Mechanistic Modeling of Non-Spherical Bacterial Attachment on Plant Surface Structures

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Introduction:

How do plant surface microstructures affect contamination?

Bacterial attachment and internalization are the first steps in food contamination. We studied the transport, attachment and internalization of non-spherical bacteria on protrusions (e.g. trichomes) and openings (e.g. stomata, cuts and wounds) commonly occurring in fresh produce.

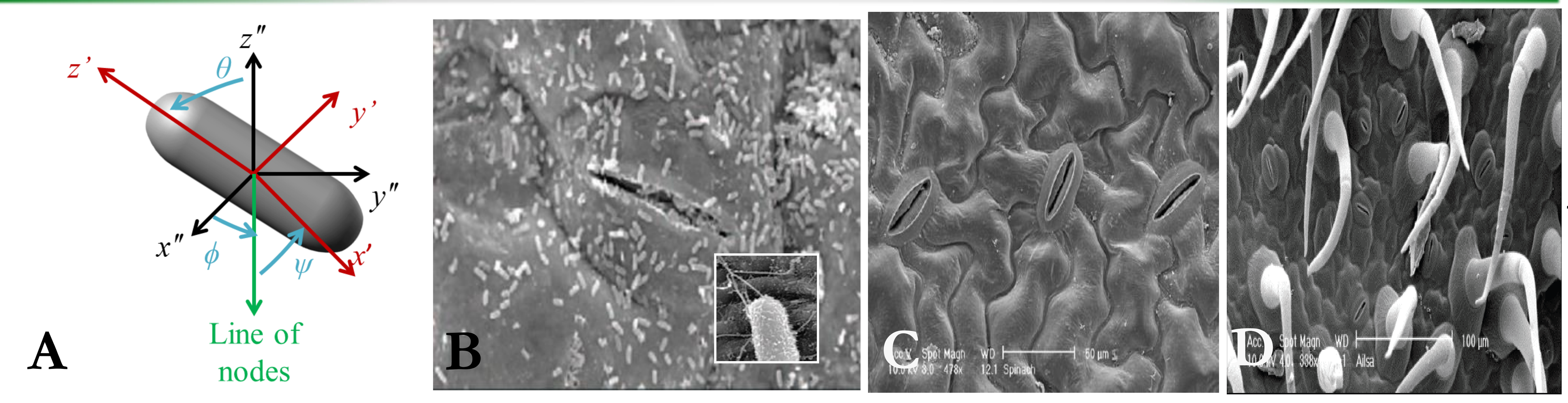


Figure 1. A) spherocylinder particle representation, B) *Escherichia coli* on spinach [1], C) SEM of stomata and grooves on spinach [2] & D) SEM of trichomes and stomata on a tomato leaf [2]

Computational Methods:

Translational Particle Motion

$$m_p \frac{d\vec{u}_p}{dt} = \vec{F}_{Trans} = f_{Drag}\vec{F}_{Drag} + \vec{F}_{Lift,AoI} + \vec{F}_{Lift,Saff} + \vec{F}_{Buoy} + \vec{F}_{PG} + \vec{F}_{VM} + \vec{F}_{wall} + \vec{F}_{Adh}$$

Rotational Particle Motion

$$\mathbf{I}\frac{d\vec{\omega}}{dt} = \mathbf{I}\vec{\omega} \times \vec{\omega} + \sum_{i \in h,r,p-p} \vec{\tau}_i$$

Particle-Wall Force

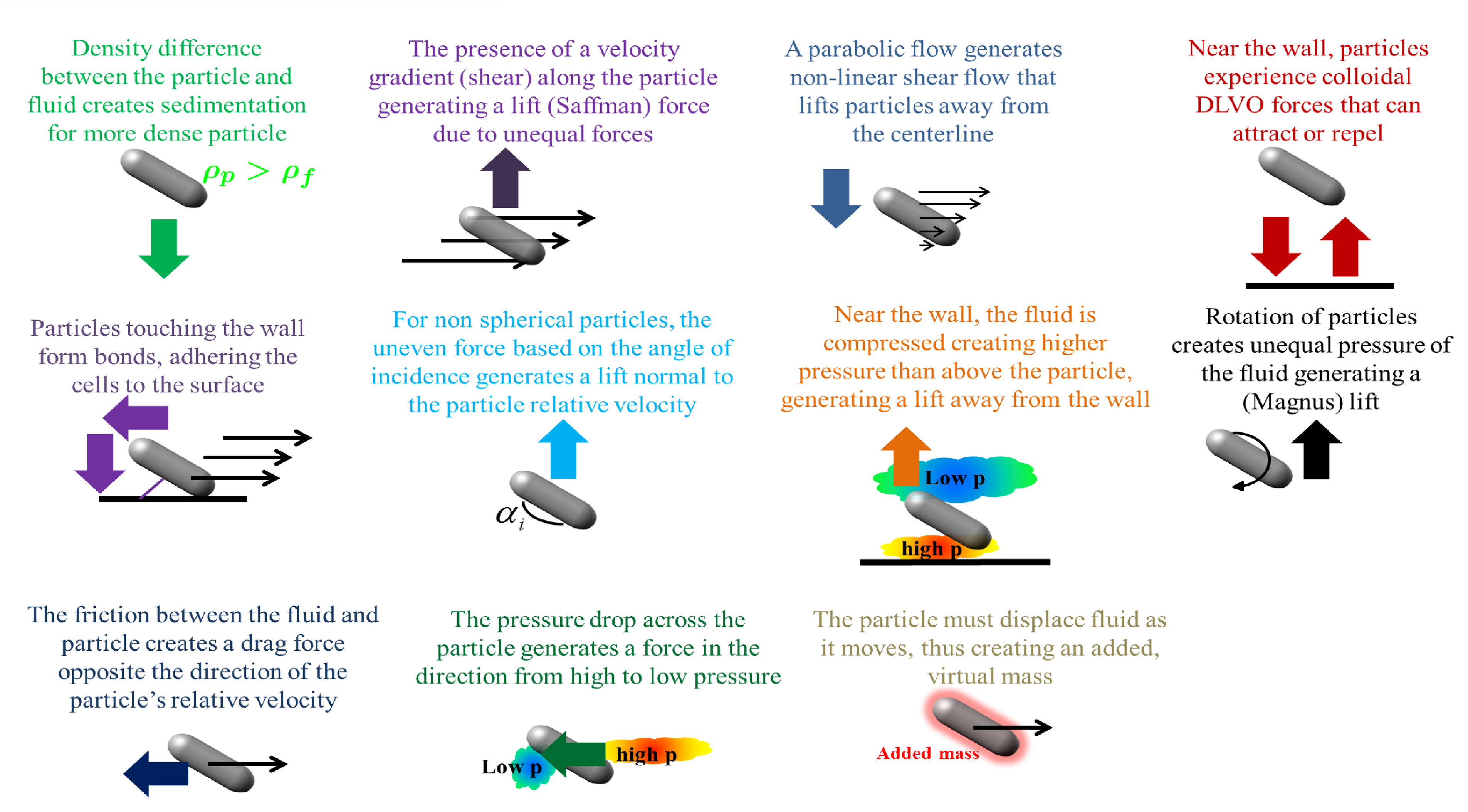
$$\vec{F}_{wall}\left(\delta_{min-w}\right) = F_{wall}^{EDL}\kappa e^{-\delta_{min-w}\kappa} - F_{wall}^{vdW}\delta_{min-w}^{-2}$$

Navier-Stokes Equation

$$\rho_f \frac{\partial \vec{u}_f}{\partial t} + \rho_f(\vec{u}_f \cdot \nabla)\vec{u}_f = \nabla \cdot \left[-p\vec{I} + \mu_f(\nabla\vec{u}_f + (\nabla\vec{u}_f)^T)\right] + \vec{F}_{f-p}$$

Eikonal Equation (Wall distance)

$$\nabla\hat{\delta} \cdot \nabla\hat{\delta} + \sigma\hat{\delta}\nabla \cdot \nabla\hat{\delta} = (1 + 2\sigma)\hat{\delta}^4$$



Rotation Results:

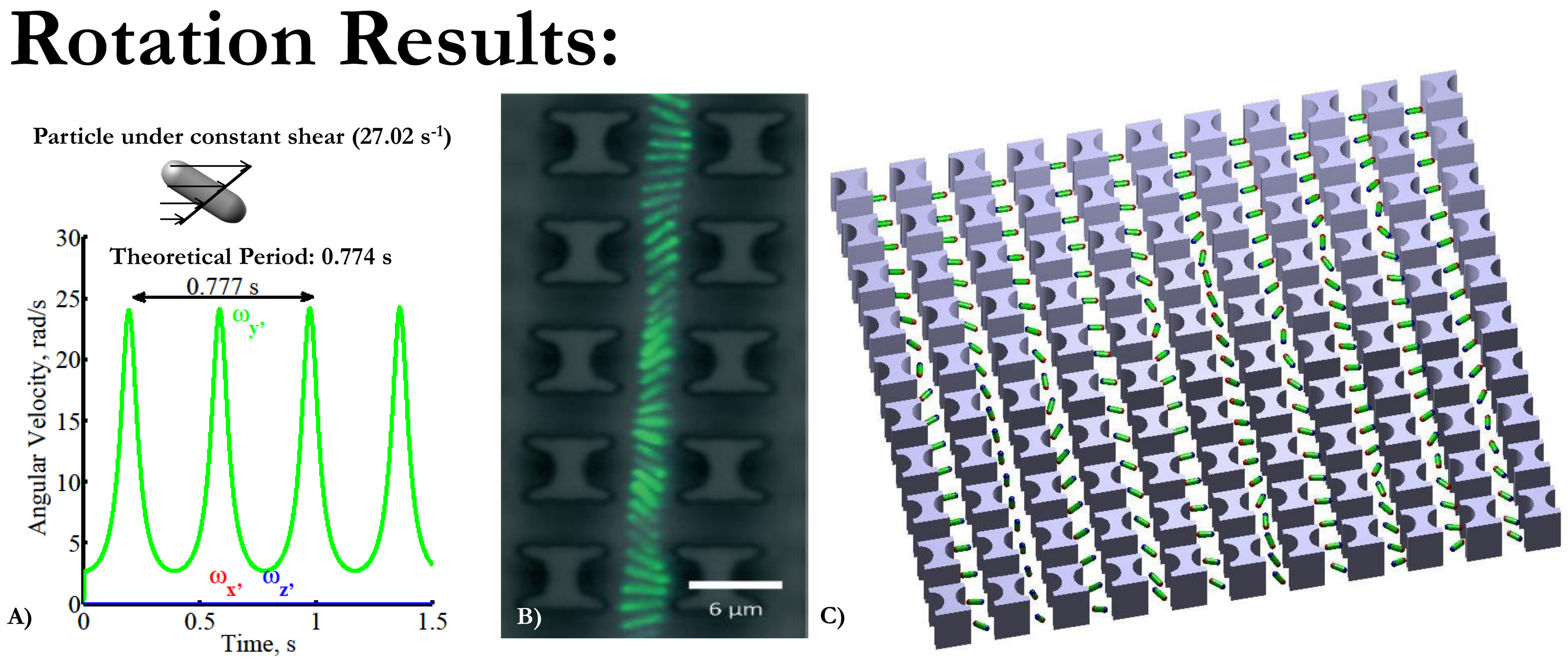


Figure 2. A) Validation at constant shear rate, B) Fluorescent cell in microfluidic device [3] and C) model simulation of 10 cells with small perturbations of initial position

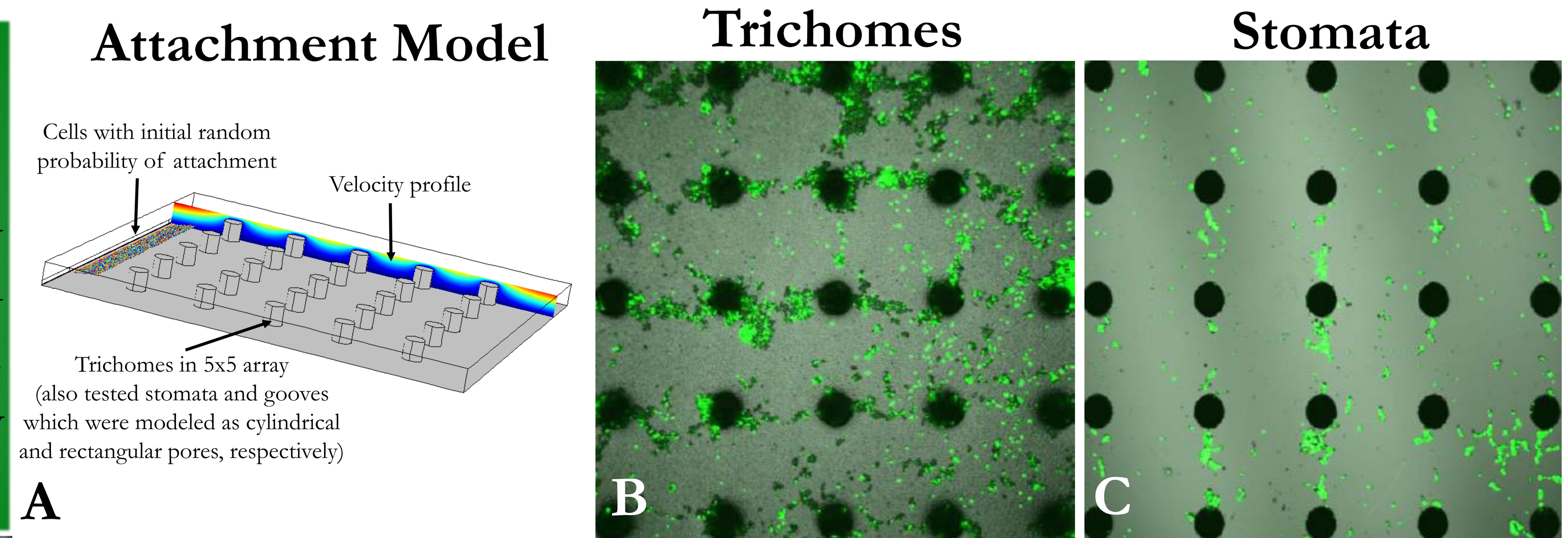


Figure 3. A) Computational model and typical raw images obtained from CSLM of fluorescent *Escherichia coli* attached to trichomes [2] (B) and stomata [2] (C)

Attachment Results:

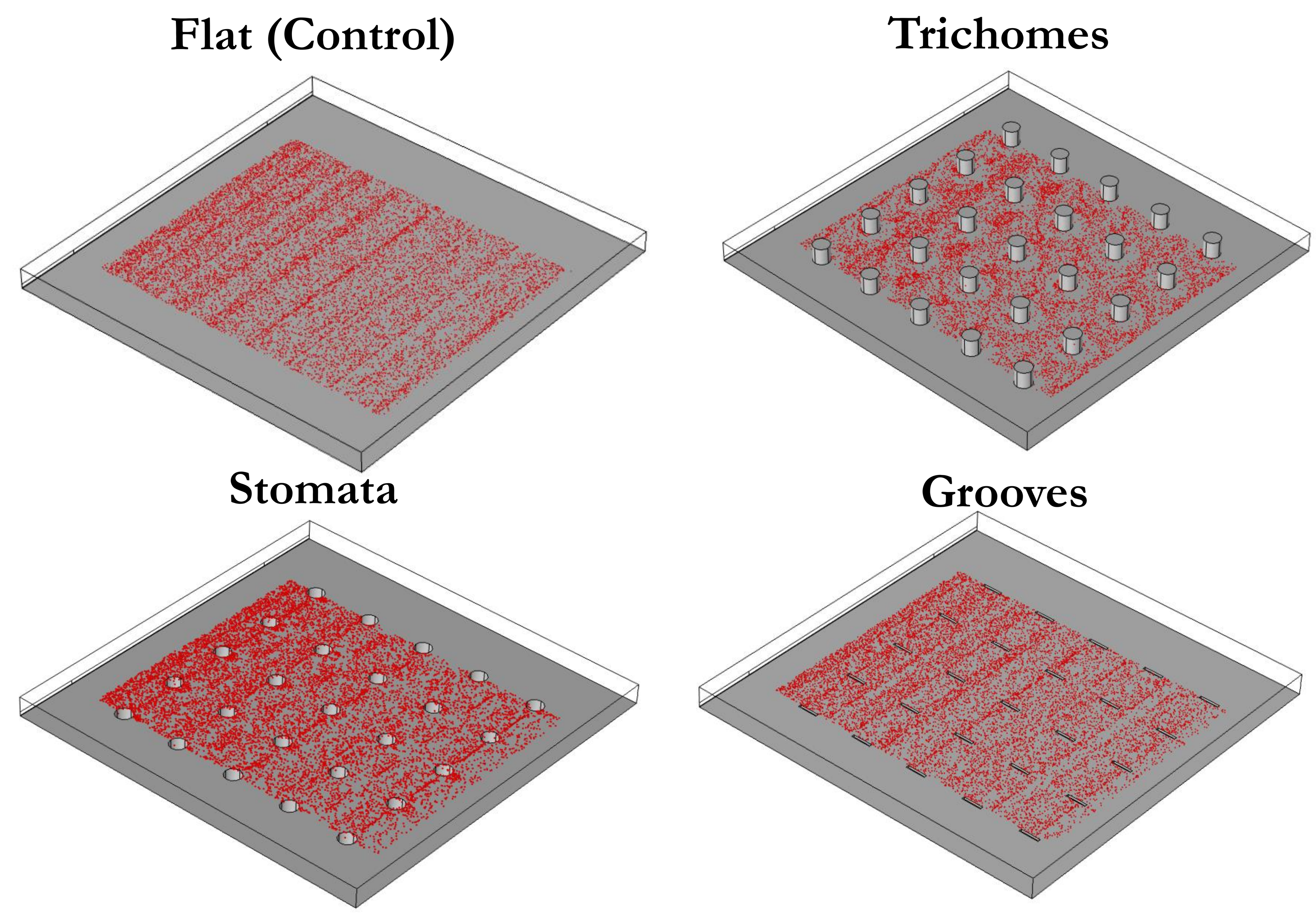


Figure 4. Example simulation results for four model situations

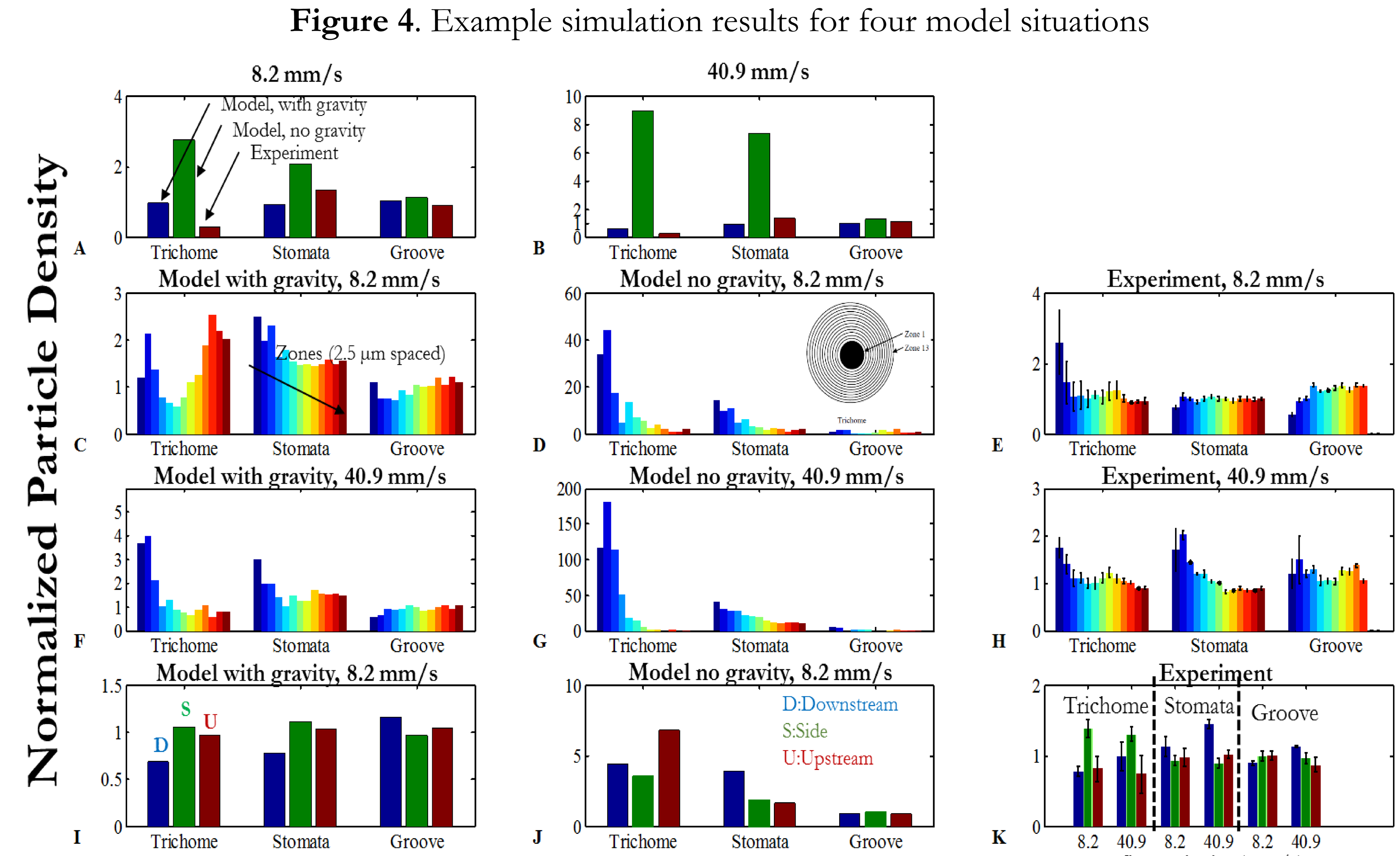


Figure 5: A-B) Total normalized particle density based on flow rate, C-E), Normalized particle density based on distance from structure (zones are radially 2.5μm from structure) at 8.2 mm/s, F-H) Normalized particle density based on distance from structure at 40.9 mm/s, I-K) Normalized particle density radially from the structure (upstream, downstream, or on the side in equal area regions).

Conclusions:

The particle tracking model provided a deeper understanding to the experimental results. Protrusions create low velocity, low shear regions increasing attachment while holes pull cells downward and increasing residence time on the surface increasing attachment

References:

1. Xicohtencatl-Cortes, J., et. Al (2009). Interaction of Escherichia coli O157: H7 with leafy green produce. Journal of Food Protection®, 72(7), 1531-1537.Sirun
2. Sirinutsomboon, B., et al.(2011). Attachment of Escherichia coli on plant surface structures built by microfabrication.*Biosystems engineering*, *108*(3), 244-252.
3. Ranjan, S., et al.(2014). DLD pillar shape design for efficient separation of spherical and non-spherical bioparticles. *Lab on a Chip*, *14*(21), 4250-4262.

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