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The mechanics of plant root growth

Many growing plant cells undergo rapid axial elongation with negligible radial expansion. Growth is driven by high internal turgor pressure causing viscous stretching of the cell wall, a complex structure containing stiff cellulose microfibrils, embedded within a pectin ground matrix and linked through a network of hemicellulose crosslinks. This microstructure produces non-linear anisotropic mechanical behaviour, and can be manipulated under enzymatic control to alter the cell growth rate. We first present a theoretical model of a growing cell, representing the primary cell wall as a thin axisymmetric fibre-reinforced viscous sheet supported between rigid end plates. Asymptotic reduction of the governing equations, under simple sets of assumptions about the fibre and wall properties, yields variants of the traditional Lockhart equation, which relates the axial cell growth rate to the internal pressure. The model provides insights into the geometric and biomechanical parameters underlying bulk quantities such as wall extensibility and shows how either dynamical changes in wall material properties or passive fibre reorientation may suppress cell elongation. We then investigate how the action of enzymes on the cell wall microstructure can lead to the required dynamic changes in macroscale wall material properties, and thus demonstrate a mechanism by which hormones may regulate plant growth. Using knowledge gained from the single cell model, we consider a mathematical model of hemicellulose crosslink dynamics incorporating both strain-enhanced breakage and enzyme-mediated breakage and reformation. The relationship between stress and strain-rate is shown to exhibit the characteristic yielding-type behaviour seen experimentally. The model shows how this stress strain-rate relationship is modified in the presence of enzymes and predicts the distribution of crosslinks and stress within the cell wall.