Application of X-ray dark-field imaging for monitoring barley seed germination

Neutrons and Food 2016

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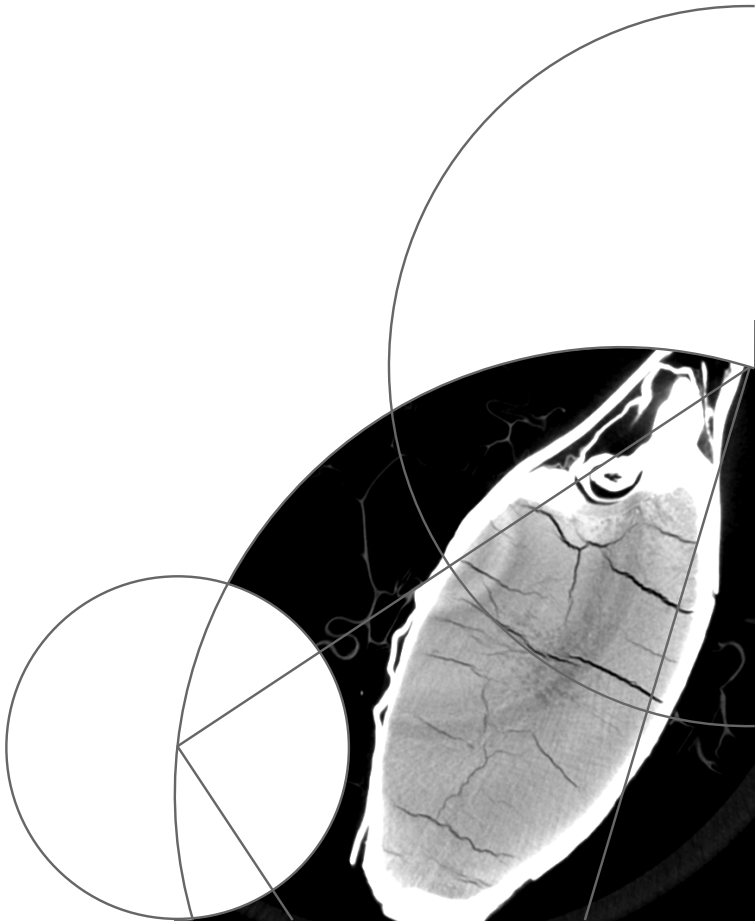


Who am i?

- Master student at the department of food science at UCPH
- Bachelor's thesis within the NEXIM project supervised by Robert Feidenhans'l
- **Disclaimer**: NOT an X-ray expert. Assistance from Mikkel Schou Nielsen.

Malt quality - problem statement

High quality malt from barley seeds is crucial in the production of high quality beer and malt whiskey

Two critical parameters for controlling the quality of malt

- Adequate uptake of water during germination
- Degree of enzymatic degradation of the seed endosperm

Laborious destructive methods used to monitor and assess these parameters

Objective

Investigate the application of X-ray dark-field imaging for monitoring barley seed germination

Focus:

- Uptake and distribution of water during a 48 hour germination period (steeping)
- Microstructural changes due to uptake of water and endosperm degradation
- Comparison with conventional X-ray transmission imaging

Dark-field vs. transmission

X-ray dark-field

- Novel non-destructive method sensitive to microstructural varations
- Contrast based on ultra small-angle X-ray scattering of microstructures
- Uses a grating interferometer

X-ray transmission

- Contrast based on X-ray attenuation

Structure of Barley Seeds

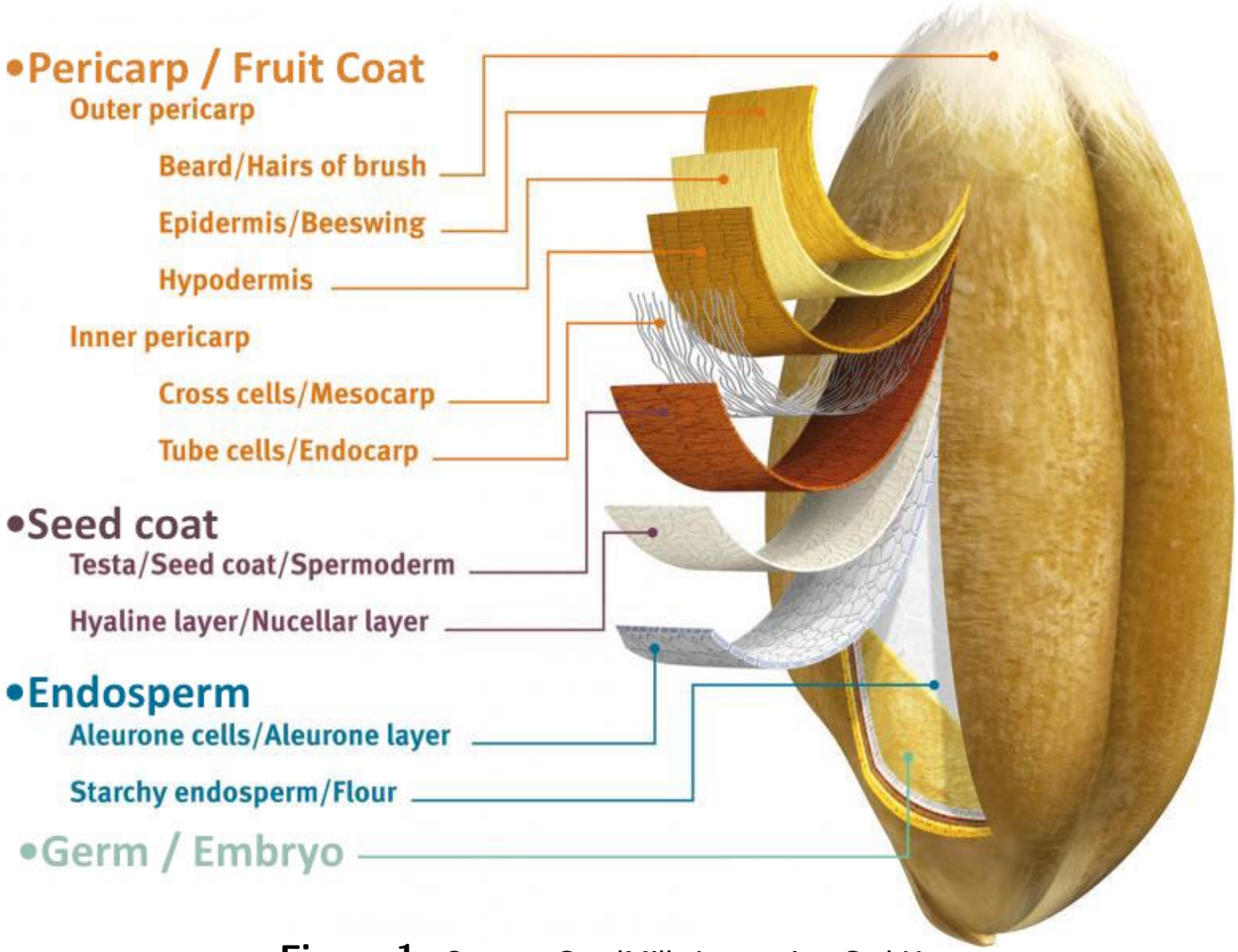


Figure 1. Source: GoodMills Innovation GmbH

Structure of Barley Seeds

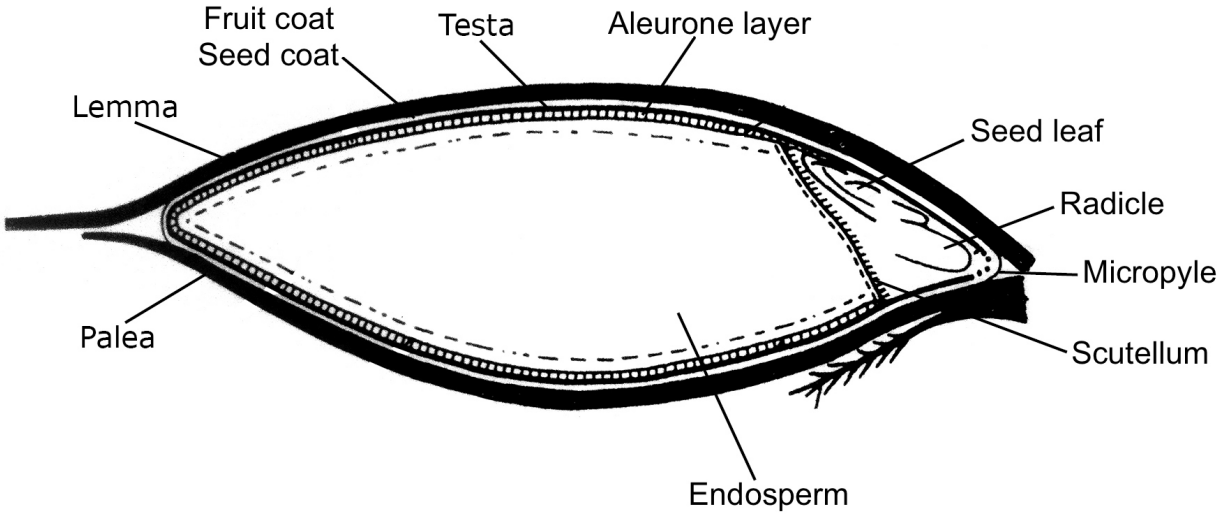


Figure 2. Schematic structure of a barley seed (adapted from Briggs (1998))

Figure 3. Barley seed with exposed endosperm. Source: GoodMills Innovation GmbH.

Structure of Barley Seeds

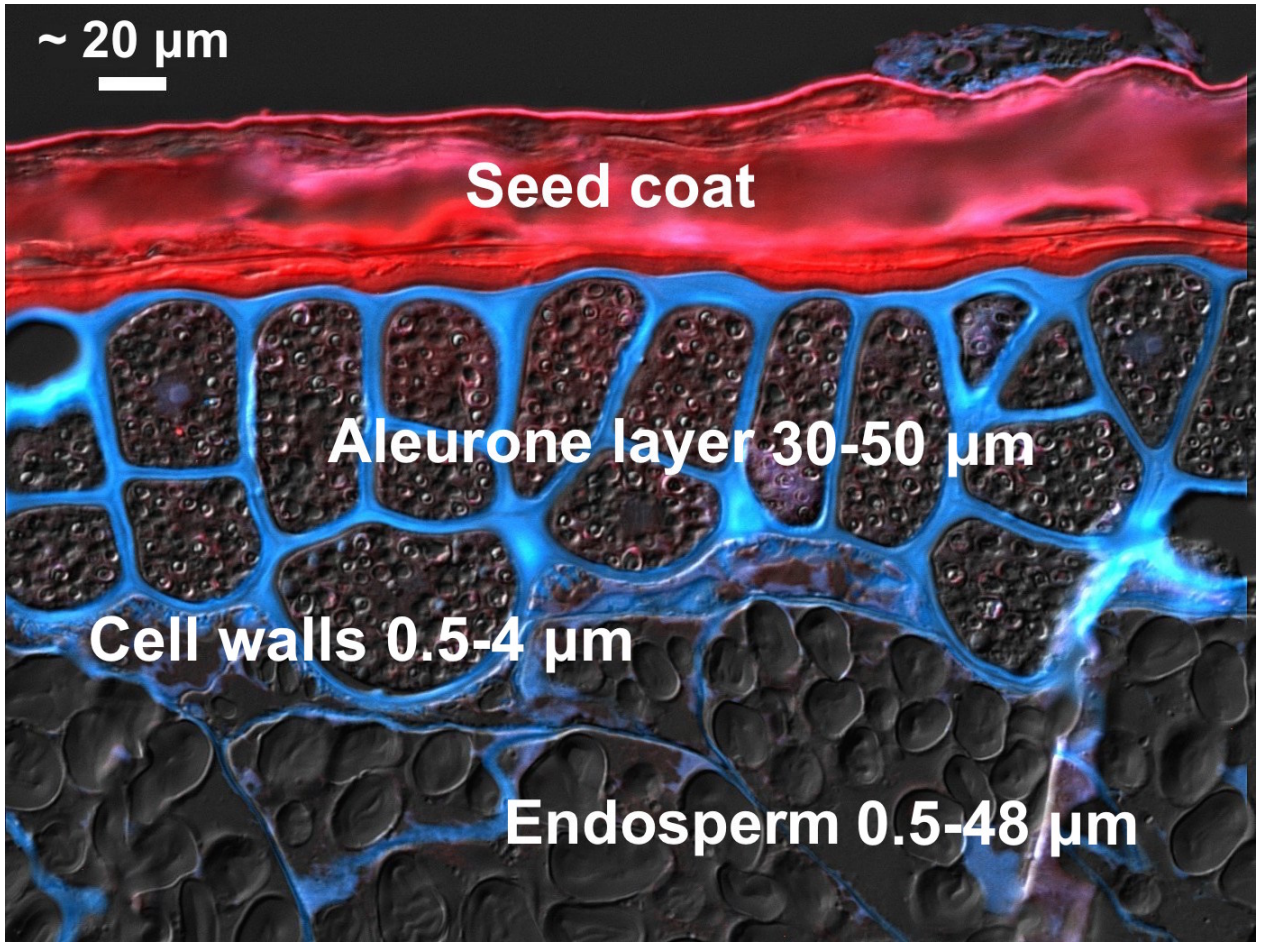


Figure 4. Section of a barley seed treated with calcofluor. Copyright: Dr. Matthew Tucker.

Imbibition and Germination

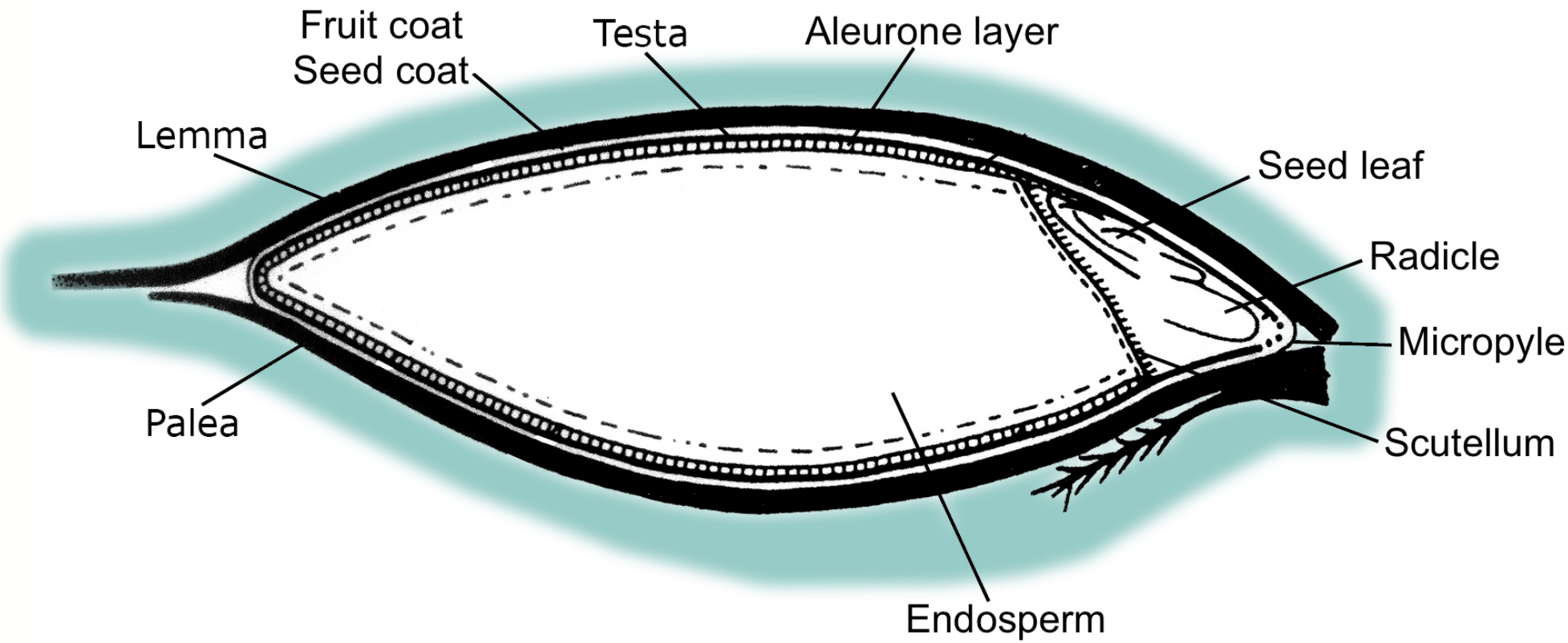
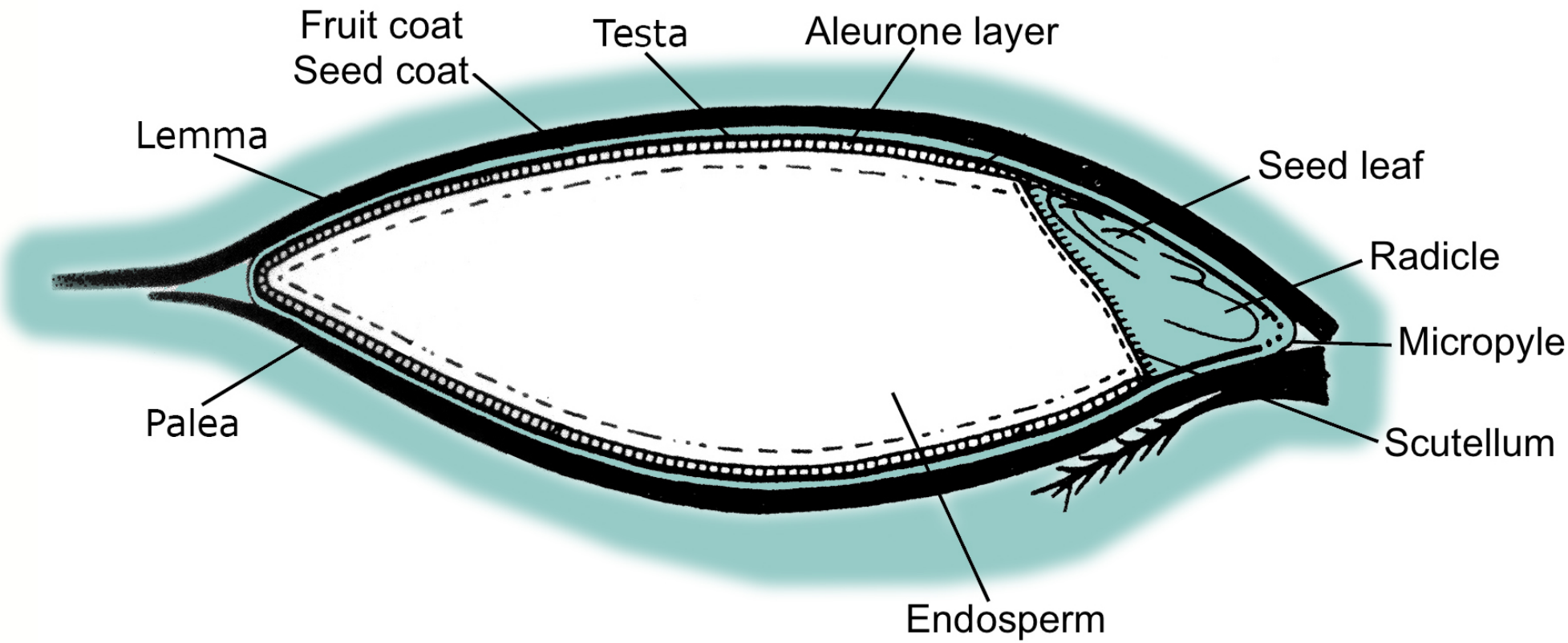


Figure 5. Schematic structure of a barley seed (adapted from Briggs (1998))

Imbibition and Germination



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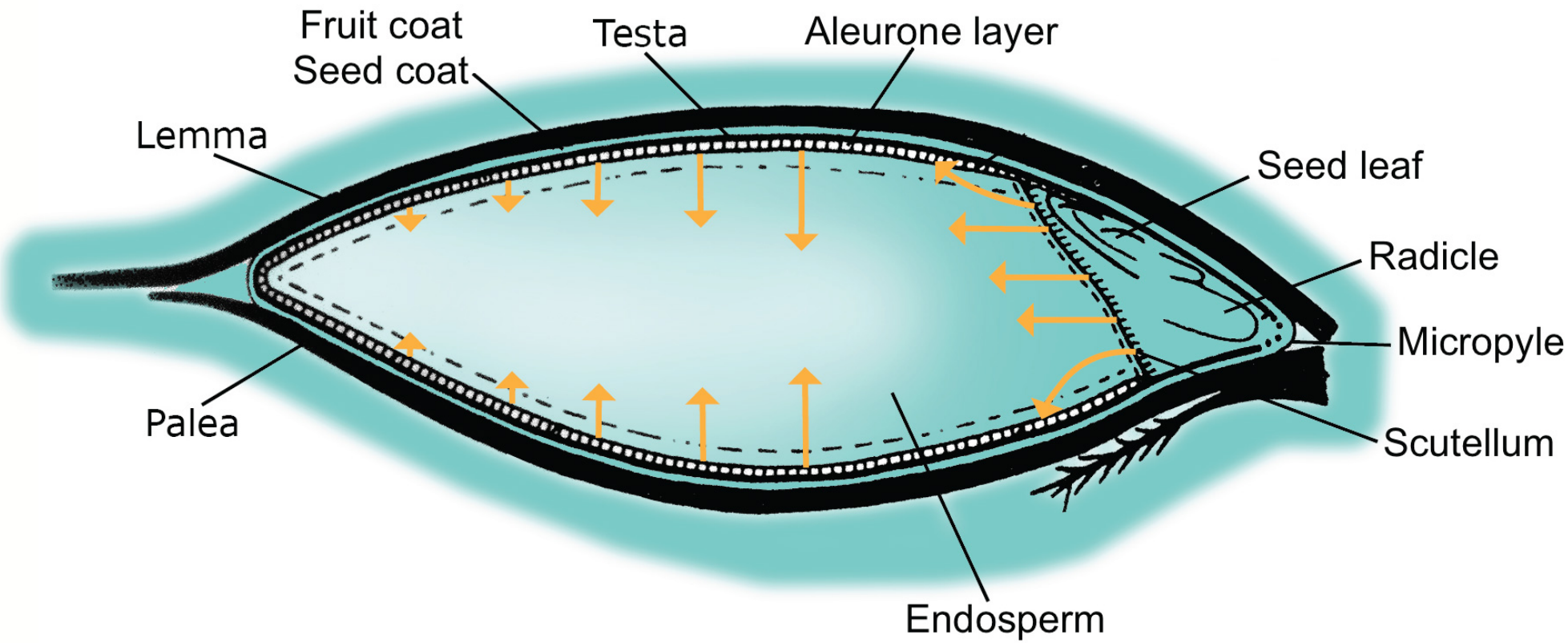
Imbibition and Germination



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Modification patterns

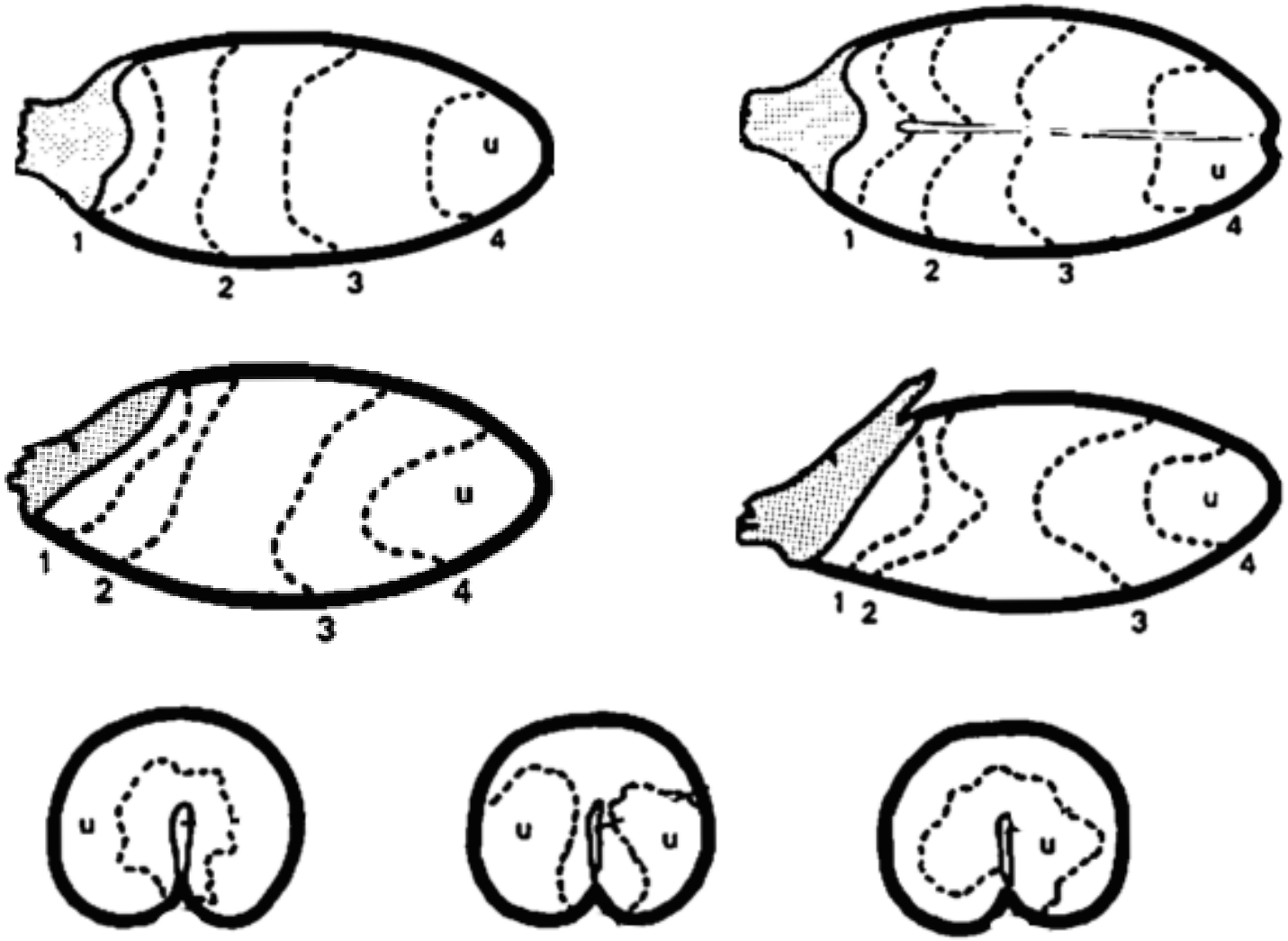


Figure 6. Modification patterns in germinating barley seeds. Adapted from (Briggs and Macdonald, 1983)

Experimental Design - 2014

- Malt quality barley seeds of the Odyssey variety harvested in 2014
- 5 seeds in each Petri dish on filter paper with 4 ml demi water, ventral side facing down

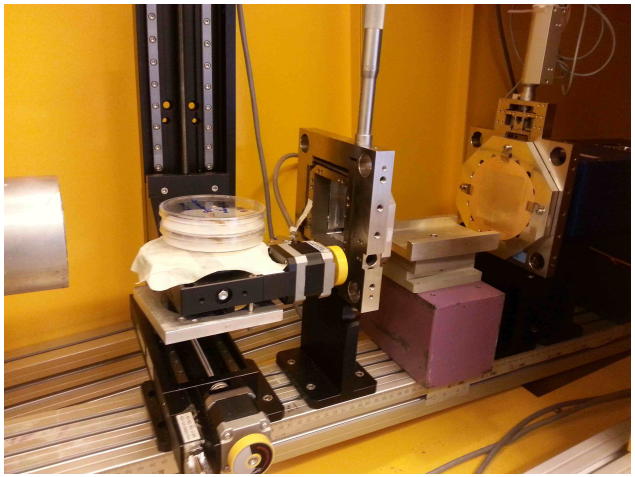
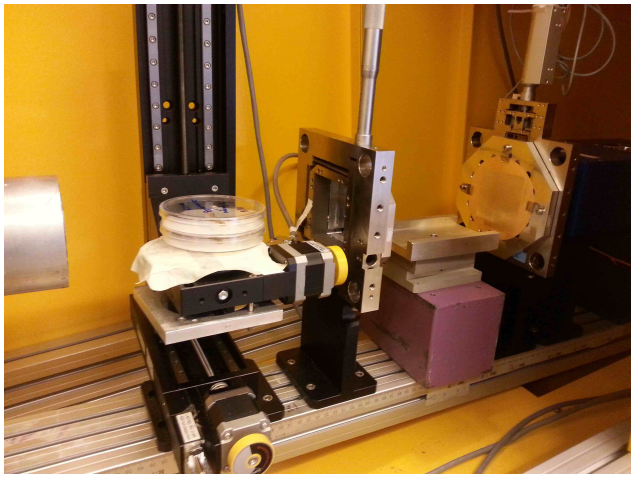


Figure 7. Experimental X-ray grating interferometer setup at the Niels Bohr Institute

Experimental Design - 2014

- Dark-field measurements for 43 and 55 hours at 19°C ⇒ 2 time series

- Structural sensitivity ∼2-60 µm
- Dosage: ∼6 and 9 Gy. Can be optimized.



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Results & discussion

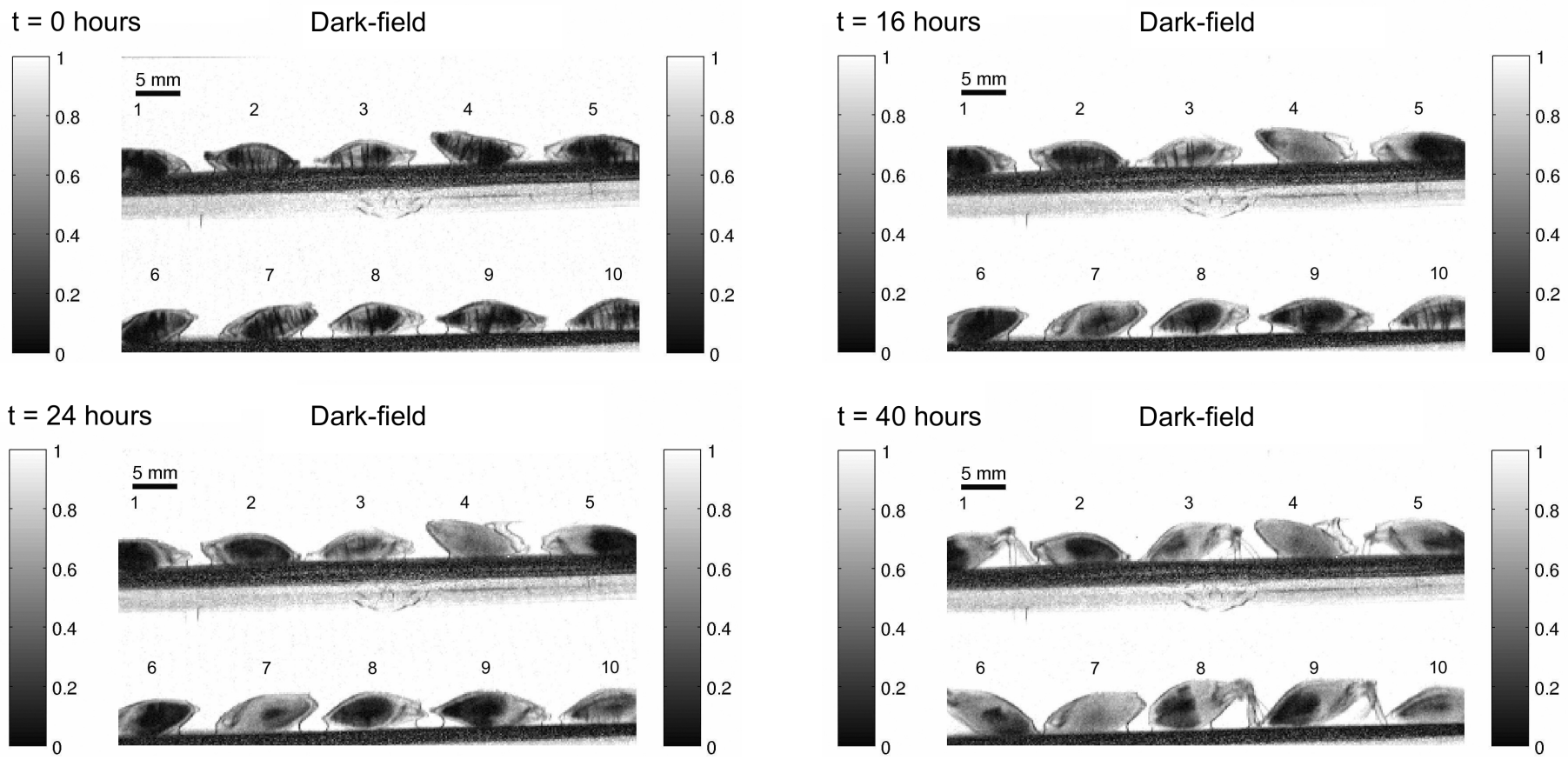

Figure 8. X-ray dark-field radiographs of steeped barley seeds at t = 0, 12, 24 and 40 hours.

Results and Discussion

Microstructural changes probably caused by

- Initial uptake of water in cells and cell walls
- **Germination $\Rightarrow$ partial degradation of cells and cell walls**
- Structural sensitivity $\sim$2-60 µm

Results and Discussion

Comparison with calcofluor treatment

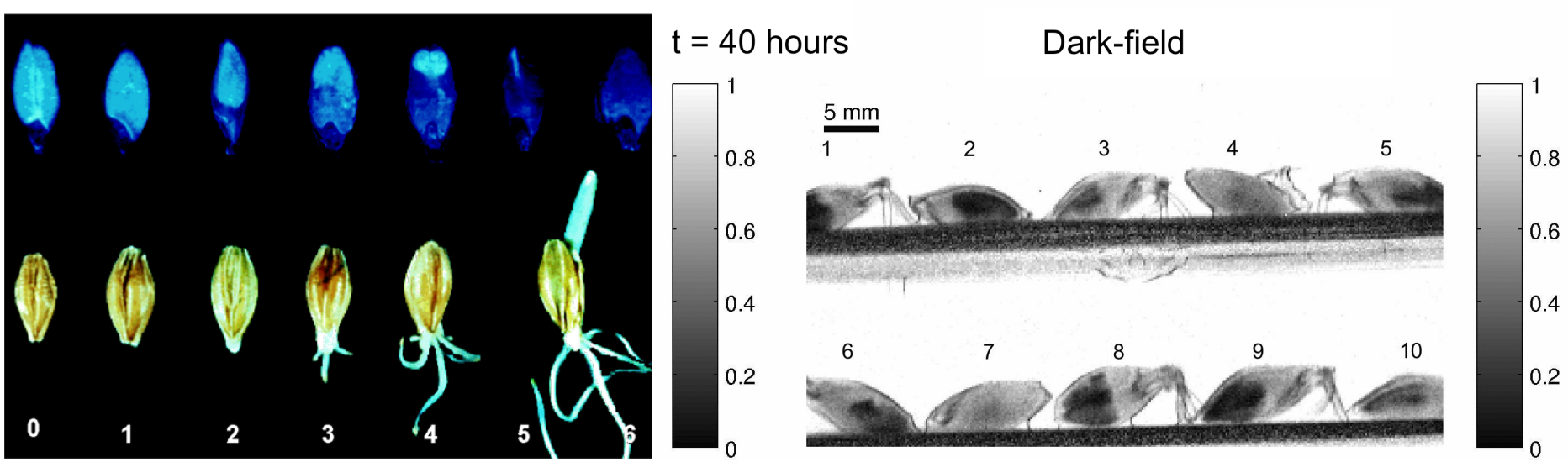

Figure 9. (left) Germinating barley seeds from 0-6 days. Treated calcofluor. Source: Carlsberg Laboratory. (right) X-ray dark-field radiograph of steeped barley seeds at t = 40 hours.

Quantitative in-situ monitoring

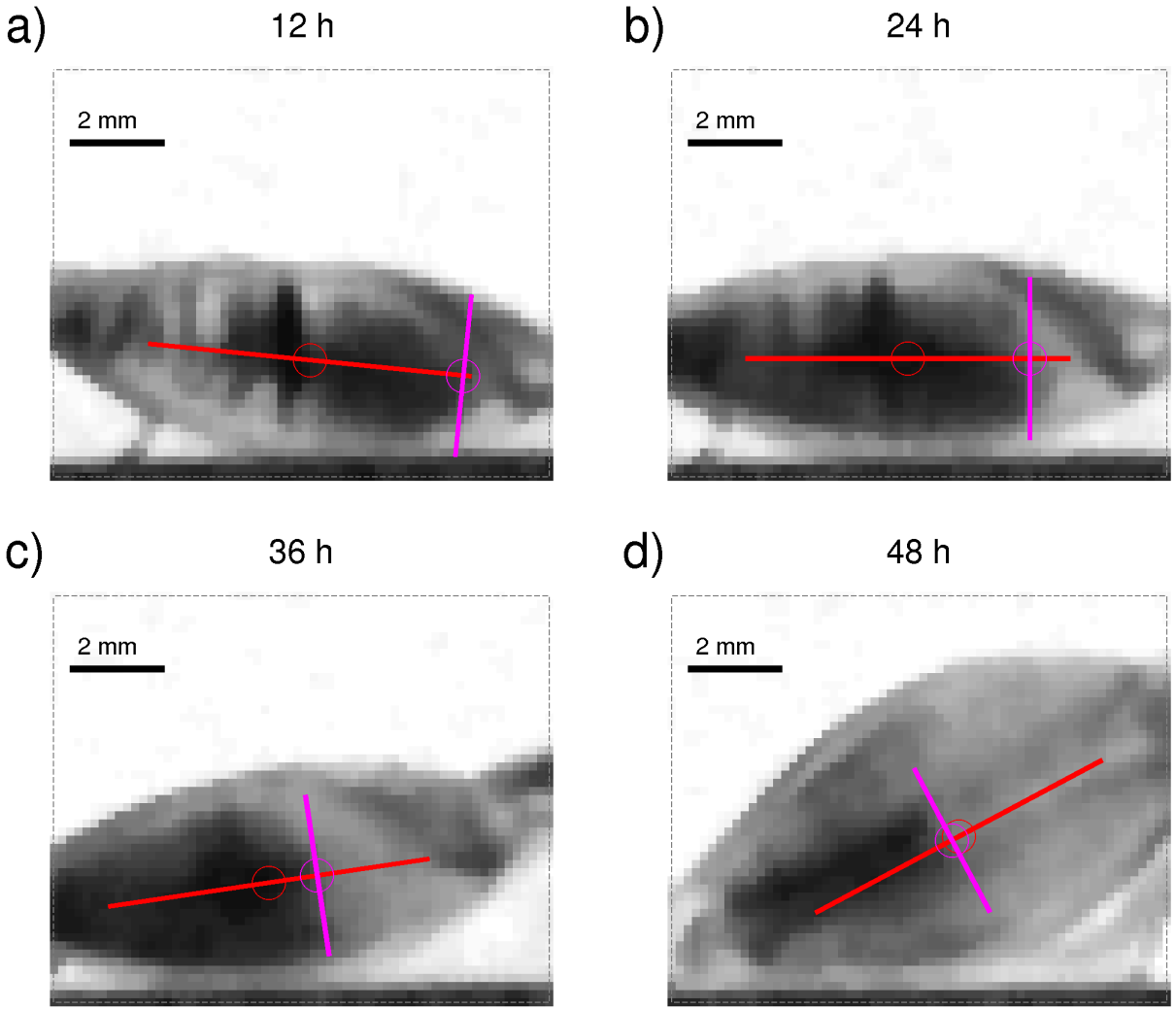

Figure 10. Dark-field radiographs of barley seed 11 at t = 12, 24, 36 and 48 hours. Through image analysis, the major axis and dark-field front were identified as indicated in red and magenta, respectively

Quantitative in-situ monitoring

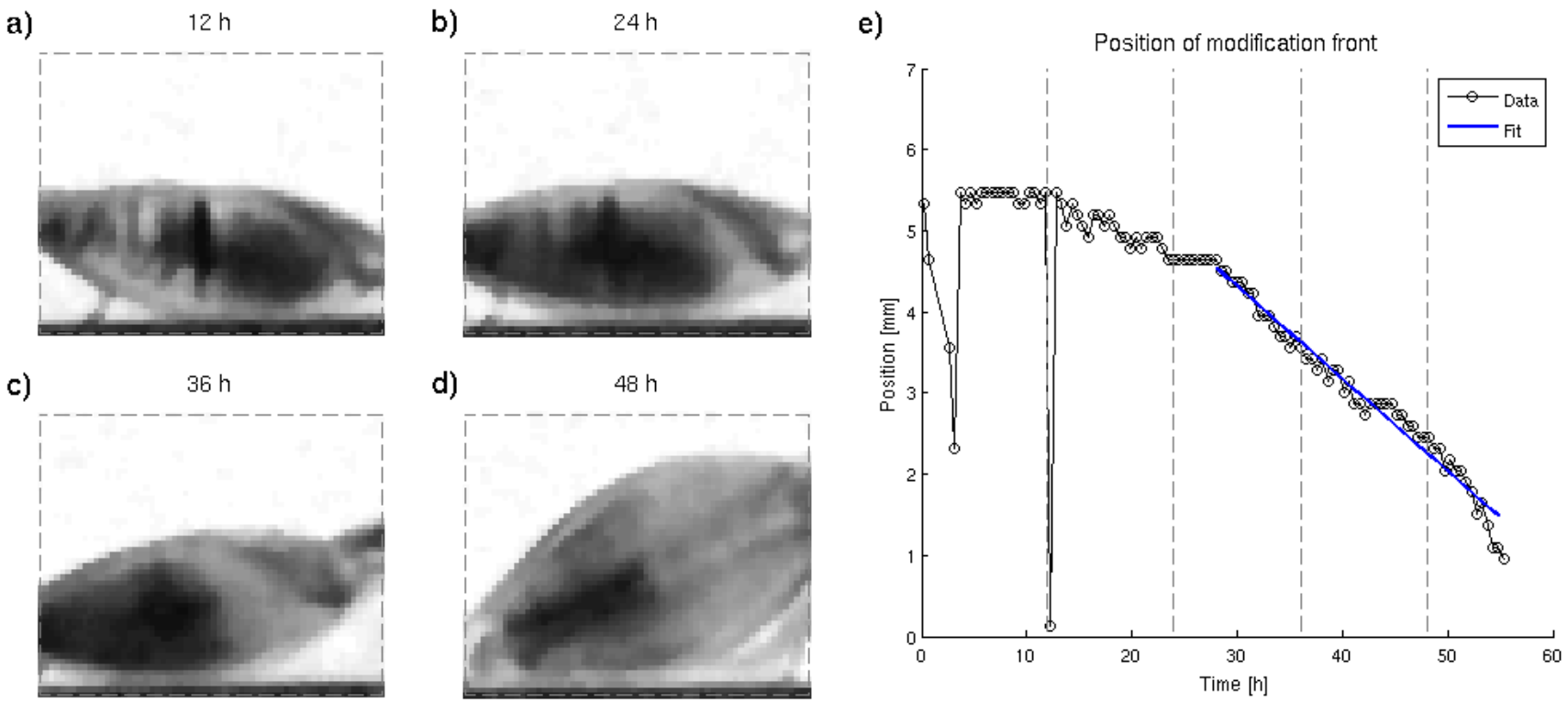

Figure 11. The position of the dark-field front with time. A linear fit is indicated in blue.

Quantitative in-situ monitoring

M.S. Nielsen, K.B. Damkjær, R. Feidenhans'l

Quantitative in-situ monitoring of germinating barley seeds using X-ray dark-field radiography

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Currently in the process of being reviewed

Results and Discussion

Observing stress cracks in barley seeds

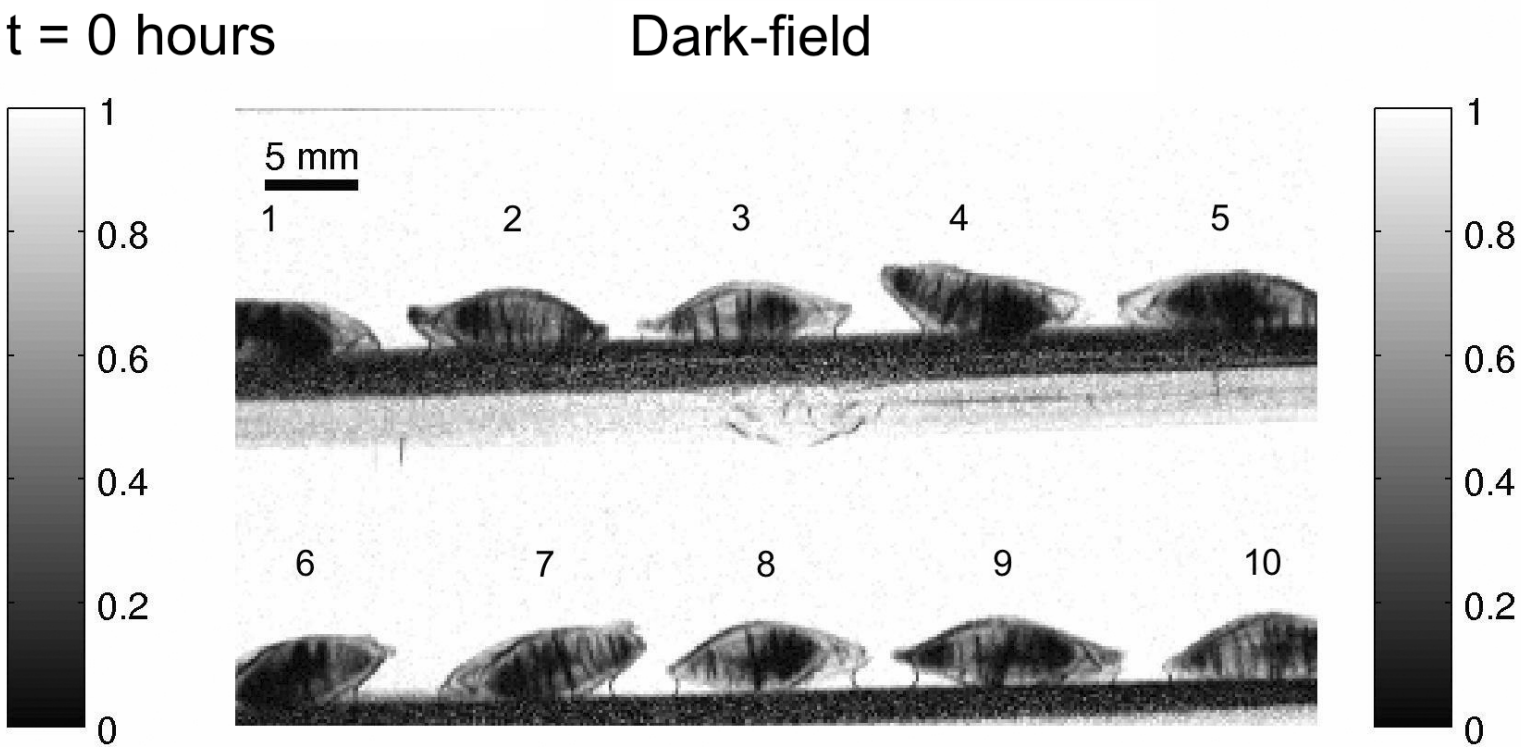

Figure 12. X-ray dark-field radiograph of steeped barley seeds at t = 0 hours

Results and Discussion

Observing stress cracks in barley seeds

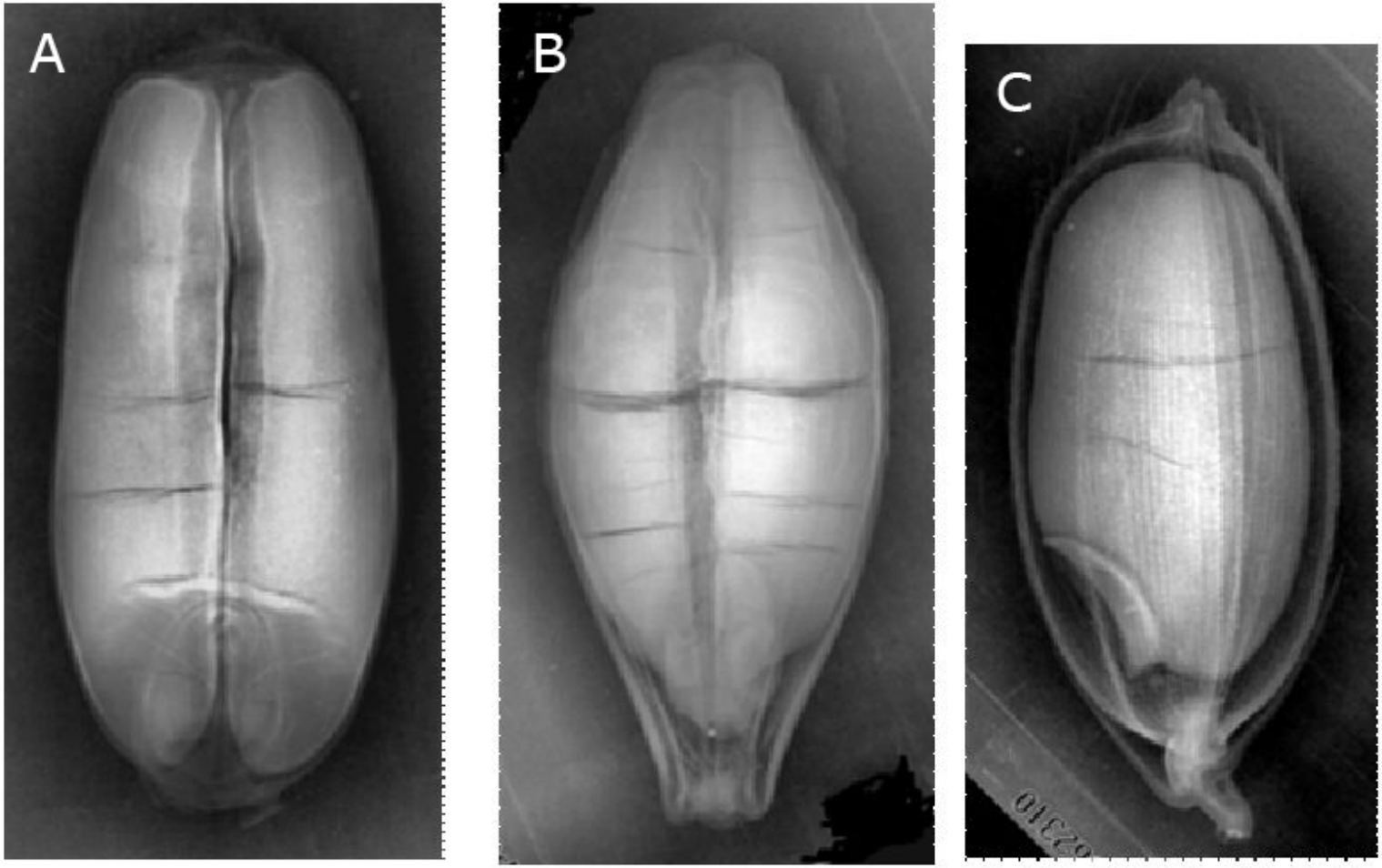

Figure 13. Stress cracks in wheat (A), barley (B) and rice (C) (Demyanchuk et al., 2013)

Conclusion

By applying X-ray dark-field imaging it was possible to

- Successfully monitor microstructural changes within barley seeds during uptake of water and germination (modification).
- Not possible using conventional X-ray transmission radiography.
- Observe stress cracks within the barley seeds

Industry potential

Faster non destructive methods such as X-ray dark-field radiography could potentially be used for

- assessing more seeds $\Rightarrow$ better statistics
- real time monitoring $\Rightarrow$ more flexible production
- investigation of the dynamics of water uptake and degradation processes in seeds in general

Outlook

- More studies needed to validate and develop method
- Comparison with calcofluor method
- Germination patterns in other seeds
- **NEUTRONS?**

Thank you for your attention

Questions?

Comments?

Suggestions?

Acknowledgments

- The NEXIM project
- Robert Feidenhans'l
- Mikkel Schou Nielsen
- Torsten Lauridsen
- Birthe Møller Jespersen
- The Imaging Industry Portal at DTU (Carsten Gundlach)

References

Aastrup, S., G. Gibbons, and L. Munck
1981. A rapid method for estimating the degree of modification in barley malt by measurement of cell wall breakdown. *Carlsberg Research Communications*, 46(1-2):77–86.

Briggs, D.
1998. *Malts and Malting*, 1st edition. Blackie Academic & Professional.

Briggs, D. E. and J. Macdonald
1983. PATTERNS OF MODIFICATION IN MALTING BARLEY. *Journal of the Institute of Brewing*, 89(4):260–273.

Demyanchuk, A., S. Grundas, and L. Velikanov
2013. Identification of wheat morphotype and variety based on x-ray images of kernels. In *Advances in Agrophysical Research*, S. Grundas and A. Stepniewski, eds., Pp. 223–267.

Kunze, W.
2010. *Technology brewing & malting*, 4th int. edition. Berlin VLB.