REUNION XYLEME 2014

MECHANICAL BEHAVIOUR OF PITS

a key role in the cavitation sensitivity

Aude Tixier, Stephane Herbette, Steven Jansen, Marie Capron, Philippe Tordjeman, Nicole Brunel, Hervé Cochard, Eric Badel

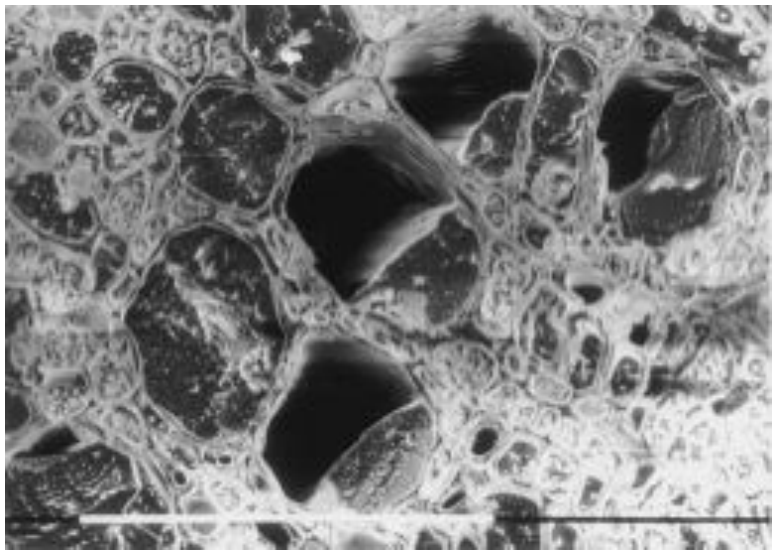
U.M.R. PIAF

DROUGHT-INDUCED XYLEM CAVITATION

NEGATIVE PRESSURES MAKE THE LIQUID XYLEM SAP METASTABLE

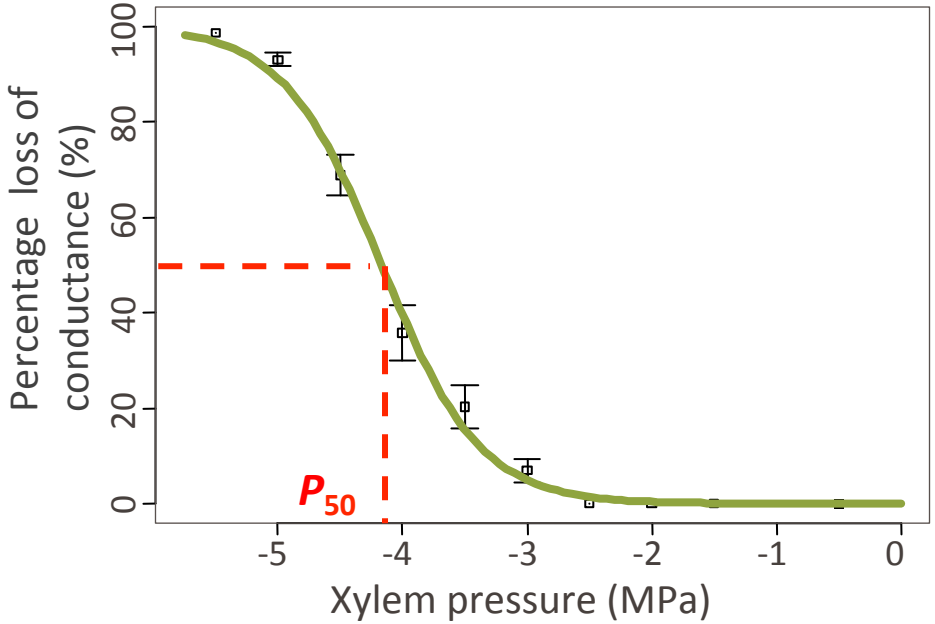
Initiation of vapour bubbles

Embolized vessels

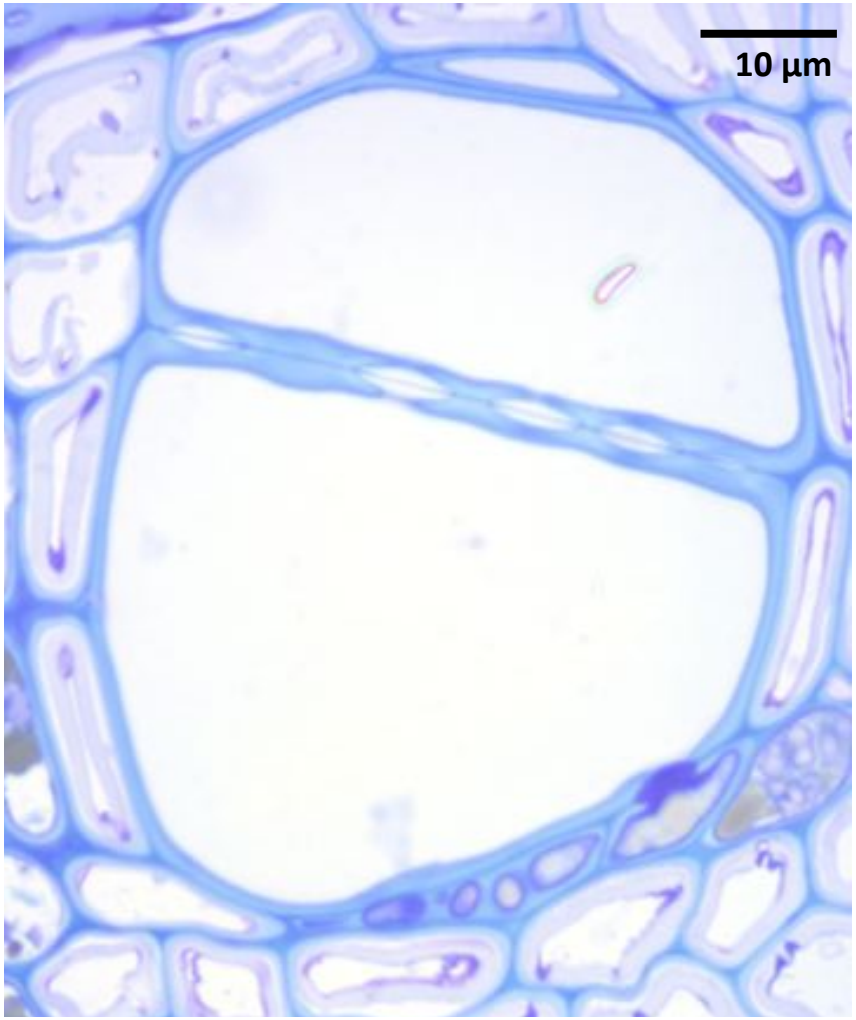


Walnut (Cochard *et al.*, 2000)

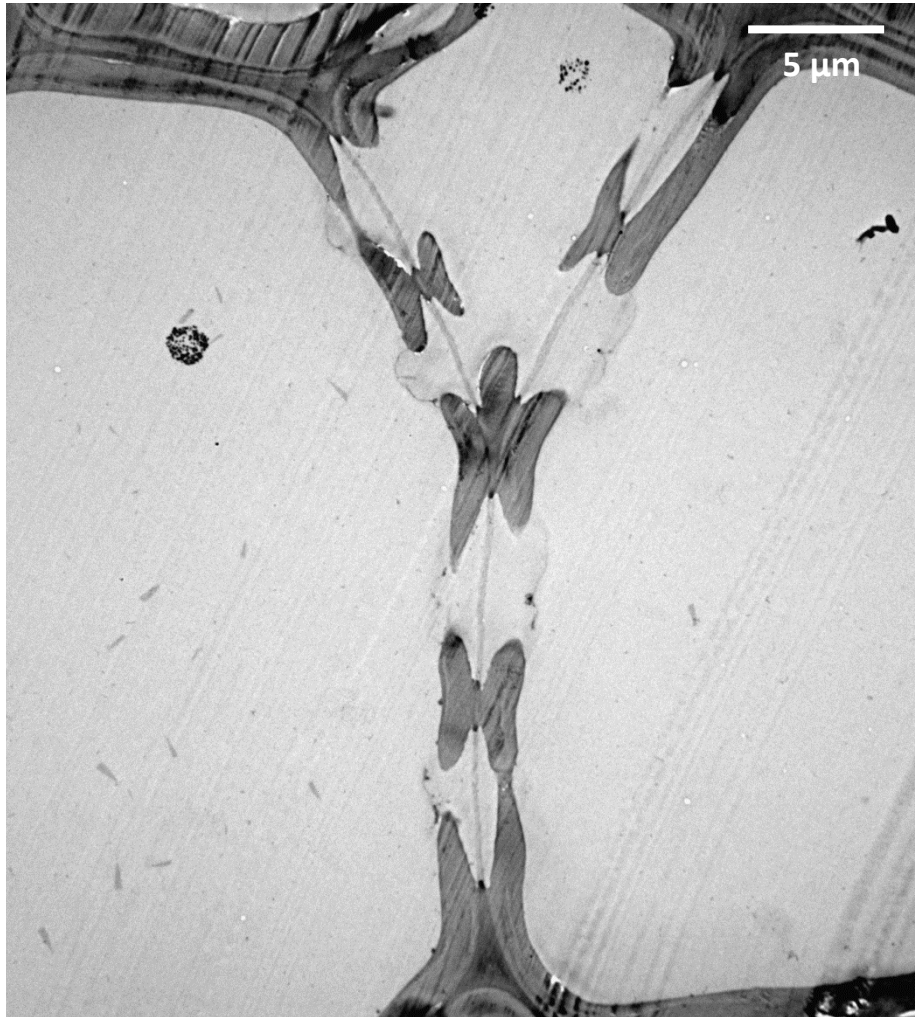
Loss of conductance



PITS CONNECT XYLEM'S VESSELS



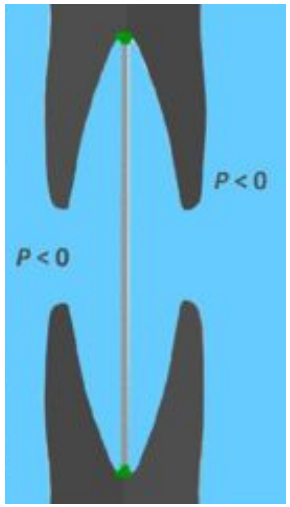
Light microscopy

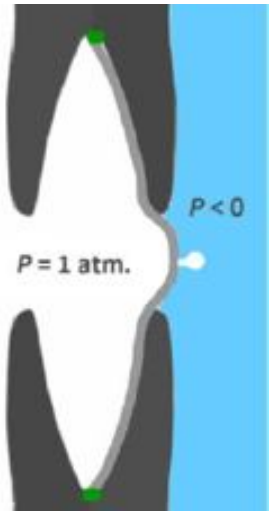


Transmission electron microscopy

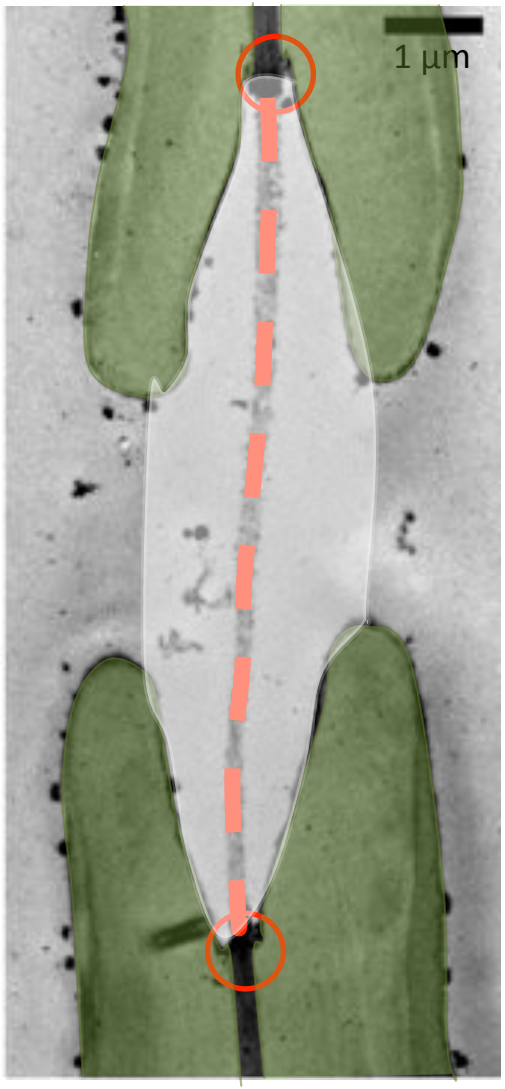
PITS CONNECT XYLEM'S VESSELS

- *A COMPROMISE BETWEEN EFFICIENCY AND SAFETY*
  - *Permitting water flow*
  - *Limiting air propagation*
- *MOST PROBABLE AIR ENTRY POINT IN A VESSEL*
  - *Air seeding through pores of pit membrane*





PITS CONNECT XYLEM'S VESSELS

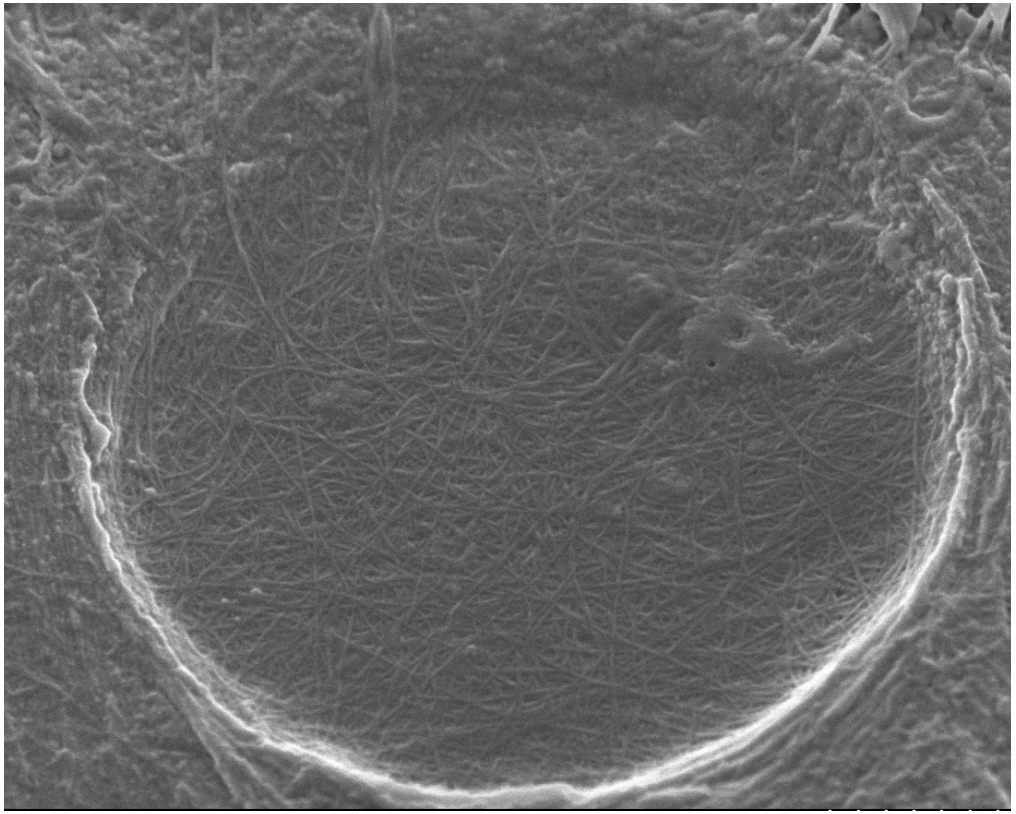


annulus

border

membrane

- ***MODIFIED PRIMARY CELL WALL***



INVOLVEMENT OF PITS IN VULNERABILITY TO CAVITATION

- ***POROSITY***

  Sano,2005 ; Jansen *et al*., 2009

- ***PIT MEMBRANE THICKNESS***

  Jansen *et al*., 2009

- ***DIMENSIONS OF THE PIT CHAMBER***

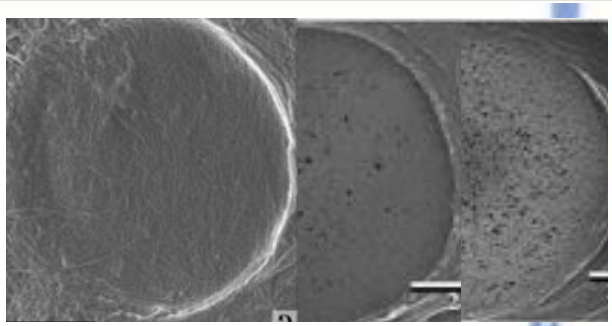
  Sperry and Hacke, 2004 ;
  Choat et al, 2004 ; Lens et al., 2011

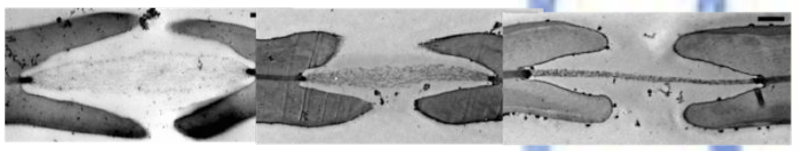
  → ***Pit chamber geometry ?***

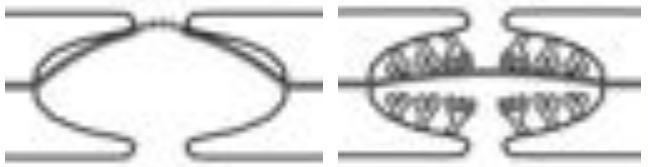
- ***MECHANICAL PROPERTIES***

- ***COMPOSITION***

  Dusotoit-Coucaud, 2013

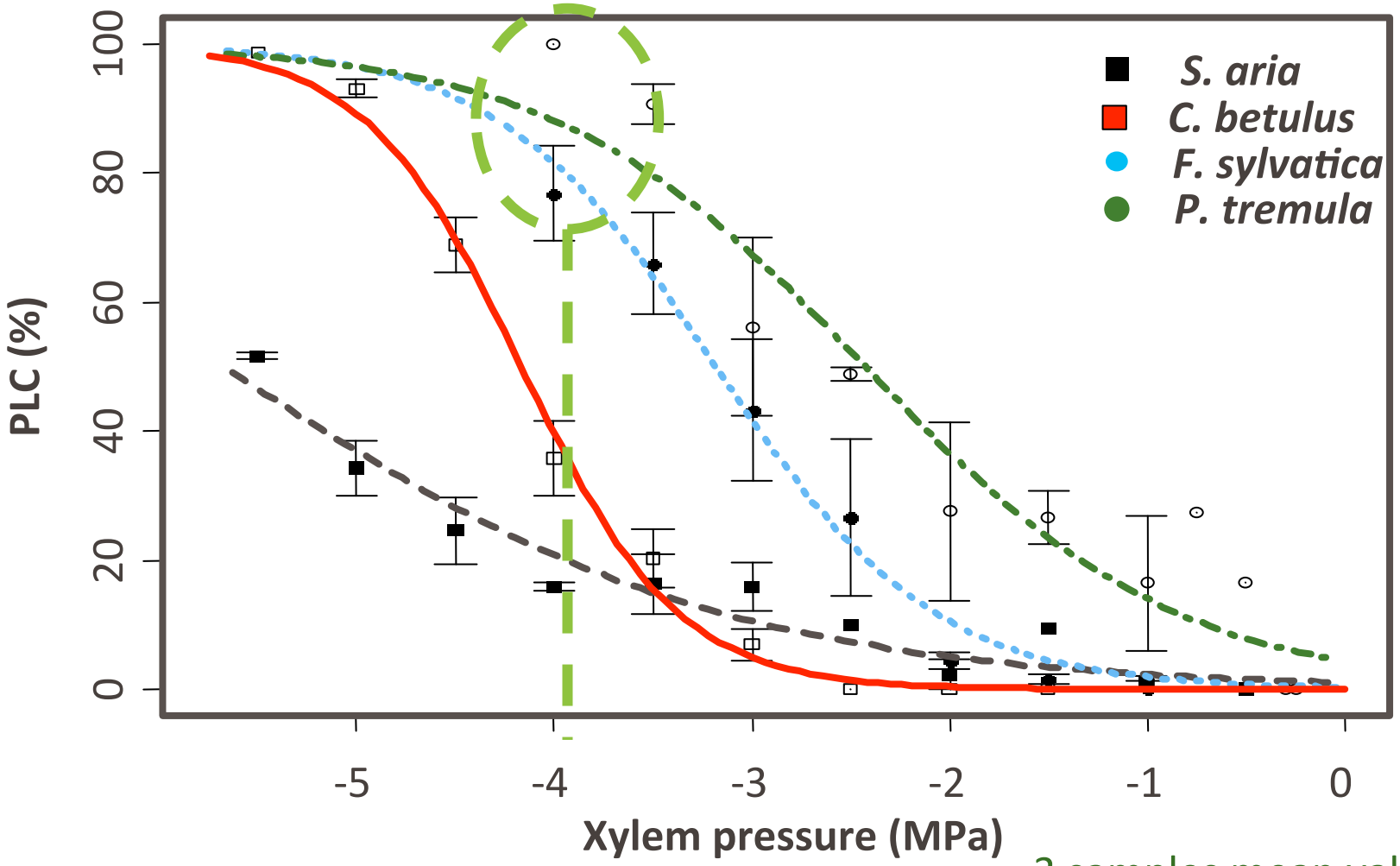






INTERSPECIFIC VARIABILITY OF THE PIT GEOMETRY

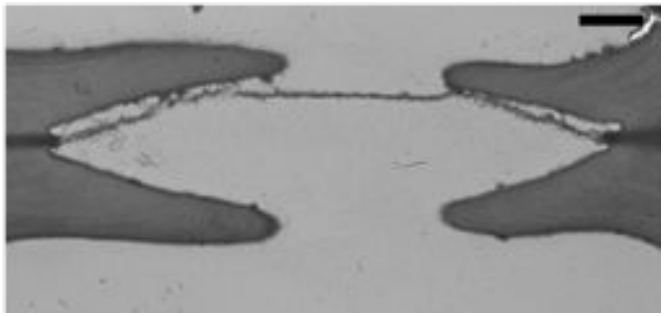
- *4 SPECIES CONTRASTED IN THEIR VC*



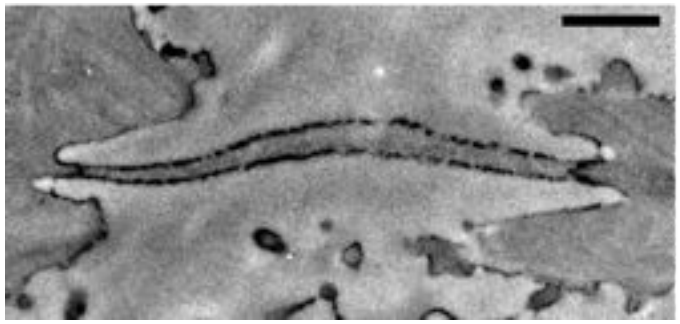
3 samples mean values ± SE

EXPERIMENTAL EVIDENCE OF STRAINS

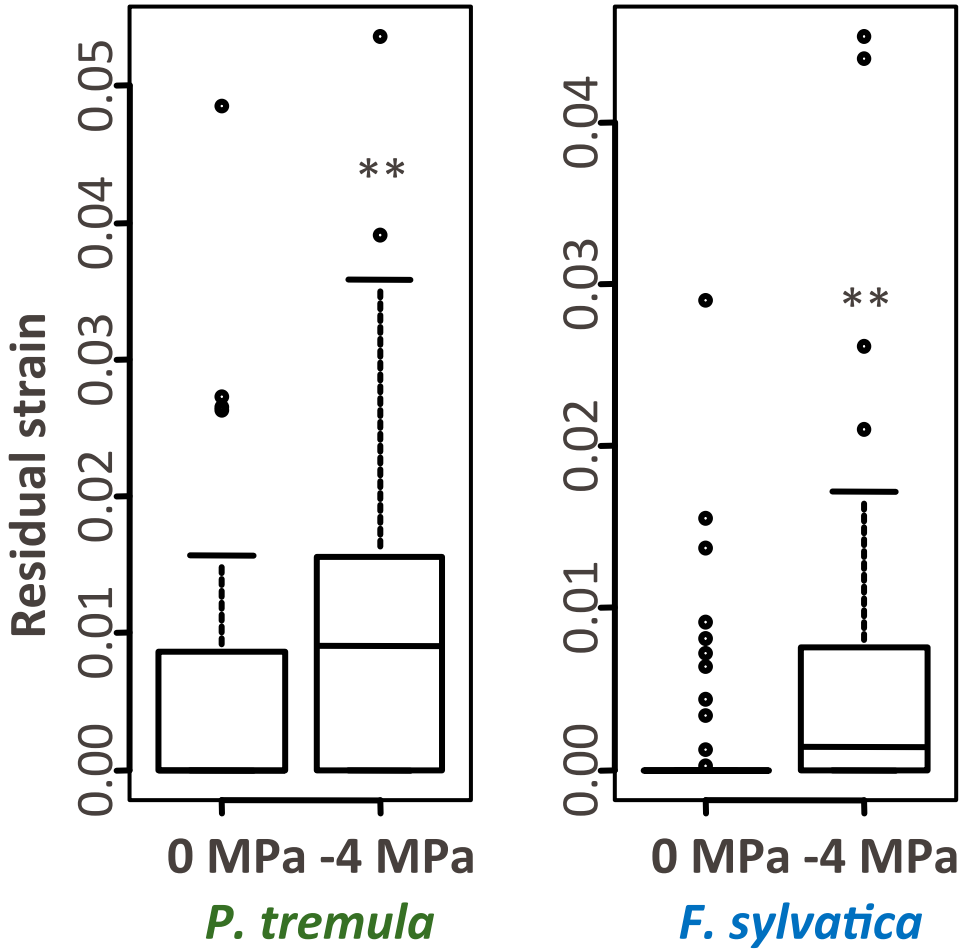
RESIDUAL STRAINS



$\varepsilon_{res} = (D_m - D_p)/D_p$



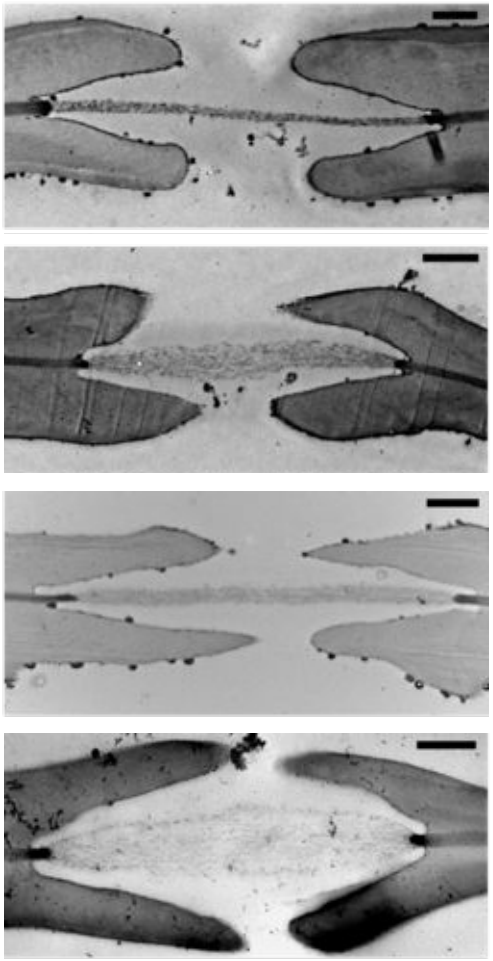
Interspecific variability



Pressure difference induces residual deformations in pit membranes

INTERSPECIFIC VARIABILITY OF THE PIT GEOMETRY

- ***TEM OBSERVATIONS***

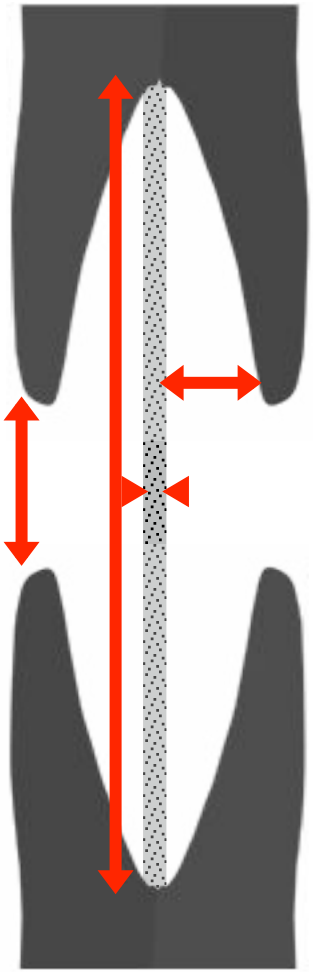


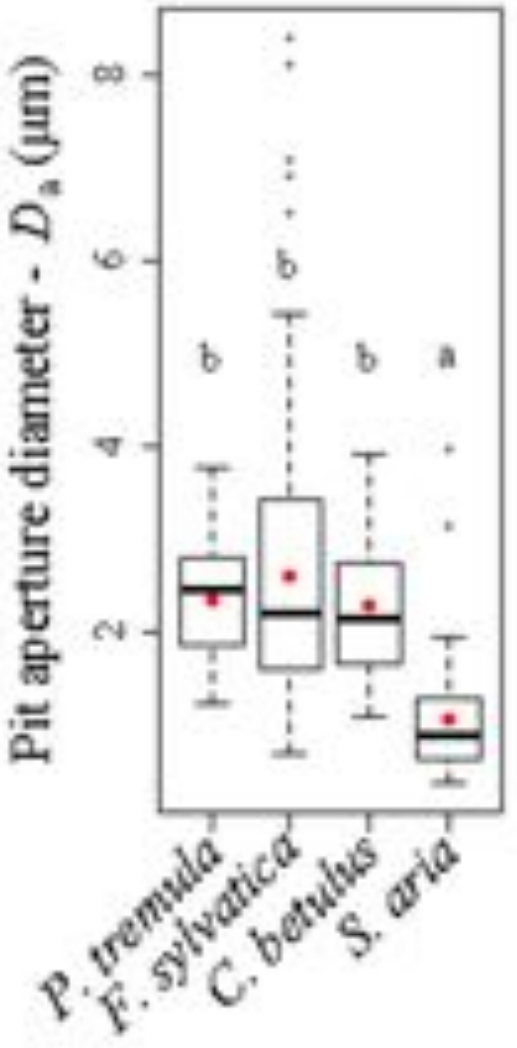
P. tremula

F. sylvatica

C. betulus

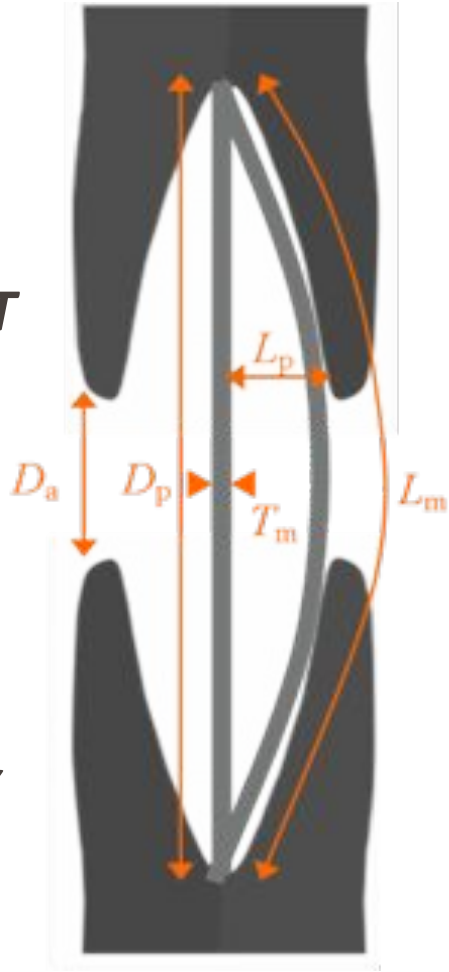
S. Aria





MECHANICAL MODEL

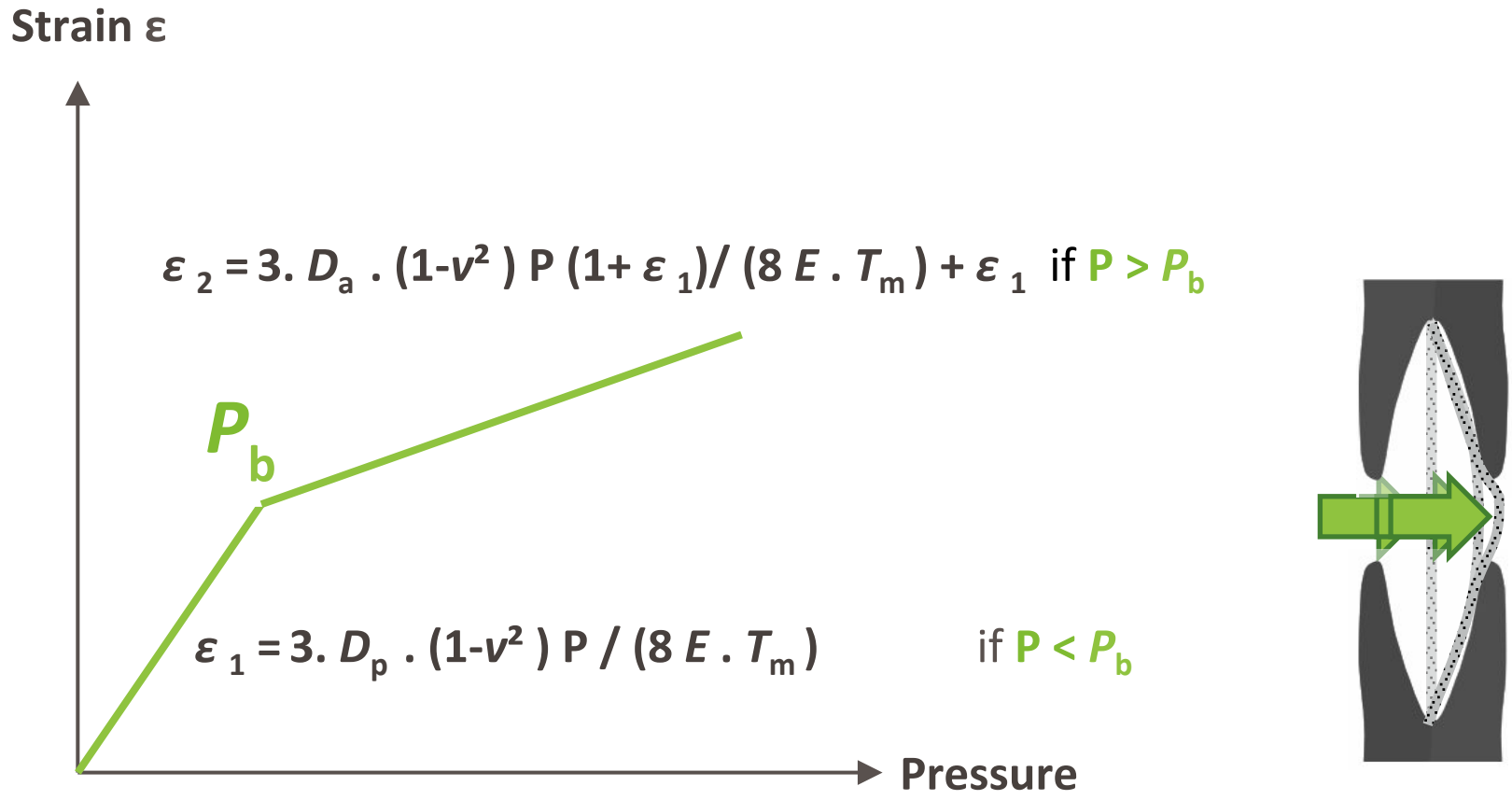
- *INTEGRATE PIT MORPHOLOGICAL FEATURES*
- *PREDICT THE MECHANICAL BEHAVIOUR OF THE PIT MEMBRANE WHEN SUBMITTED TO A PRESSURE DIFERRENCE*
- *INVOLVEMENT OF THE PIT GEOMETRY IN INTERSPECIFIC VARIABILITY OF THE VULNERABILITY TO CAVITATION*



MECHANICAL MODEL

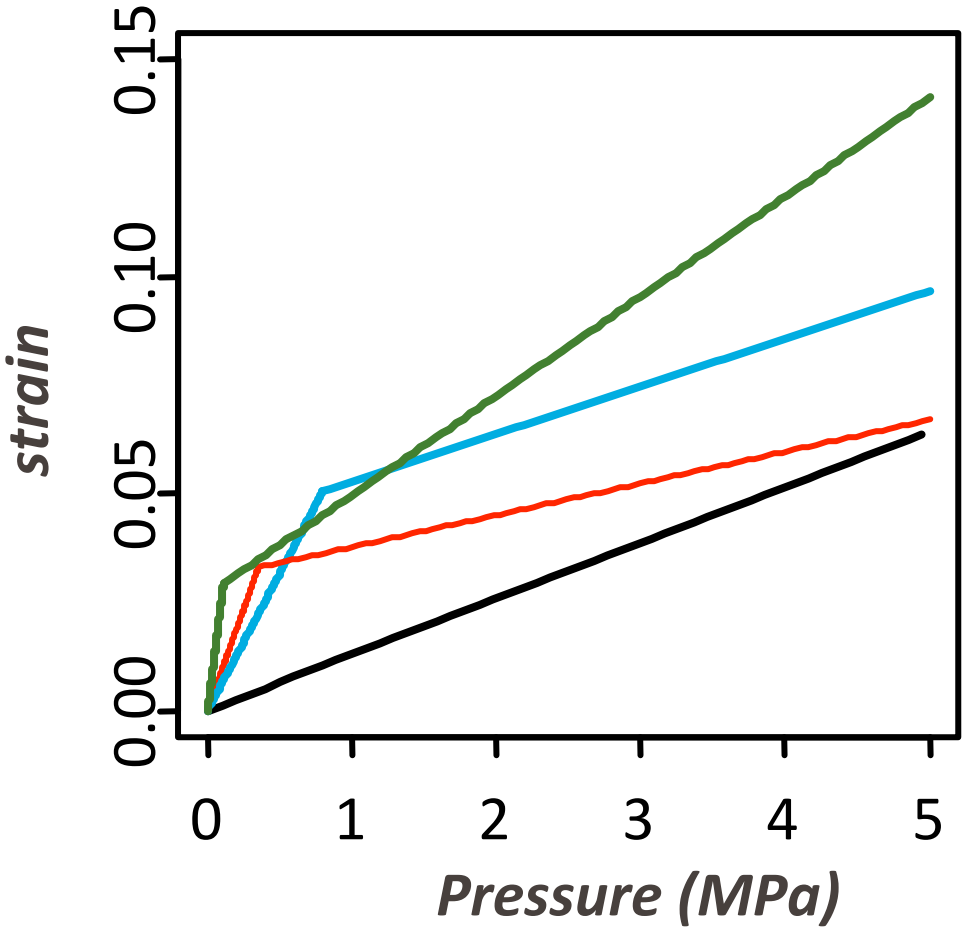
CLAMPED CIRCULAR PLATE UNDER A UNIFORMLY DISTRIBUTED LOAD

$$W_{(P)} = P \cdot [(R^2 - r^2)]^2 / (64. D)$$

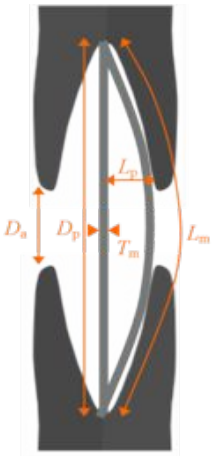


MECHANICAL MODEL

MECHANICAL BEHAVIOR OF PITS WHEN SUBMITTED TO A PRESSURE

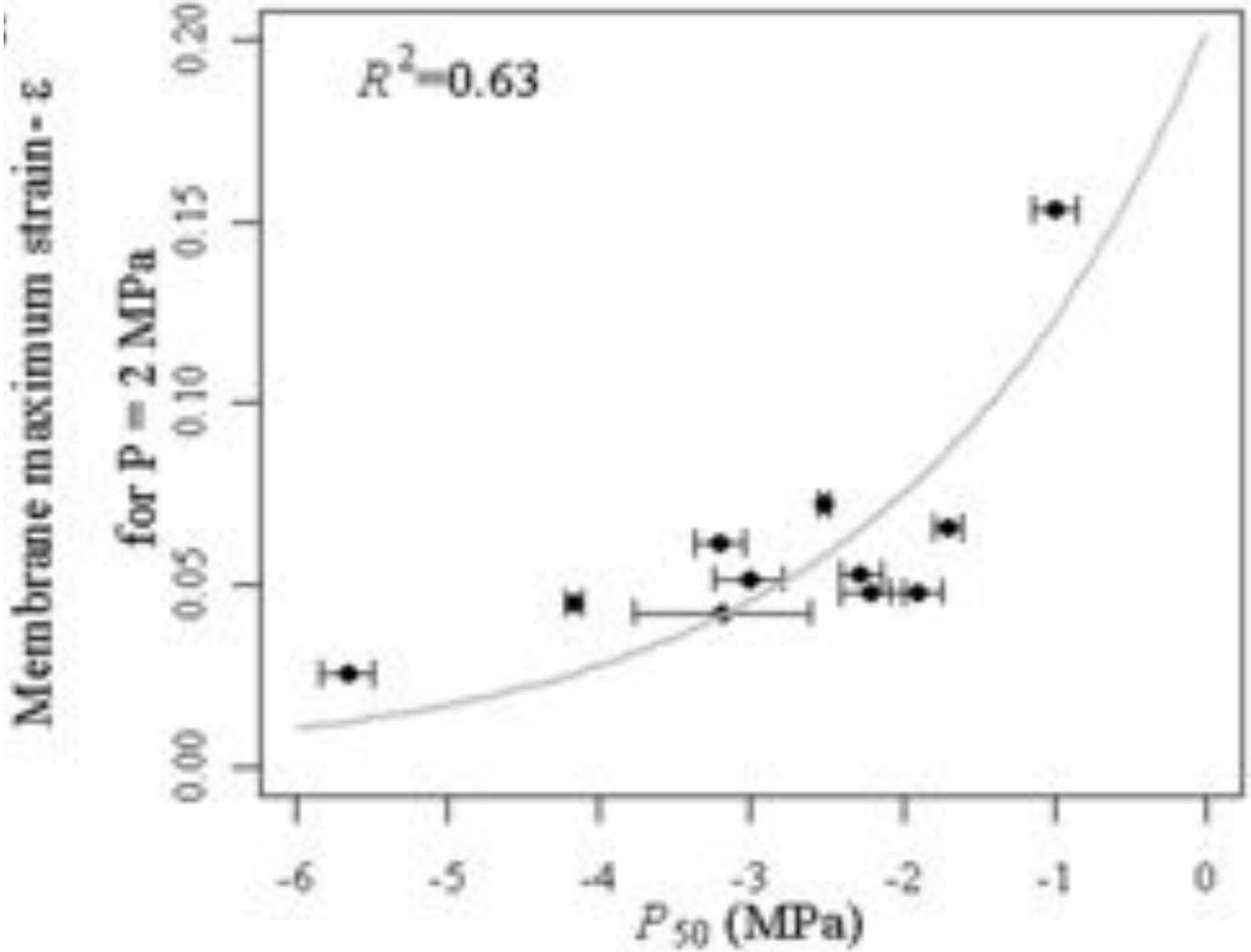


SPECIES	P_{50}
Populus tremula	-2.42 MPa
Fagus sylvatica	-3.18 MPa
Carpinus betulus	-4.17 MPa
Sorbus aria	-5.67 MPa



MECHANICAL MODEL

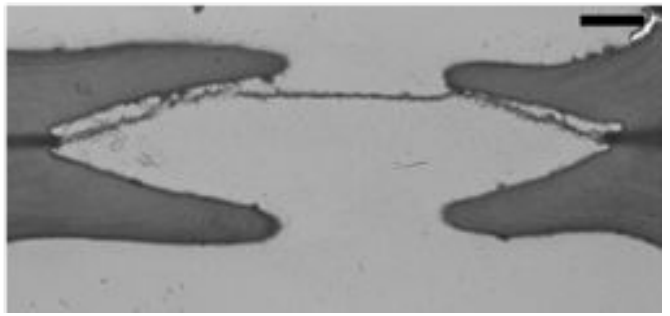
- ***MECHANICAL BEHAVIOR OF PITS IN 11 SPECIES***



CONCLUSIONS

- *AIR SEEDING THROUGH PIT MEMBRANES SHOULD OCCUR AFTER DEFLECTION AGAINST APERTURE*
- *PIT GEOMETRY IS CORRELATED WITH P50*
- *STRAINS EXPERIENCED BY THE PIT MEMBRANE ARE DETERMINANT FOR VULNERABILITY TO CAVITATION*

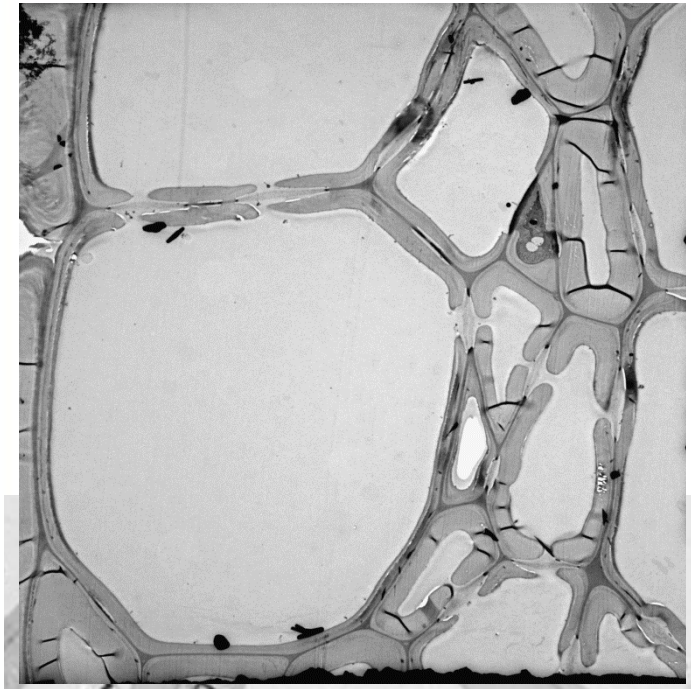
→ *MEMBRANE BREAKAGE ?*

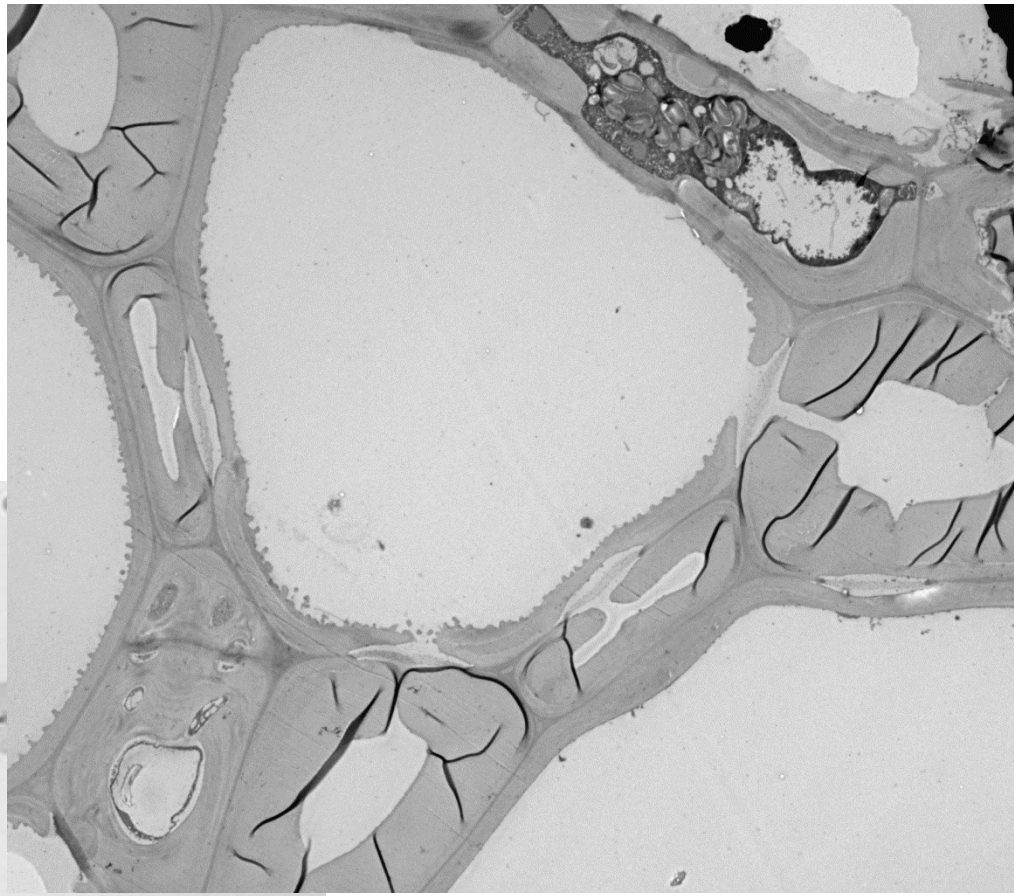


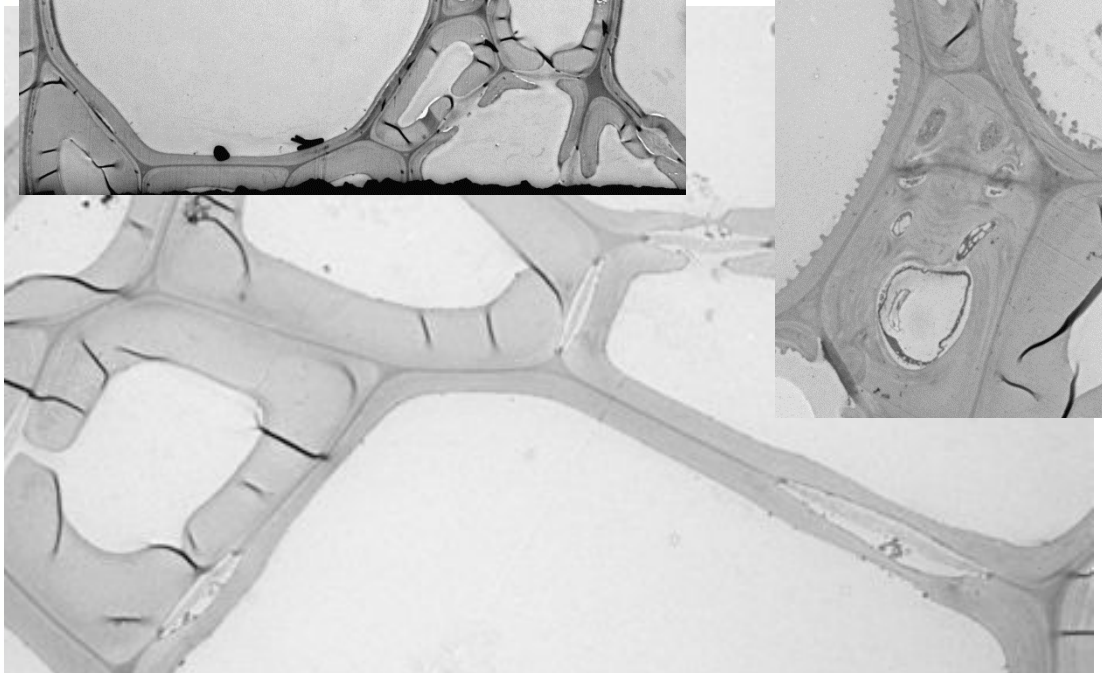
THANK YOU FOR YOUR ATTENTION

I am looking for a postdoctoral fellowship. I am interested in water transport, plant development and responses to stress.

aude.tixier@yahoo.fr

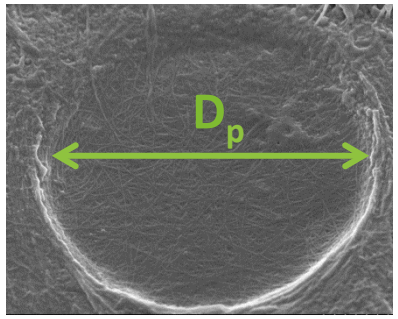






MODELE MECANIQUE

PLAQUE FINE ENCASTREE [FIXEE] SUR SON POURTOUR



Déformation : $\varepsilon = (L - L_0)/ L_0$

Déformation plastique → Déformation résiduelle

Déformation élastique

$\varepsilon_2 = 3. D_a . (1-\nu^2) P (1+ \varepsilon_{Pb})/ (8 E . T_m) + \varepsilon_{Pb}$ si $P > P_b$

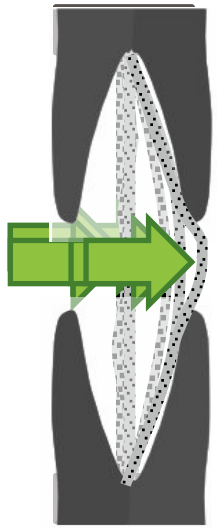
ε_{Pb}

Pente : E = $\frac{1}{\text{Module de Young}}$

$\varepsilon_1 = 3. D_p . (1-\nu^2) P / (8 E . T_m)$ si $P < P_b$

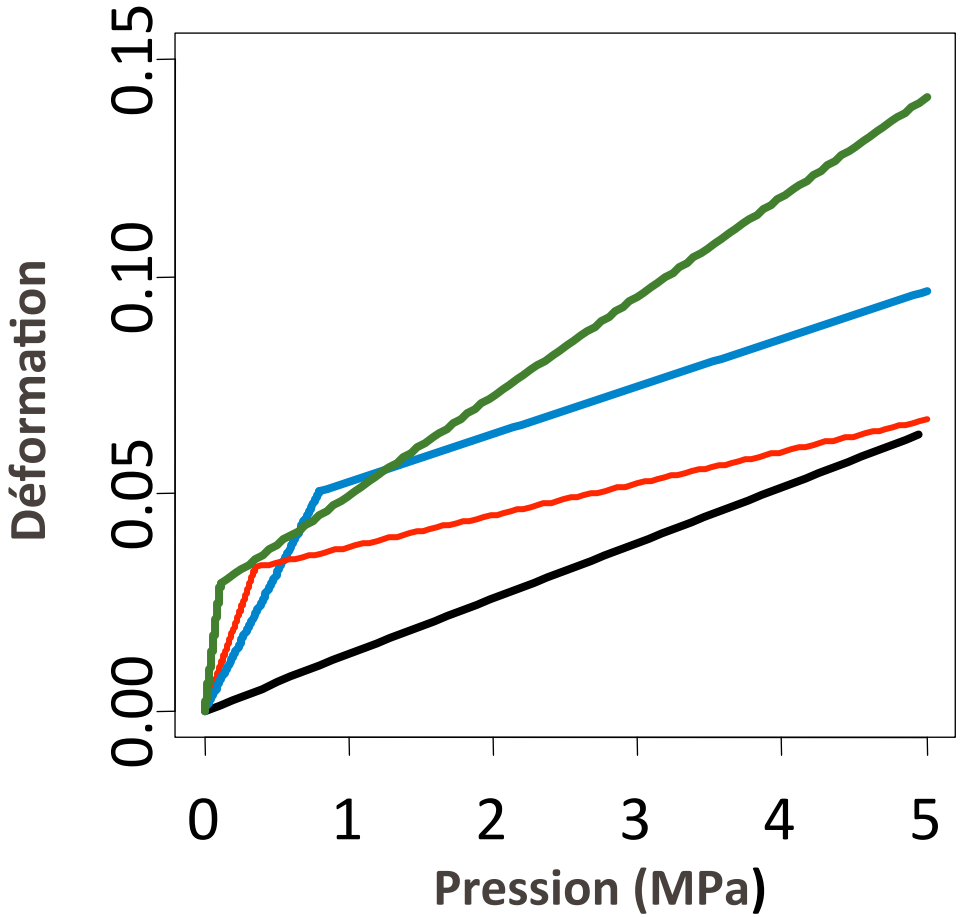
Pression (P)

P_b

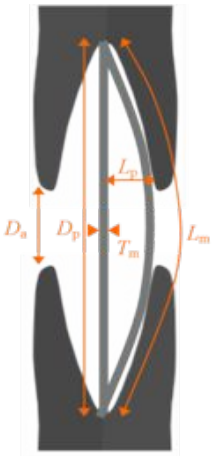


MODELE MECANIQUE

COMPORTEMENT MECANIQUE DE PONCTUATIONS SOUMISES A UNE PRESSION

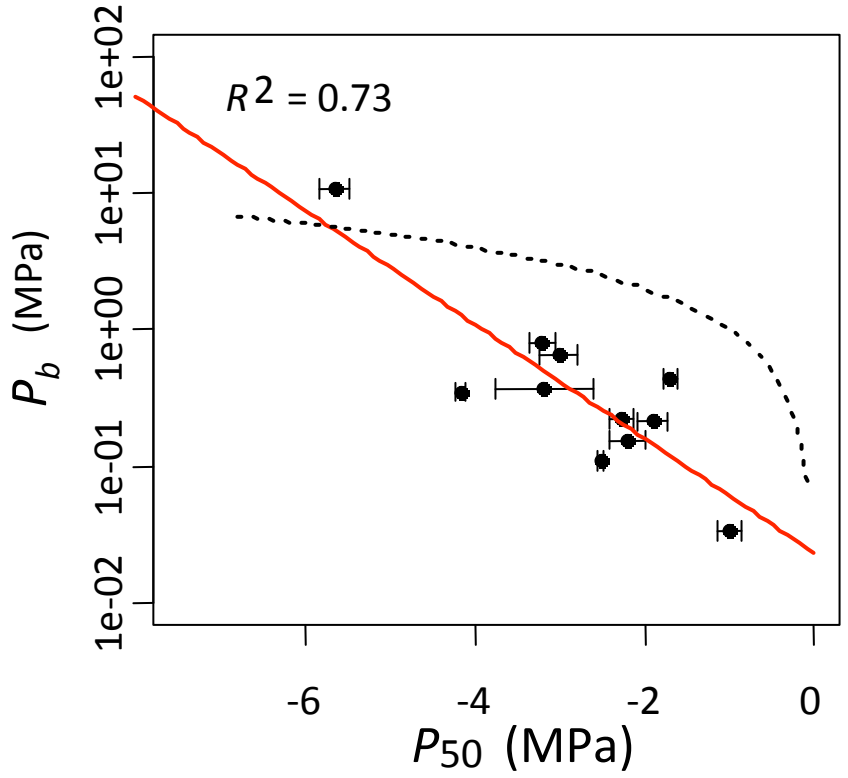


ESPECES	P_{50}
Populus tremula	-2.42 MPa
Fagus sylvatica	-3.18 MPa
Carpinus betulus	-4.17 MPa
Sorbus aria	-5.67 MPa



MODELE MECANIQUE

COMPORTEMENT MECANIQUE DE PONCTUATIONS DE 11 ESPECES

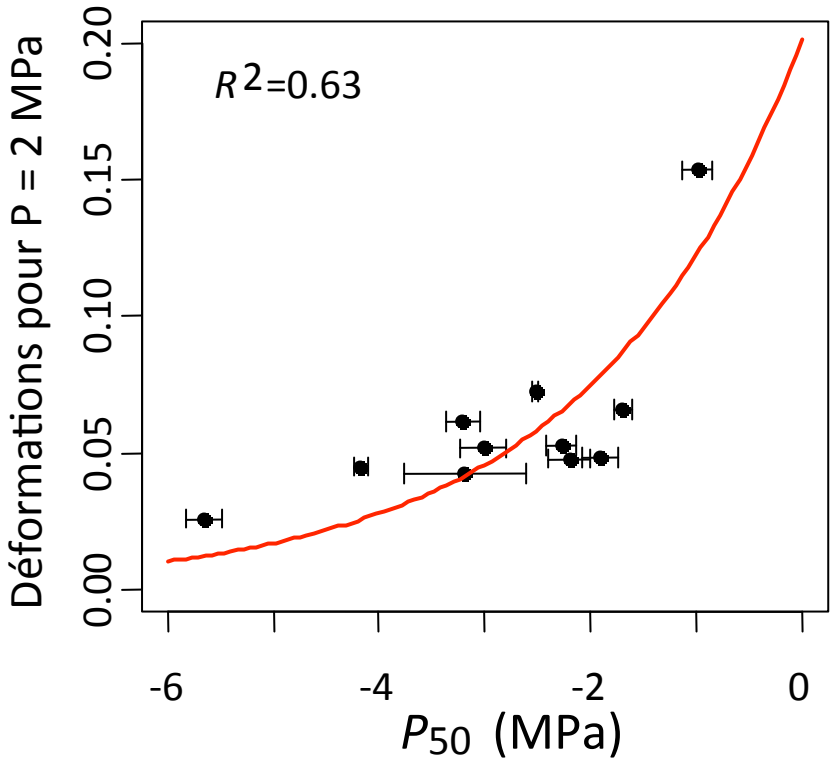


.La géométrie de la ponctuation est corrélée avec le P_{50}

.La cavitation a lieu après aspiration de la membrane contre les bordures

MODELE MECANIQUE

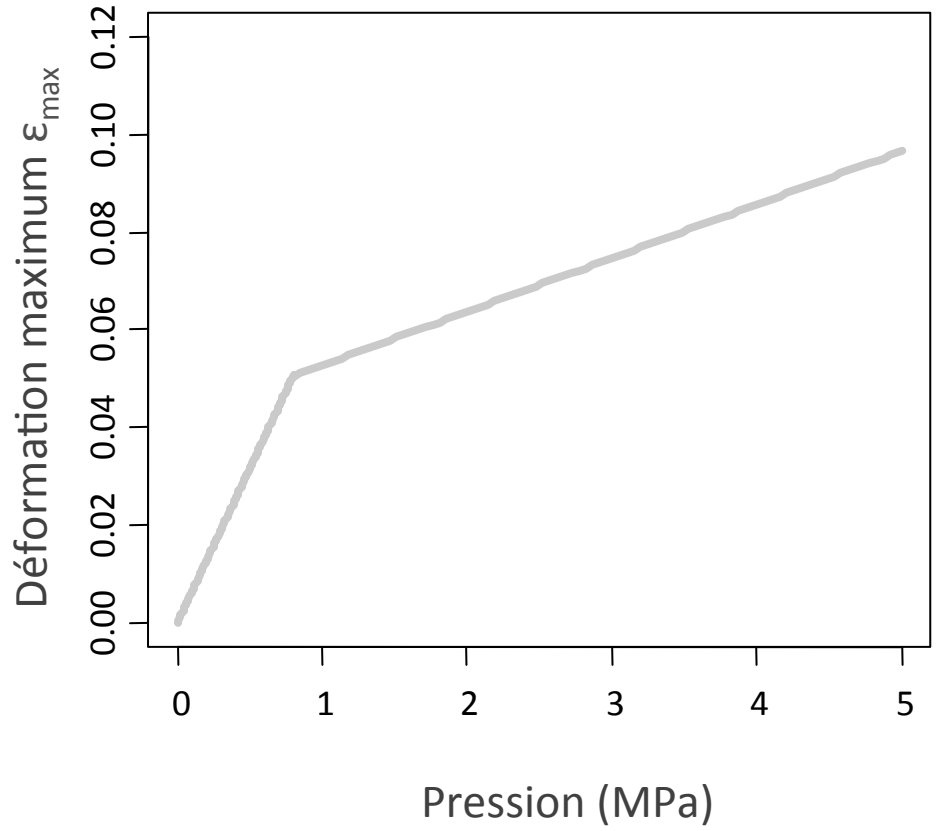
COMPORTEMENT MECANIQUE DE PONCTUATIONS DE 11 ESPECES



.Les déformations subies par la membrane sont déterminantes pour la vulnérabilité à la cavitation

MODELE MECANIQUE

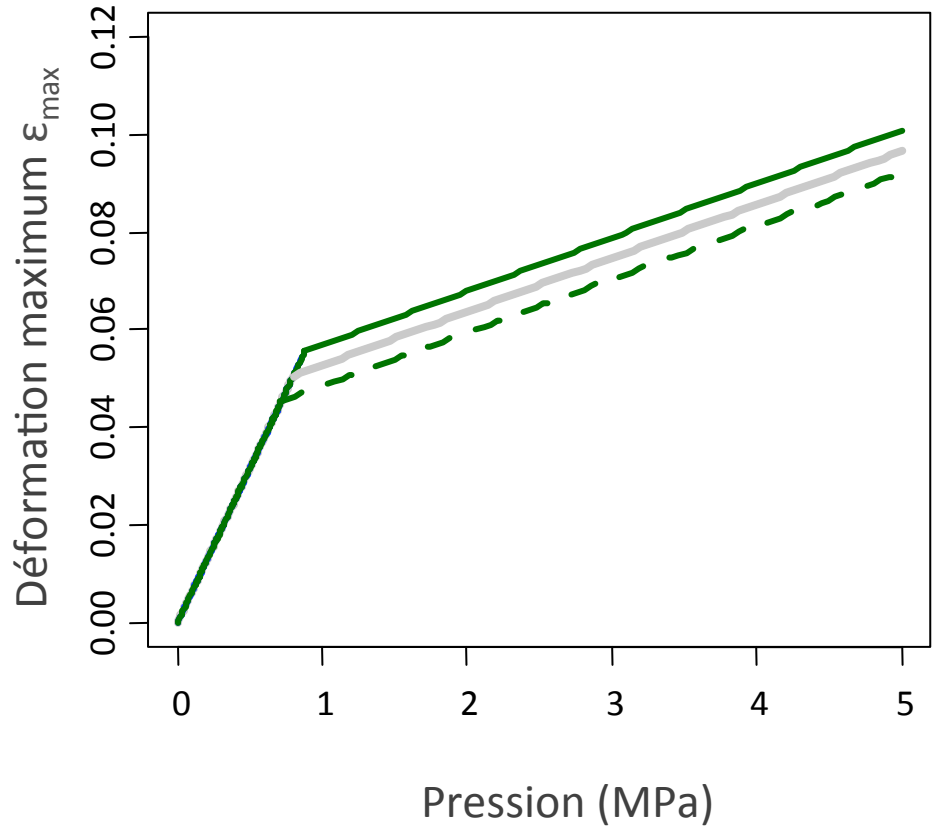
ANALYSE DE SENSIBILITE



Fagus sylvatica

MODELE MECANIQUE

ANALYSE DE SENSIBILITE



Fagus sylvatica

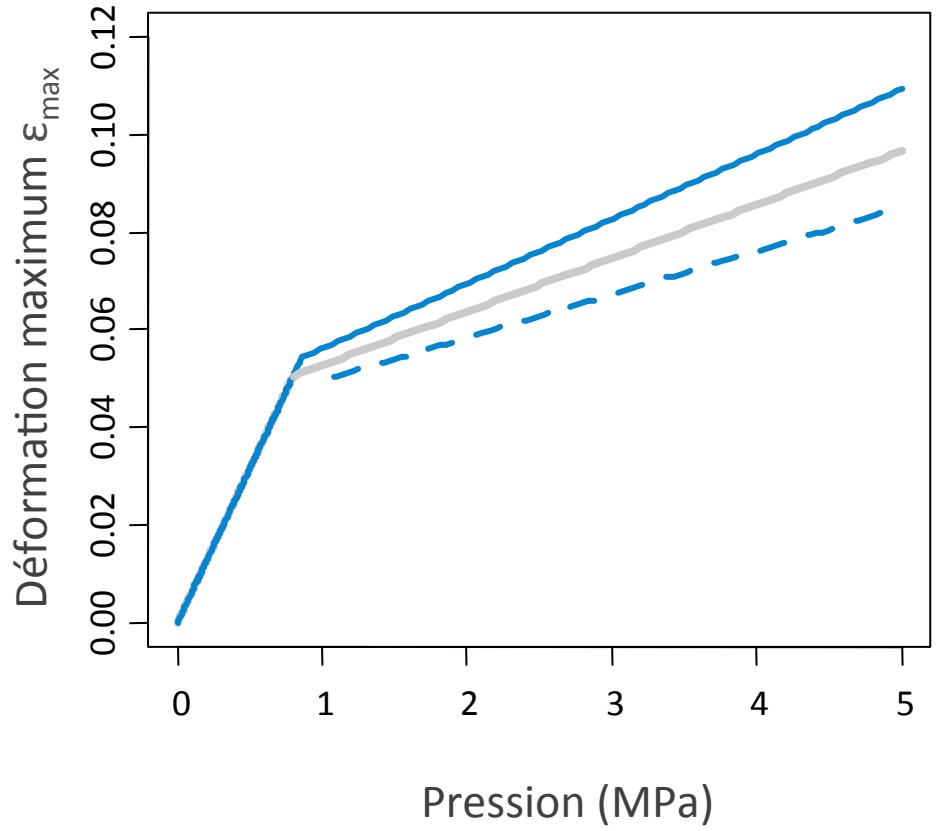
Variation de 10 % de la profondeur de chambre

—— **+10 %**

---- **- 10%**

MODELE MECANIQUE

ANALYSE DE SENSIBILITE



Fagus sylvatica

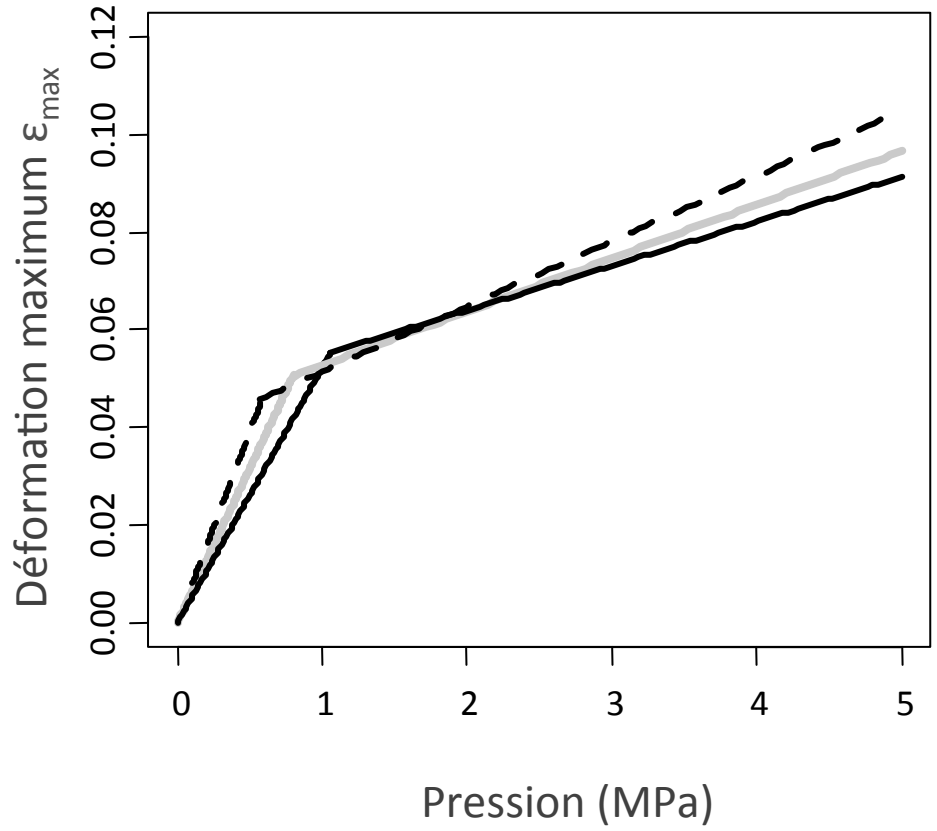
Variation de 10 % de l'ouverture de chambre

—— **+10 %**

---- **- 10%**

MODELE MECANIQUE

ANALYSE DE SENSIBILITE



Fagus sylvatica

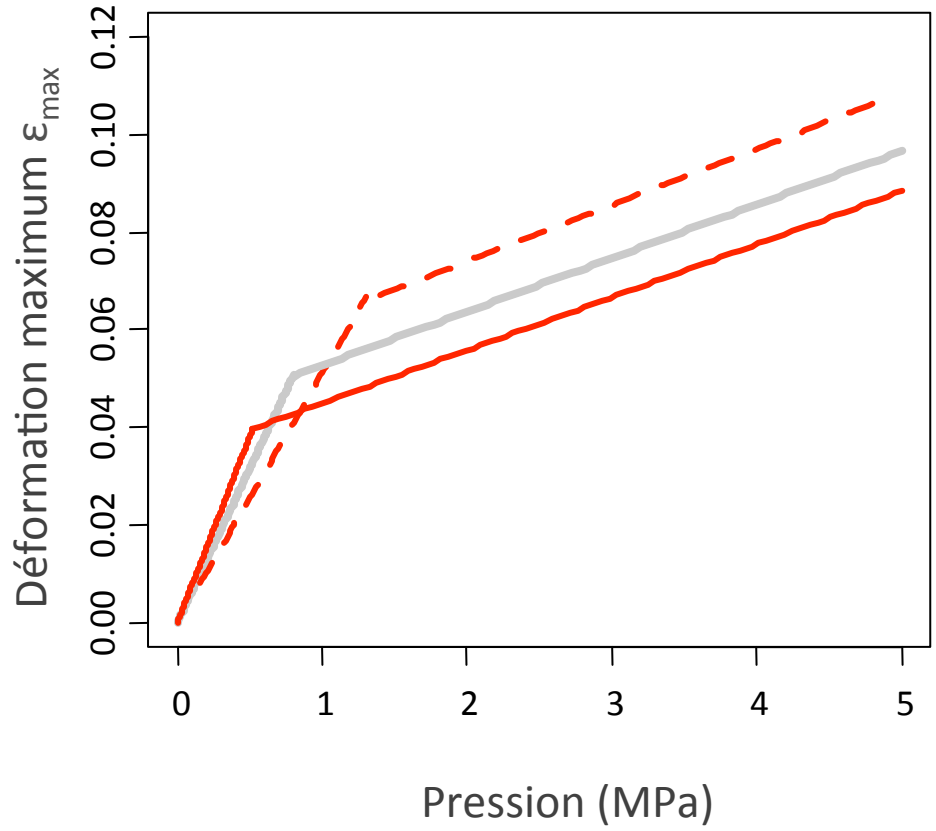
Variation de 10 % de l'épaisseur de membrane

—— **+10 %**

---- **- 10%**

MODELE MECANIQUE

ANALYSE DE SENSIBILITE



Fagus sylvatica

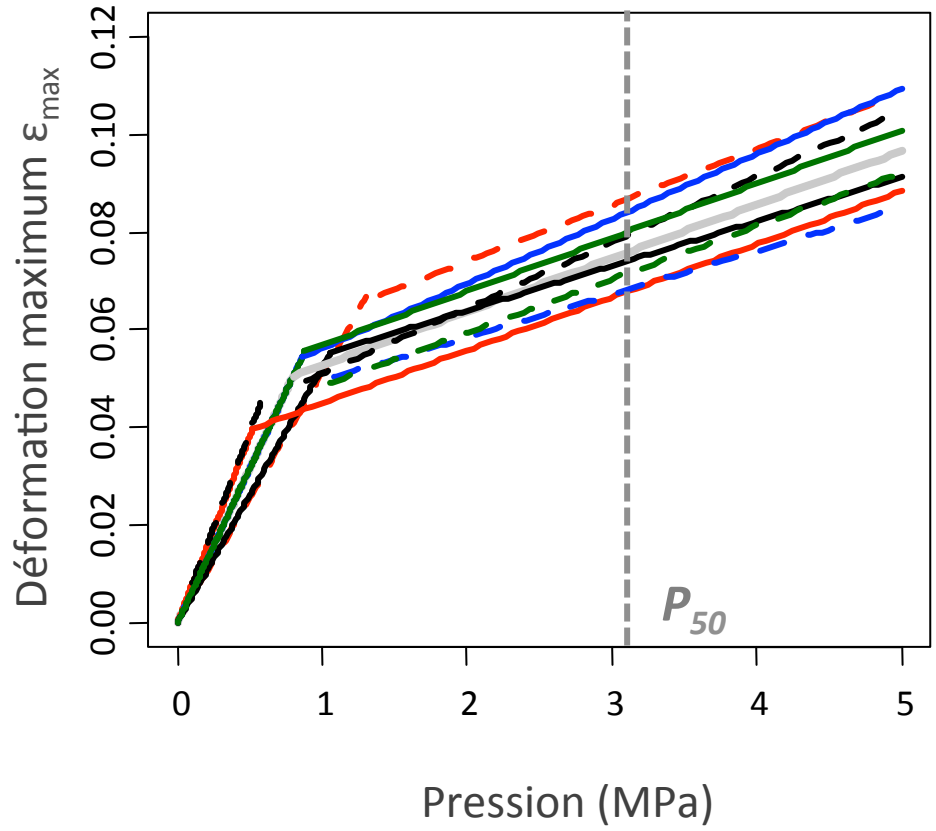
Variation de 10 % du diamètre de membrane

—— +10 %

---- - 10%

MODELE MECANIQUE

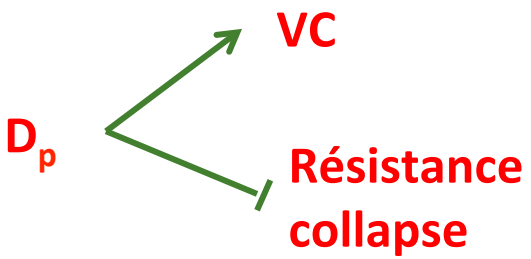
ANALYSE DE SENSIBILITE



LE DIAMÈTRE DE MEMBRANE EST LA DIMENSION DONT LES VARIATIONS AURAIENT LE PLUS D'EFFET SUR LES DÉFORMATIONS

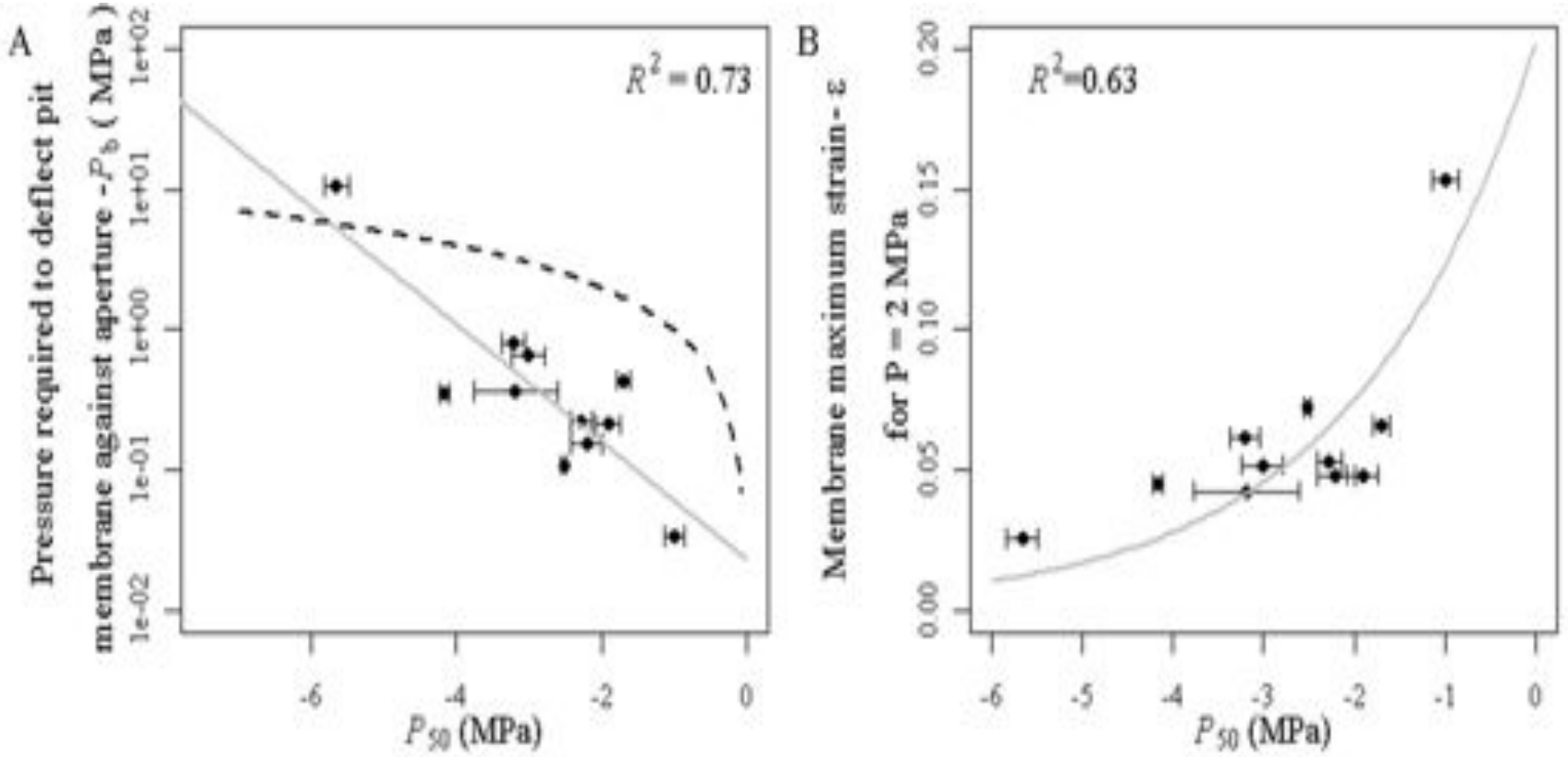
.Faibles variations interspécifiques

.Contraint par d'autres fonctions ?



MECHANICAL MODEL

MECHANICAL BEHAVIOUR OF PITS IN 11 SPECIES



.The pressure required to deflect the pit membrane against aperture is correlated to P_{50}

. Air seeding through pit membranes should occur after aspiration of the membrane

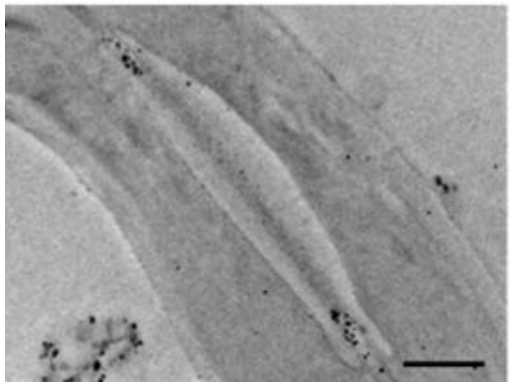
. Pit geometry is correlated to P_{50}

PERSPECTIVES

BASES <u>MOLECULAIRES</u> DE LA VULNERABILITE A LA CAVITATION

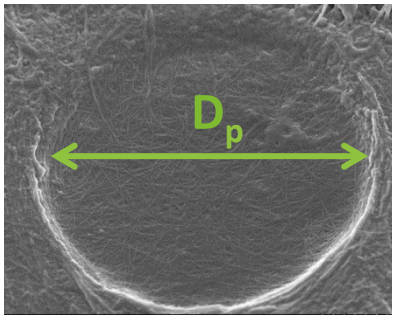
.Phénotypage des lignées transgéniques

. Rôle des PG ?



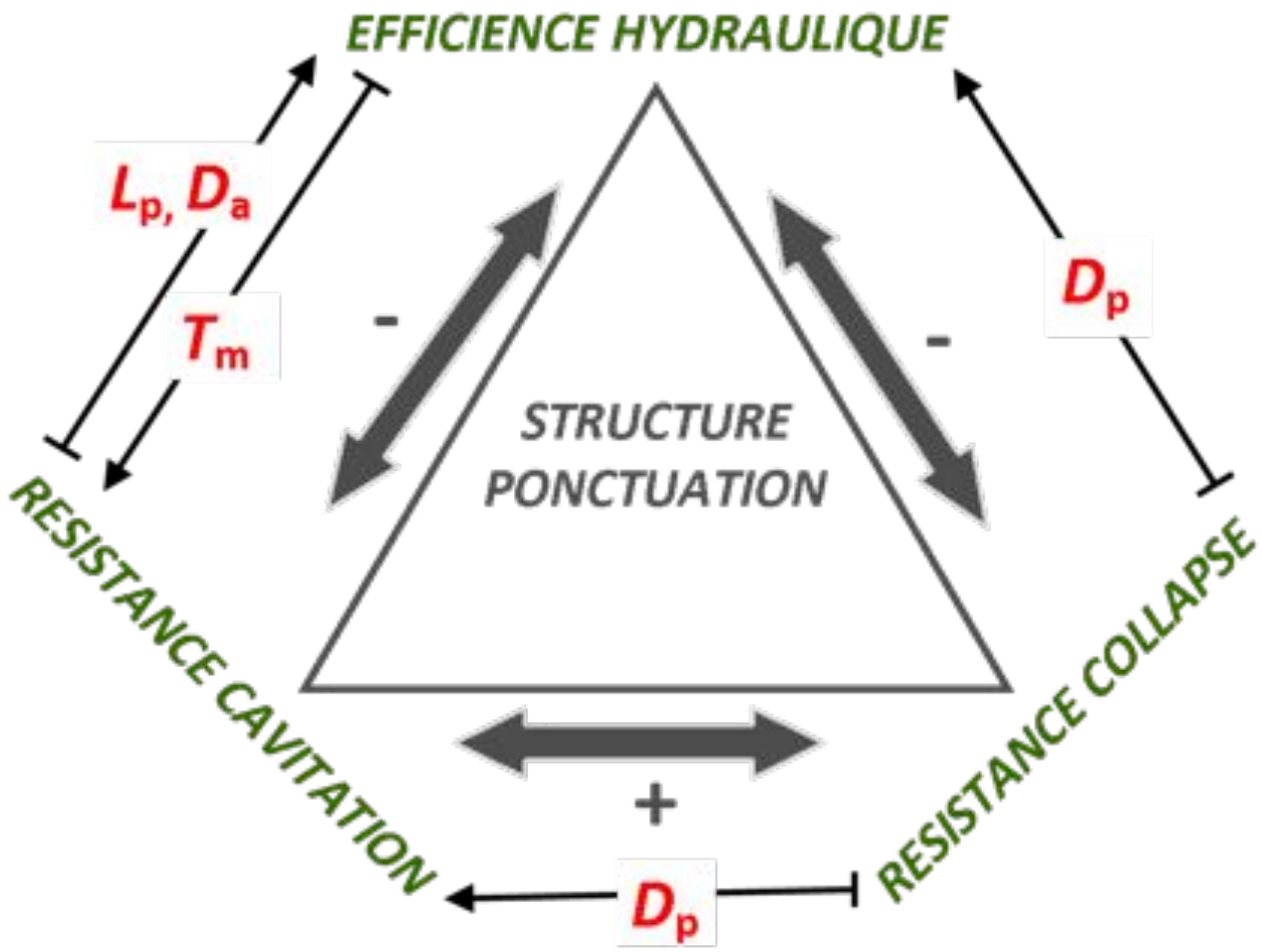
Herbette *et al.,* 2013

Pectines au niveau de l'anneau



. Gènes impliqués dans la géométrie et la disposition des ponctuations ?

PERSPECTIVES

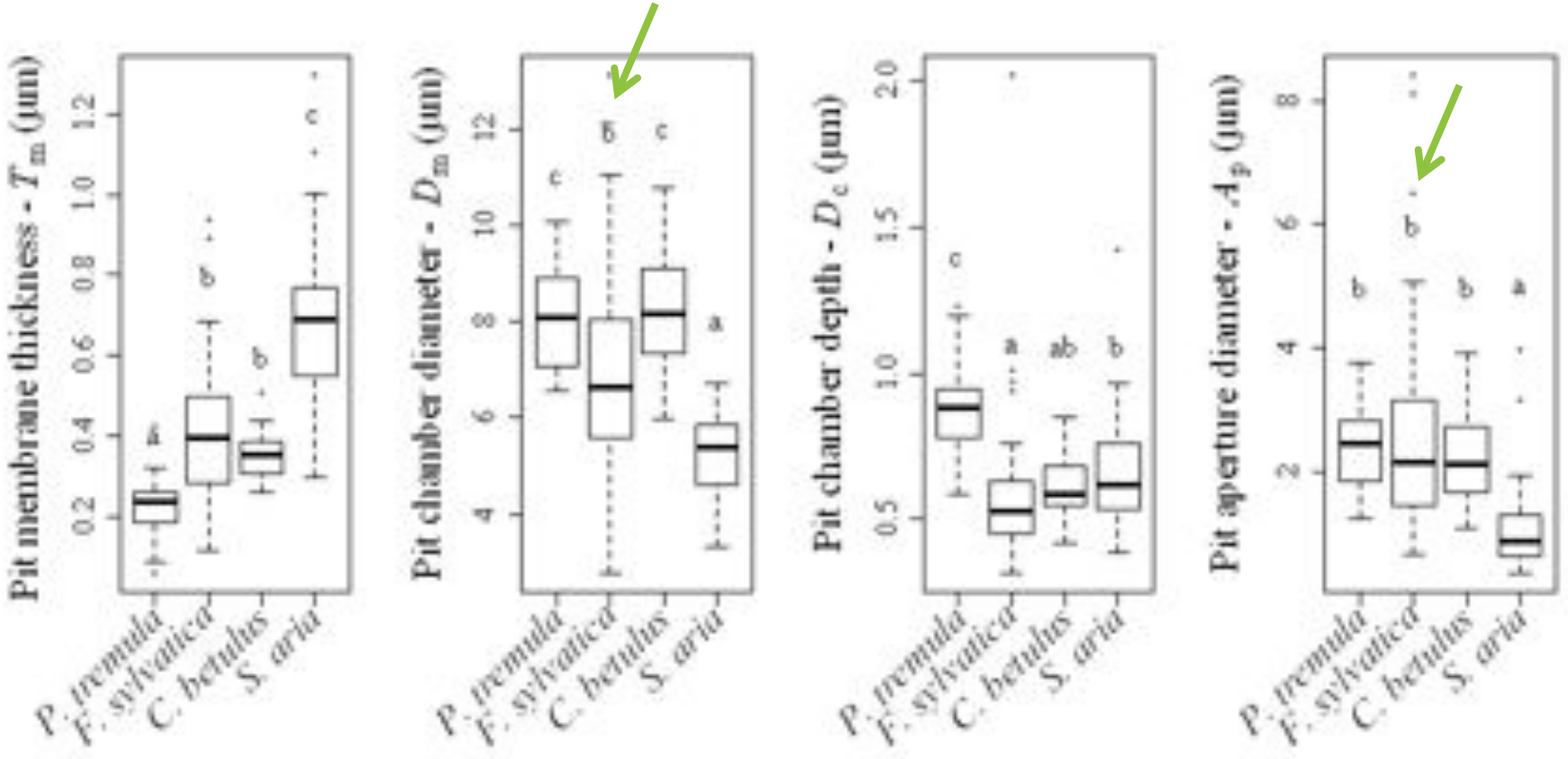


Facteurs déterminants la géométrie de la ponctuation ?

PIT MECHANICAL MODEL

VULNERABILITY TO CAVITATION CURVES

Specie	P_{50} (Mpa)	n pit
Control samples		
Sorbus aria	- 5.67^{d} (± 0.17)	52
Carpinus betulus	- 4.17^{c} (± 0.06)	24
Fagus sylvatica	- 3.18^{b} (± 0.16)	69
Populus tremula	- 2.42^{a} (± 0.03)	32
Embolised samples (- 4 Mpa)		
Fagus sylvatica	- 3. 18^{b} (± 0.16)	59
Populus tremula	- 2. 42^{a} (± 0.03)	51

Variabilité interspecifique de la morphologie des ponctuations

TEM OBSERVATIONS