

Fruits under Stress: How Cucumbers Tailor Chemistry and Macromolecular Architecture to Maintain Surface Barriers

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Plant surfaces are macromolecular composites that are organized to optimize barrier performance and integrity. Our overall goal is to understand how the outer coverings of edible fruits maintain protective functions that include regulation of water transport and prevention of pathogen ingress, despite challenges from mechanical stress, environmental extremes, or impaired epidermal development. Taking the cucumber as a model organism, a series of complementary investigative approaches are being used to contrast the cutin-dominated cuticle of the common cucumber with the suberized or lignin-like periderm of the Sikkim cucumber variety. Multi-scale microscopy and histochemistry demonstrate a developmental shift from a smooth epidermis to a multilayered phellem characterized by distinct suberin lamellae and lignin-like deposition. GC-MS profiling reveals that periderm formation involves a shift from C₁₆/C₁₈ hydroxyfatty acid cutin monomers toward very-long-chain aliphatics (>C₂₀ fatty acids, alcohols, hydroxyacids), and phenolics (ferulic acid, hydroxybenzoic acids, and lignin-like *p*-hydroxyphenyl, guaiacyl and syringyl chemical moieties). Solid-state ¹³C nuclear magnetic resonance spectroscopy confirms an increase in oxygenated and phenolic-rich biopolymer assemblies, suggesting a macromolecular architecture with augmented cross-link density and compatible with a significantly elevated glass transition temperature measured by differential scanning calorimetry. Moreover, atomic force microscopy of the peridermal surfaces reveals major enhancements in stiffness, adhesion, and elastic resistance to

deformation for the Sikkum cucumber fruits. These findings identify key chemical and architectural attributes that make the cucumber fruit periderm a mechanically robust, thermally stable composite and also establish this material as a candidate for sustainable biopolymer design.

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