Screening Elite Loblolly Pine Families for Structural Integrity with Near Infrared-Based Chemometric Models

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Background

Pinus taeda (Loblolly Pine) : Introduction

- Native to 14 States
- Dominates on 13.4 million ha of southeastern forests
- Accounts for over 50% of the standing pine volume
- Most economically important tree species in the USA
- Supplies 18% of the world's industrial round wood
- Provides 110,000 direct and indirect jobs
- Contributes $30 billion to the economy

http://www.plantmaps.com/nrm/pinus-taeda-loblolly-pine-native-range-map.php

Rationale

Estimate an array of traits from one chemistry-sensitive measurement




Apply Models to 14 Pine Families

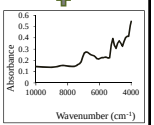
Chemical Applications
Structural Integrity
Bioenergy Potential

Chemometric models

Cellulose
Lignin
Extractives
Hemicelluloses

Density
Strength
Stiffness

Energy
Volatiles
Carbon
Ash



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Screening Loblolly Pine Families for Structural Applications

Objectives

- Develop NIR-based partial least squares (PLS) regression models to rapidly predict the density, modulus of elasticity and modulus of rupture of loblolly pine families
- Screen out loblolly pine families based on the above properties

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Material and Methods

Materials

Whole loblolly pine trees

- 15 loblolly families - two trees each
- Two forest sites - Yulee Florida, Nahunta, Georgia – one family each
- 14 year old trees
- DBH range – 11.5 cm to 23.4 cm
- Mean DBH – 17.4 cm
- Cross cut trees into 1.5 m lengths
- 50 cm bolts for experiments
- Sampling representative of butt, mid and top sections of trees

2 x 4 southern pines boards

- West Fraser Inc. Opelika, Alabama

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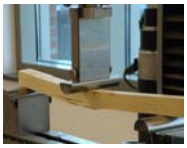
Material and Methods

Methods: Mechanical testing

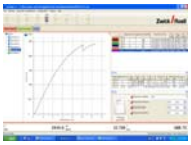
Static (Three-point) bending (ASTM D143)

- Test specimen dimensions: 2.5 x 2..5 x 41 cm
- Storage conditions: 22.5 °C and 55% RH
- Average MC at time of testing: 9%
- Test face: Tangential
- Span: 36 cm
- Test speed: 1.3 mm / min



Zwick-Roell Testing Machine loaded with sample

- Basic density :- Ratio of mass to volume
- Modulus of elasticity (MOE) / Stiffness :– Ratio of stress to strain
- Modulus of rupture (MOR) / Ultimate strength :– Maximum load carrying capacity



Zwick-Roell Testing Machine data output

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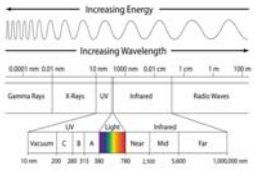
Material and Methods

Methods: Infrared spectroscopy



Infrared in the electromagnetic spectrum
http://www.cyberphysics.co.uk/topics/light/emspect.htm

- Underlying Principle: Measures the wavelength and intensities of the absorption and transmittance of infrared light by a sample

PerkinElmer Spectrum Model 400 NIR spectrometer

- Spectra collected from 10000 – 4000 cm^{-1}
- Scanned thirty-two times at a resolution of 4 cm^{-1}
- Averaged into one spectrum for analysis

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Material and Methods

Methods: Model development and evaluation

Calibration and Cross-validation of PLS Models (n = 190)

- Perkin Elmer Spectrum Quant+ software
- First derivatives of NIR spectra as X - variables and conventional lab results as Y - variables

External Validation (n = 70)

- Independent test set

Performance Evaluation

- SECV – Standard error of cross validation
- SEP – Standard error of prediction
- RPD – Ratio of performance to deviation
- LVs – Latent variables (Factors) used to develop models
- R^2 – Coefficient of determination

Prediction (n = 351)

Increment cores from 351 live trees representing 14 loblolly pine families planted on two sites

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Results

Conventional lab results used for model development

	Property	Mean	SD	Min	Max
Total set n = 260	MOE (MPa)	8848	2909	2380	17300
	MOR (MPa)	82	25	25	148
	Density (g/cm³)	0.52	0.09	0.37	0.79
Training set n = 190	MOE (MPa)	8923	2534	2380	15100
	MOR (MPa)	82	21	26	132
	Density (g/cm³)	0.52	0.08	0.37	0.75
Test set n = 70	MOE (MPa)	8643	3759	2540	17300
	MOR (MPa)	81	33	25	148
	Density (g/cm³)	0.55	0.12	0.39	0.79
Loblolly pine families n = 180	MOE (MPa)	8433	3128	2380	17300
	MOR (MPa)	82	28	35	148
	Density (g/cm³)	0.54	0.09	0.37	0.79
Commercial lumber n = 80	MOE (MPa)	9782	2084	5780	14300
	MOR (MPa)	81	15	41	112
	Density (g/cm³)	0.49	0.06	0.39	0.63

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Results

Fit statistics of PLS regression models using 1st-derivative treated NIR spectra

	Density (g/cm³)	MOR (MPa)	MOE (MPa)
Number of LVs	3	4	4
SEC	0.036	9.59	1100
SECV	0.042	11.33	1267
R^2_{cv}	0.7	0.71	0.75
RPD_{cv}	1.81	1.87	2
SEP_{iv}	0.065	19.4	2011
R^2_{iv}	0.19	0.41	0.45

* Subscript cv means cross-validation; iv means independent validation

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Results

Prediction and screening of families: Density

- Mean densities of the families ranged from a low of 0.37 g/cm³ (SD = 0.02) to a high of 0.50 g/cm³ (SD = 0.07)
- Mean densities of the juvenile loblolly pine families were comparable to density reported for older loblolly pine trees
- *P-values* of Two-way ANOVA (α = 0.05) testing the effect of family, site and family x site interaction

Property	Family	Site	Family x Site
Density	< 0.0001	0.0294	0.0055

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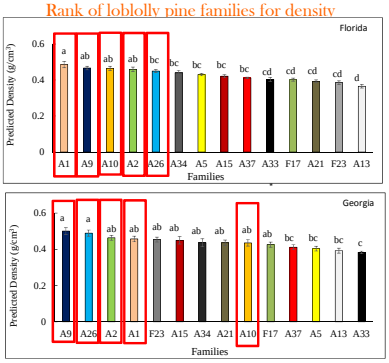
Results

Rank of loblolly pine families for density



High density
A9, A1, A2, A26

* Bars with different letters are significantly different at 95% confidence level (Tukey's HSD Test)

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Results

Prediction and screening of families: MOR

- The range of predicted MOR values were from 34 MPa to 150 MPa
- Mean MOR of the pine families were comparable to reported MOR of older loblolly pine trees
- *P-values* of Two-way ANOVA testing the effect of family, site and family x site interaction

Property	Family	Site	Family x Site
MOR	< 0.0001	0.3747	0.0005

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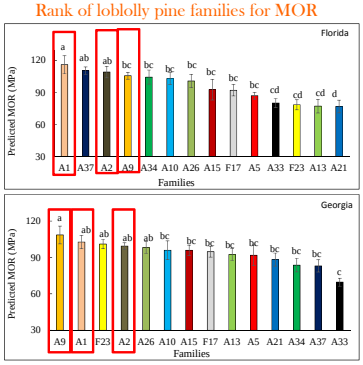
Results

Rank of loblolly pine families for MOR



High MOR
A1, A2, A9, A26

* Bars with different letters are significantly different at 95% confidence level (Tukey's HSD Test)

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Results

Prediction and screening of families: MOE

- The range of predicted MOE values were from 2981 MPa to 15830 MPa
- *P-values* of Two-way ANOVA testing the effect of family, site and family x site interaction

Property	Family	Site	Family x Site
MOE	<0.0001	0.5625	0.5198

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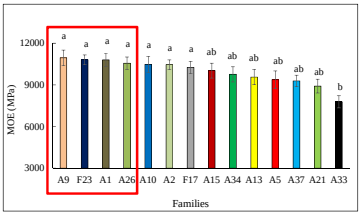
Results

Rank of loblolly pine families for MOE



High MOE
A9, F23, A1, A26

* Bars with different letters are significantly different at 95% confidence level (Tukey's HSD Test)

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Results

Validation of NIR-predicted MOE using Acoustics-estimated MOE

- $MOE_{AC} = V^2\rho$
  - Where:
  - MOE_{AC} Acoustics-estimated MOE
  - V - Tree velocity
  - ρ - density
- Tree velocity computed as the ratio of the distance (m) between two probes (in m) and the time (s) it takes the stress wave to travel from the transmitter to the receiver
- One-way ANOVA comparing NIR-MOE and Acoustics-MOE had *p-value* of 0.45

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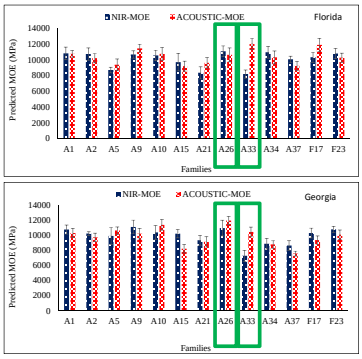
Results

Validation of NIR-predicted MOE using Acoustics-predicted MOE



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Results

	MOR			MOE			Log velocity		
	Coefficient	SE	R^2	Coefficient	SE	R^2	Coefficient	SE	R^2
Model 2	74.47***	2.06	54.4	7.97***	0.29	56.4	4.44***	0.05	60.04
Cellulose	6.94**	2.29		1.44***	0.32		0.30***	0.06	
Hemicellulose	8.29**	2.38		1.37***	0.34		0.19**	0.06	
Lignin	-1.06^{ns}	2.23		-0.12^{ns}	0.31		-0.06^{ns}	0.06	
Disk density	9.99***	2.13		1.15***	0.31		0.20**	0.06	
MFA	-1.06^{ns}	2.21		-0.07^{ns}	0.30		0.07^{ns}	0.05	

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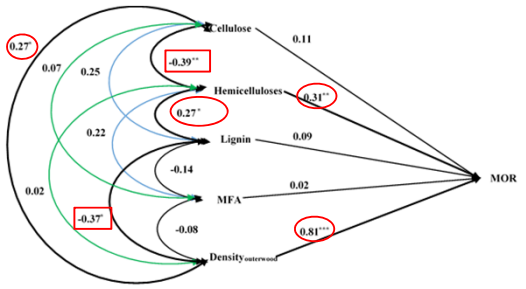
Results



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Conclusions

- NIR-based partial least squares (PLS) regression models developed to rapidly predict the density, modulus of elasticity and modulus of rupture of loblolly pine families
- Families A1, A9 and A26 performed well on both sites and the properties studied
- NIR-MOE and acoustic MOE are statistically similar

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Thank you!

Questions?