Impact du vieillissement sur la structure et les propriétés des fibres de lin:
Cas des fibres modernes et archéologiques

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Université de Bretagne Sud, Institut IRDL

Séminaire inter GDR

Jeudi 16 juillet 2026

ANUBIS PROJECT

Agenda

- Brief context and introduction
- Specificities and sensitivity of plant fibres, focus on kink-bands
- Case of archaeological fibres

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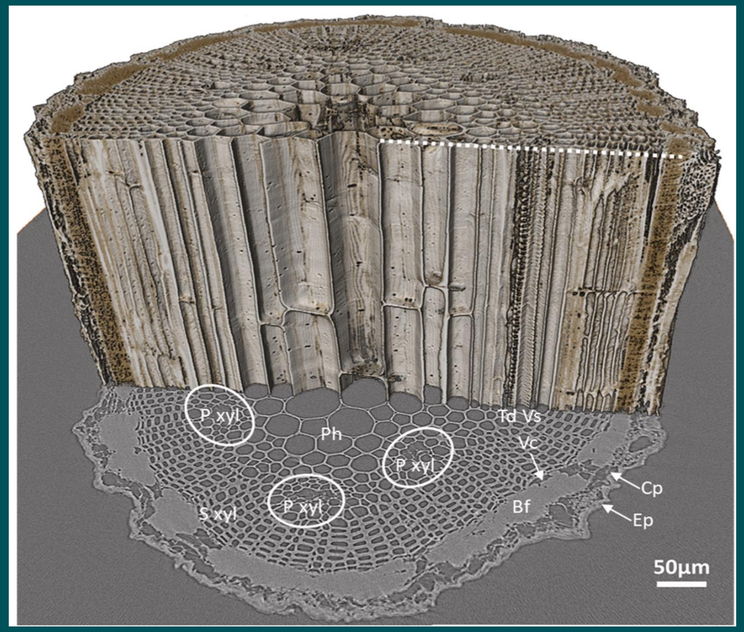
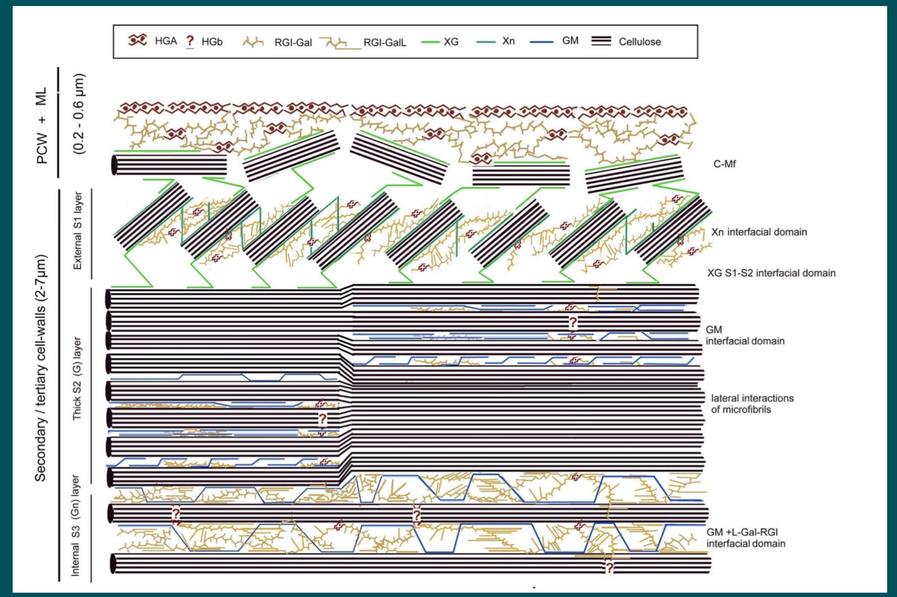
- **Brief context and introduction**
- **Specificities and sensitivity of plant fibres, focus on kink-bands**
- **Case of archaeological fibres**

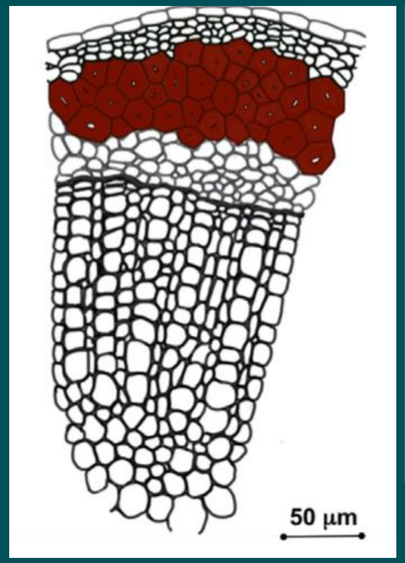
Brief description of flax fibre

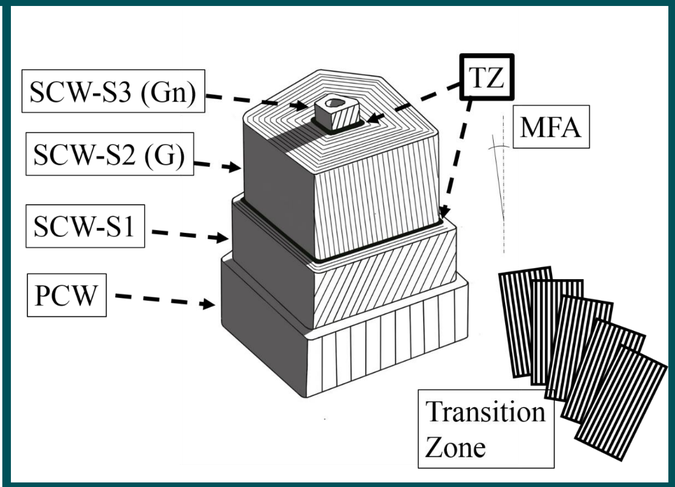


Nuez, Comp Part A, 2020

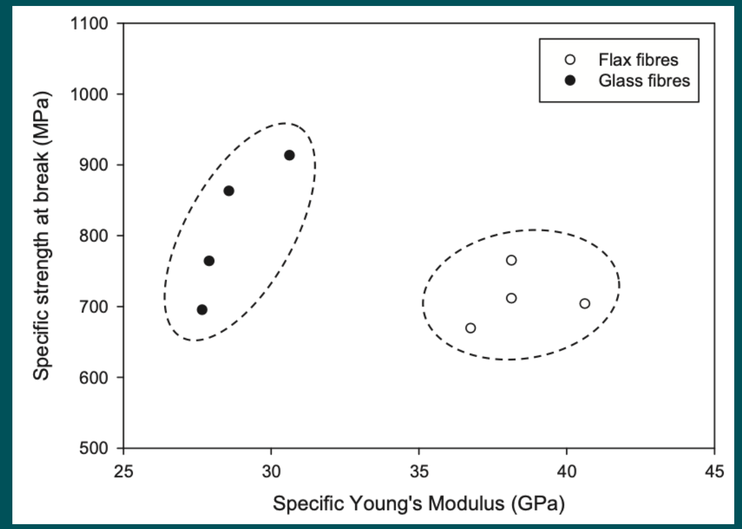


Rihouey et al., 2017





Baley et al. Bioinsp & Biom, 2018

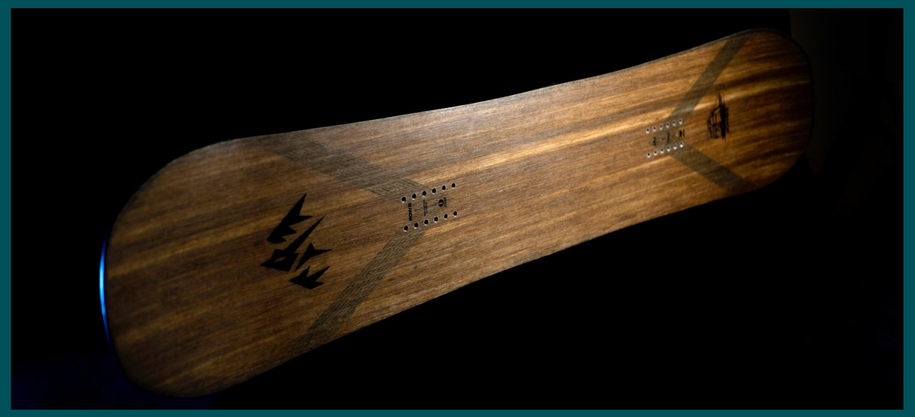


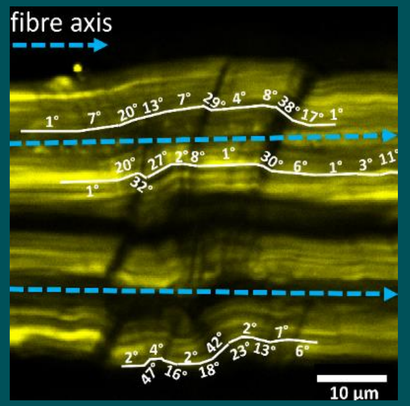
Lefeuvre et al., Material Letters, 2014

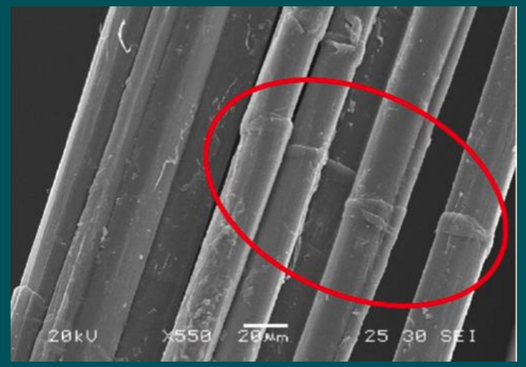
Scientific context

A range of applications, sometimes in extreme environments

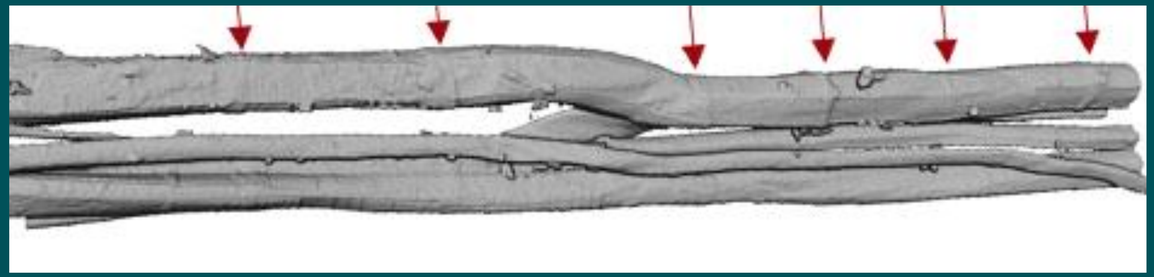
Need for a better understanding of fibre ageing mechanisms, particularly in sensitive areas







Melelli et al., ICP, 2021



Bourmaud et al., ICP, 2022

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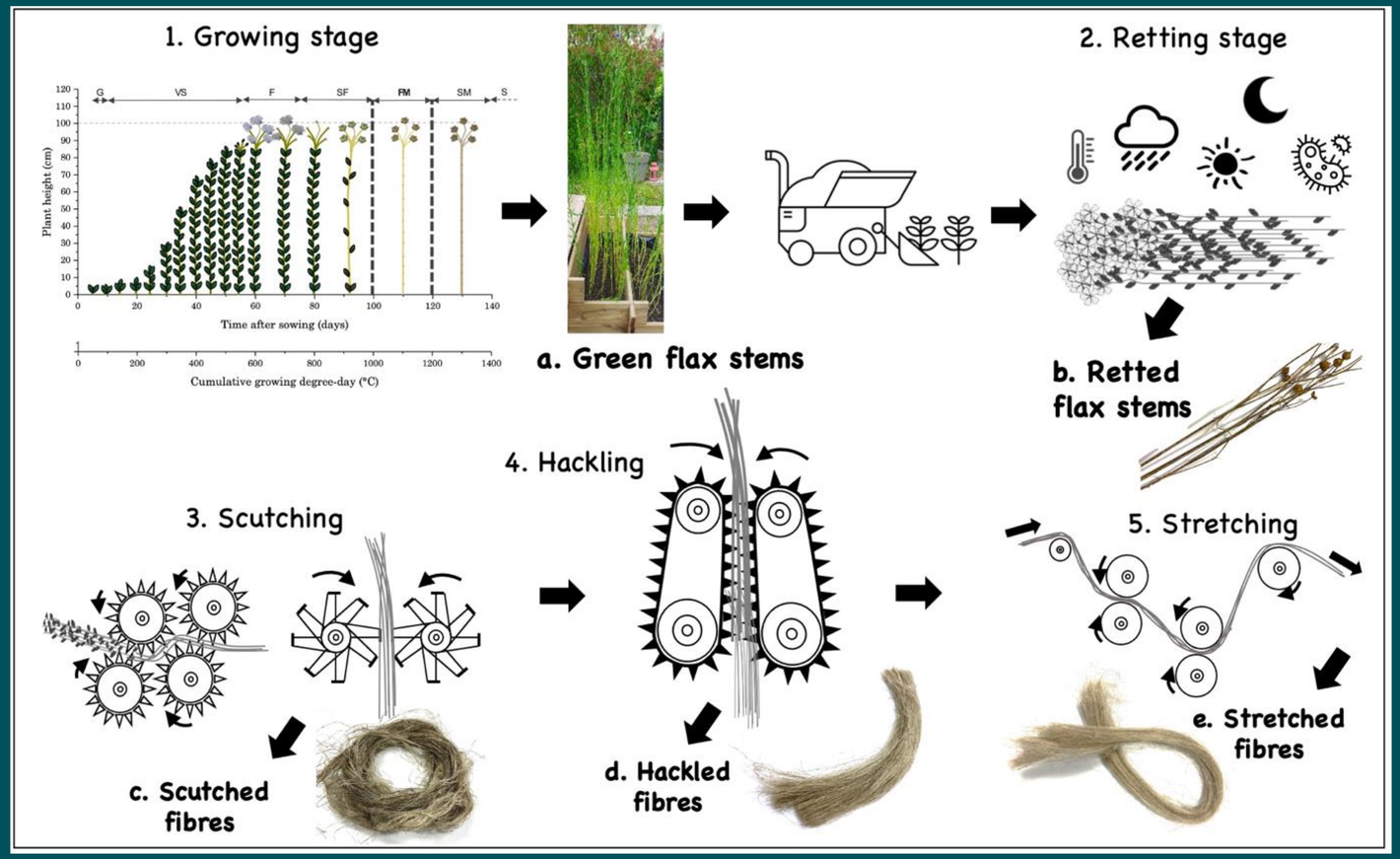
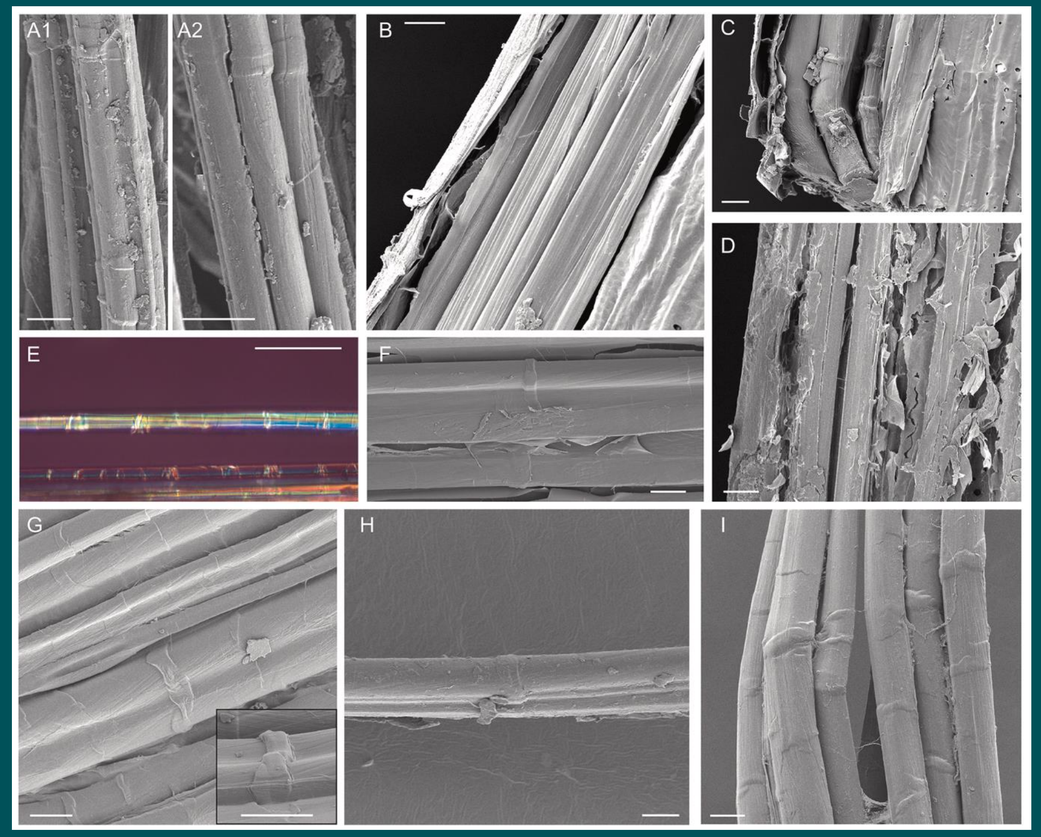
ELUCIDATING THE ORIGIN OF KINK BANDS - ANATOMIX

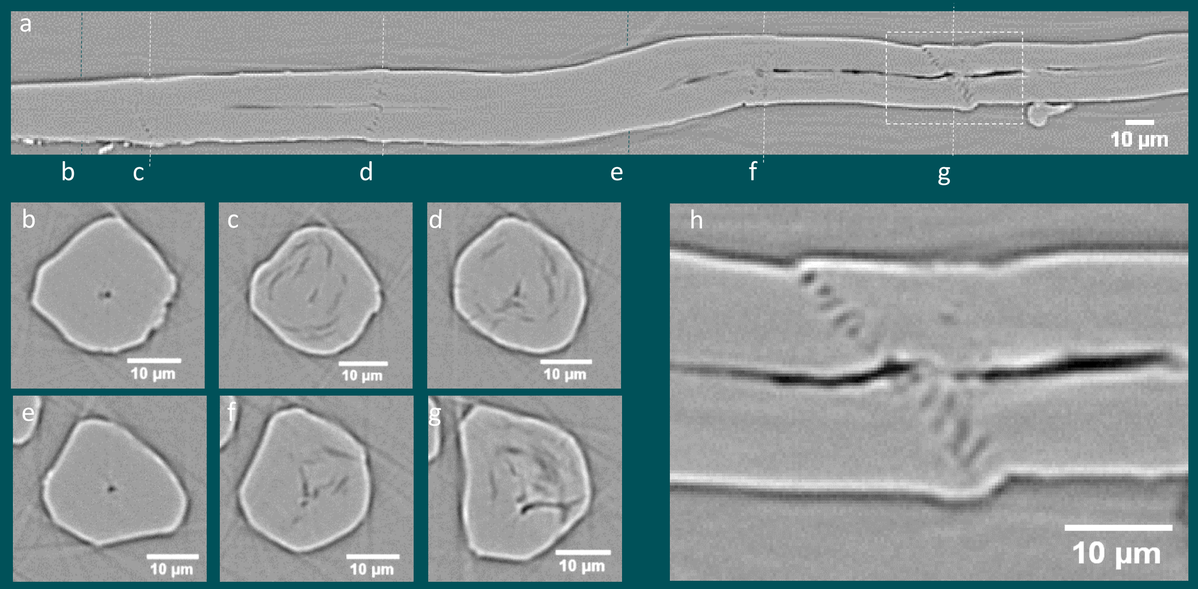


Bourmaud et al, Ind Crops & Prod, 2022

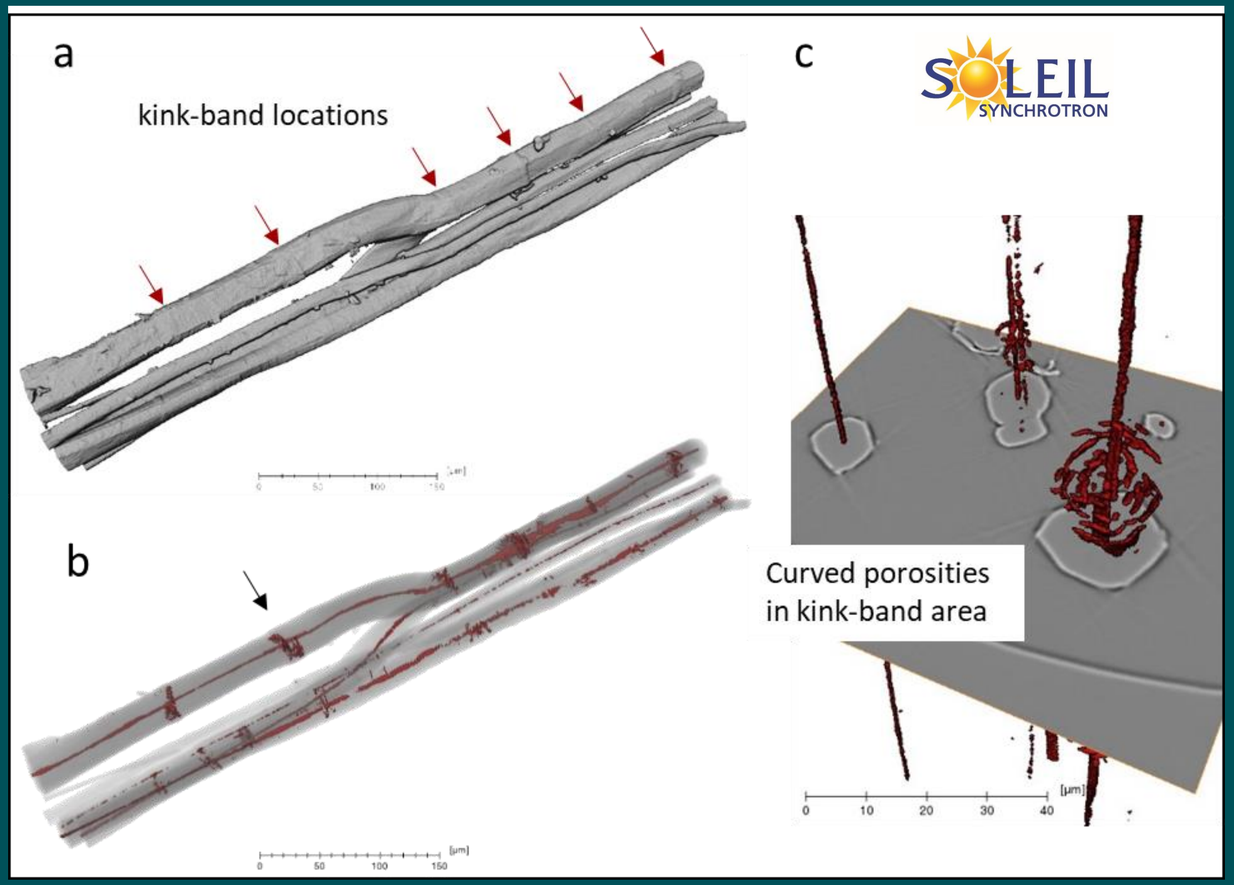


Kozlova et al, Ind Crops & Prod, 2022

ELUCIDATING THE DEVELOPMENT OF KINK BANDS - ANATOMIX



Observations on extracted fibres



Bourmaud et al, Ind Crops & Prod, 2022

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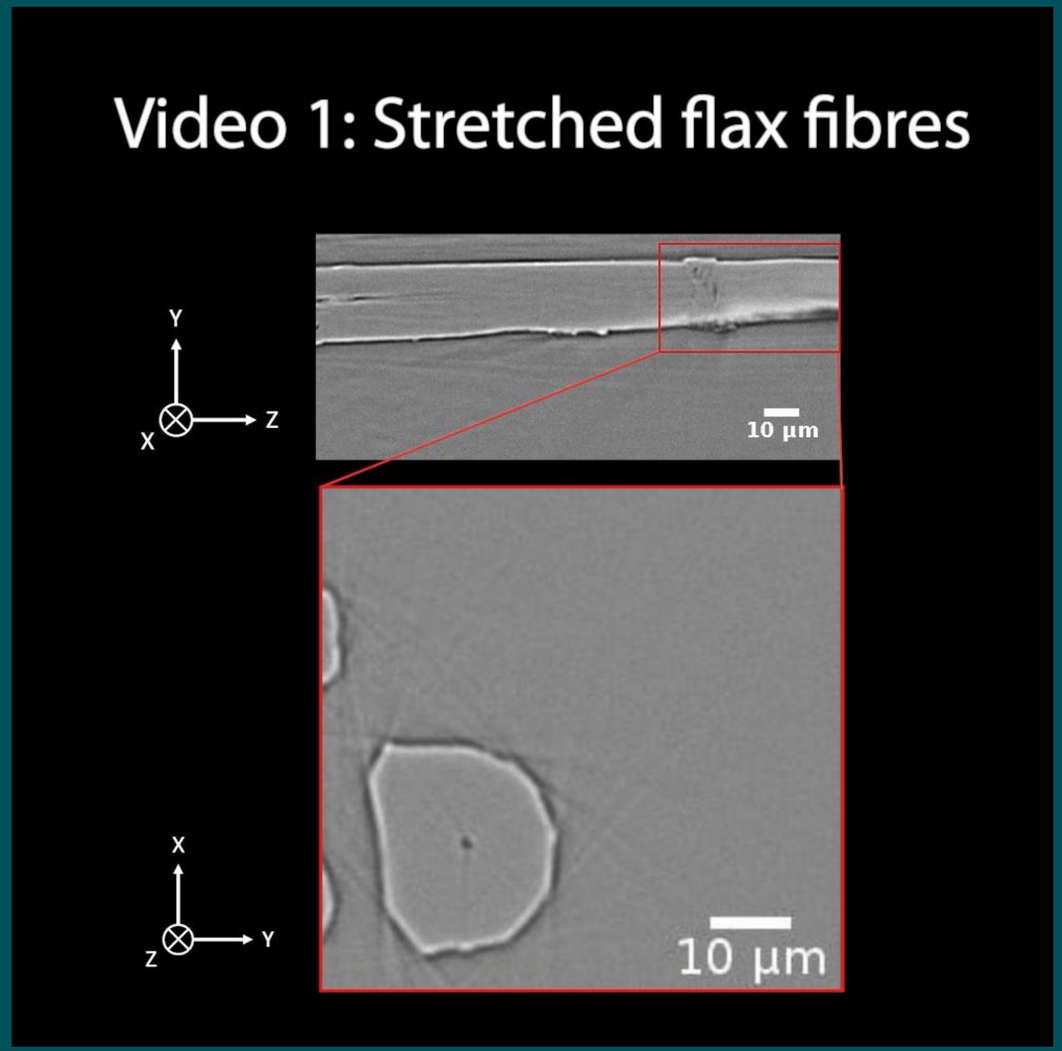
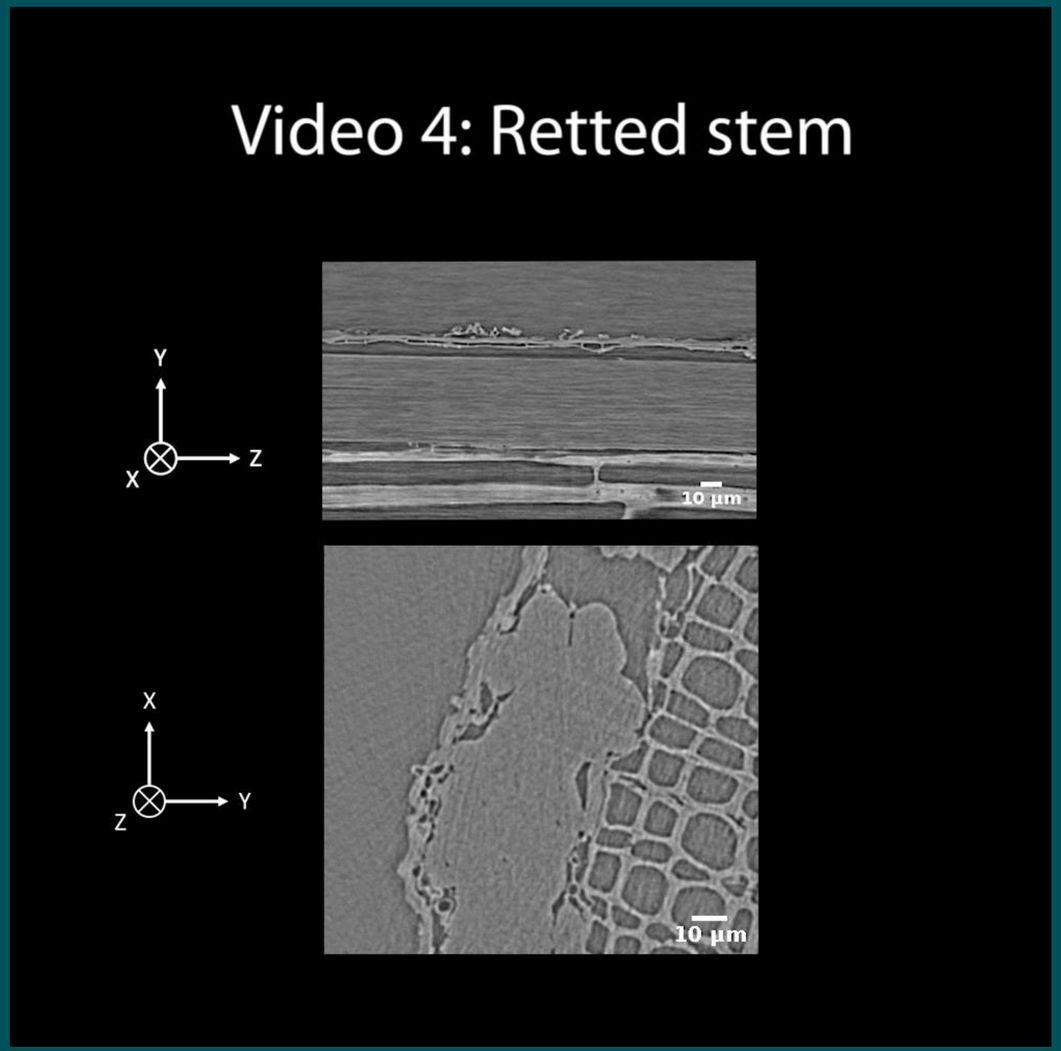
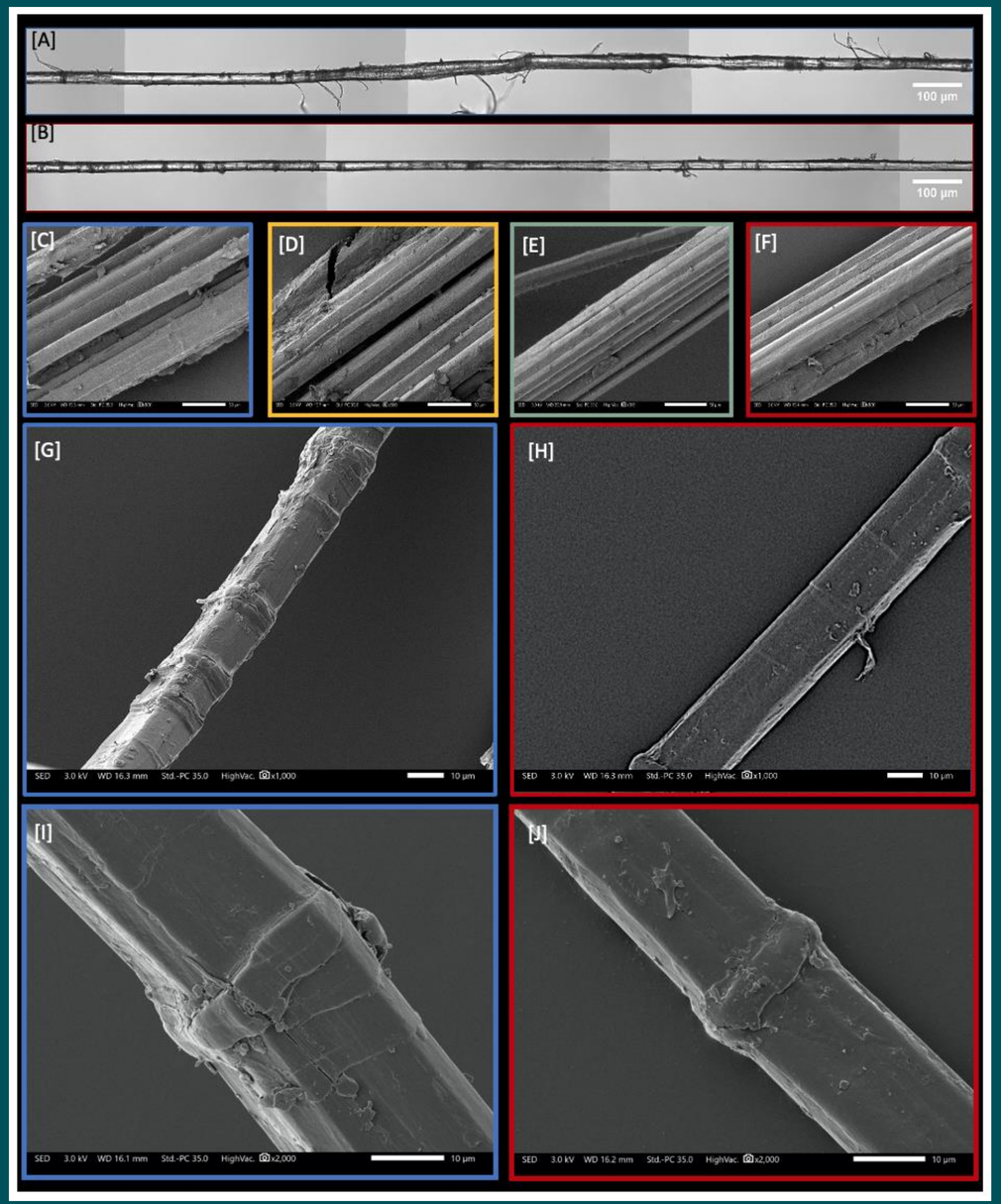
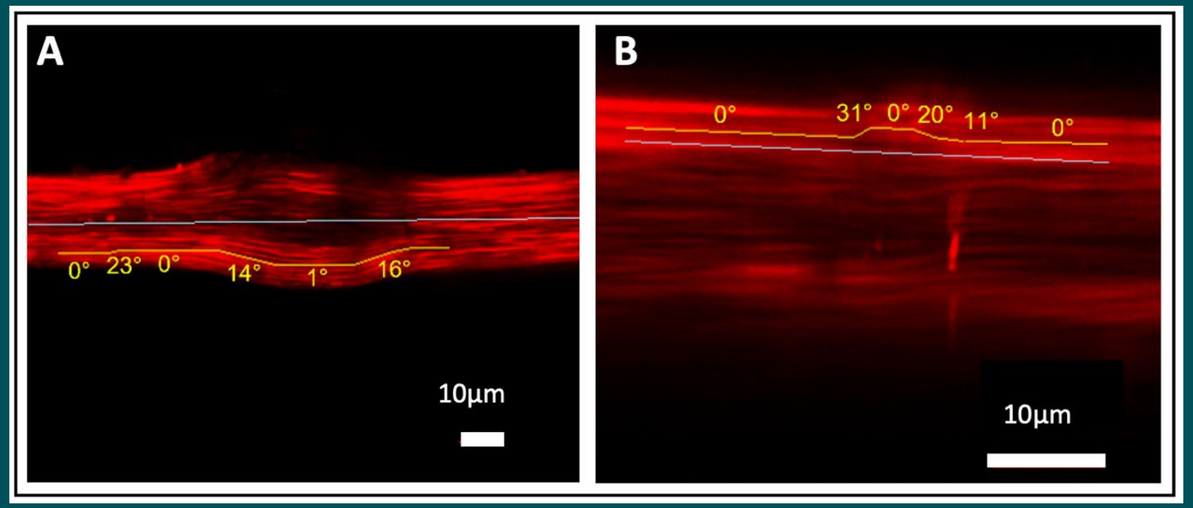


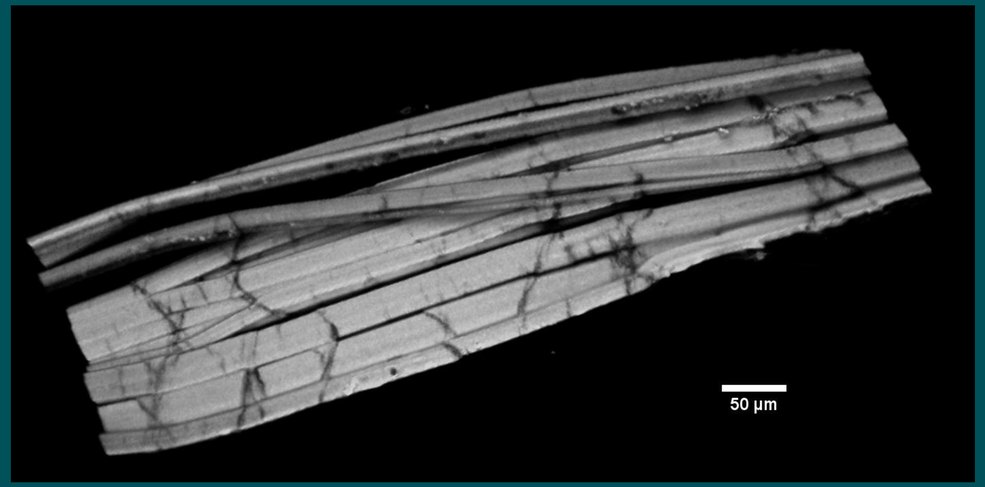


Bourmaud et al, Ind Crops & Prod, 2022

KINK BANDS







Morgillo et al. Ind Crops & Prod, 2023

COMPLEX STRUCTURE OF KINK BANDS - ANATOMIX

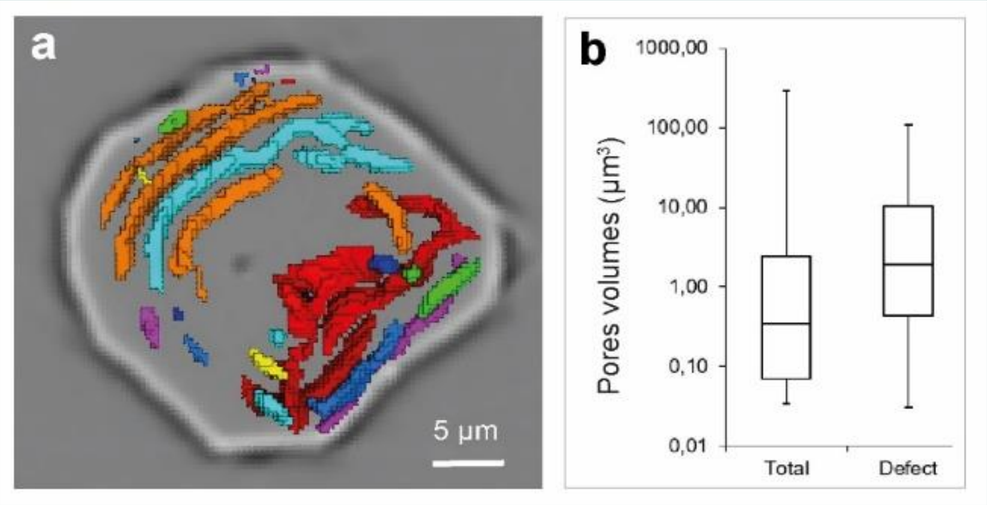


Figure 4. Defect already observed in Fig. 2a but here the voids have been separated, colours help to see the distinction (a), box-plot of the void volumes generated by kink-bands (b), the left box represents the porosities of the whole zones studied, the left box represents the porosities of the whole zones studied, the right box concerns only the Fig. 4a defect

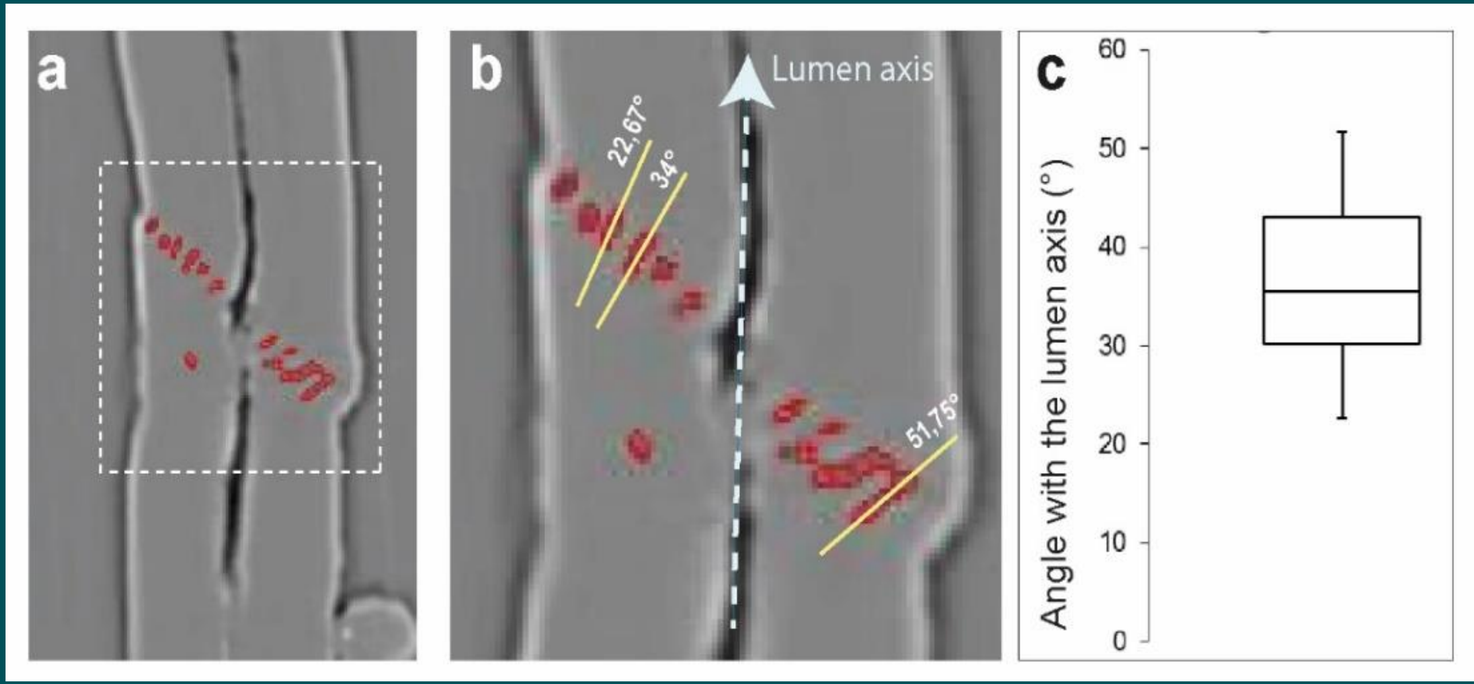
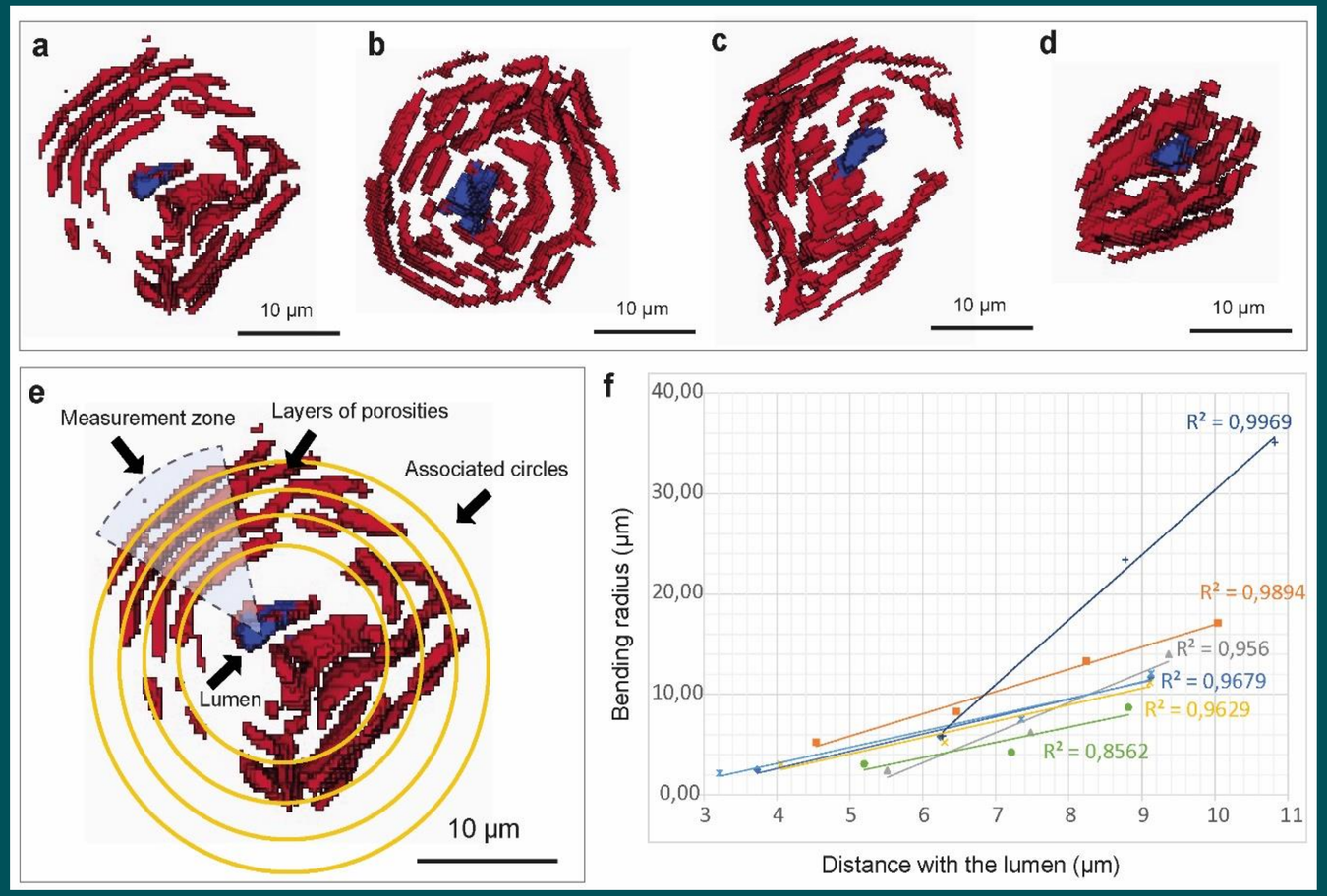


Figure 5. Tomographic slice images of fibres along transverse planes, where voids are highlighted (a), measurements of the angle of voids with the axe of the lumen (b) boxplots of 13 measured angle in zone where the misalignment is the most clearly visible (c)

Quereillac et al, Ind Crops & Prod, 2023

DEEP INVESTIGATION OF KINK BANDS - ANATOMIX



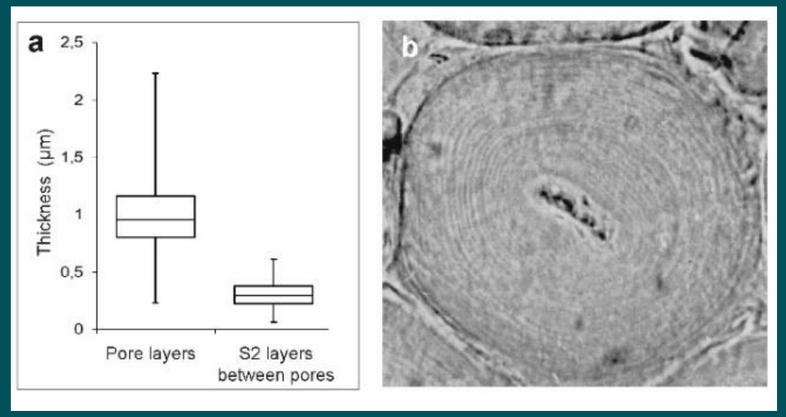
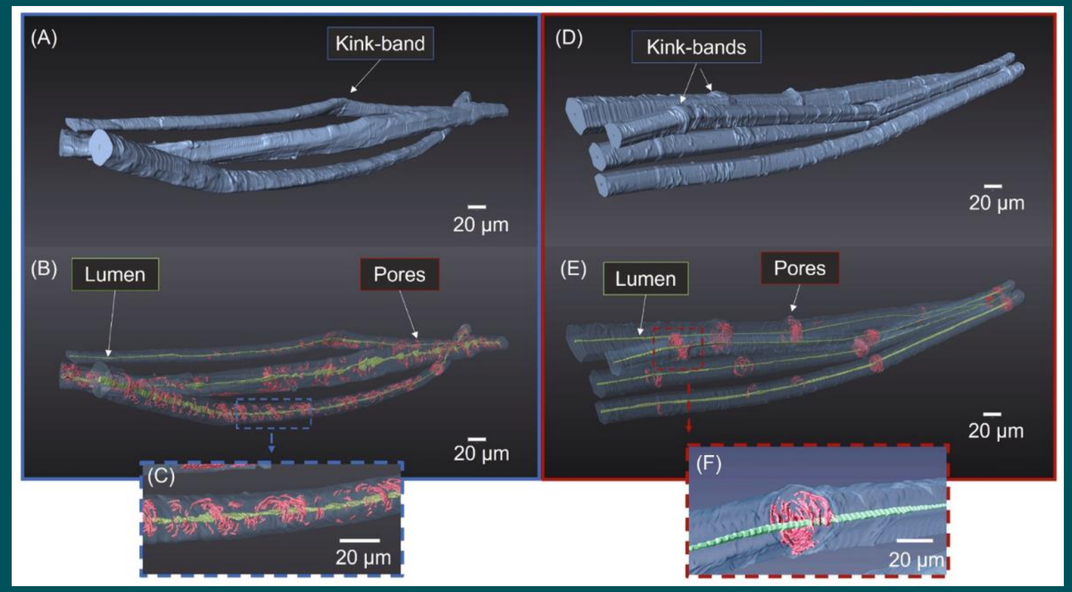


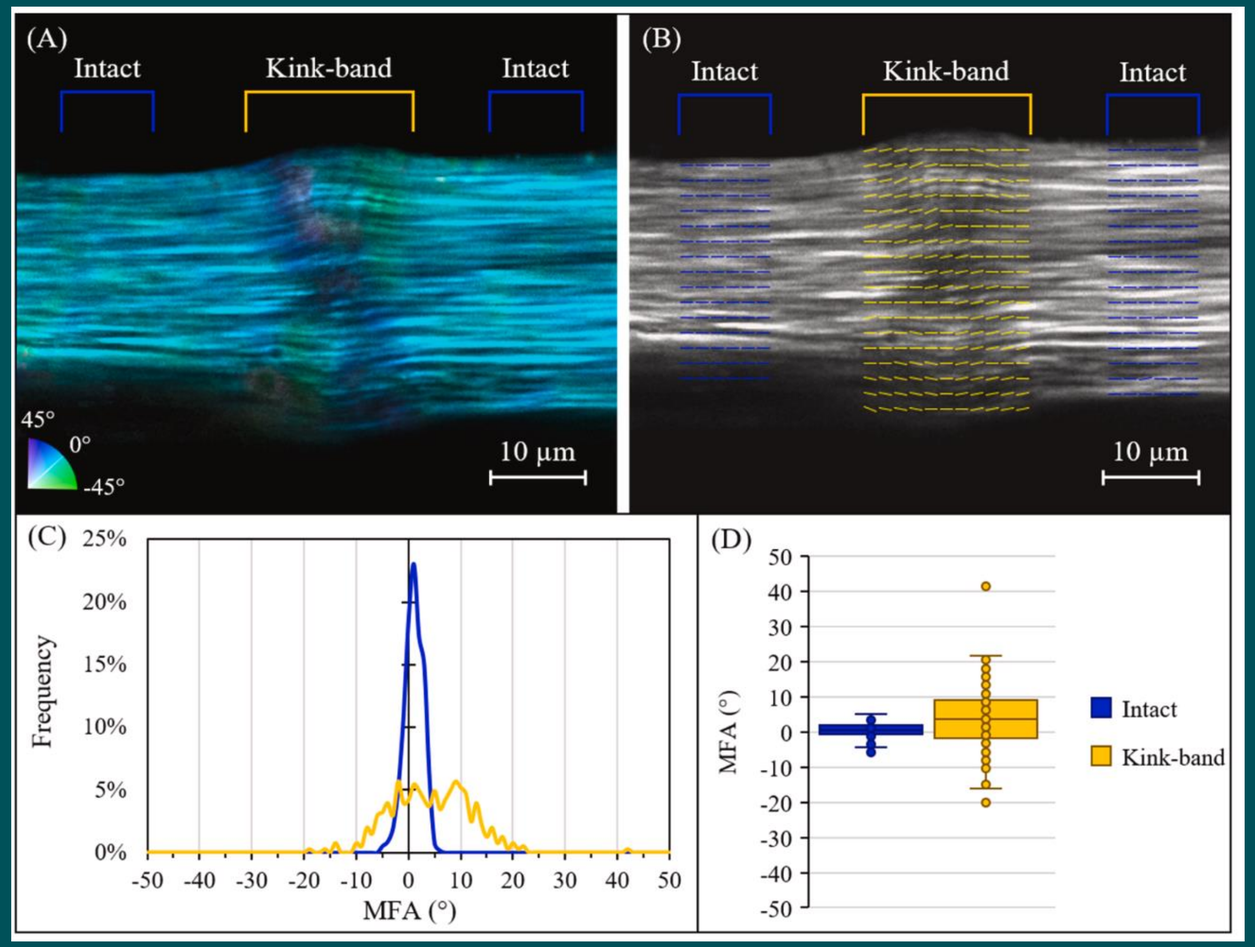
Figure 3. Box-plot presenting the pores thickness and the distance between two pores (a), cross-section of a flax fibre evidencing the successive cellulose layers (b) (Hock, 1942)

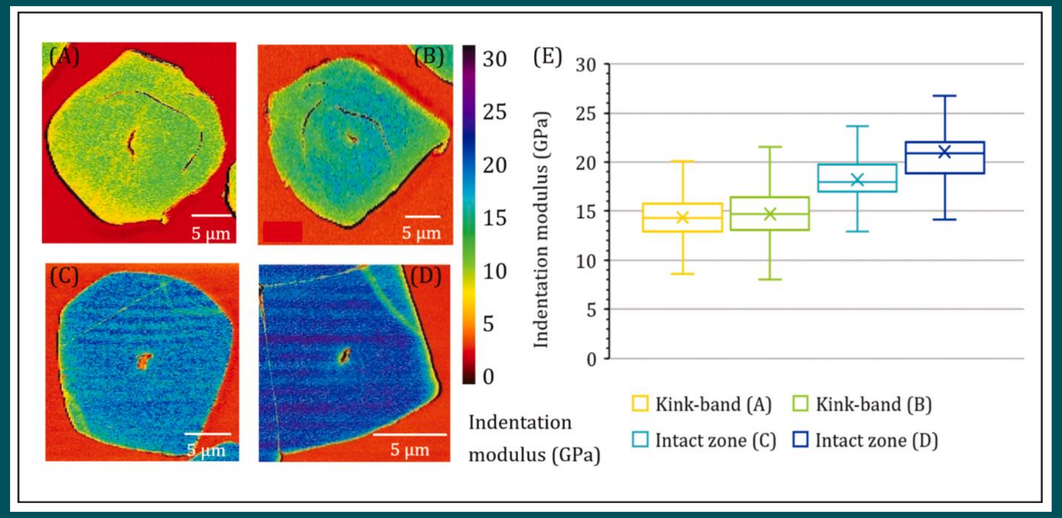


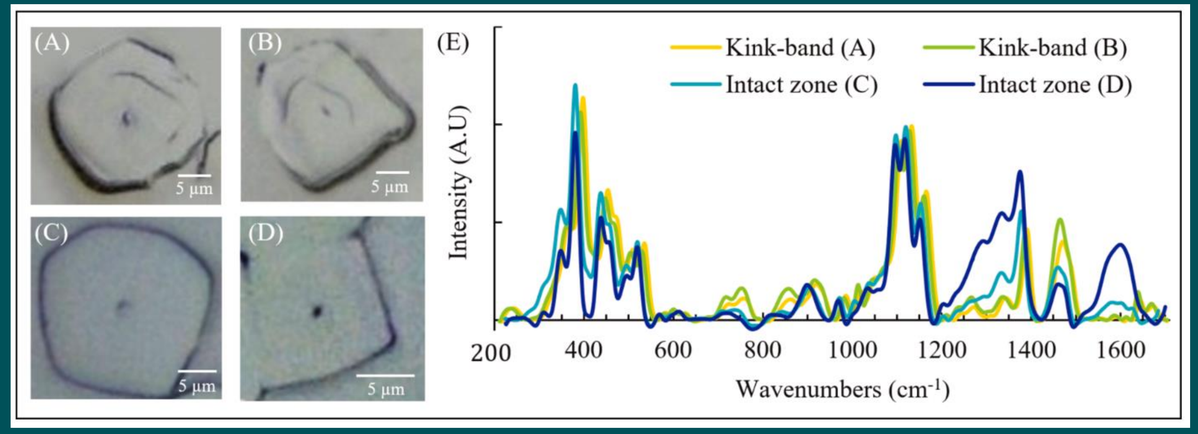
Quereilhac et al, Ind Crops & Prod, 2023, Hock. J. Res. Natl, 1942

Morgillo et al, Ind Crops & Prod, 2023

DEEP INVESTIGATION OF KINK BANDS







Morgillo et al, Comp Part A, 2025

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Archaeological context

LOUVRE

MUSEO EGIZIO 1824 —— 2024

4230 – 3986 BCE

FISHING NET
ASCLEPIAS - PERU

INI

2458 - 2209 BCE

GEBEL EL-ZEIT 2

1533 - 1432 BCE

Ramses II

1279 - 1213 BCE

Cleopatra VII

r. 51 – 30 BCE

PEBOS

IIIrd century
200 – 300 CE

Predynastic period
(5500 – 3550 BCE)

Old Kingdom
(2675 – 2130 BCE)

Second Intermediate Period (1630 - 1539 BCE)

New Kingdom
(1539 - 1075 BCE)

Roman Empire
(30 – 476 CE)

0

4324 – 4053 BCE

FISHING NET

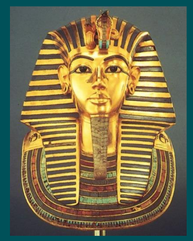
2560 BCE

Great Pyramid of Giza (Cheops)

1617 - 1451 BCE

GEBEL EL-ZEIT 1

1336 - 1327 BCE

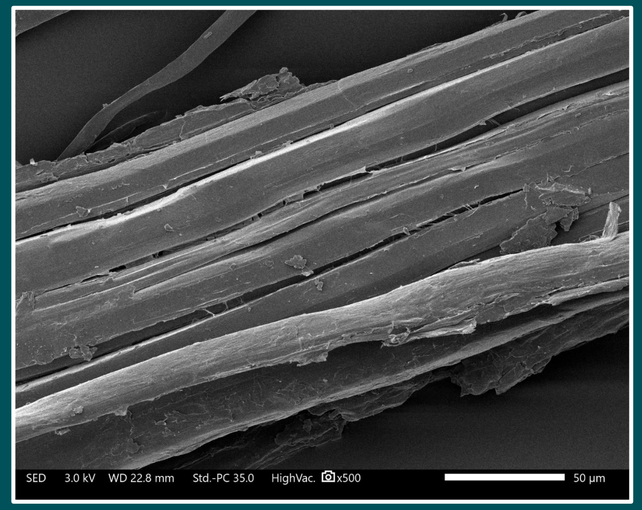


Tutankhamun

1390 – 1120 BCE

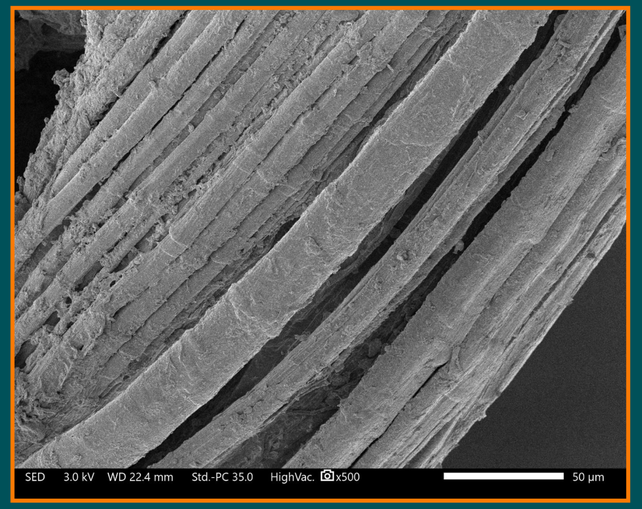
FISHING NET

SEM - Yarns



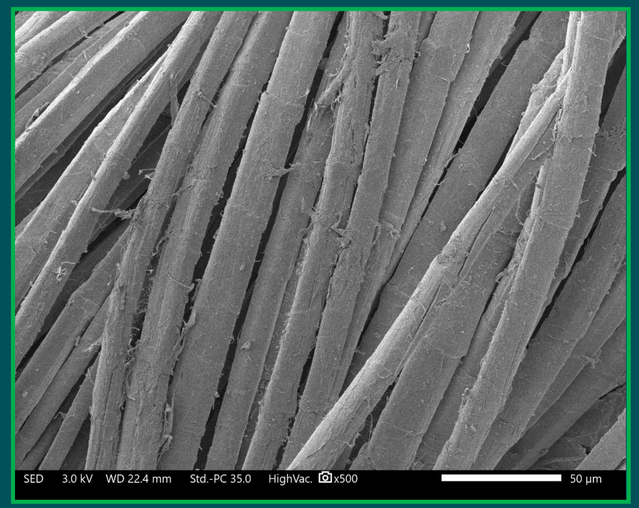
MODERN

GEBEL EL-ZEIT I



GEBEL EL-ZEIT II

INI



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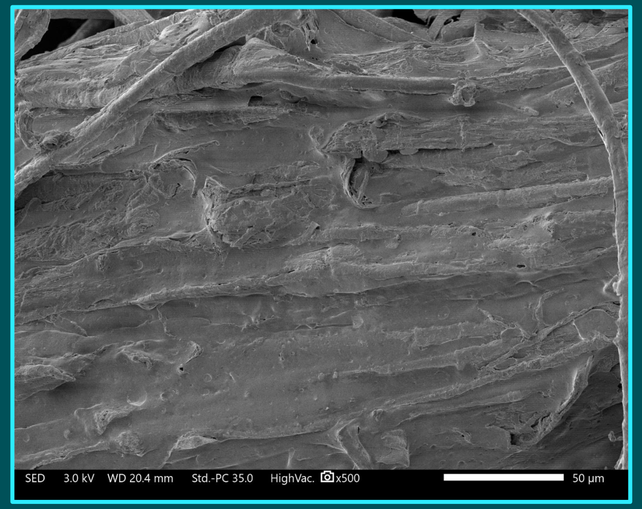
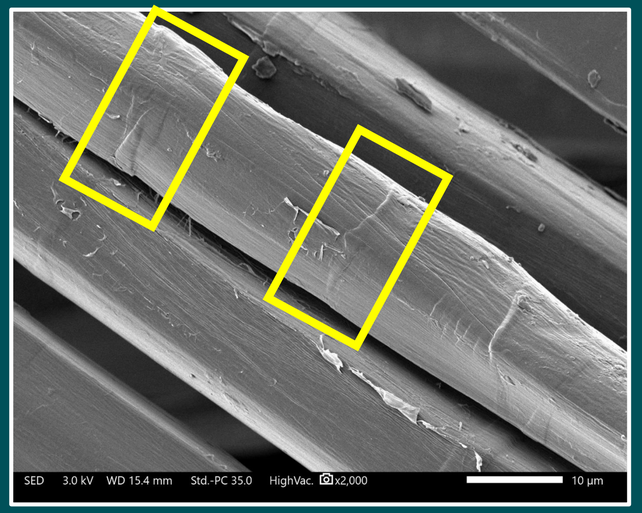


FISHING NET

SEM - Yarns



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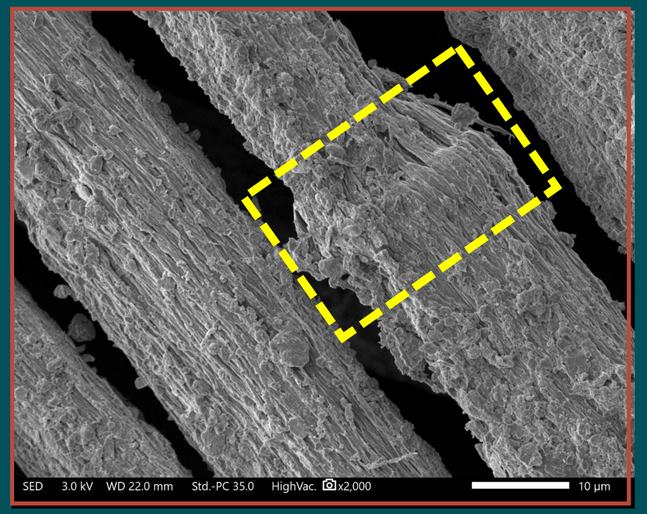

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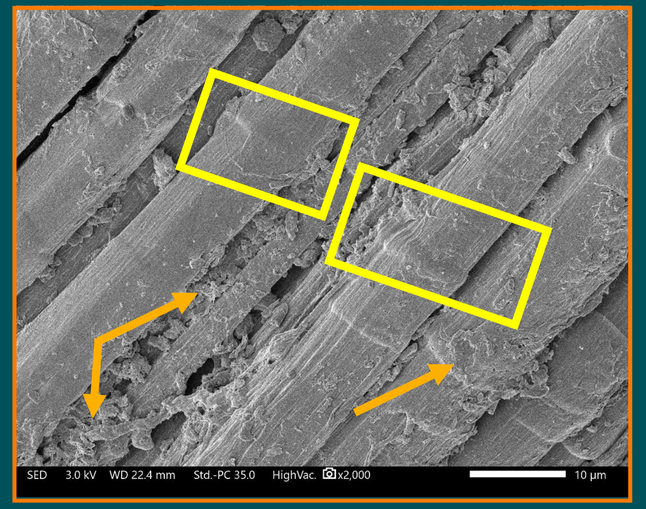

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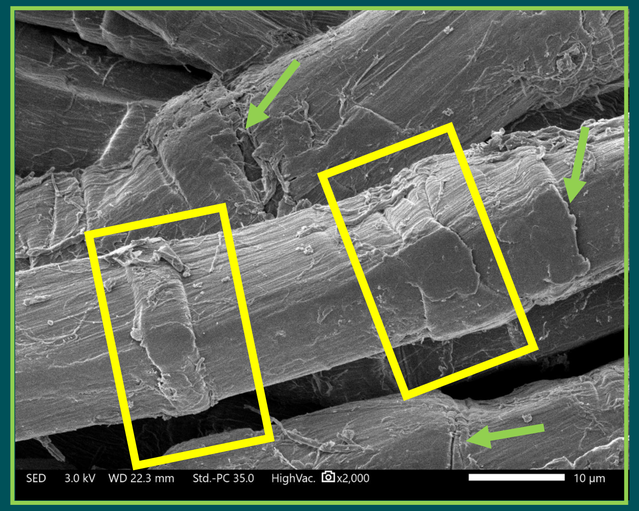

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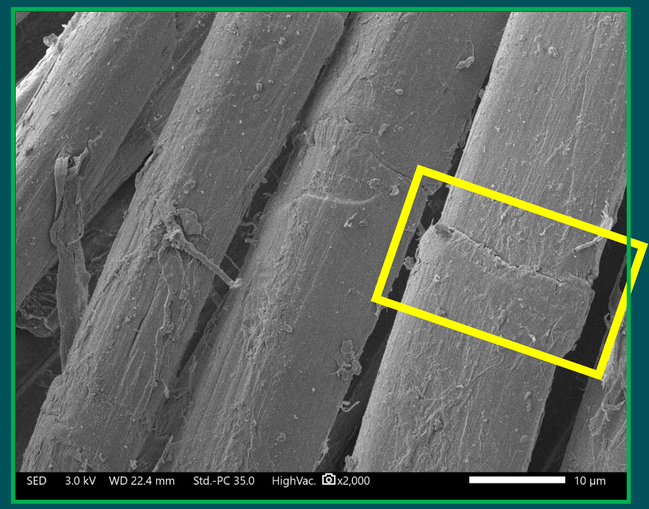

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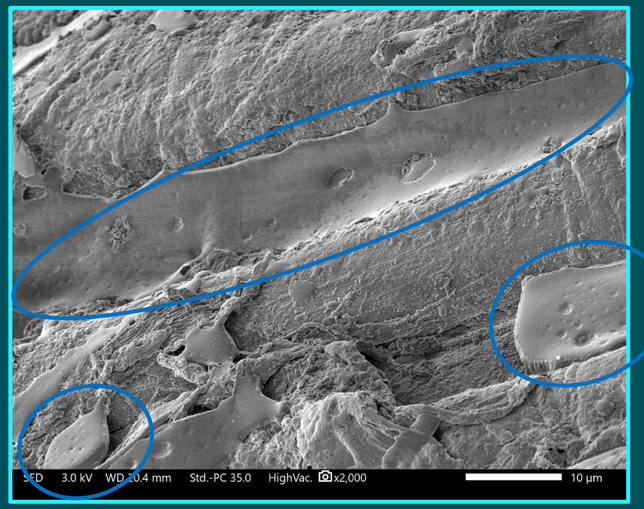


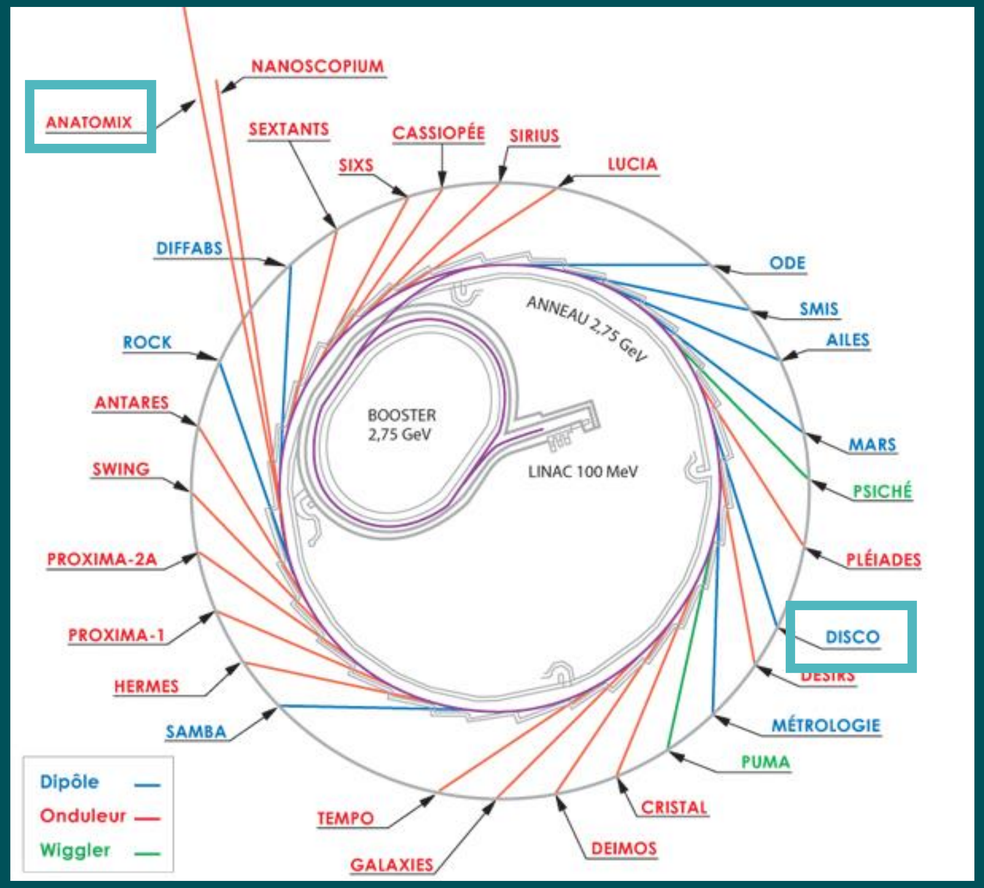
FISHING NET

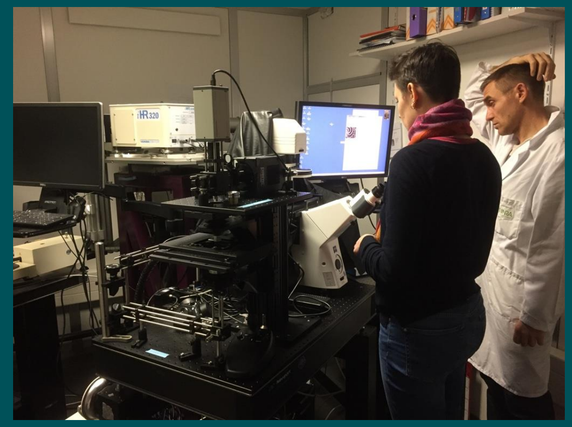
Synchrotron facilities

DISCO : Deep UV range, down to 120 nm, high resolution, investigations at single fibre scale

ANATOMIX: Micro-tomography - Acquisition speed – 350 voxel size – Approx 3 min for a 600 μm^3 volume

Micro-CT on FLAX fibres

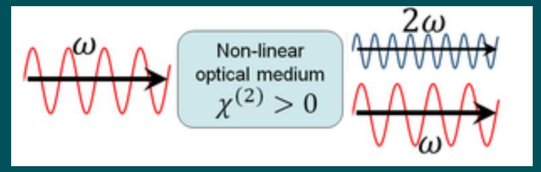


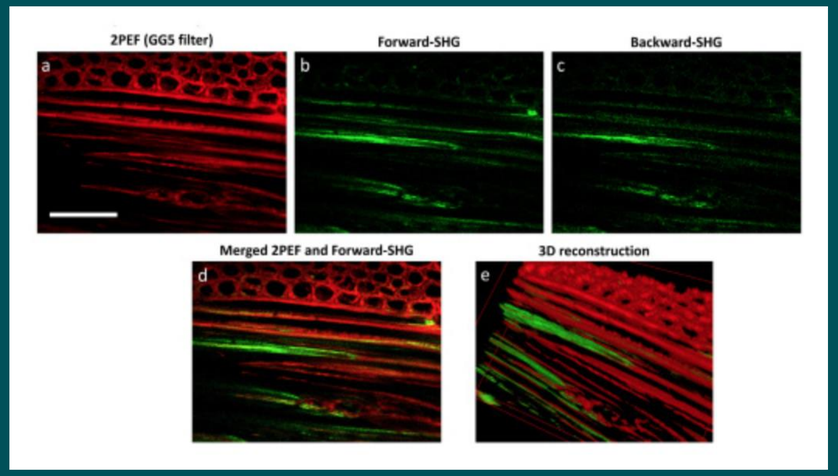


Biochemical investigations

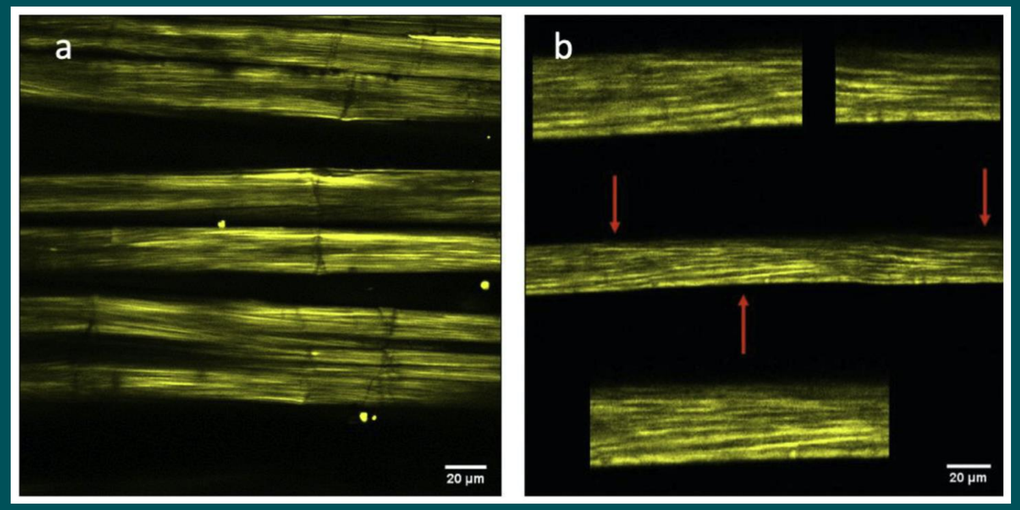
MFA investigations

Multiphoton microscopy investigations

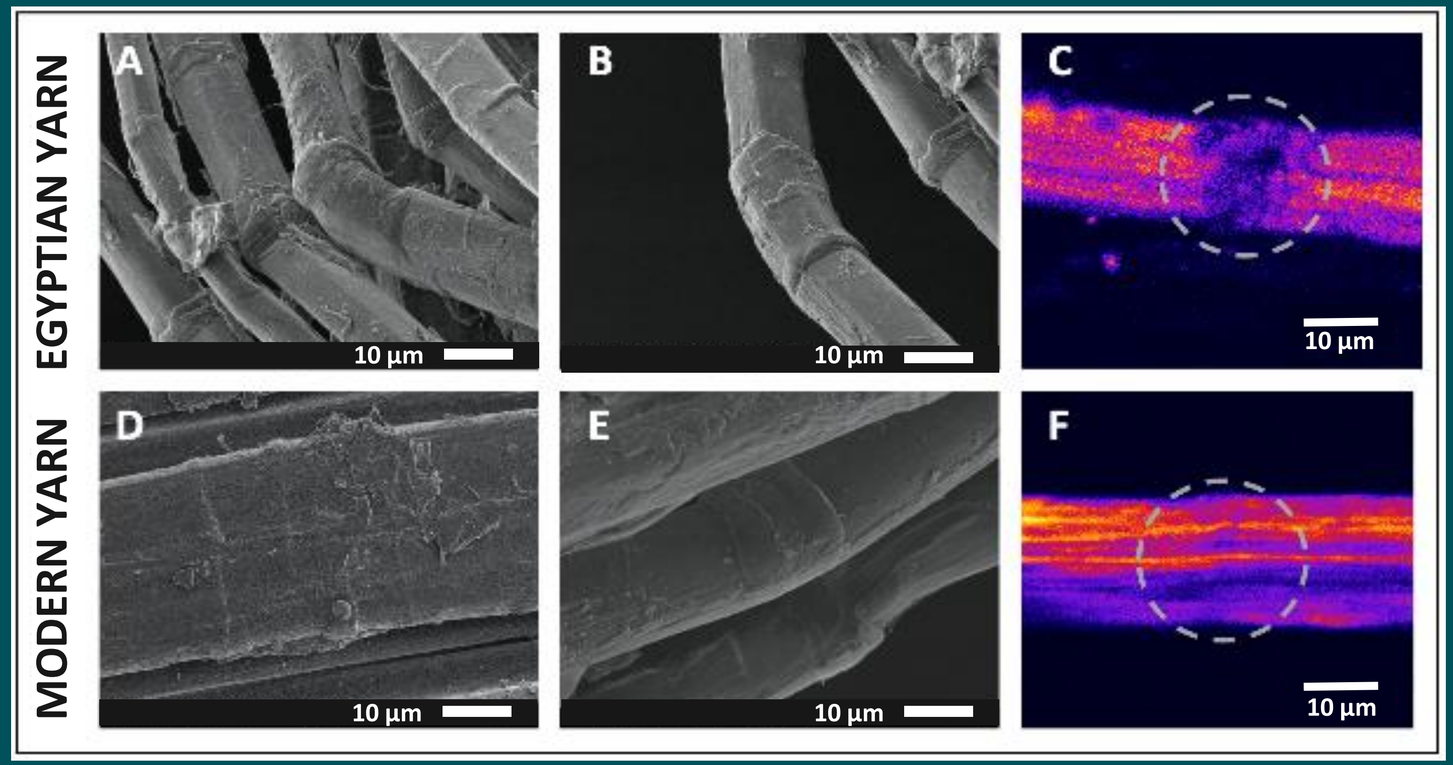




Latour et al, Optics Express, 2012



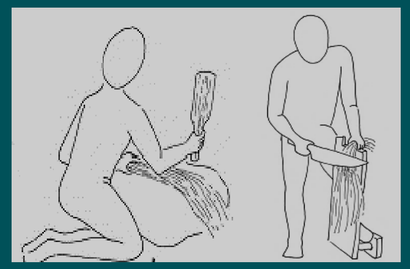
Melelli et al, Ind Crops & Prod, 2021



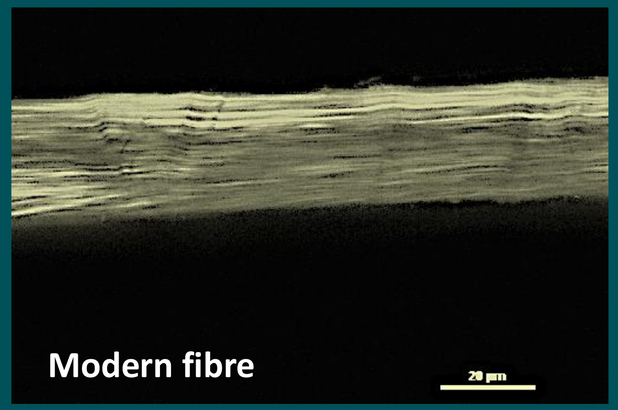
Melelli et al, Nature Plants, 2021

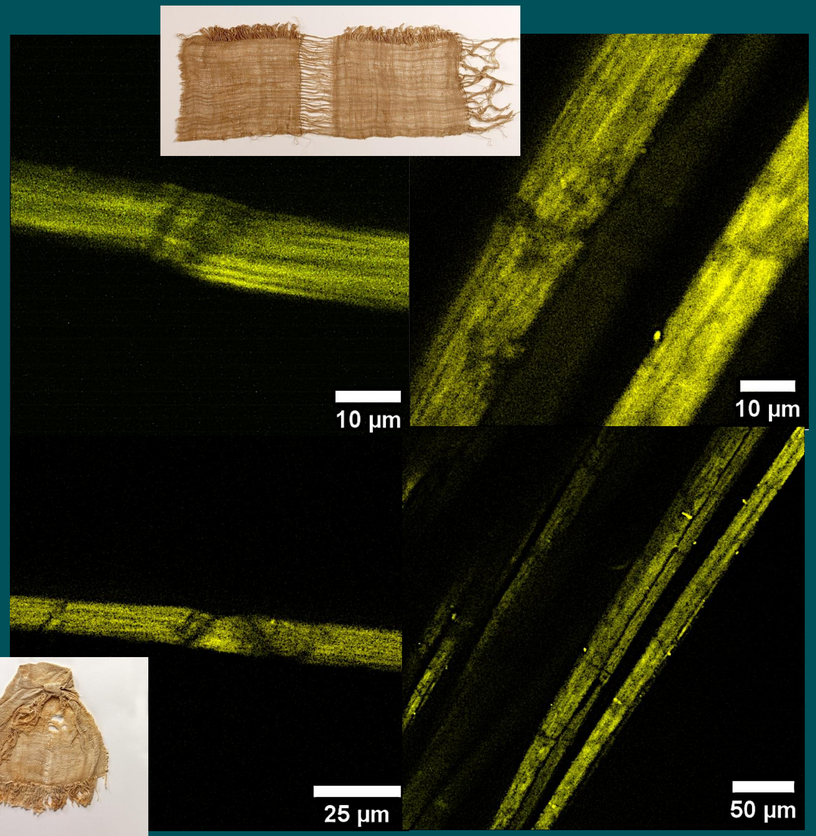
- Kink bands deeply fractured in the Egyptian yarn
- Kink bands are bigger and with a different shape in the egyptian yarn

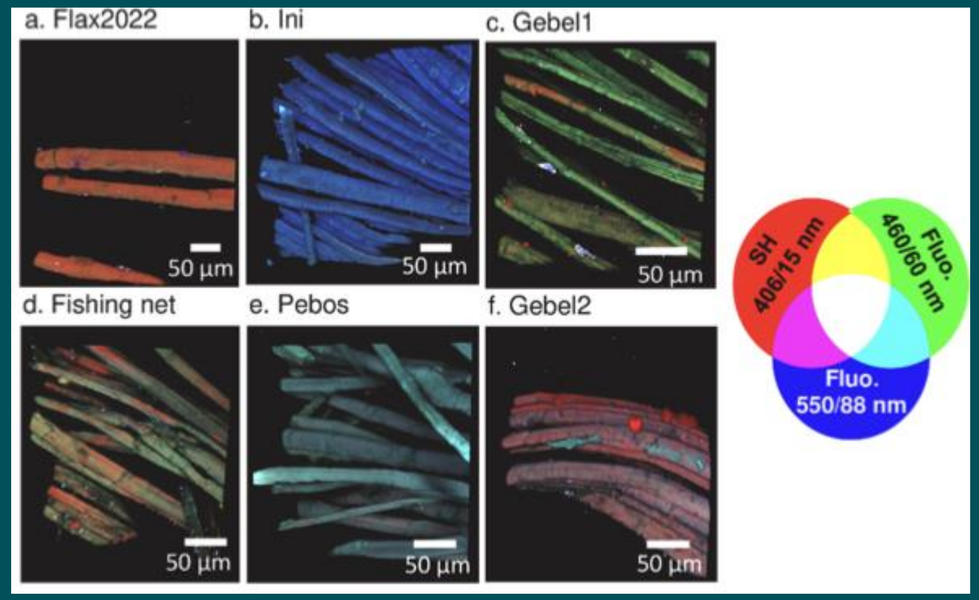
Multiphoton microscopy investigations

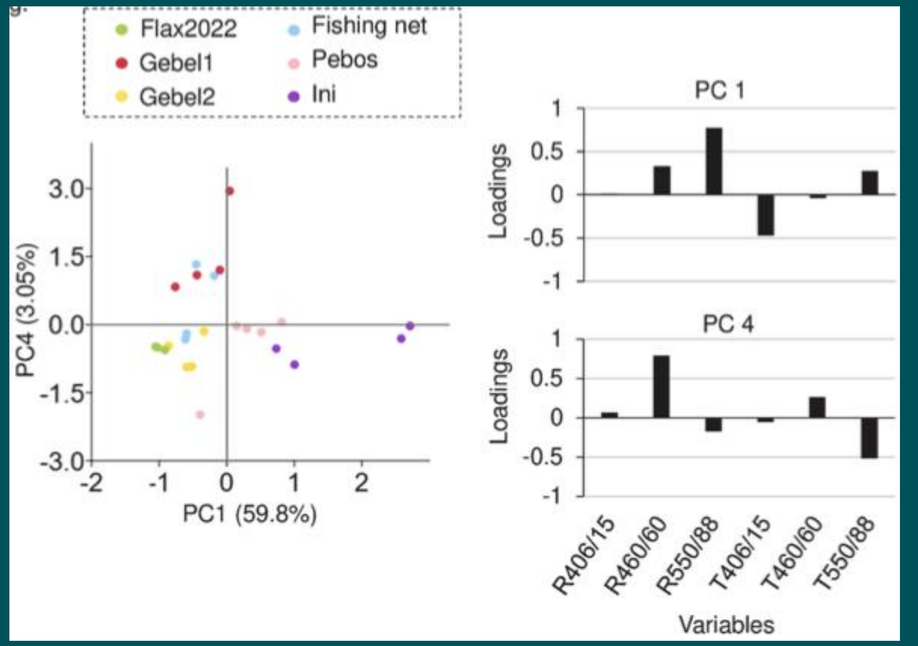


Andersson Strand, *Paléorient*, 2012



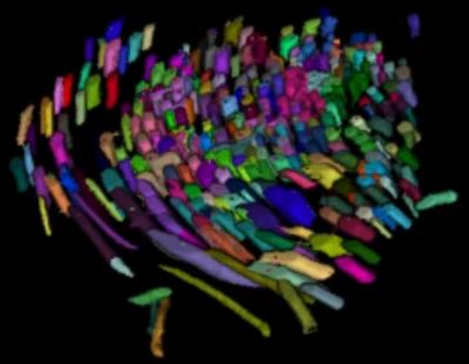






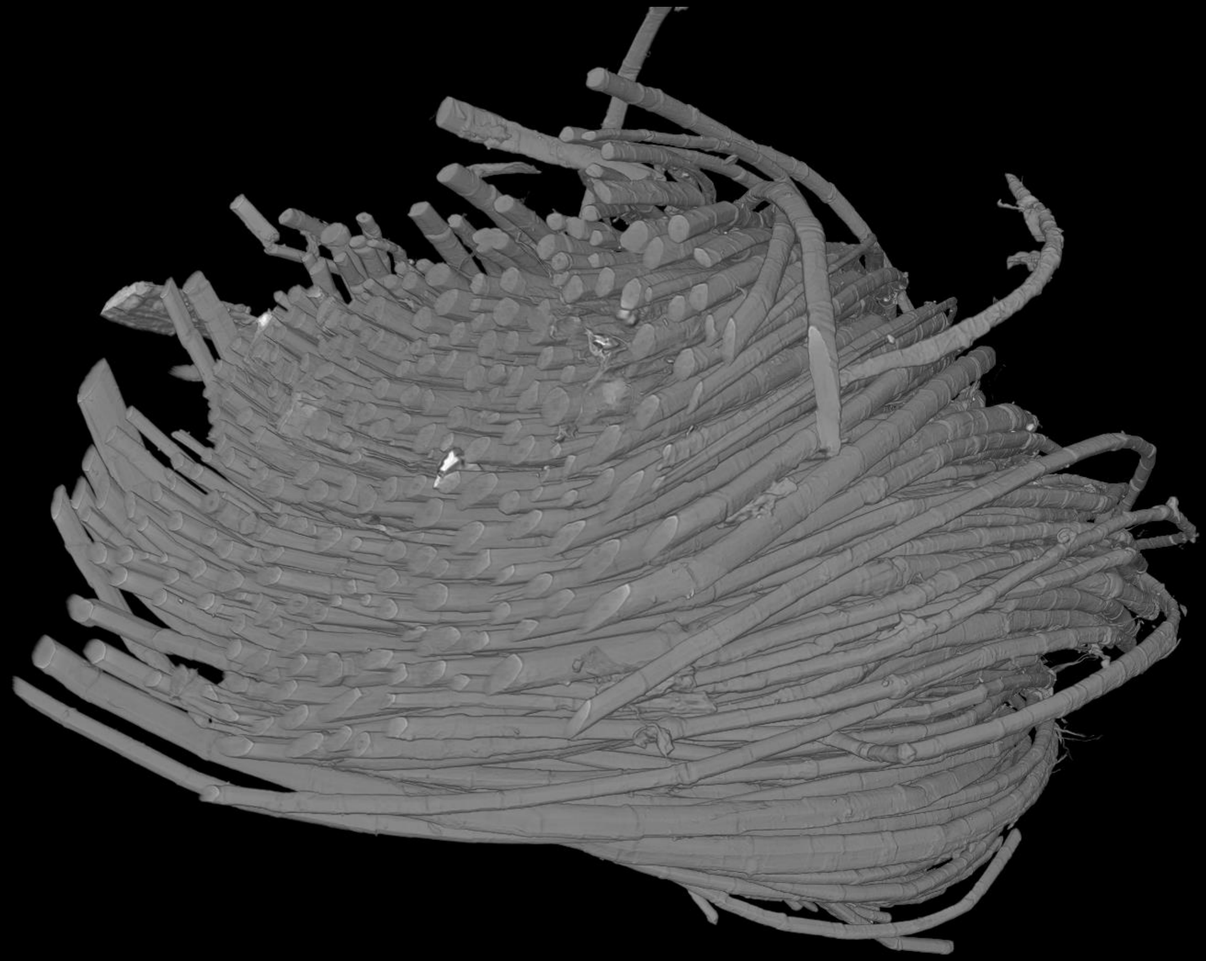
Micro-tomography investigations

PEBOS Sample



Morgillo et al., Comp part A, 2025

Micro-tomography investigations



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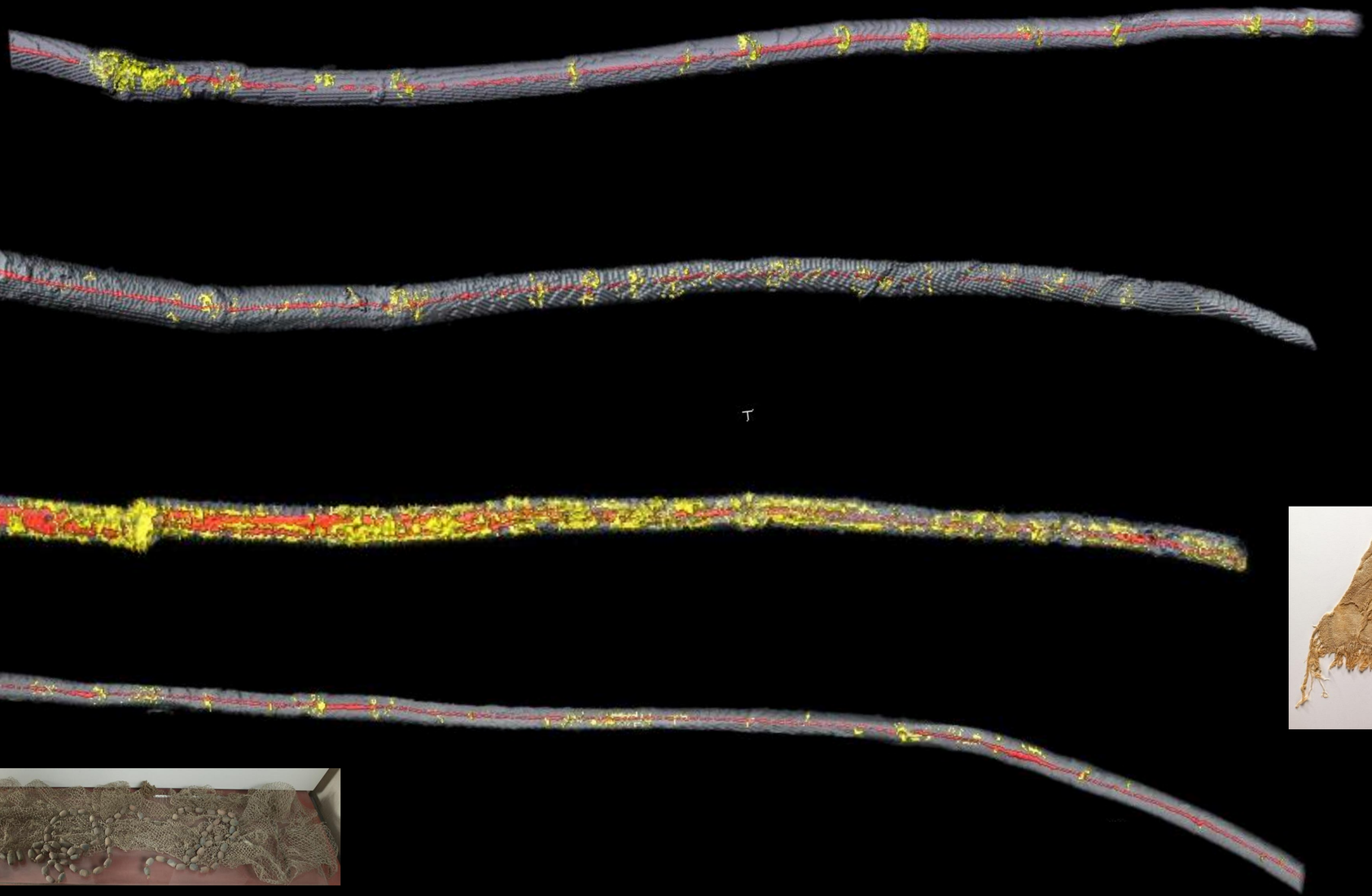

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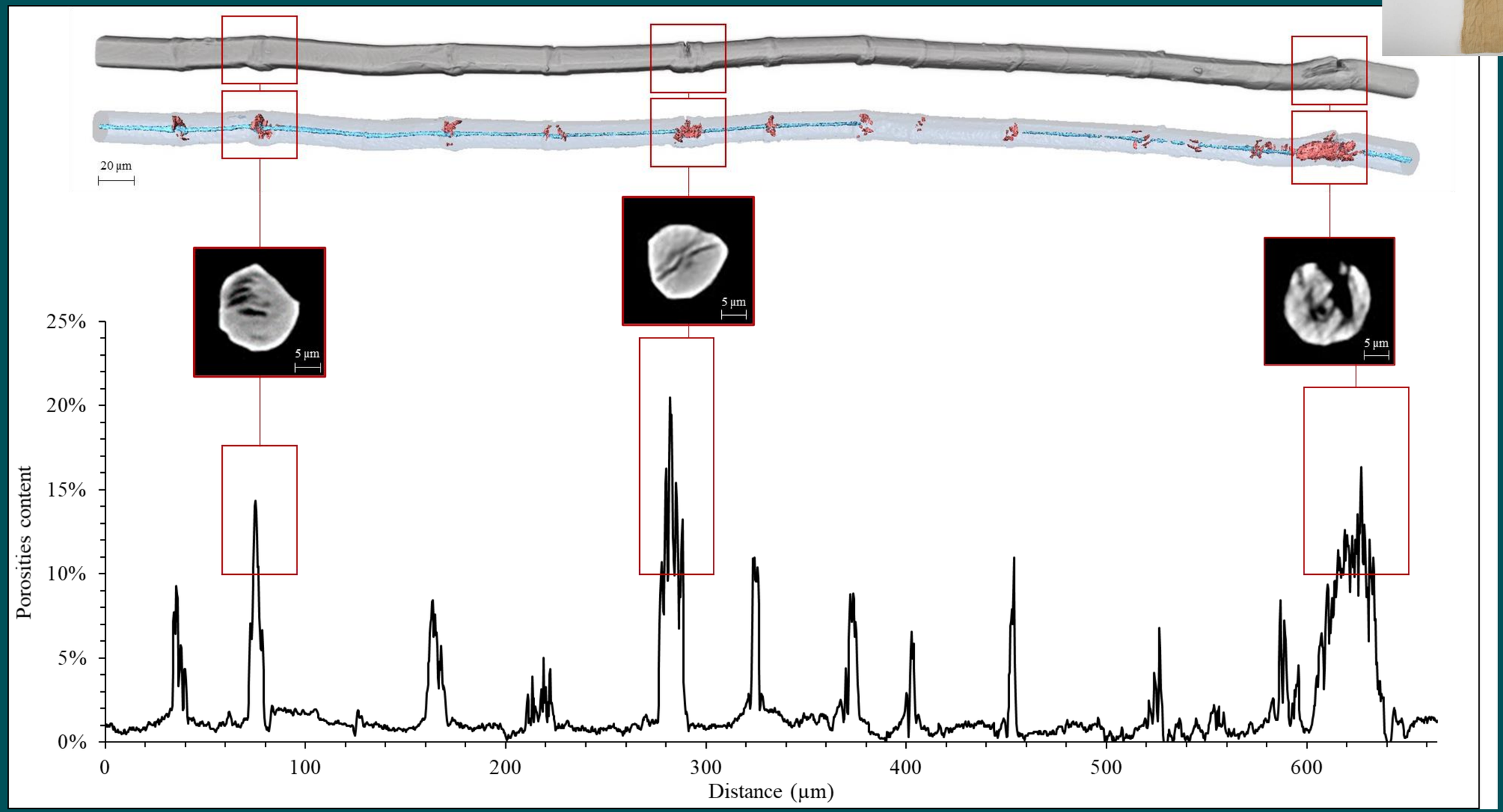
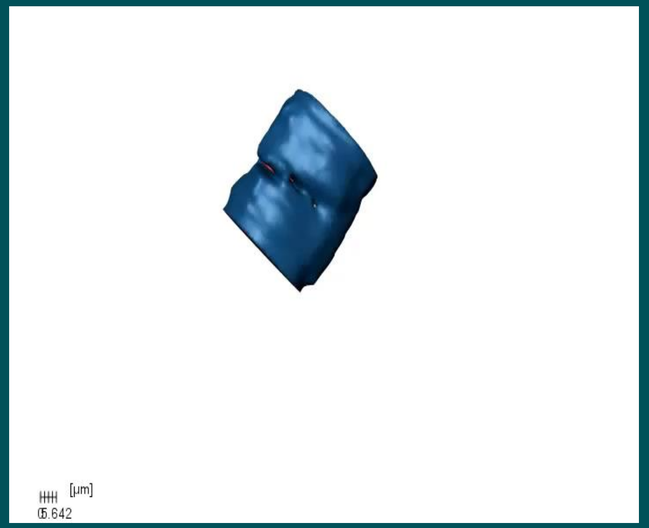
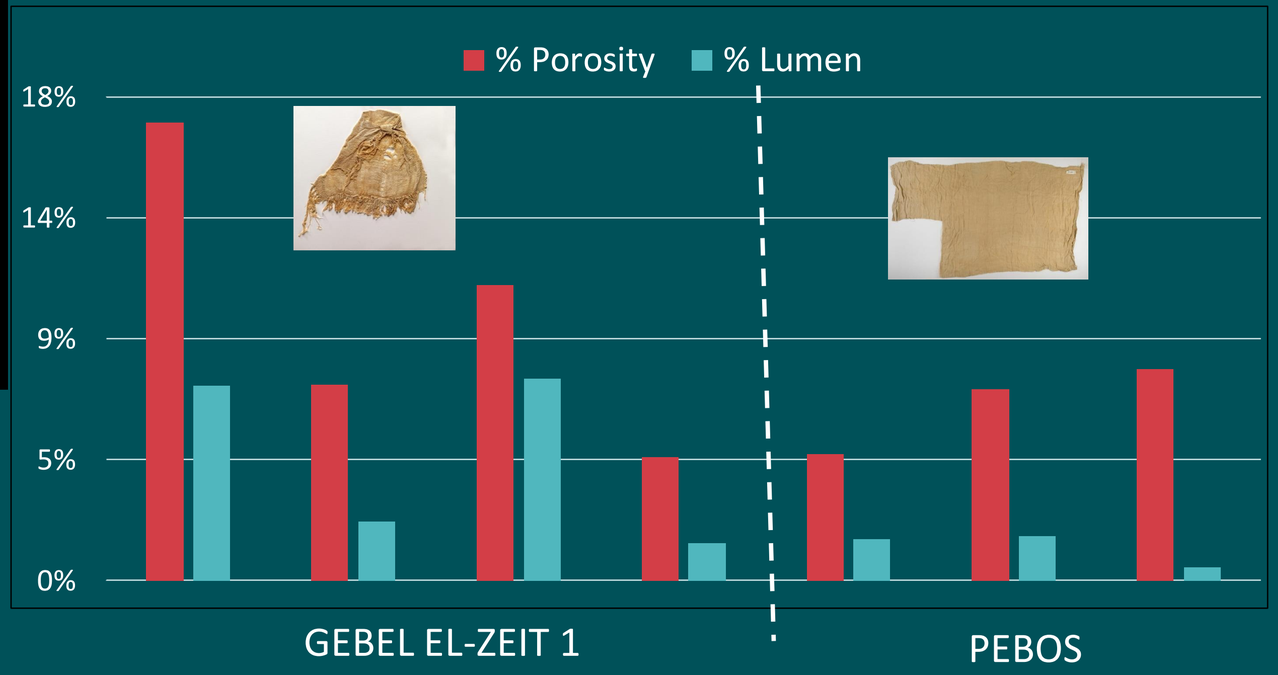
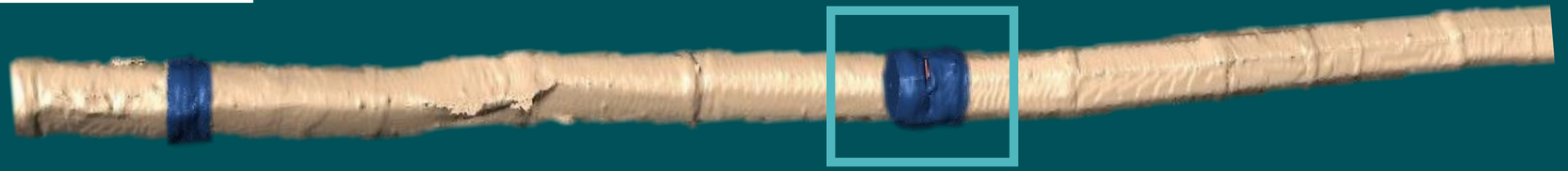


Morgillo et al., Comp part A, 2025

Micro-tomography investigations





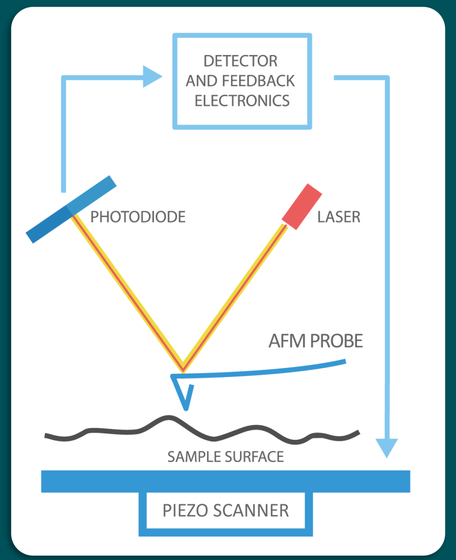


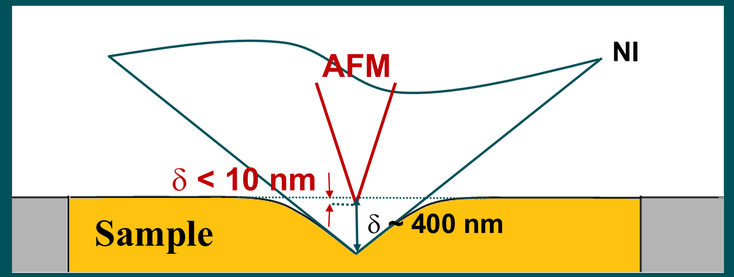
Morgillo et al., Comp part A, 2025

Mechanical properties

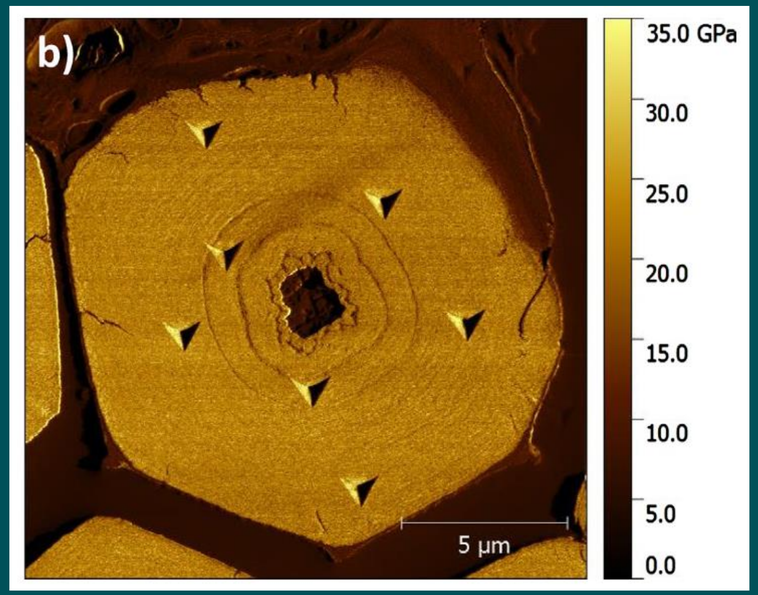
AFM (PF-QNM)

- Observation of porosities inside the fibers
- Evaluation of mechanical properties of fiber cell walls



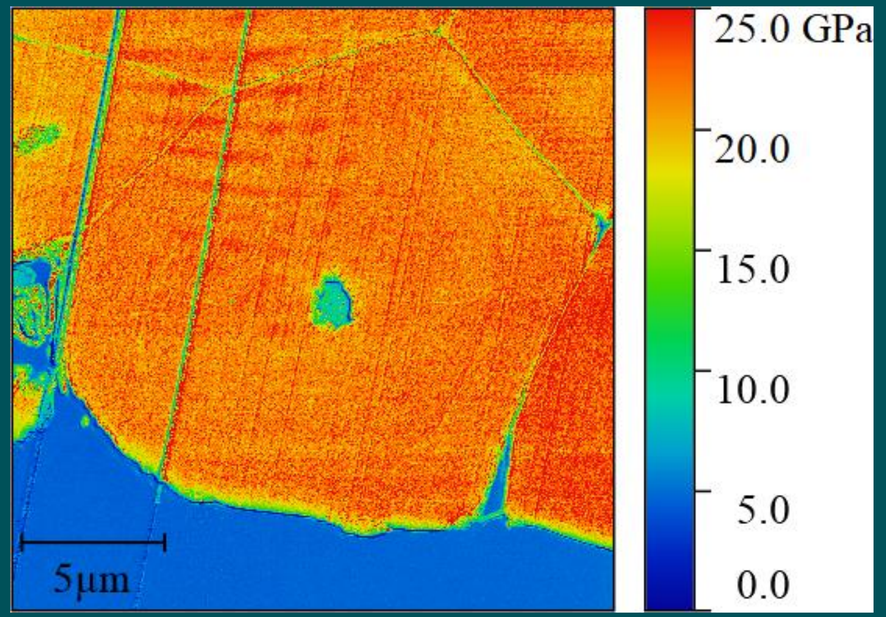


Indentation modulus of contemporary flax fiber



21.3 ± 2.2 GPa

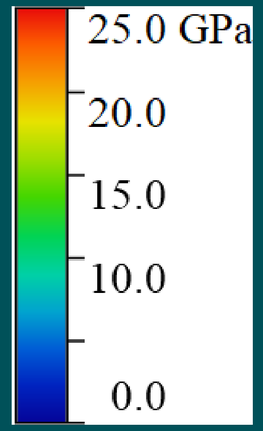
Indentation modulus of contemporary flax fiber



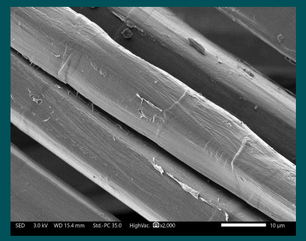
21.6 ± 1.7 GPa

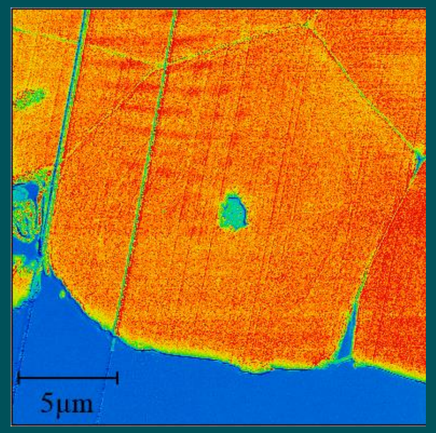
Arnould et al. Industrial Crops and Products, 2017

Mechanical properties – AFM PF-QNM

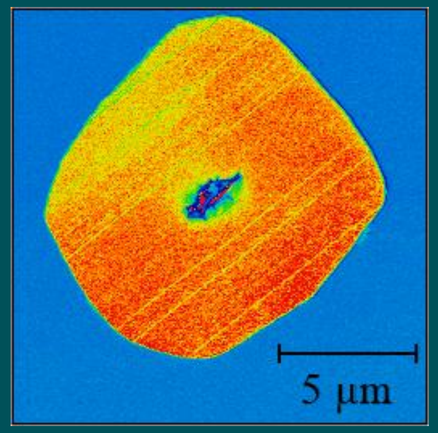


MODERN FIBRE



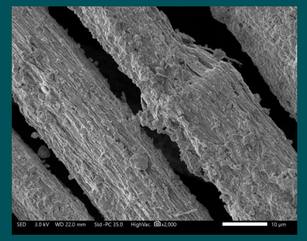


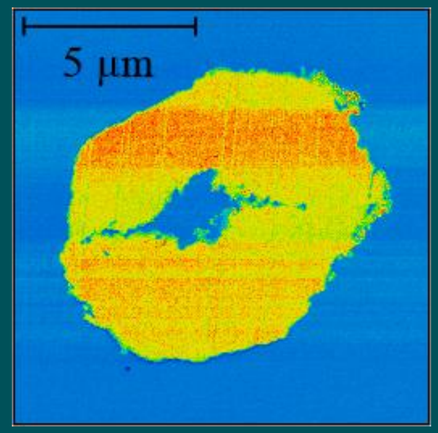
21.6 ± 1.7 GPa



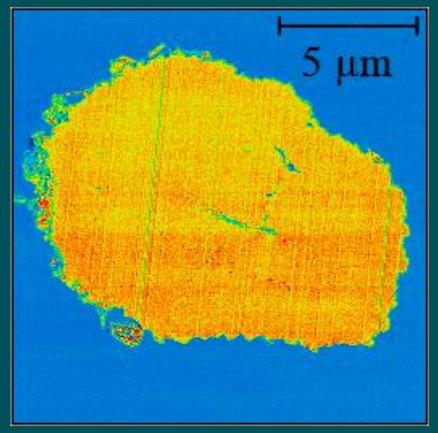
21.4 ± 2.0 GPa

GEBEL ZEIT I



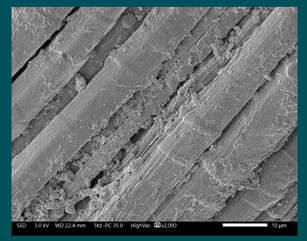


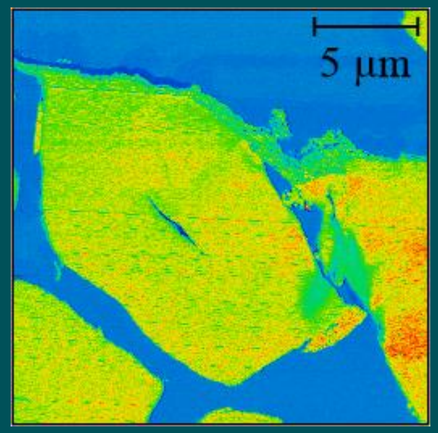
19.1 ± 1.6 GPa



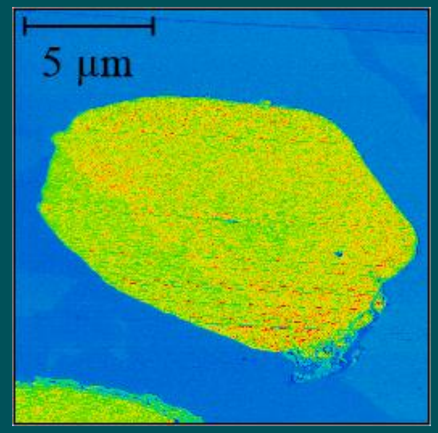
19.7 ± 1.2 GPa

GEBEL ZEIT II





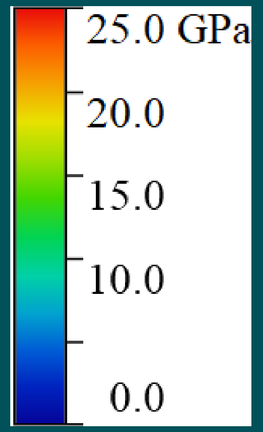
16.6 ± 1.5 GPa



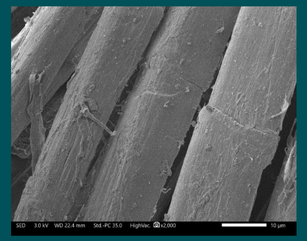
16.6 ± 1.8 GPa

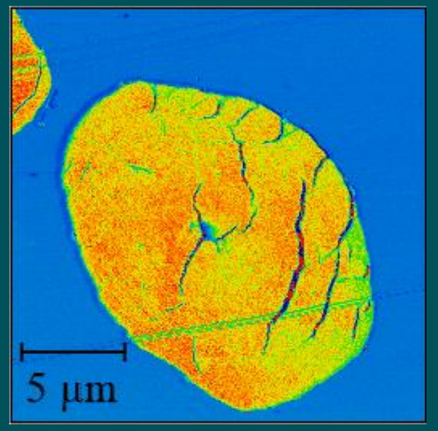
Goudenhooft et al.,
Cartb Pol, 2024

Mechanical properties – AFM PF-QNM

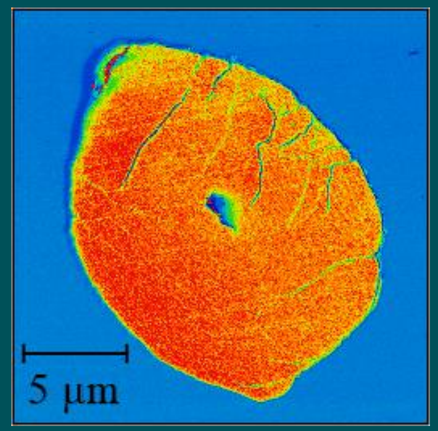


PEBOS



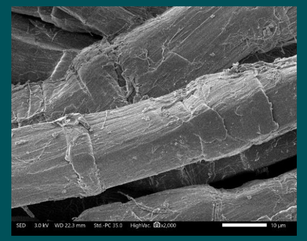


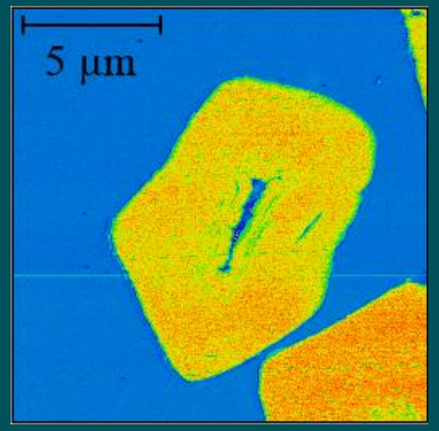
19.8 ± 1.7 GPa



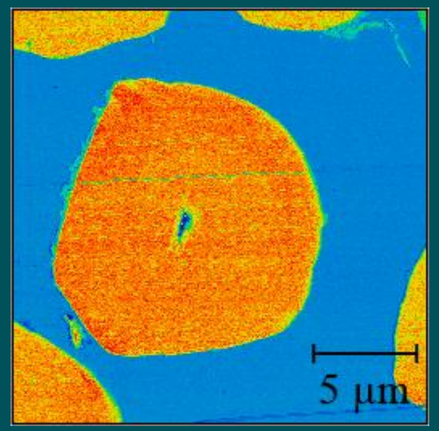
22.5 ± 1.7 GPa

INI



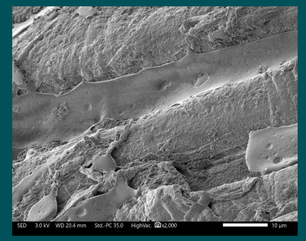


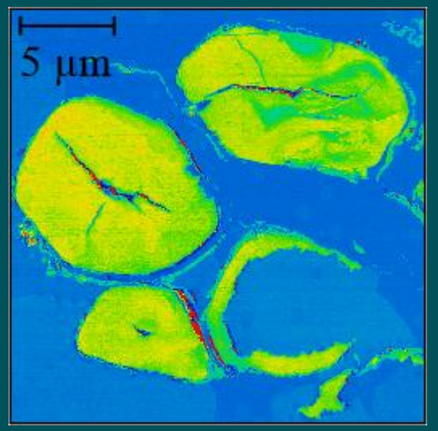
19.0 ± 1.3 GPa



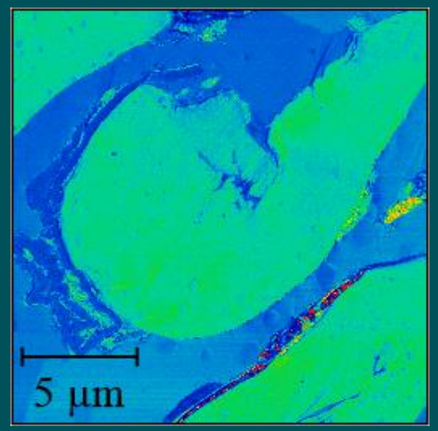
21.7 ± 1.2 GPa

FISHING NET





16.9 ± 1.1 GPa

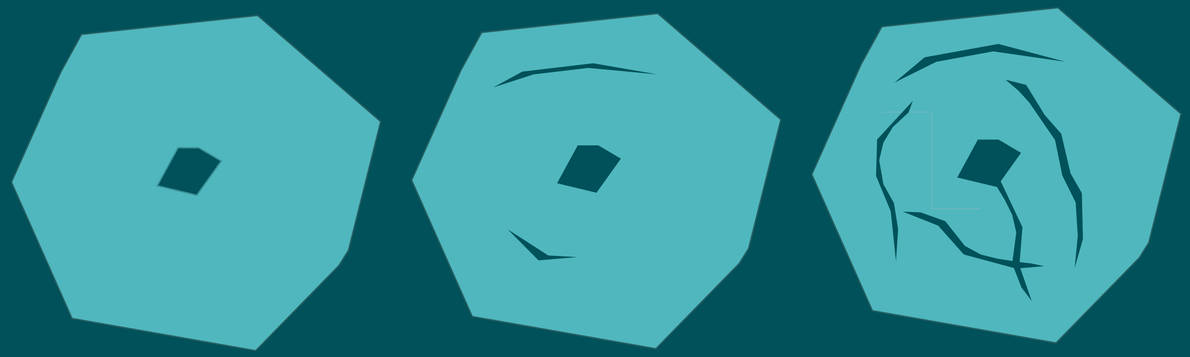


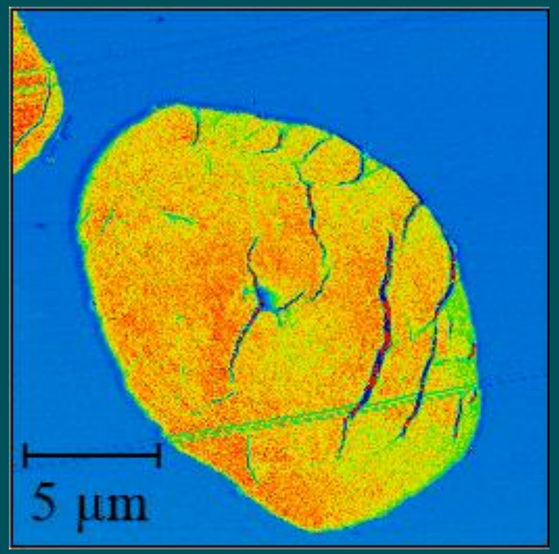
9.3 ± 0.9 GPa

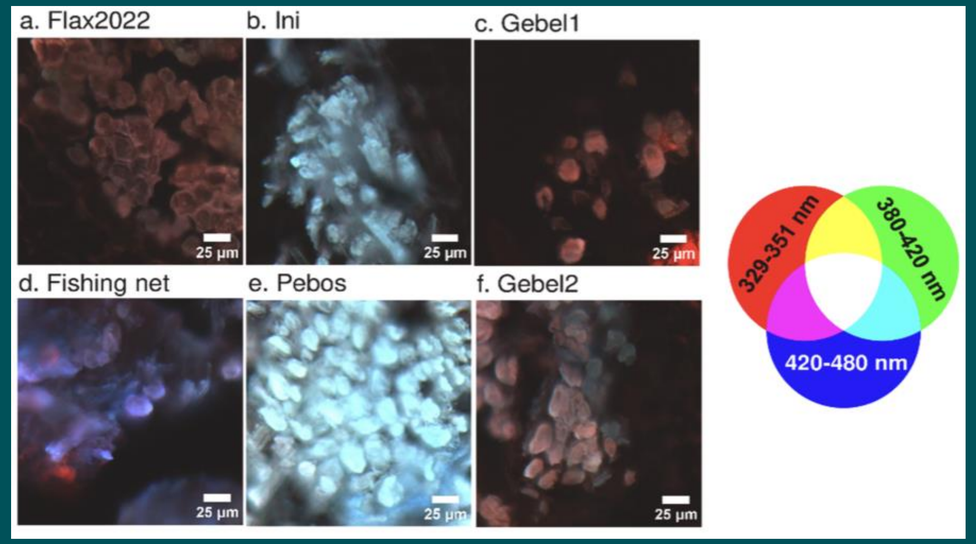
Goudenhooft et al.,
Cartb Pol, 2024

Conclusions

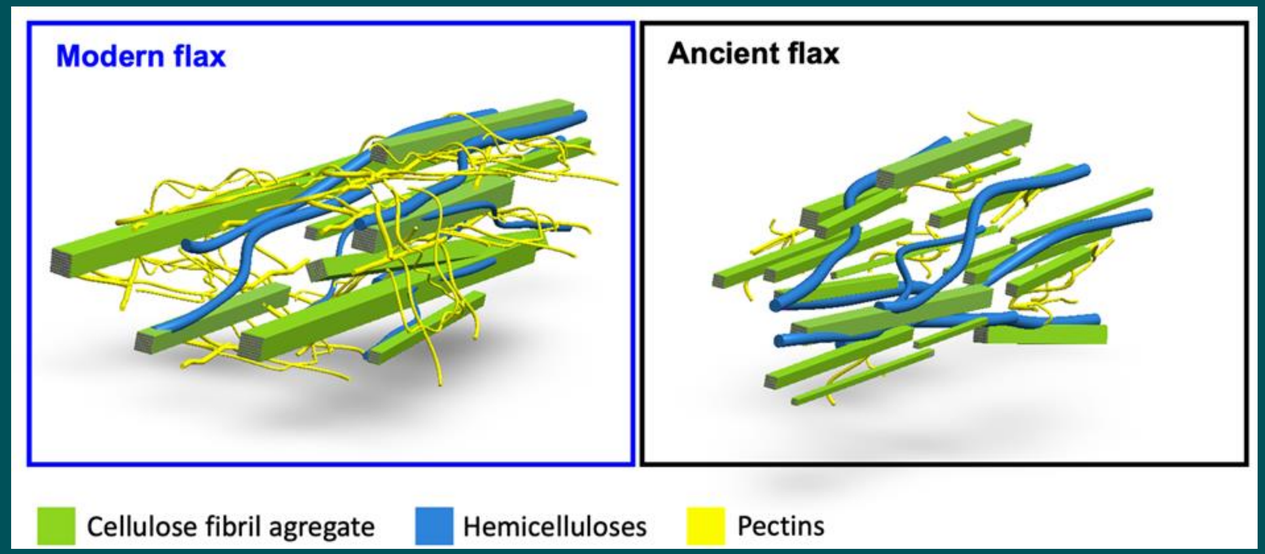
1 Cell wall cracks







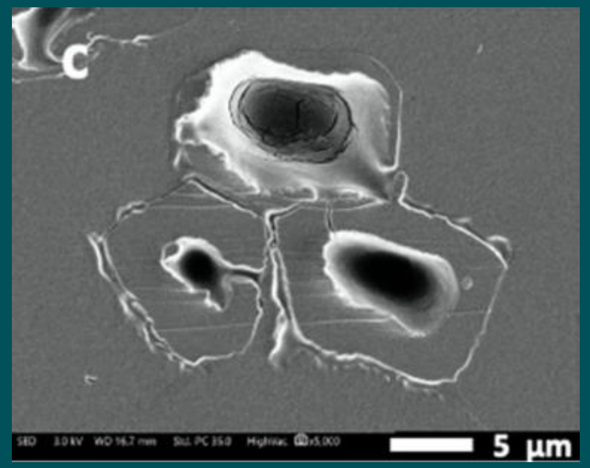
Melelli et al, Polymer Degradation and Stability, 2024

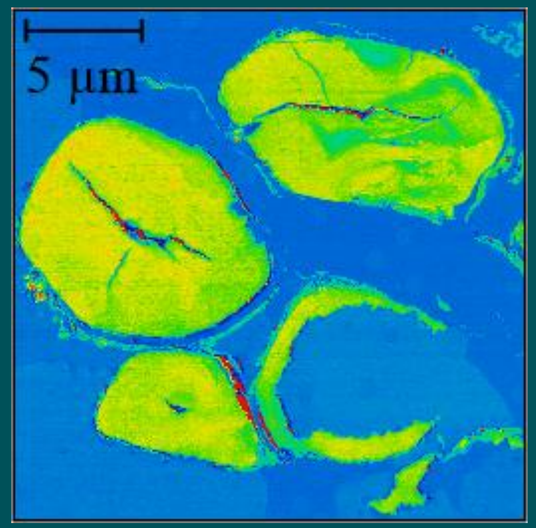


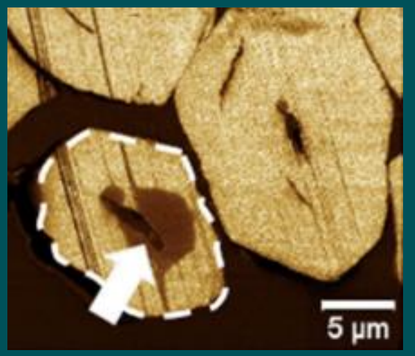
Goudenhooft et al, Carbohydrate Polymers, 2024

Conclusions

2 Degradation from lumen



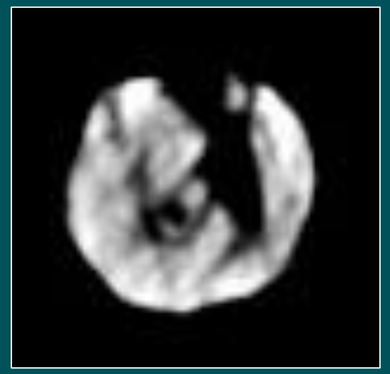


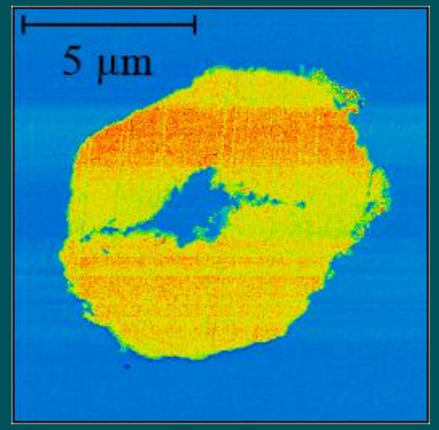


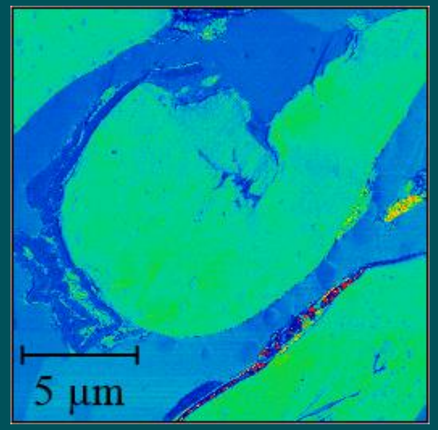
Melelli et al, Polymers, 2021

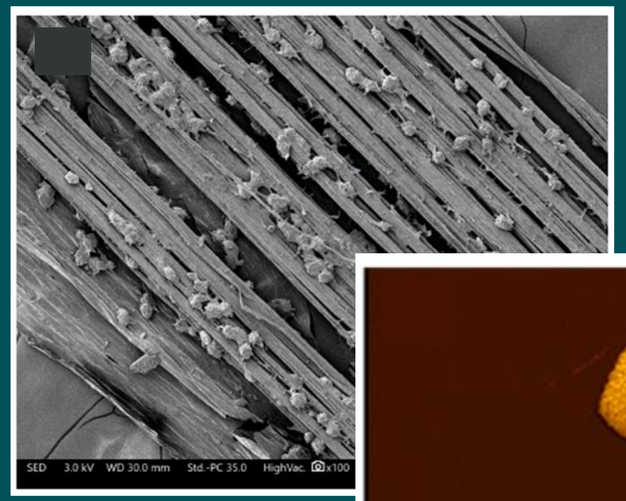
Conclusions

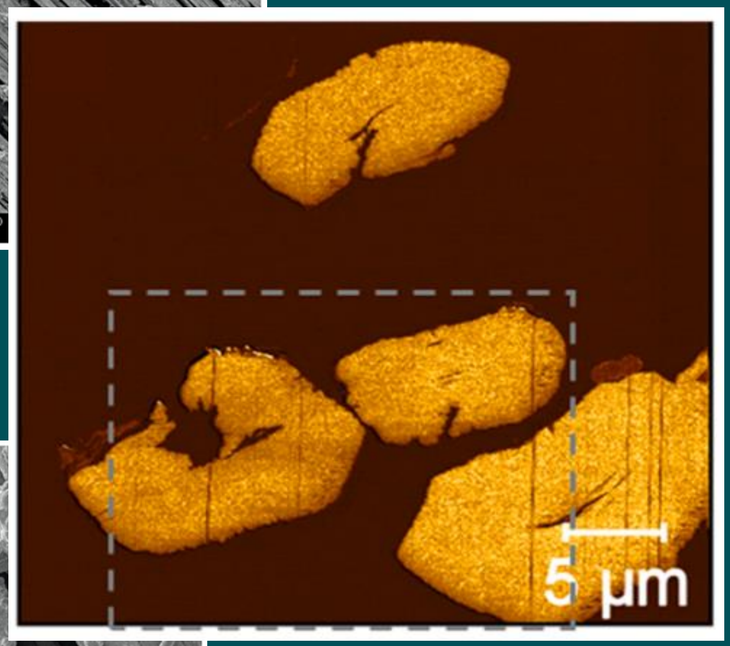
3 Degradation from the outside of the fibre

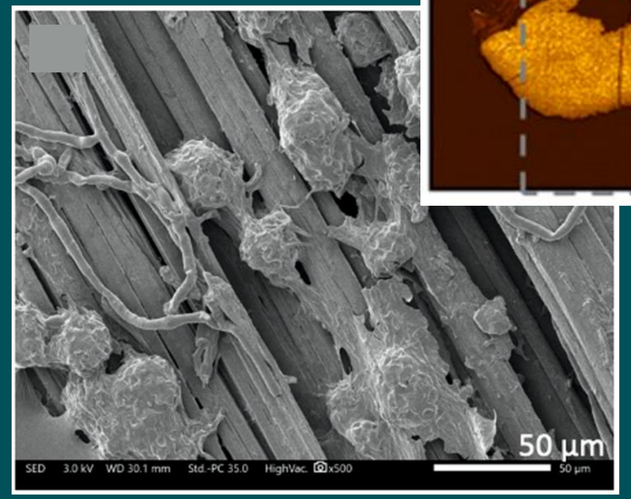












Nuez et al, Ind Crops & Prod, 2021

THANK YOU FOR YOUR ATTENTION

ANUBIS PROJECT


Elouan Guillou


Camille Goudenhooft


Roberta Cortopassi


Camila Alday


Davis Beresford Jones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Mario Sheel


Jonathan Perrin


Anita Quiles


Loren Morgillo


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Frédéric Jamme


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