Hydraulic signals induced by bending in artificial and natural branches : link with plant mechanoperception and long-distance signaling in trees

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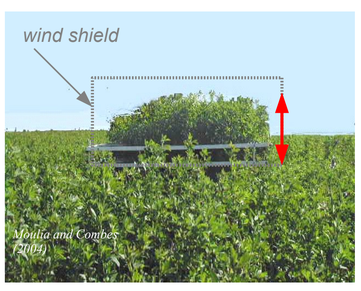
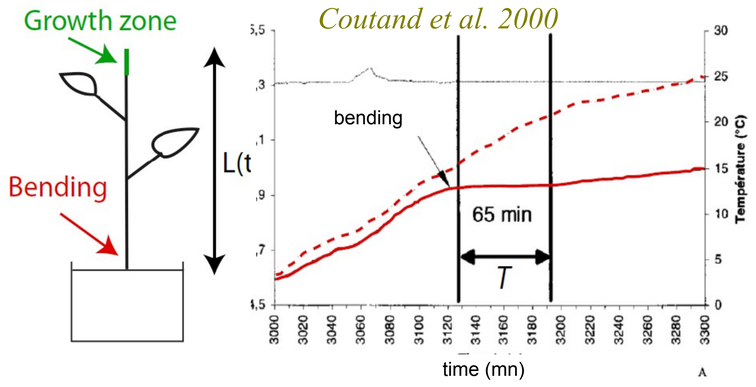
Growth response to mechanical stimuli (Thigmo-morphogenesis)

Moulia and Combes 2004



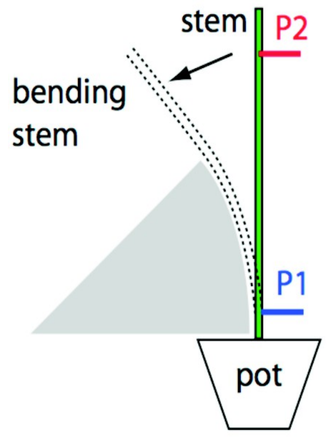


Coutand et al. 2000

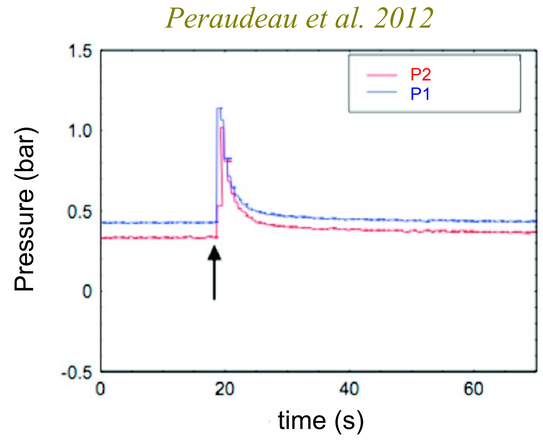
→ Origin of the long distance signaling?
Pressure pulse hypothesis?
Julien 1993, Malone 1994

Recent evidence of hydro/mechanical coupling in plants

É. Badel, H. Cochard, B. Moulia (PIAF)



Peraudeau et al. 2012



→ Physical mechanisms? (amplitude, speed, damping)

Our approach : study of the poroelastic reponse of artificial and natural branches

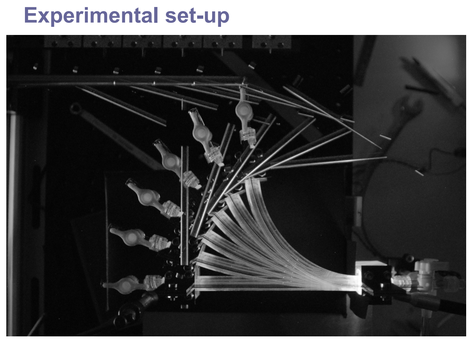
Artificial branches : physical modelling

Original 3D microfluidic device:
elastomeric *PDMS* beam drilled with *μ*-channels

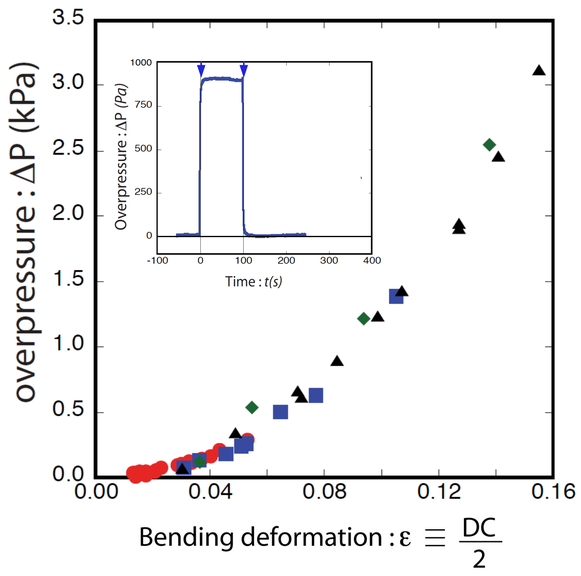
Porosity ~3-10 %

Artificial (PDMS) branches
Young modulus E
2. MPa
diameter of the channels
500 μm
Permeability
200–700 μm²

Experimental set-up



Low porosity: silicon (two different protocol of bending)
High porosity: silicon oil
Ucon oil / water mixture



→ Pressure response to bending is non-linear:

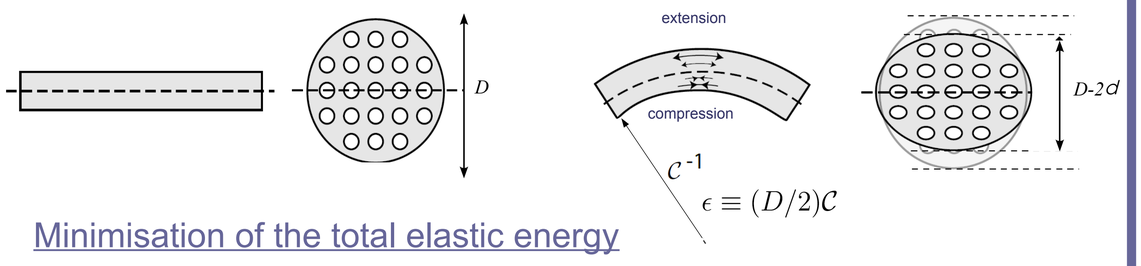
$$\Delta P \sim \epsilon^2$$

Physical explanation and key parameters

Model : bending a porous beam induces a squeezing of the cross-section

initial state

final state



Minimisation of the total elastic energy

$$\left.\begin{aligned} U_{bend}(\delta) &\approx \frac{EV}{32}(D-2\delta)^2\mathcal{C}^2 \\ U_{squeeze}(\delta) &\approx \frac{EV}{2}\left(\frac{2\delta}{D}\right)^2 \end{aligned}\right\} \quad \frac{2\delta}{D} \propto \epsilon^2 \quad \Rightarrow \quad \frac{\Delta V_c}{V_c} = -(1-\nu_{2D})\frac{2\delta}{D} \propto \epsilon^2$$

Relation pressure / volume: bulk modulus B

$$\Delta P = B\frac{\Delta V_c}{V_c} \quad \Rightarrow \quad \boxed{\Delta P \sim B\epsilon^2}$$

Quantitative measurements on natural branches

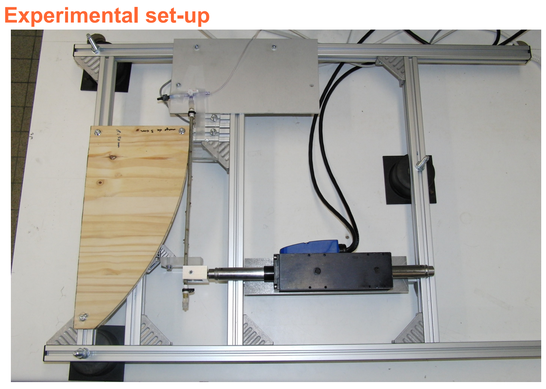
Natural branches properties

Length L ~ 20cm, Diameter D ~ 1cm
Porosity ~ 1-20 %

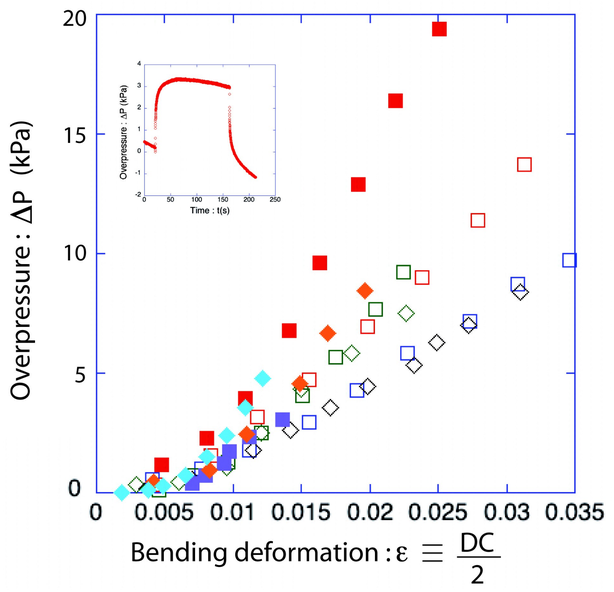
Cytological section

Hybrid Poplar	Green Oak
Young modulus E	
2.2 ± 1.0 GPa	3.7 ± 0.6 GPa
Mean diameter of the channels	
31 ± 14 μm	51 ± 17 μm
Permeability	
1.2 ± 0.4 μm²	1.3 ± 0.5 μm²

Experimental set-up

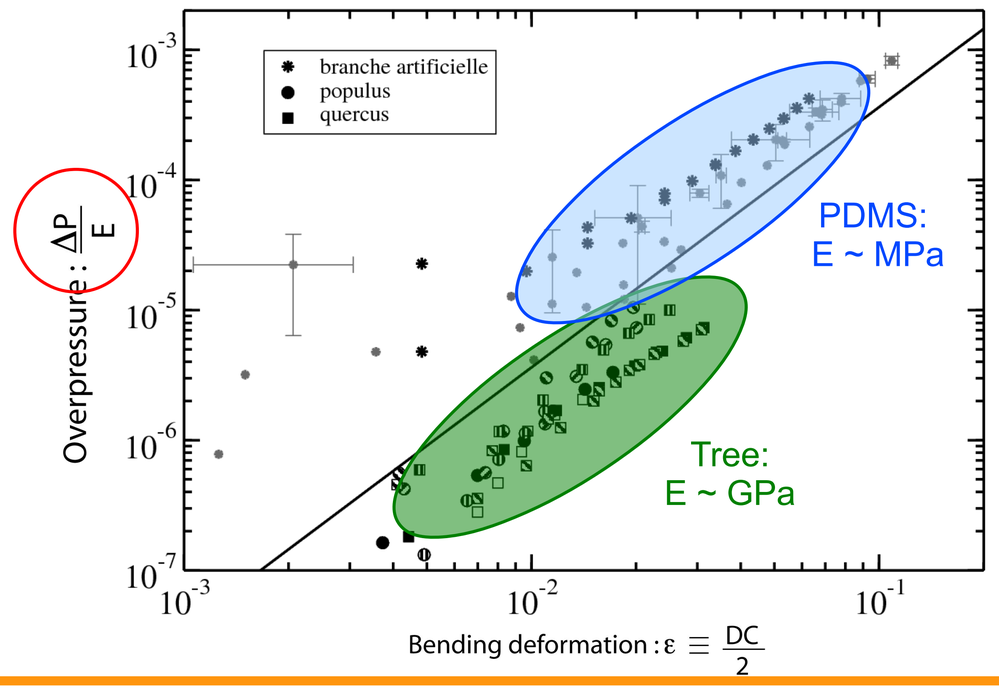


Green Oak (*Quercus Ilex*)(two different protocol for deformation)
Hybrid poplar (*Populus Tremula x Alba*)



→ Same non-linear pressure response !

Comparison between artificial and natural branches



Perspectives:

- Generalisation to other species
- Role of these hydromechanical coupling in plants mechanoperception