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Microstructure-based multiscale prediction of pruning cutter wedge angle for jujube branches

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A B S T R A C T

The biomechanical properties of jujube branches constitute fundamental parameters for evaluating cutting performance of pruning machinery and optimizing the wedge angle of cutting tools. To investigate how microstructural heterogeneity across different branch regions influences cutting behavior, we integrated X-ray CT imaging with nanoindentation testing. Representative volume elements (RVEs) were constructed from experimentally resolved microstructures to enable multiscale finite element modeling of the pruning process, thereby revealing microscale mechanisms governing cutting resistance. Microstructural characteristics—including porosity, cell wall thickness, and water content—were quantified across five positions along the branch, and their effects on the homogenized (equivalent) shear modulus were systematically evaluated. Results show that both increasing porosity and elevated water content significantly reduce the equivalent shear modulus, with porosity exhibiting a markedly stronger attenuating effect. Crucially, the recommended wedge angle is governed primarily by the ratio of longitudinal-to-transverse shear modulus; based on mechanical sensitivity analysis, the recommended design angle is $\alpha = 21.75°$. This study provides a biomechanical basis for the rational design and performance optimization of specialized pruning tools for jujube trees.

A R T I C L E I N F O

Keywords:
Jujube branch;
Nanoindentation;
X-ray computed tomography;
Representative volume element;
Multiscale finite element analysis;
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