The physiological mechanisms behind the earlywood-to-latewood transition: a process-based modelling approach

Fabrizio Cartenì
fabrizio.carteni@unina.it
Xylogenesis

Cell production

Cell differentiation

- Enlargement
- Secondary cell wall deposition and lignification
Research question:

What are the factors that can explain the variation of tracheids anatomical features?
Cell enlargement

Wall deposition

Wall lignification

- Water availability
  - x
  - Wall elasticity
  - ✔
  - Lumen perimeter
  - ✔

- Temperature
  - x
- Photoperiod
  - x
- Sugar availability
  - ✔
Model assumptions

- Enlargement is slowed down by wall thickening
- Cellulose and lignin deposition rates increase with sugars availability
- Cellulose and lignin deposition rates increase with lumen perimeter
- Cells mature when the wall is completely lignified

Model equations:

\[
\frac{dCA}{dt} = v_c \cdot CA \left( 1 - \frac{CA}{CA_{max}} \right) \left( 1 - \min \left( 1, \frac{WT}{WT^*} \right) \right)
\]

\[
\frac{dWA}{dt} = v_w \cdot S \left( 1 - \frac{WA}{WA_{max}} \right) \left( 1 - \frac{1}{\left( 1 + \frac{(CA - WA)}{m_w} \right)^{s_w}} \right) \text{Death}
\]

\[
\frac{dLWA}{dt} = v_l \cdot S \left( 1 - \frac{1}{\left( 1 + \frac{(CA - LWA)}{m_L} \right)^{s_L}} \right) \text{Death}
\]
Temporal dynamics of tracheid development

**Low sugar availability**
- Cell area
- Lumen area
- Wall area
- Lignified area

**High sugar availability**

Days from beginning of differentiation

- Thickness threshold
- Wall thickness
Temporal dynamics of tracheid development

Low sugar availability

Earlywood

High sugar availability

Latewood
Temporal dynamics of tracheid development

Sugar availability

Low

High
Temporal dynamics of tracheid development

Sugar availability

Low

High
Model calibration

Experimental site 1:
Italy (2001)
46°27’ N, 12°08’ E

Species:
- Pinus cembra
- Picea abies
- Larix decidua
Model calibration

Experimental site 2: Quebec (1999-2004)
48°13’ N, 71°15’ W
Species:
• *Picea mariana*

49°58’ N, 72°30’ W
Species:
• *Abies balsamea*
**Introduction**

- Model description
- Tracheids
- Tree rings
- Conclusions

### Sugar availability

- *Pinus cembra*
- *Picea abies*
- *Larix decidua*

### Lumen radial diameter

- *Pinus cembra*: $R^2=0.99$
- *Picea abies*: $R^2=0.86$
- *Larix decidua*: $R^2=0.99$

### Wall thickness

- *Pinus cembra*: $R^2=0.93$
- *Picea abies*: $R^2=0.88$
- *Larix decidua*: $R^2=0.91$

### Lumen area

- *Pinus cembra*: $R^2=0.98$
- *Picea abies*: $R^2=0.90$
- *Larix decidua*: $R^2=0.99$
Introduction

Model description

Tracheids

Tree rings

Conclusions

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**Picea mariana**

**Abies balsamea**

- **Sugar availability**
  - *Picea mariana* (R²=0.96)
  - *Abies balsamea* (R²=0.96)

- **Lumen radial diameter**
  - *Picea mariana* (R²=0.96)
  - *Abies balsamea* (R²=0.96)

- **Wall thickness**
  - *Picea mariana* (R²=0.92)
  - *Abies balsamea* (R²=0.93)

- **Lumen area**
  - *Picea mariana* (R²=0.97)
  - *Abies balsamea* (R²=0.99)

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Observed and simulated percentages of latewood in the tree ring

<table>
<thead>
<tr>
<th>Species</th>
<th>Observed (%)</th>
<th>Simulated (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Pinus cembra</em></td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><em>Picea abies</em></td>
<td>1.4</td>
<td>0.9</td>
</tr>
<tr>
<td><em>Larix decidua</em></td>
<td>55.6</td>
<td>57.8</td>
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<tr>
<td><em>Picea mariana</em></td>
<td>26.5</td>
<td>29.4</td>
</tr>
<tr>
<td><em>Abies balsamea</em></td>
<td>11.6</td>
<td>11.6</td>
</tr>
</tbody>
</table>

Estimated timings of cell enlargement and cell-wall thickening
Final considerations:

- The model was able to reproduce observed tree ring patterns
- We considered basic cellular processes
- Results support the metabolic theory
- Carbon availability can explain both rates and durations of xylogensis
- Better understanding of the dynamic functioning of the system

Ongoing work:

- Include cell division
- Include external factors (e.g. water, temperature and photoperiod)
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