Structural Characterization of Poplar Variants Provides New Insights into Plant Cell Wall Recalcitrance

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Project Goals: To realize the potential of lignocellulosic biomass to play a major role in generation of renewable biofuels, key limitations in biomass pretreatment and microbial fermentation need to be addressed. For both processing steps, presence of nonaqueous co-solvents can disrupt key biological structures. In the case of biomass, this disruption is desirable, as it facilitates the solubilization and fractionation of lignocellulosic polymers for subsequent cellulosic conversion and lignin valorization. In contrast, the solvents can inhibit fermentation by disruption of microbial cell membranes. The Scientific Focus Area in Biofuels is developing "Visualization of Solvent Disruption of Biomass and Biomembrane Structures in the Production of Advanced Biofuels and Bioproducts" for multiple-length scale, real-time imaging during processing with non-aqueous co-solvents to provide the fundamental information that is needed to improve conversion of renewable lignocellulosic biomass to biofuels.

Poplar is a fast-growing hardwood but field-grown poplars vary significantly in cell wall properties that affects efficiency of biomass conversion technologies[1]. Understanding the structural differences that impact biomass recalcitrance is crucial to valorize this important bioenergy source. A genome wide association study identified two naturally occurring poplars, BESC-316 and GW-11012, that had 22% and 18% reduced klason lignin content and syringyl/guaiacyl ratio of 2.58 and 3.13, respectively. The lower lignin content genotype showed greater sugar release before and after hot water pretreatment compared to the higher lignin counterpart[2]. Atomic force microscopy using PeakForce quantitative nanomechanical property mapping found that modulus of elasticity was significantly higher in secondary cell walls than the compound middle lamella in both variants. Lignin content in these poplars did not affect modulus of elasticity, dissipation and deformation forces of cell walls. Transmission electron microscopy revealed that for the same type of anatomical cells, lignin distribution varies significantly in poplar variants. Moreover, lower syringyl/guaiacyl ratio of high lignin variant agreed with the assertion that lower S/G ratio in poplar can negatively affect sugar yield. The structural properties of BESC-316 and GW-11012 were studied using small-angle neutron scattering (SANS) and wide-angle X-ray scattering (WAXS) before and after hot water pretreatment. Cellulose microfibril arrangement in GW-11012 is consistent with aggregated microfibrils and differed significantly from the well-ordered cellulose microfibrils in BESC-316 before pretreatment. Post-pretreatment, little change was seen in cellulose arrangement for GW-11012 whereas BESC-316 showed aggregation of microfibrils. After pretreatment, both genotypes have very similar scattering patterns indicating that the structural changes that occurred in the cell walls were similar. Cellulose accessibility measured using the modified Simons' stain before and after pretreatment was similar for GW-11012 and BESC-316. Our data suggest that lignin distribution and cellulose organization both play an important role in lowering lignocellulose recalcitrance. Through the application of recently developed AFM PeakForce quantitative nanomechanical property mapping and first use of SANS for comparing field-grown poplar variants, this study presents new advancements in understanding cell wall recalcitrance of poplar.

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References

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