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

Neutrons and Food 2016

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Introduction
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- Objective
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Barley Seeds
- Structure of Barley Seeds
- Imbibition and Germination
- Modification

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Acknowledgments
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 variations
- 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

- **Pericarp / Fruit Coat**
  - Outer pericarp
  - Beard/Hairs of brush
  - Epidermis/Beeswing
  - Hypodermis
  - Inner pericarp
  - Cross cells/Mesocarp
  - Tube cells/Endocarp

- **Seed coat**
  - Testa/Seed coat/Spermoderm
  - Hyaline layer/Nucellar layer

- **Endosperm**
  - Aleurone cells/Aleurone layer
  - Starchy endosperm/Flour

- **Germ / Embryo**

**Figure 1.** Source: GoodMills Innovation GmbH

Slide 7 — Application of X-ray dark-field imaging for monitoring barley seed germination
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

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

Figure 7. Experimental X-ray grating interferometer setup at the Niels Bohr Institute
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 $\mu$m
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.
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.
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 ⇒ better statistics
- real time monitoring ⇒ 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  

Briggs, D.  

Briggs, D. E. and J. Macdonald  

Demyanchuk, A., S. Grundas, and L. Velikanov  

Kunze, W.  