Wood Chemistry, Stiffness, and Disease Resistance

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My Background

Education:

LOUISIANA STATE UNIVERSITY

PH.D. - Wood Quality and Products

VirginiaTech 1872

MS – Wood Engineering
BS – Forest Products

Industrial Experience:

INTERNATIONAL PAPER

LOUISIANA PACIFIC – Building Products

Outline

- Introduction & Problem Identification
- Objectives
- Materials and Methods
- Results and Discussion
- Future Work
- Conclusions

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Introduction

When Breeding for Chemistry and Disease, What about Stiffness?

Problem Identification

Forest Products

- Important for us to know the ***chemical composition*** and ***stiffness*** of these genetically superior families.
- Important to pick families that have a combination of good forest product and tree health characteristics.

Forest Health

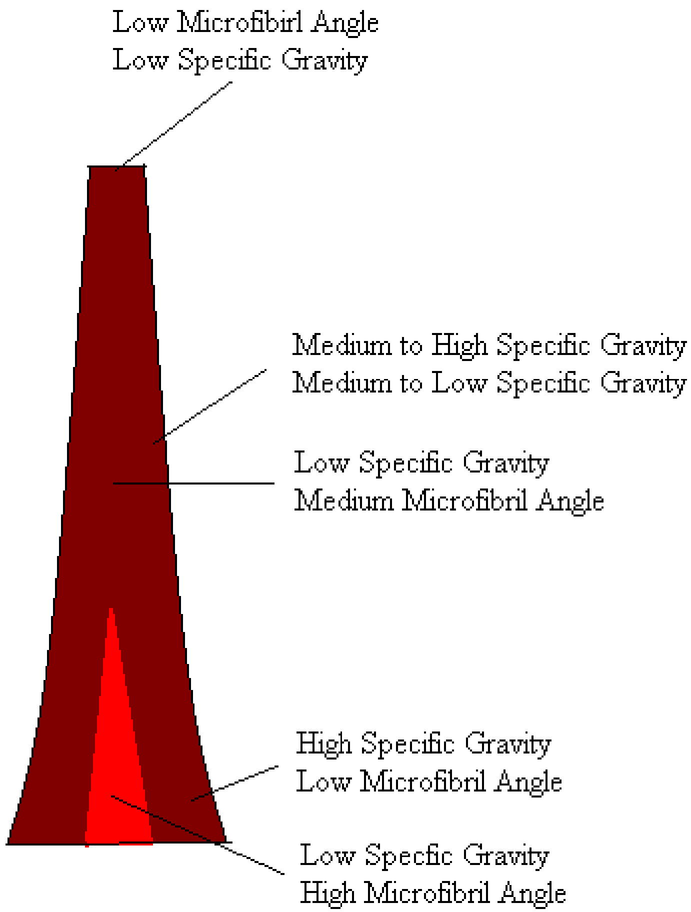
- Pine Decline/Disease has been on the rise.
- There is a need to rapidly screen trees for disease resistance
- There is a need to identify genetic families with superior disease resistance.

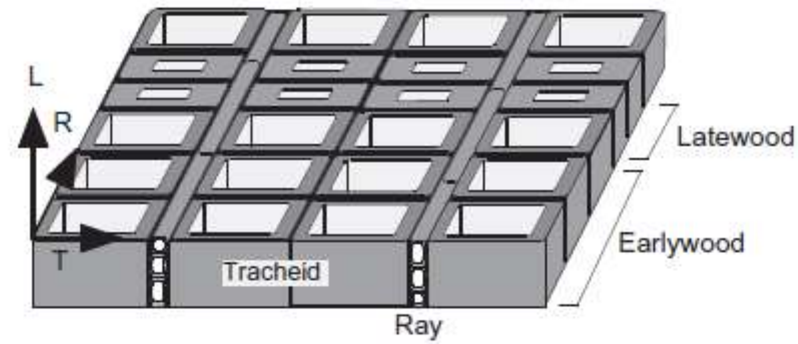
Connecting Fiber Properties to Product Performance

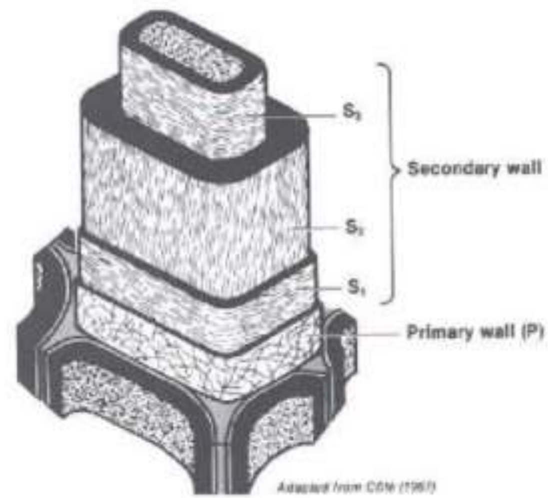
What happens if you:	Burst	Tensile	Tear	Compression	Clear Lumber MOE	Pulp Yield	Lumber Longitudinal Shrinkage
Decrease fibril angle from 40 to 30 degrees	?	↑ 2.5%	↑	↑ 3%	↑ 100%	No effect	↓ 66%
Increase cell length by 10%	↓ 10%	↓ 6%	↑ 15%	↓ 3%	↑	No effect	No effect
Increase cell wall thickness by 10%	↓ 6%	↓	↑ 15%	↓ 19%	↑	↑ 1%	No effect
Increase % latewood by 10%	↓ 3%	↓	↑ 7%	↓	↑	↑ 1%	No effect
Decrease lignin by 1 percentage point	No effect to small reduction	No effect to small reduction	↓ 4-10%	↓	↓	↑1-1.5 percentage point	Small improvement
Increase cellulose by 1 percentage point	No effect	No effect	↑ 7.5%	No effect	↑ 10%	↑0.5 percentage point	No effect

Many references: Available by Request

Tackling Stiffness: A Challenge to Measure

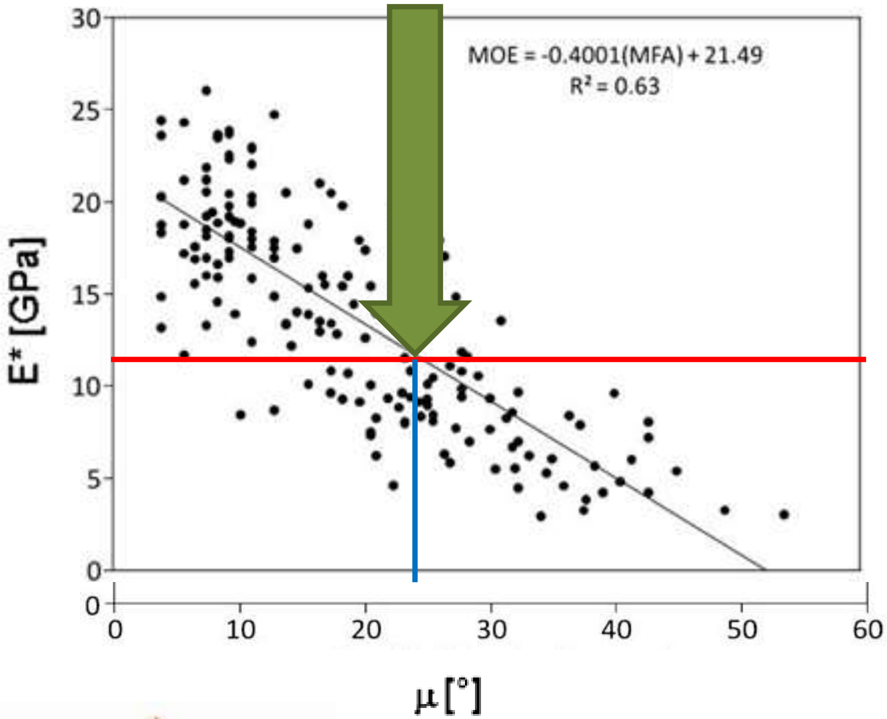


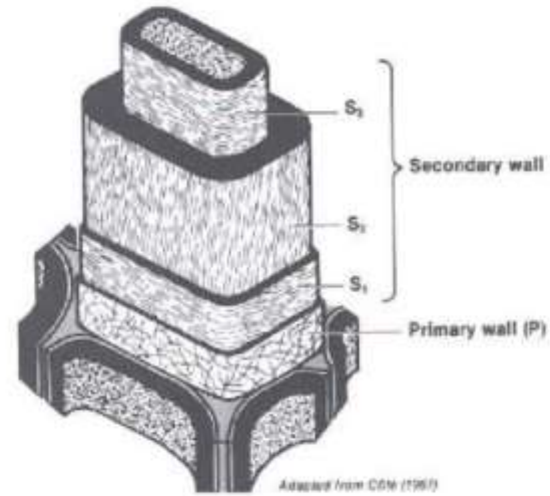




What Microfibril Angle is needed for Adequate Stiffness?

Point at which 50% of the samples meet SPIB stiffness threshold (longleaf pine)





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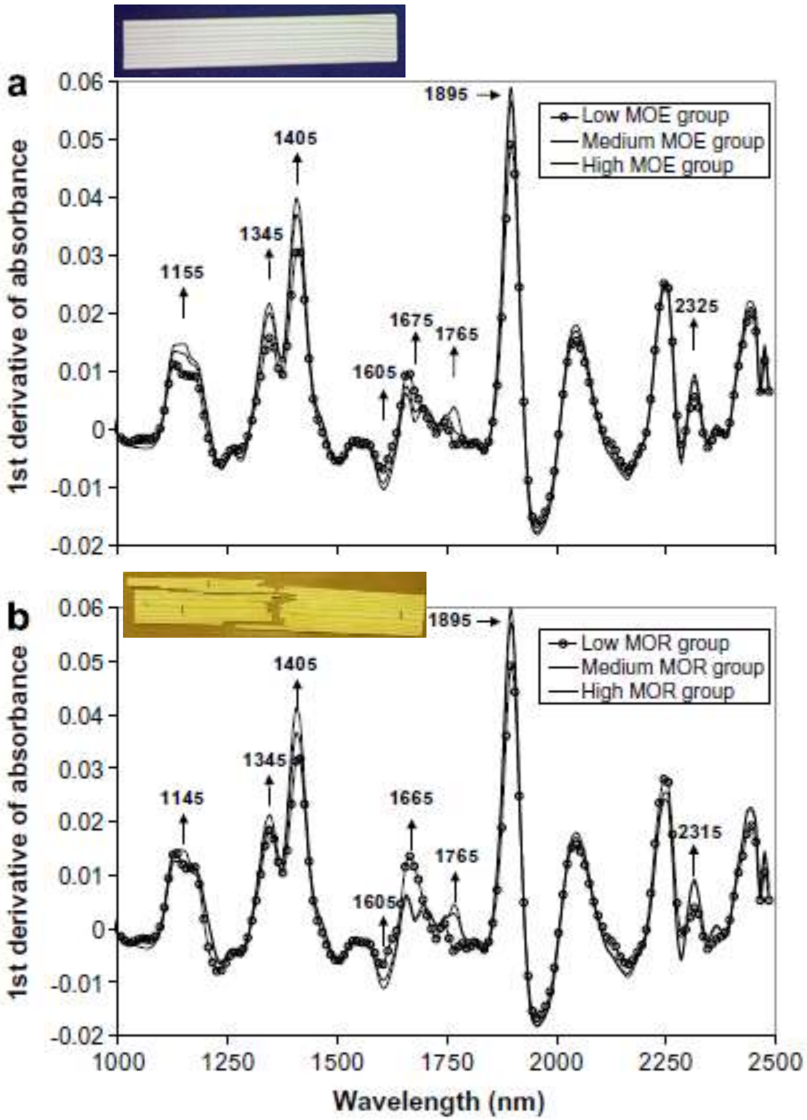
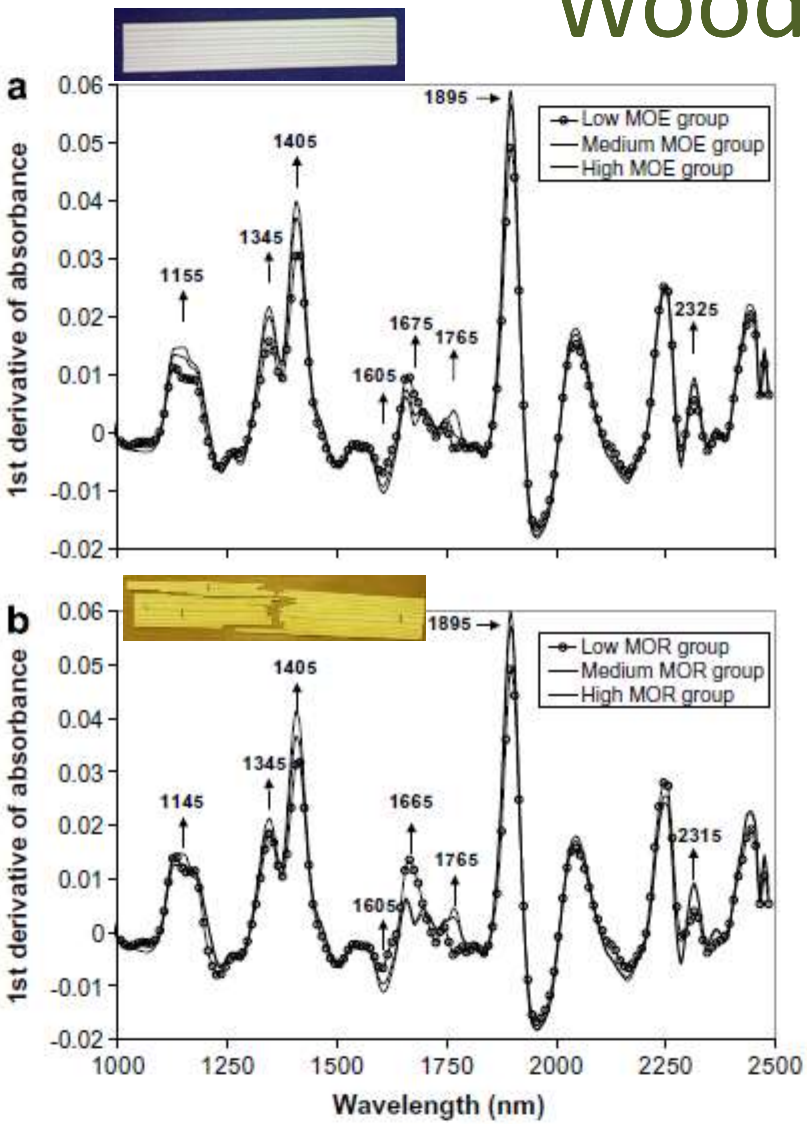
Via, B. K., So, C. L., Shupe, T. F., Groom, L. H., & Wikaira, J. (2009). Mechanical response of longleaf pine to variation in microfibril angle, chemistry associated wavelengths, density, and radial position. Composites Part A: Applied Science and Manufacturing, 40(1), 60-66.

How Does Chemistry Play a Role in Wood Strength? Stiffness?

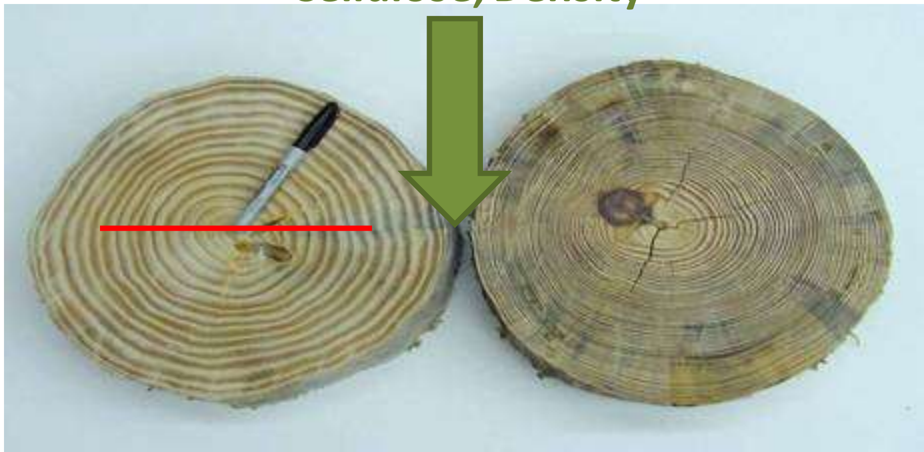


Wavelength (nm)	Polymer/chemistry assignment	Reference
1135	Aromatic portion of lignin	Tsuchikawa et al. 2004
1423	Amorphous region of cellulose	Tsuchikawa et al. 2004
1580	Crystalline region of cellulose	Tsuchikawa et al. 2004
1672	Aromatic portion of lignin	Soukupová et al. 2002 Schwanninger et al. 2004 Tsuchikawa et al. 2004, Yeh et al. 2004, Terdwongworakul et al. 2005
1758	Alpha cellulose	Terdwongworakul et al. 2005
1900	Lignin from foliar and branch material	Soukupová et al. 2002
2330	CH stretch in hemicellulose	Tsuchikawa et al. 2004

How Does Chemistry Play a Role in Wood Strength?

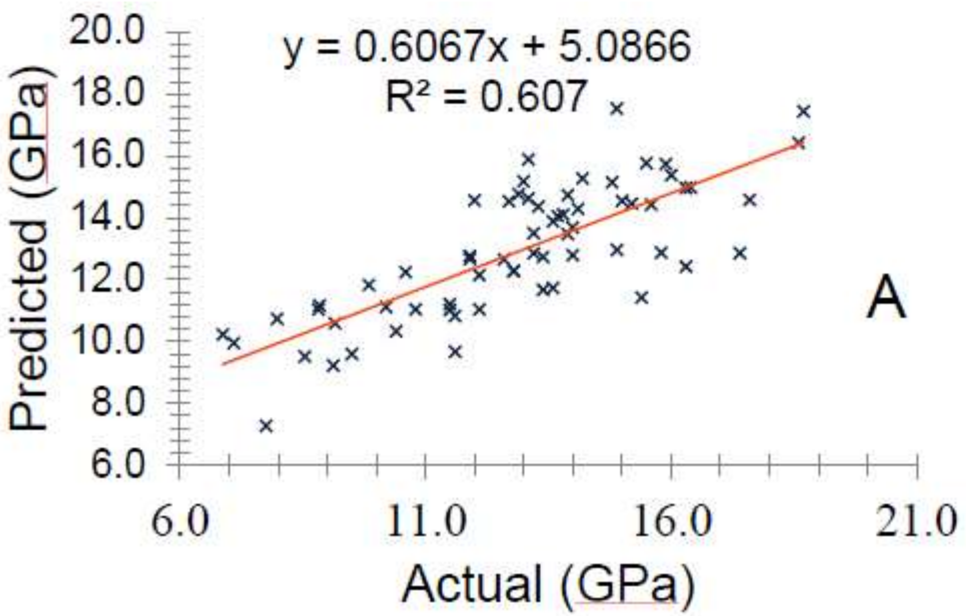


Cellulose, Density



Lignin, Microfibril Angle

Linking Wood Chemistry to Tensile Strength



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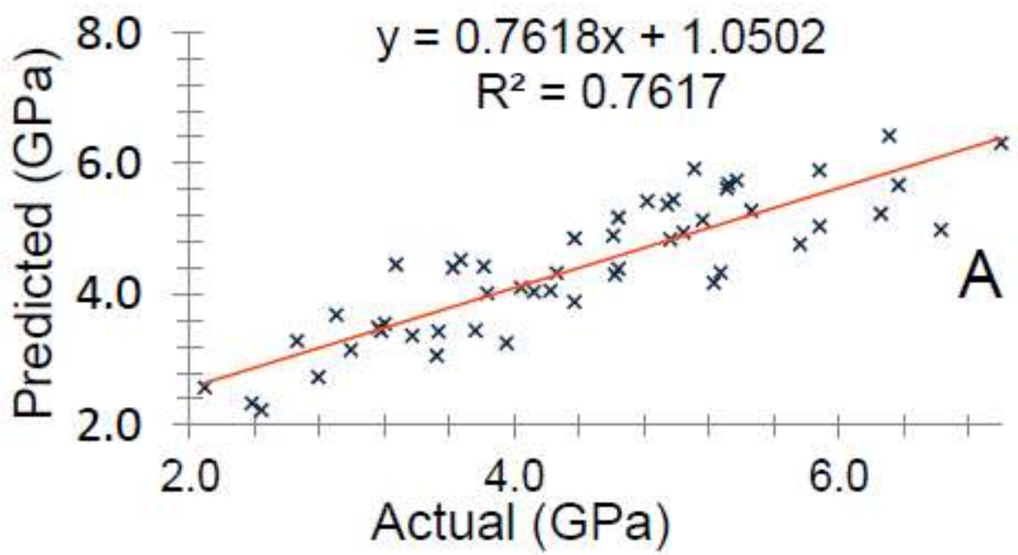
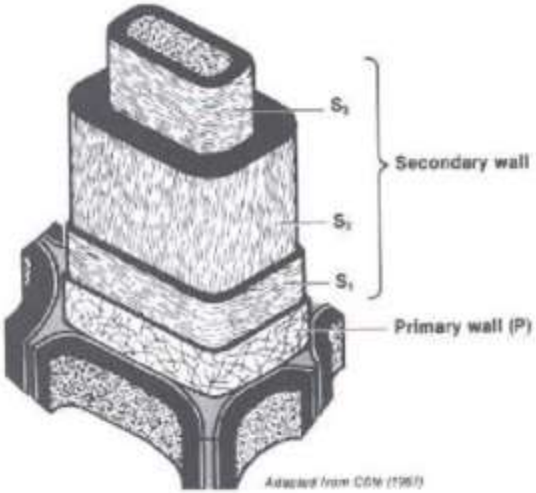
Kohan, N. J., Via, B. K., & Taylor, S. E. (2012). PREDICTION OF STRAND FEEDSTOCK MECHANICAL PROPERTIES WITH NEAR INFRARED SPECTROSCOPY. *BioResources*, *7*(3), 2996-3007.

Linking Wood Chemistry to Bending Strength



Kohan, N. J., Via, B. K., & Taylor, S. E. (2012). PREDICTION OF STRAND FEEDSTOCK MECHANICAL PROPERTIES WITH NEAR INFRARED SPECTROSCOPY. *BioResources*, *7*(3), 2996-3007.

What Parameter is Missing?



Introduction

Wood Chemistry and Disease Resistance

Reduction in Fungal Growth with the Addition of Monoterpenes

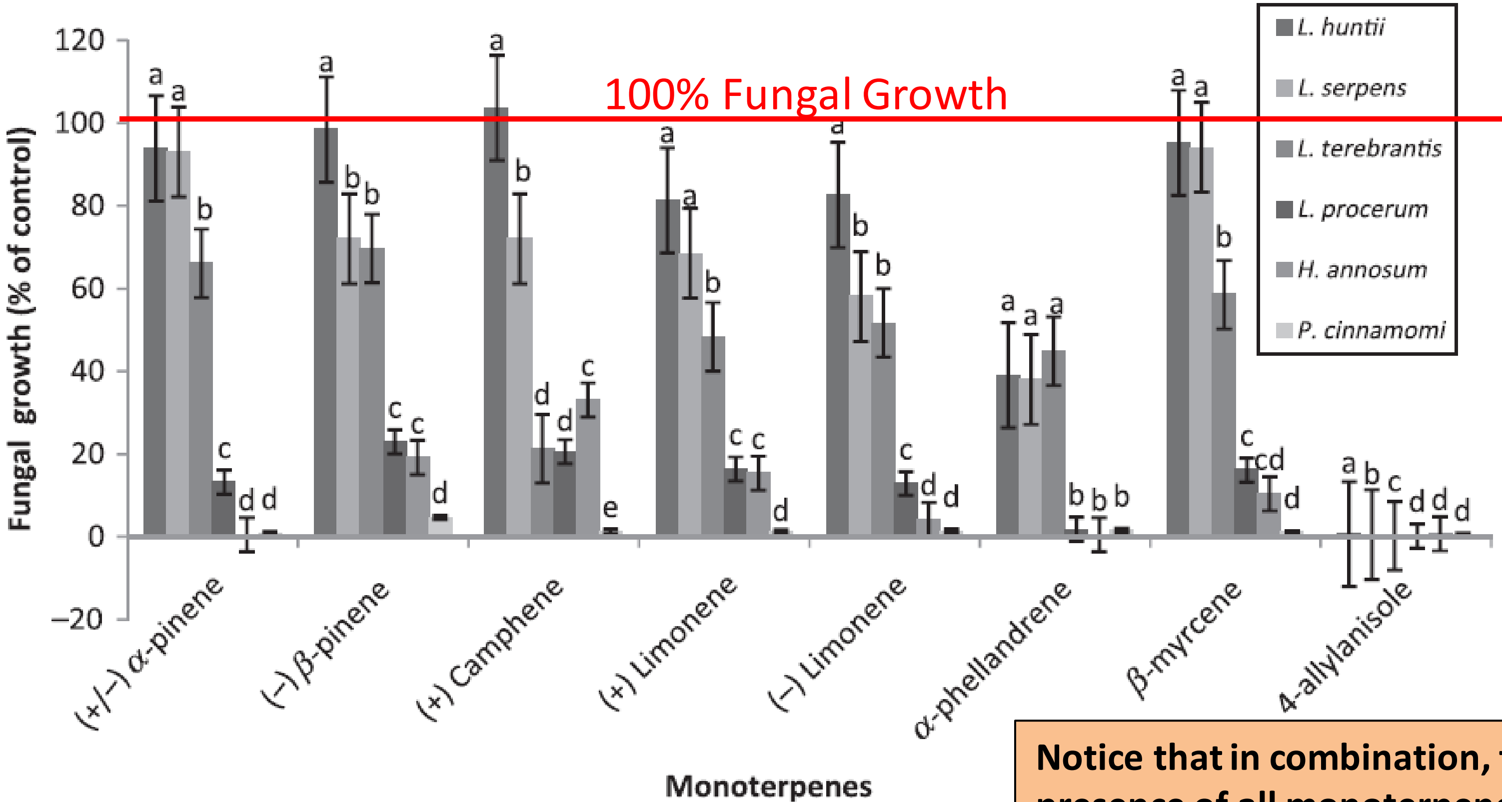


Image Reprinted from:
Eckhardt, L. G., Menard, R. D., & Gray, E. D. (2009). Effects of oleoresins and monoterpenes on in vitro growth of fungi associated with pine decline in the Southern United States. *Forest Pathology*, *39*(3), 157-167.

Notice that in combination, the presence of all monoterpenes are useful in defense against fungal growth & could be represented by total extractives content.

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Total Extractives Content: Easier to Measure with NIR

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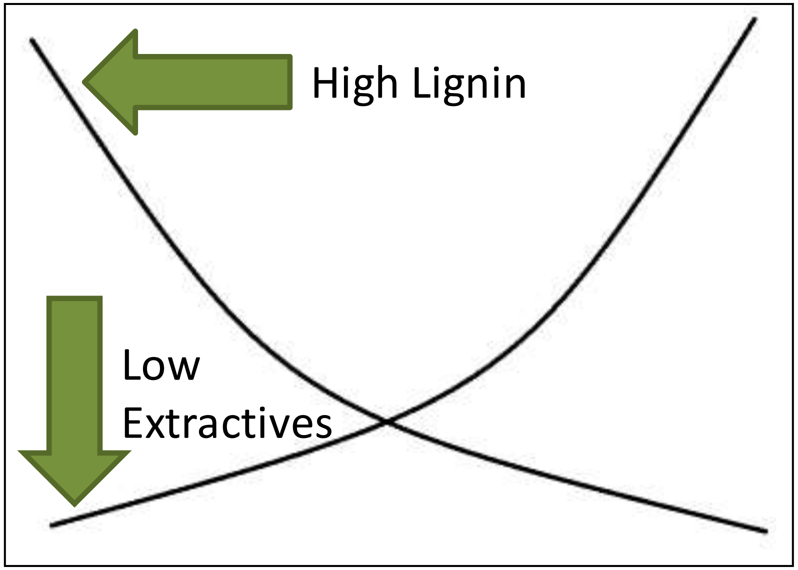
What about Lignin for Defense against Disease?

- Pro's
  - Higher in Faster Grown Trees.
  - Also Contains Phenolic Type Compounds which may provide Toxicity to Fungi.
  - May be useful for bioenergy
- Con's
  - Undesirable for pulp & paper.
  - Generally an indicator of lower strength characteristics.
  - Generally co-varies with microfibril angle.
  - Larger molecular weight coupled with being bound within the cell wall make it less assessable to ***"critters."***

Hypothesis: Extractives to Lignin Tradeoff During Cell Wall Synthesis



Shupe et al. (1997) showed a tradeoff between lignin and extractives. For a given age, increased growth resulted in more lignin and less extractives.

Shupe, T. F., Hse, C. Y., Choong, E. T., & Groom, L. H. (1997). Differences in some chemical properties of innerwood and outerwood from five silviculturally different loblolly pine stands. *Wood and fiber science*, *29*(1), 91-97.

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Objectives

- To develop NIR calibrations for wood chemistry of southern pine (from another study).
- To take these NIR calibrations and screen 14 genetic families from 2 sites for differences in:
  - Lignin
  - Cellulose
  - Hemicellulose
  - Extractives

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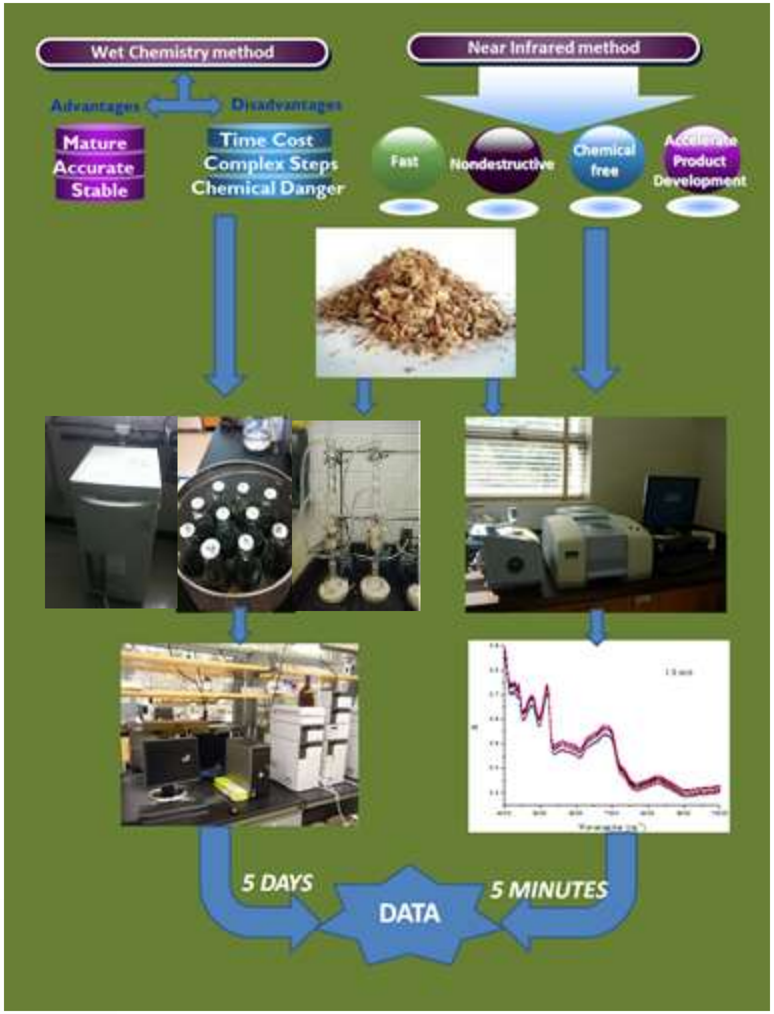
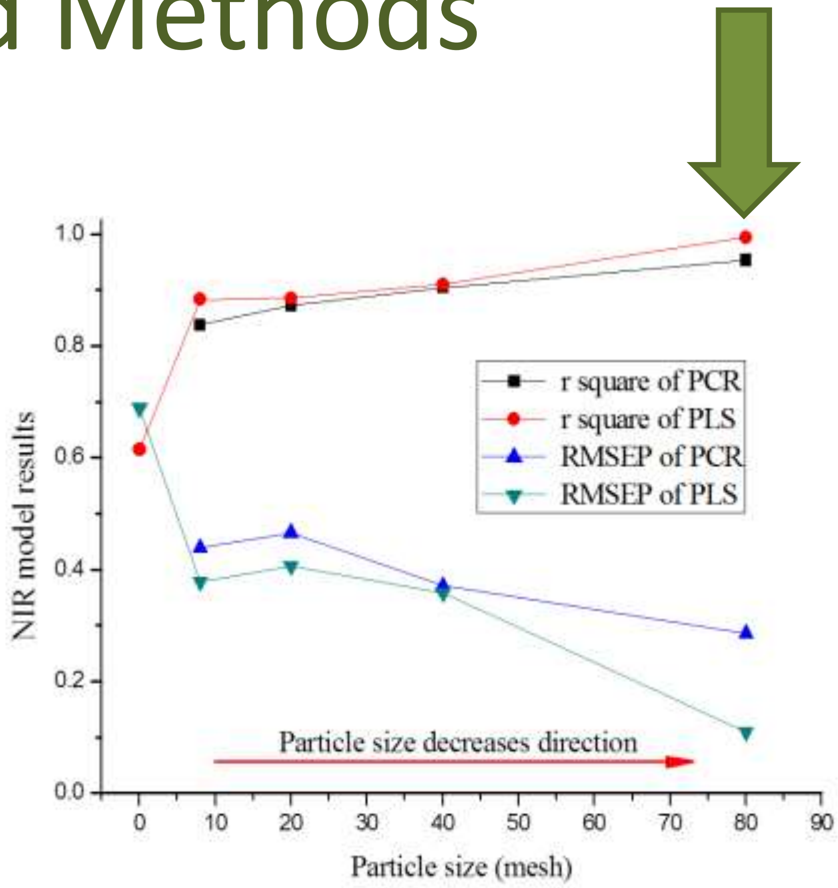
Materials and Methods





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Materials and Methods

Apply Models to Pine Families for Stiffness and Bioenergy

LIGNIN

CELLULOSE

HEMICELLULOSE

EXTRACTIVES

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Results and Discussion

Lumber Calibration Model

Table 1 Results of NIR models before and after wavenumber selection

Chemistry	Pretreatment	Before wavenumber selection			After wavenumber selection		
		r^2	RMSEP	RPD	r^2	RMSEP	RPD
Extractives	FD	0.96	0.62	1.19	0.91	0.37	2.00
Lignin	FD	0.90	0.53	1.98	0.99	0.19	5.53
Holocellulose	FD+MSC	0.95	0.85	2.08	0.96	0.27	6.56
Cellulose	FD	0.96	1.34	1.13	0.95	0.68	2.22
Hemicellulose	FD+MSC	0.90	1.12	1.40	0.82	1.05	1.50

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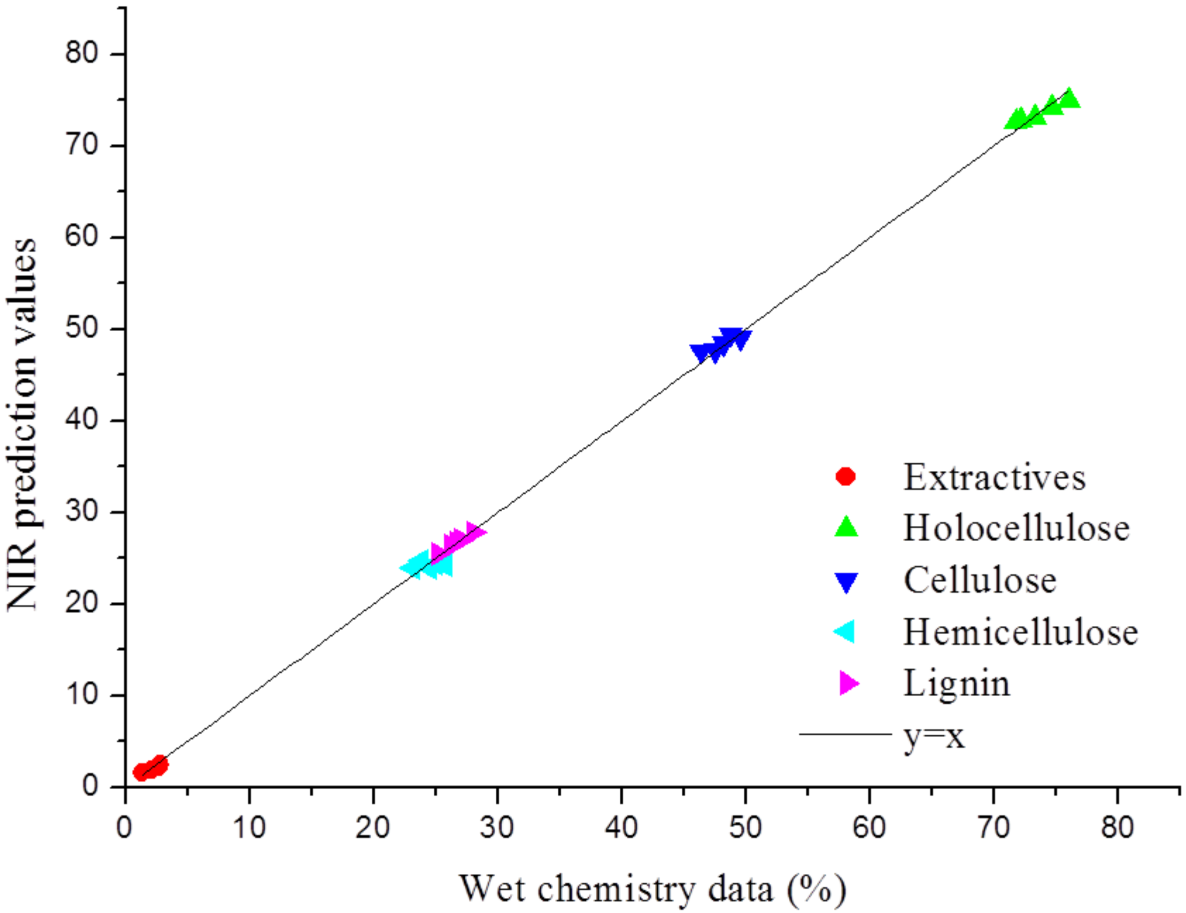
Accepted with Revisions:
Wei Jiang, Via et al. 2013. Wood Science and Technology.

Results and Discussion

Lumber Calibration Model



Accepted with Revisions:
Wei Jiang, Via et al. 2013. Wood Science and Technology.

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Results and Discussion

Analysis of 14 Families at Two Sites

Randomized Block Design

Trait	Source	F-Value	Pr > F
Lignin	Block (Site)	60.59	<0.0001
	Family	0.80	0.6626
	Block x Family	1.47	0.1286
Extractives	Block (Site)	102.01	<0.0001
	Family	1.36	0.1757
	Block x Family	2.30	0.0065
Cellulose	Block (Site)	3.83	0.0512
	Family	7.7	<0.0001
	Block x Family	7.44	<0.0001
Hemicellulose	Block (Site)	0.01	0.9398
	Family	21.13	<0.0001
	Block x Family	7.81	<0.0001

Lignin: Comparison of Means

Alpha	0.1
Error Degrees of Freedom	326
Error Mean Square	1.256785
Critical Value of t	1.64954
Least Significant Difference	0.5229
Harmonic Mean of Cell Sizes	25.01538

NOTE: Cell sizes are not equal.

Means with the same letter are not significantly different.

t Grouping			Mean	N	family
	A		28.6389	27	A37
	A				
B	A		28.4954	28	A33
B	A				
B	A	C	28.4046	24	A2
B	A	C			
B	A	C	28.3775	28	F17
B	A	C			
B	A	C	28.3531	26	A26
B	A	C			
B	A	C	28.3350	24	A5
B	A	C			
B	A	C	28.3335	26	F23
B	A	C			
B	A	C	28.2815	20	A15
B	A	C			
B	A	C	28.1254	24	A9
B		C			
B		C	28.0996	26	A10
B		C			
B		C	28.0700	24	A34
B		C			
B		C	28.0590	29	A1
		C			
		C	27.9724	21	A13
		C			
		C	27.9630	27	A21

Log - (Untitled) | Block Design FL GA Wood...

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Extractives: Comparison of Means

Alpha	0.1
Error Degrees of Freedom	326
Error Mean Square	1.128132
Critical Value of t	1.64954
Least Significant Difference	0.4954
Harmonic Mean of Cell Sizes	25.01538

NOTE: Cell sizes are not equal.

Means with the same letter are not significantly different.

t Grouping					Mean	N	family
			A		6.7202	28	F17
			A				
	B		A		6.5301	28	A33
	B		A				
	B		A	C	6.4842	27	A21
	B		A	C			
	B	D	A	C	6.3829	27	A37
	B	D	A	C			
E	B	D	A	C	6.2993	26	A10
E	B	D		C			
E	B	D		C	6.2015	24	A2
E	B	D		C			
E	B	D		C	6.1707	24	A5
E	B	D		C			
E	B	D		C	6.1275	29	A1
E	B	D		C			
E	B	D		C	6.0928	24	A9
E		D		C			
E		D		C	5.9918	26	F23
E		D					
E		D			5.9691	24	A34
E		D					
E		D			5.9508	20	A15
E		D					
E		D			5.8975	26	A26
E							
E					5.8740	21	A13

Log - (Untitled)   Block Design FL GA Wood...

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Cellulose: Comparison of Means

```
Alpha                                   0.1
Error Degrees of Freedom                326
Error Mean Square                  0.352037
Critical Value of t                 1.64954
Least Significant Difference         0.2767
Harmonic Mean of Cell Sizes        25.01538

      NOTE: Cell sizes are not equal.

Means with the same letter are not significantly different.

      t Grouping            Mean       N    family

              A          51.7667      21    A13
              A
    B         A          51.6150      24    A2
    B
    B         C          51.4742      26    A10
    B         C
    B         C          51.4650      26    F23
    B         C
    B         C          51.4513      24    A9
    B         C
    B         C          51.3900      20    A15
              C
    D         C          51.2162      29    A1
    D
    D         E          51.0804      28    F17
    D         E
    D         E    F     51.0646      24    A5
    D         E    F
    D    G    E    F     50.9441      27    A21
         G    E    F
         G    E    F     50.8600      24    A34
         G    E    F
         G    E    F     50.8261      28    A33
         G         F
         G         F     50.7977      26    A26
         G
         G               50.7485      27    A37
```

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Hemicellulose: Comparison of Means

Alpha	0.1
Error Degrees of Freedom	326
Error Mean Square	0.086294
Critical Value of t	1.64954
Least Significant Difference	0.137
Harmonic Mean of Cell Sizes	25.01538

NOTE: Cell sizes are not equal.

Means with the same letter are not significantly different.

t Grouping		Mean	N	family
	A	24.64042	24	A34
	A			
B	A	24.55643	28	A33
B				
B	C	24.44692	26	A26
	C			
	C	24.41333	27	A37
	C			
	C	24.35815	27	A21
	D	24.21517	29	A1
	D			
	D	24.18154	26	F23
	D			
	D	24.16500	20	A15
	D			
	D	24.15708	24	A5
	D			
E	D	24.11038	26	A10
E				
E	F	23.98143	28	F17
	F			
G	F	23.86583	24	A9
G				
G		23.78750	24	A2
G				
G		23.76810	21	A13

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Summary of Family Performance

Forest Products

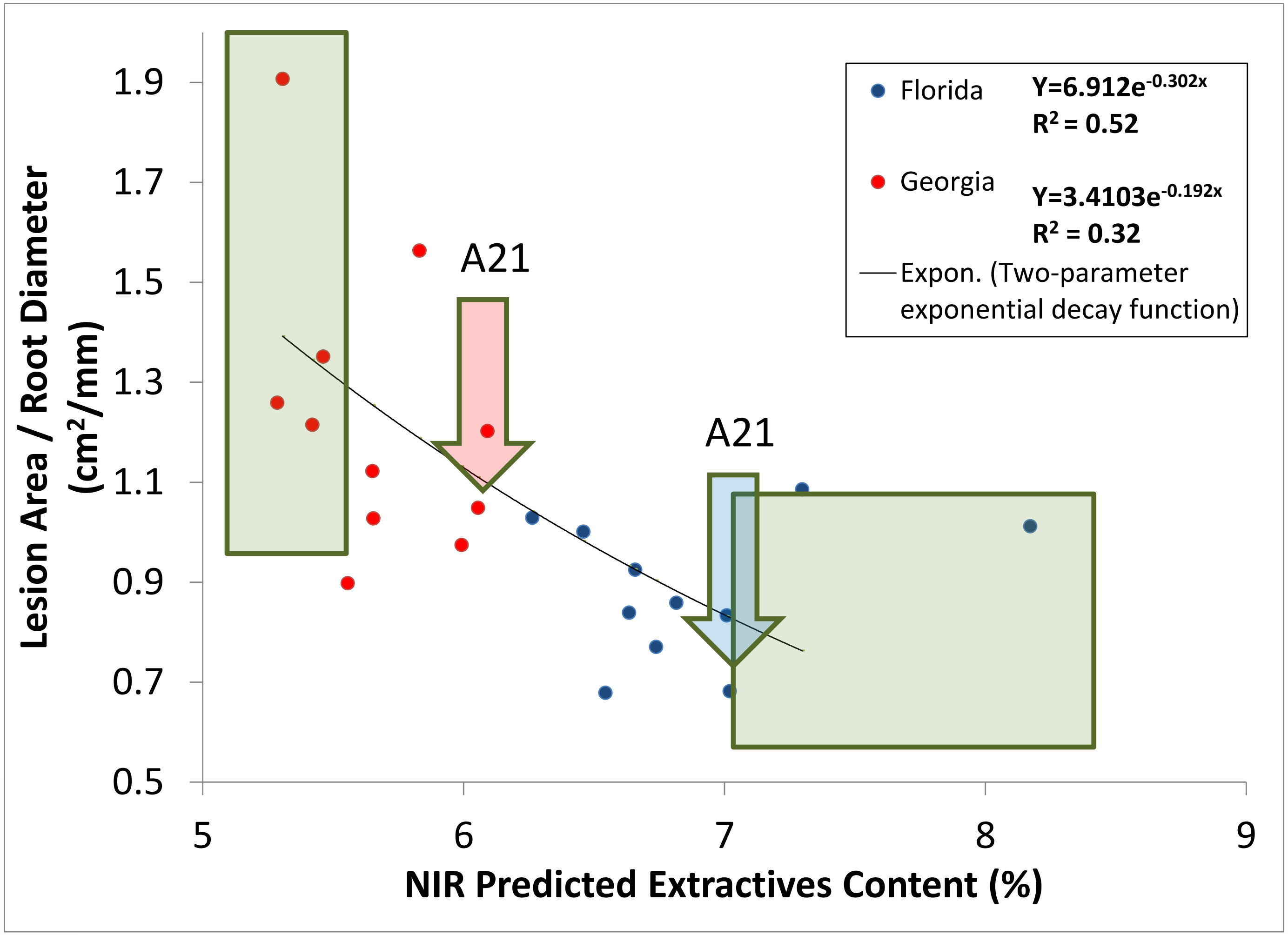
- Low lignin, high cellulose
- Is extractives a problem? Not for lumber. Maybe for paper.

Disease Resistance

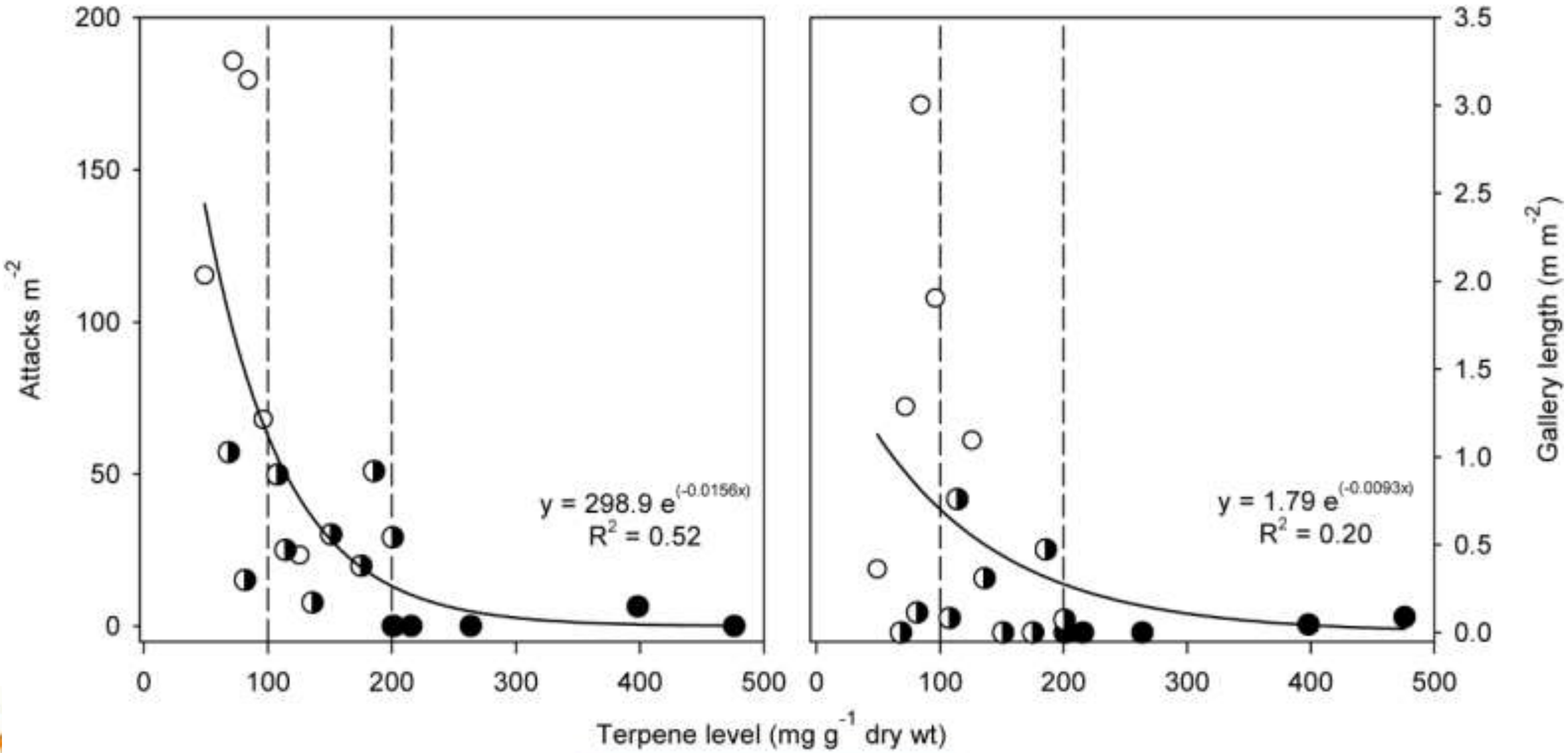
- High extractives
- Probably not high lignin (conflicts with products)

Family	Lignin	Cellulose	Extractives
A1	Low	Medium	Medium
A21	Low	Medium-Low	High
A13	Low	High	Low
A34	Low	Medium-Low	Medium-Low
F17	High	Medium	High
A33	High	Low	High
A37	High	Low	High
A10	Medium-Low	High	High

Control of Lesion Area through Enhanced Extractives Content

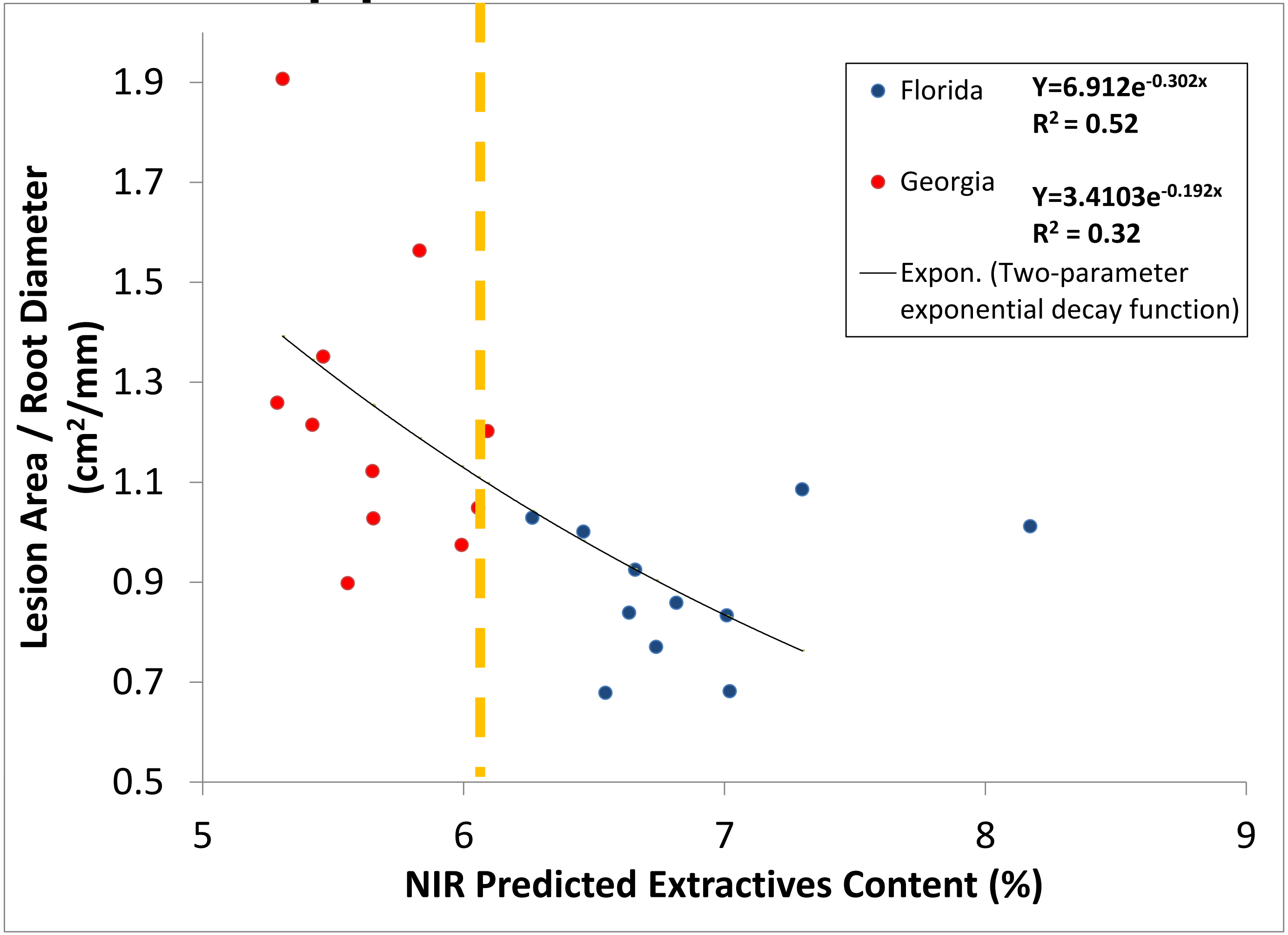


A "Dose-Dependent" Explanation for *Picea abies* (L.) Resistance to Bark Beetle Colonization



Zhao T, Krokene P, Hu J, Christiansen E, Björklund N, et al. (2011) Induced Terpene Accumulation in Norway Spruce Inhibits Bark Beetle Colonization in a Dose-Dependent Manner. PLoS ONE 6(10): e26649. doi:10.1371/journal.pone.0026649

The "Dose-Dependent Theory" Applied to Our Data



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Conclusions

- Lesion by diameter ratio followed an exponential decay function with extractives content.
- Several families exhibited a low lesion to diameter ratio with increased extractives, but Family A21 exhibited the best *"Umbrella"* traits for both wood quality and disease resistance.
- Family Rankings for extractives content were not consistent between sites due to a strong Site x Family interaction (pr>F = <0.0065).

Future Work

Pine Decline/Disease

- Determine the critical amount of extractives necessary to fight pine decline/disease.
- Target specific trees/families to fill in the gaps to better define the relationship between pine decline/disease and extractives content.

Forest Products

- Add microfibril angle (or ultrasonics) to the measurement program.
  - Find families with best combination of traits.
  - Consider the Forest Products Cooperative. See me during reception if interested.