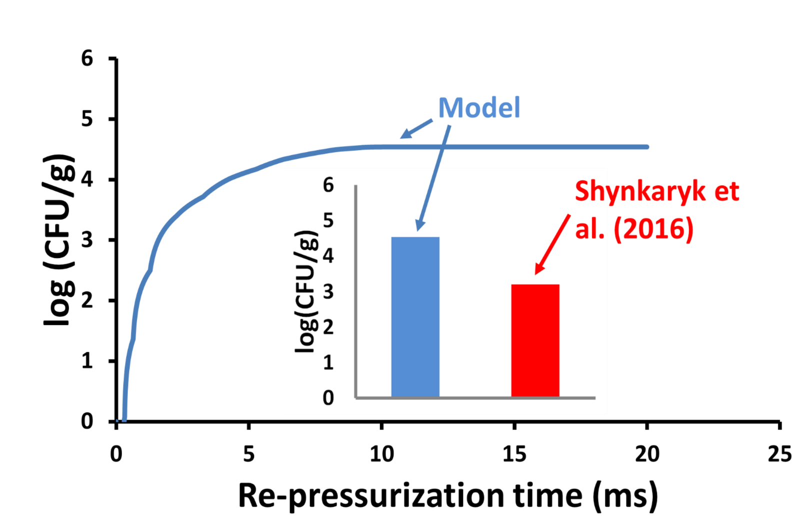
Leaf temperature



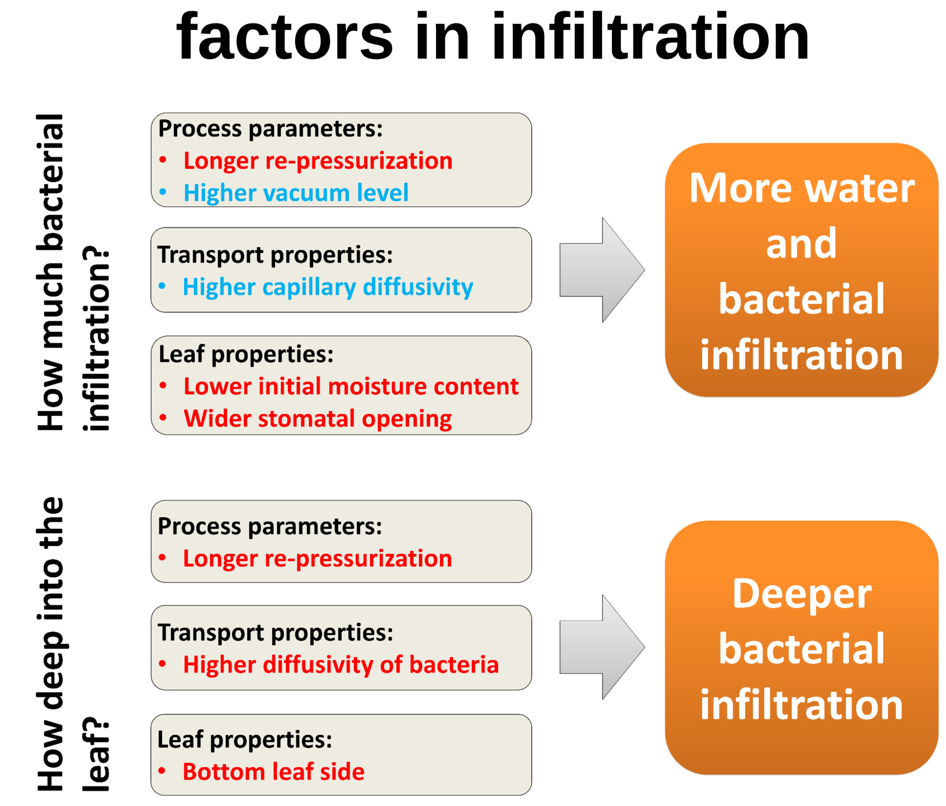
More water is infiltrated with longer re-pressurization



Bacterial infiltration



Primary (red) and secondary (blue) factors in infiltration



CONCLUSIONS: Vacuum cooling can lead to passive infiltration of bacteria through stomata due to pressure gradient as vacuum is released, i.e., the pressure is increased back to atmospheric.

REFERENCES:

Ozturk, H.M., Ozturk, H.K. 2009. International Journal of Refrigeration 32, 402-410. Shynkaryk, M.V. et al. 2016. Journal of Food Engineering 191, 10-18.

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