Factors Underlying a Latitudinal Gradient in the S/G Lignin Monomer Ratio in Natural Poplar Variants

Background/Objective

- Lignin is a phenolic polymer in plant cell walls that provides mechanical support and facilitates water and nutrient transport through the vascular system. While lignin composition is known to change in response to environmental factors, its natural variation and adaptive significance remain poorly understood.

Approach

This study assessed a latitudinal gradient in plant lignin monomer composition using:

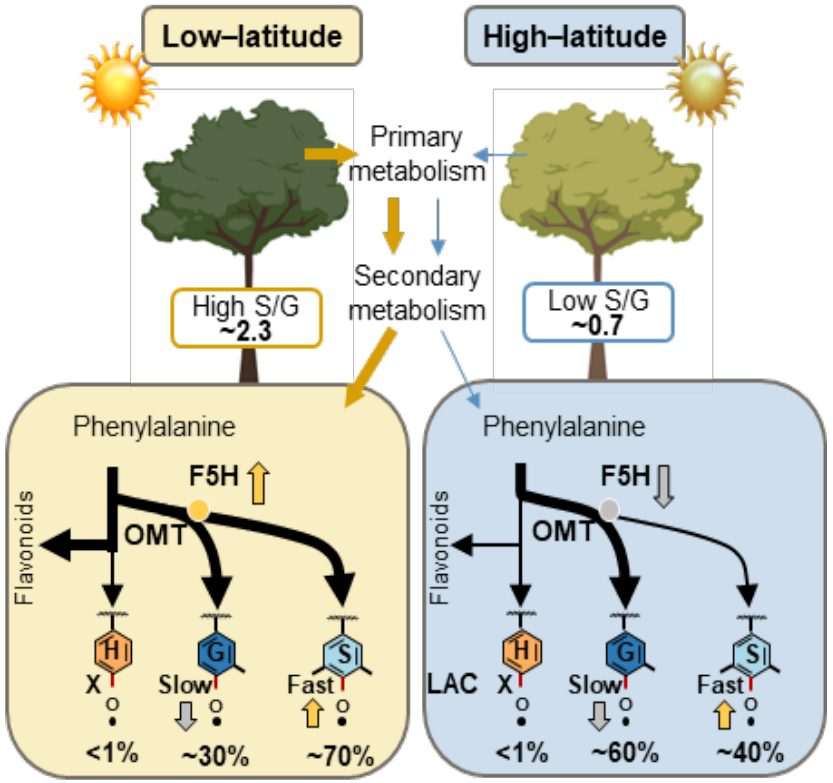
- Genome Wide Association Study (GWAS) to identify genes linked to lignin formation
- Enzyme specificity studies to determine substrate preference
- Geographic analyses to explore the molecular factors underlying the latitudinal distribution of lignin
- Transcriptome and metabolome analysis to uncover the regulatory mechanisms of lignin composition

Results

- Genomic data revealed many significant associations, suggesting that lignin biosynthesis is a complex polygenic trait.
- An increase in the S/G ratio from northern to southern geographic origin of the trees sampled was discovered, along with a corresponding metabolic and transcriptional reprogramming of xylem cell wall biosynthesis.
- A mutation in a cell wall laccase is genetically associated with higher S/G ratios that predominate in trees from warmer lower latitudes.

Significance/Impacts

- Our results suggest the ecological function of lignin differs across latitudes and is partially conferred by cell wall laccases. Gaining a deeper understanding of this lignin-based adaptability could be applied to predict how forests will respond to future changes in climate towards developing more sustainable forestry practices.



Line thickness represents metabolic flux in the lignin pathway. Ferulate 5-hydroxylase (F5H) is upregulated in high S/G trees and downregulated in low S/G trees. O-methyltransferases (OMTs) were the most highly expressed lignin genes in young xylem samples. LAC, laccase-mediated monolignol oxidation reactions. Warmer temperatures at lower latitudes may drive an enhanced metabolic flux from primary to secondary metabolism. The differential expression levels and regulation of key lignin biosynthetic genes, particularly OMTs and F5Hs, come into play to favor G- or S-monolignol formation. Additionally, the rate and substrate specificity of laccases determine the incorporation of available monomers into the lignin polymer, thus influencing the final S/G lignin monomer ratio.

Zhu W. et al. *Proc Natl Acad Sci U S A.* (2025),. doi: 10.1073/pnas.2503491122