

Possibilities for monitoring product quality and adjustment of drying conditions

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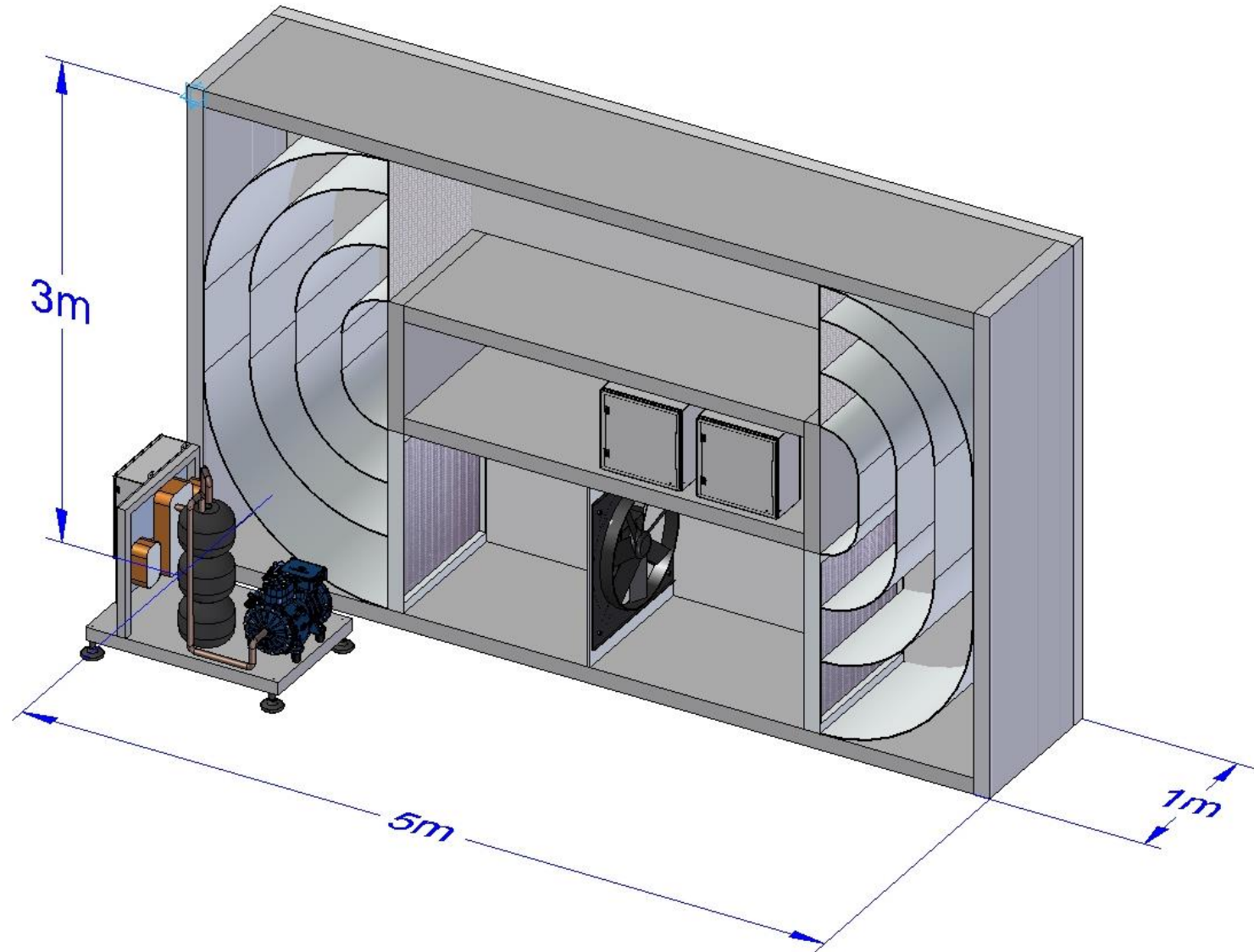
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Initial Situation

Possible settings

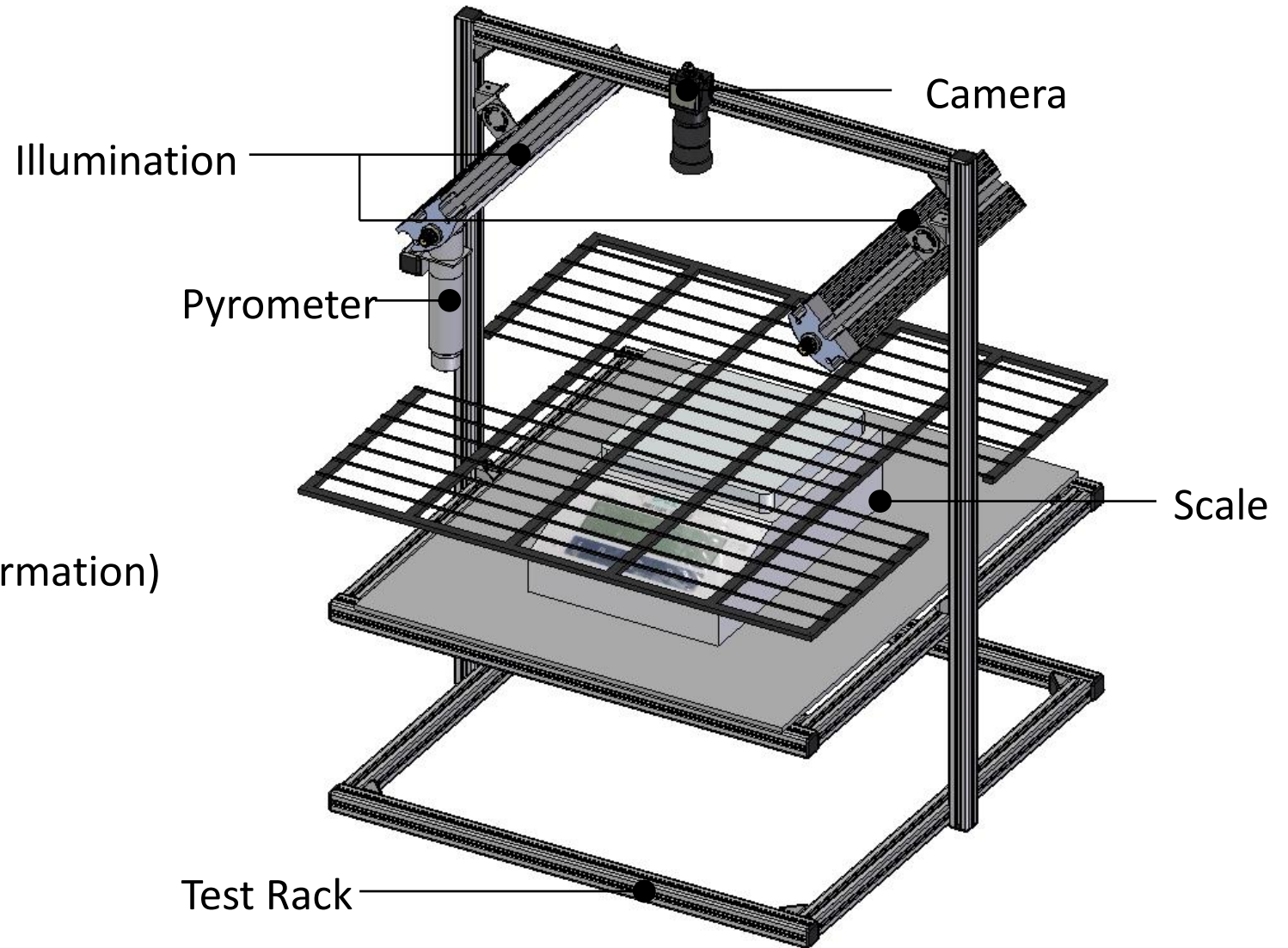
- Set temperature
- Set air velocity
- Set glycol temperature
- Record of Temperature
- Record of relative Humidity
- Record of Air Velocity



Modifications

New sensors

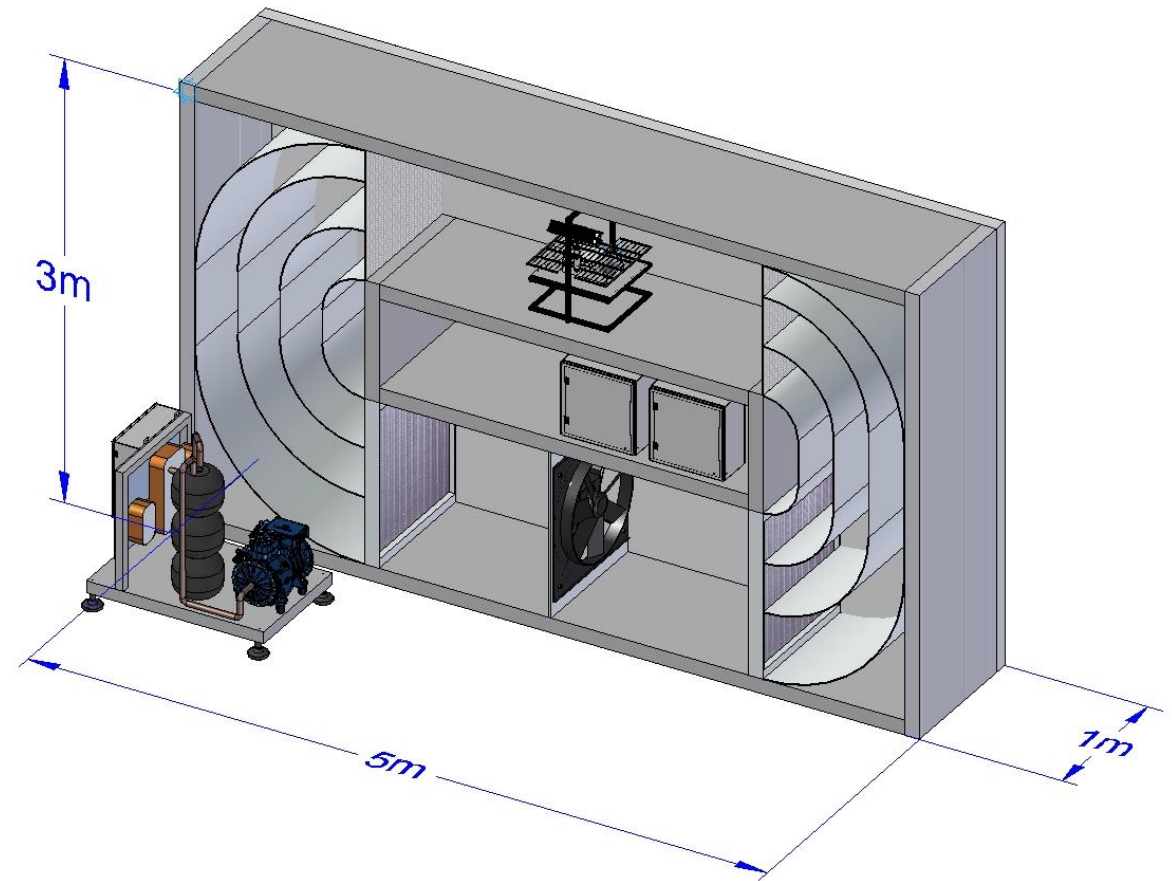
- Scale (drying kinetics)
- Pyrometer (surface temperature)
- Camera system with illumination (color alternation, shrinkage and deformation)



Modifications

New features

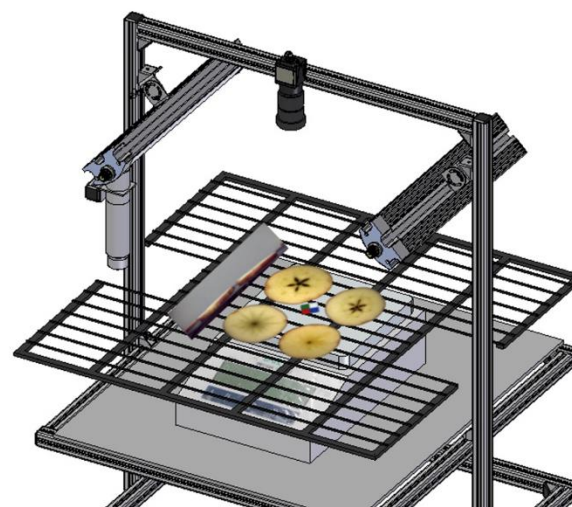
- Graphical user interface with control system
- Regulation of T, RH and Air velocity
- Continuous data acquisition
- No interruption of the drying process
- Analyse of optical parameters
- Own programmable drying process conditions



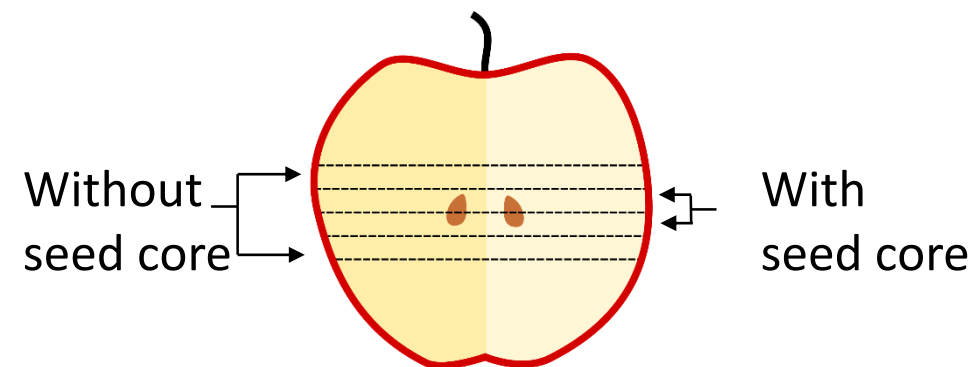
Experiments setup

Setup

- Apple slices 5mm thickness
- One underneath the pyrometer
- Each test series at least 3x
- 4 Test series in the middle of the drying chamber



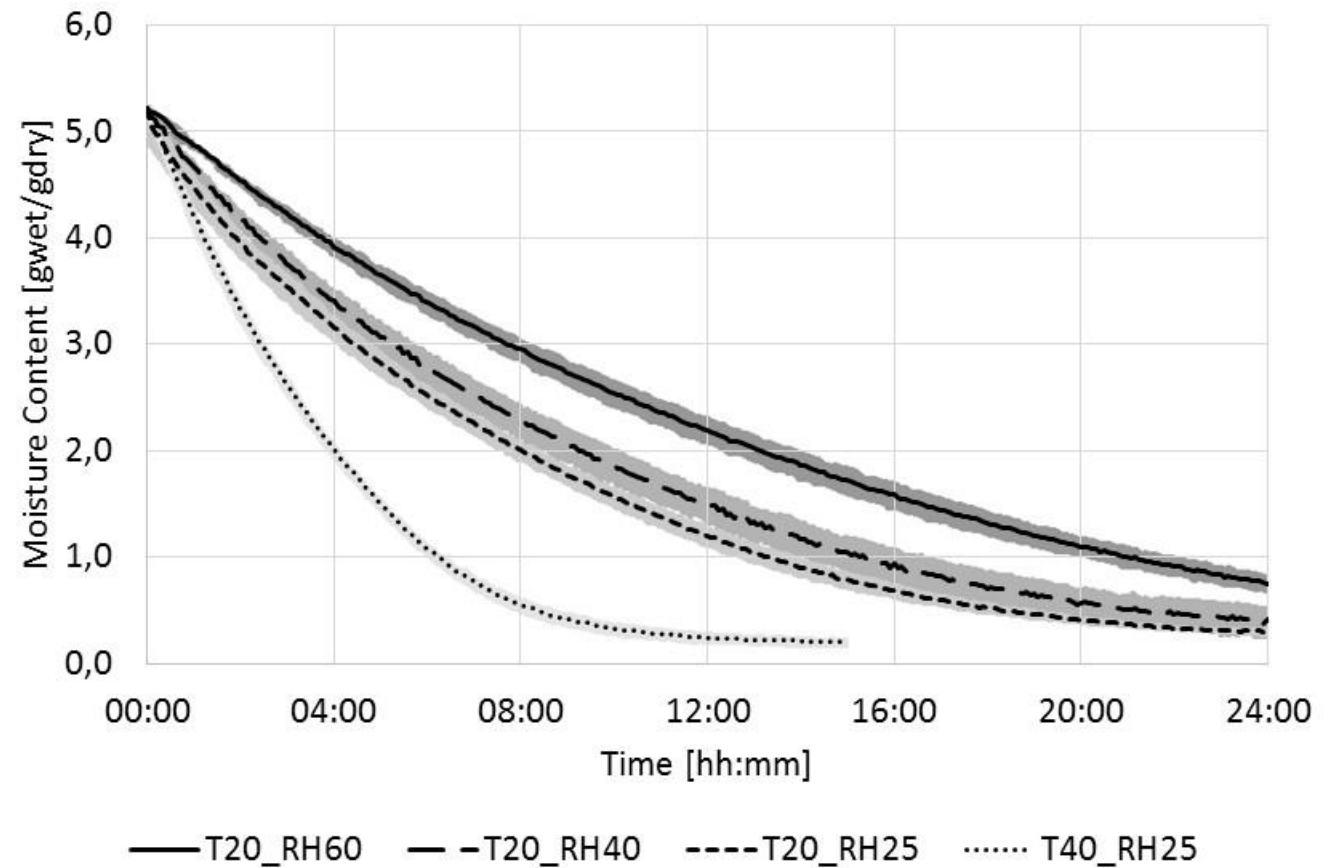
Test name	Temp. dry air	Rel. humidity	Air velocity
T20_RH60	20 GradC	60%	1,5m/s
T20_RH40	20 GradC	40%	1,5m/s
T20_RH25	20 GradC	25%	1,5m/s
T40_RH25	40 GradC	25%	1,5m/s



Results drying kinetics

Moisture Ratio

- Drying matter determined with vacuum freeze drying
- Equilibrium Moisture Content determined with **climate chamber (one week of drying)**

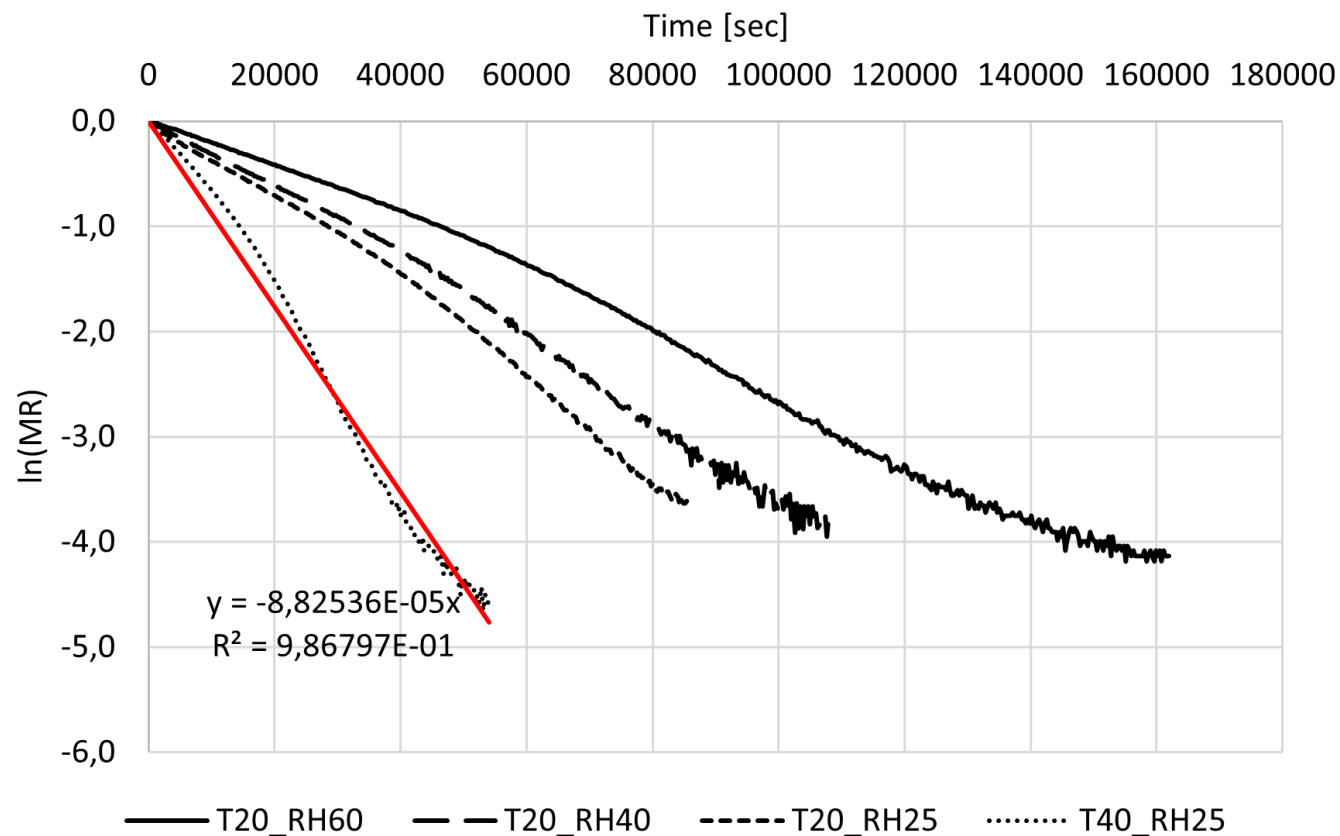


Results drying kinetics

Effective Diffusivity [1]

	D_{eff} [m ² /s]
T20_RH60	2,7E-10
T20_RH40	3,6E-10
T20_RH25	4,1E-10
T40_RH25	8,9E-10

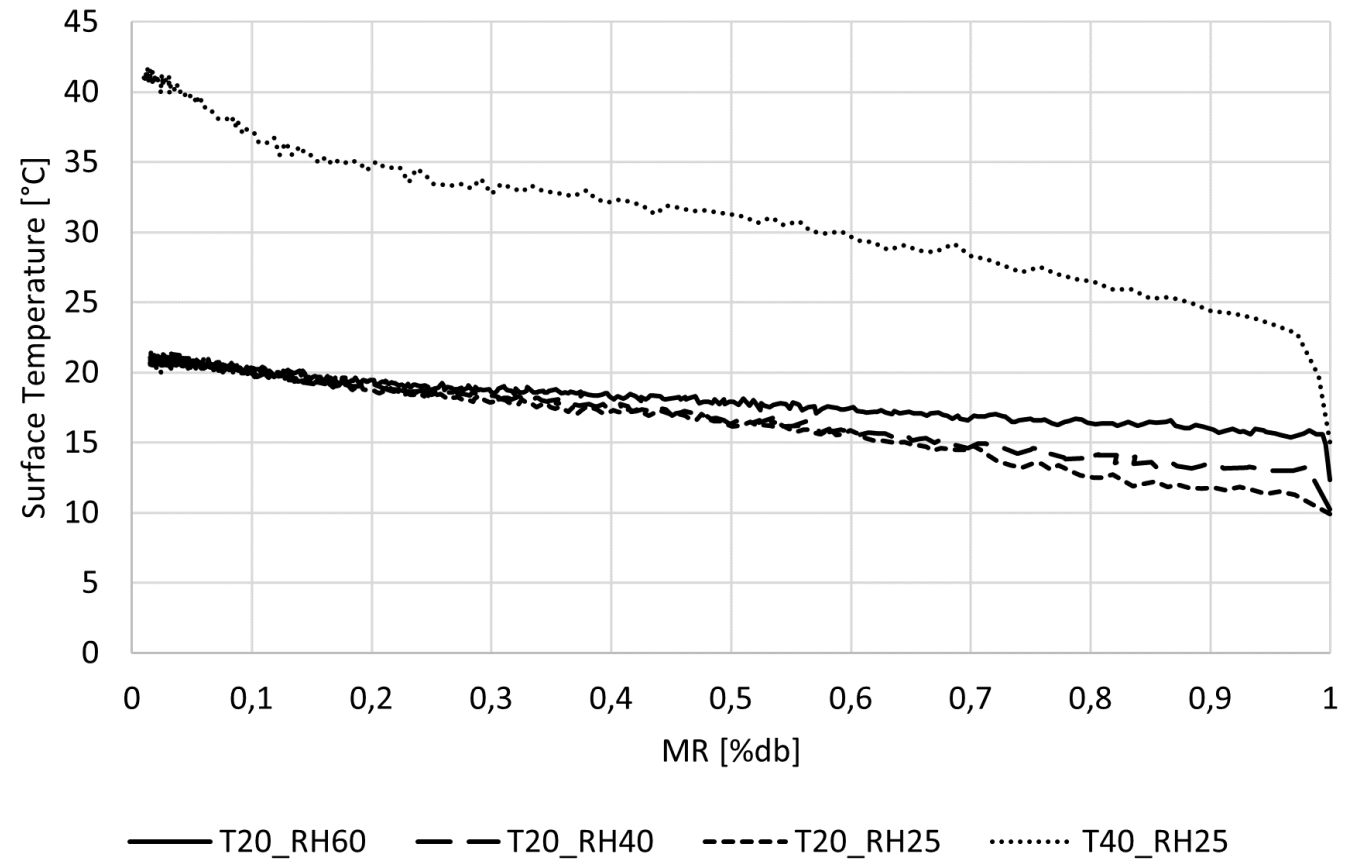
$$D_{eff} = - \left(\frac{4 \left(\frac{thickness}{2} \right)^2}{\pi^2} \right) * (slope\ of\ line)$$



Results drying experiments

Surface Temperature

- One apple slice underneath the pyrometer
- Average of at least 3 apple slices
- Warm up at the beginning (stored at 8°C in the fridge)
- Linear increase with MR



Optical parameters (shrinkage and deformation)

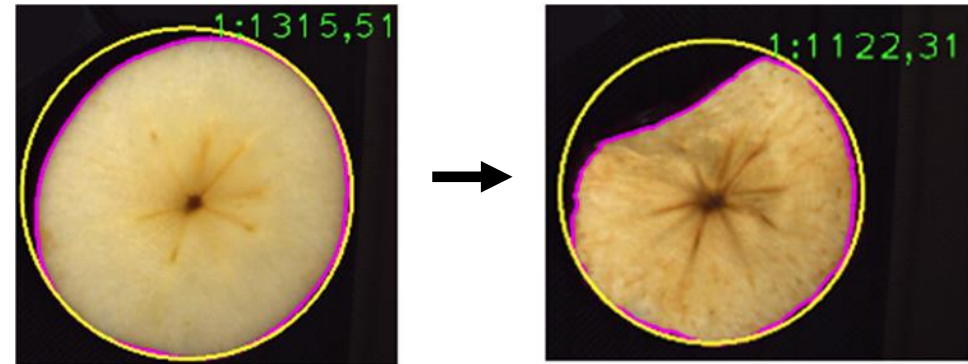
Measuring Principles

- Analyzed with Java Tool and OpenCV [2]
- Shrinkage by $\frac{A_{actual}}{A_{t0}}$
- Deformation by $\frac{A_{actual}}{A_{ref}}$
- A_{ref} is the minimum reference shape

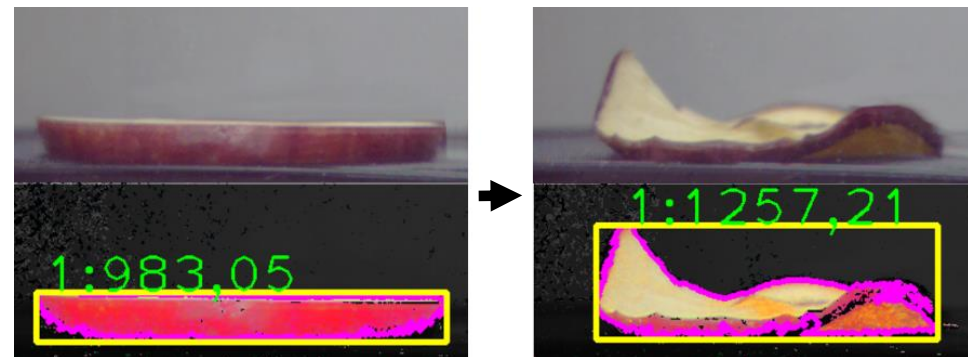
[Demo Video Top View\(30sec\)](#)

[Demo Video Sidelong View \(30sec\)](#)

Top view, circle as reference shape



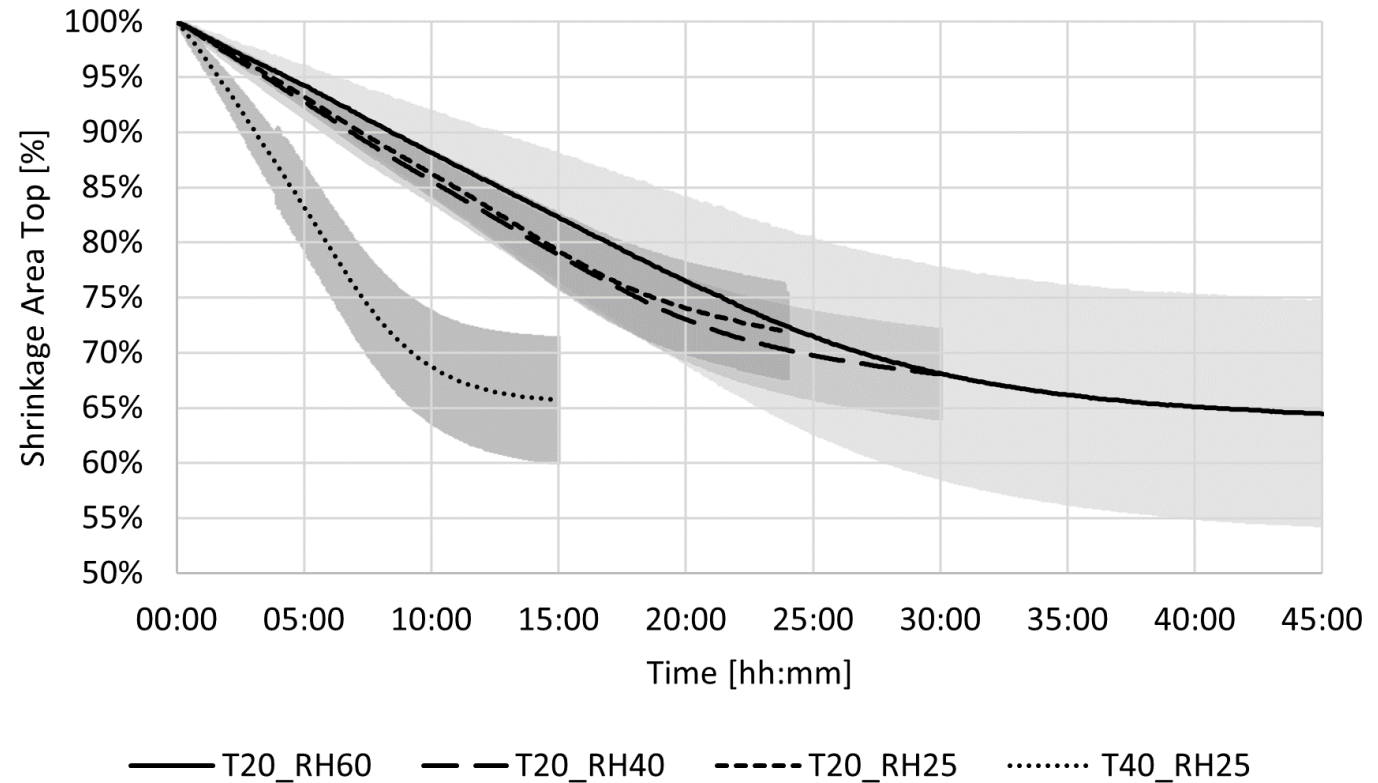
Sidelong view, rectangle as reference shape



Results optical parameters

Shrinkage Top View

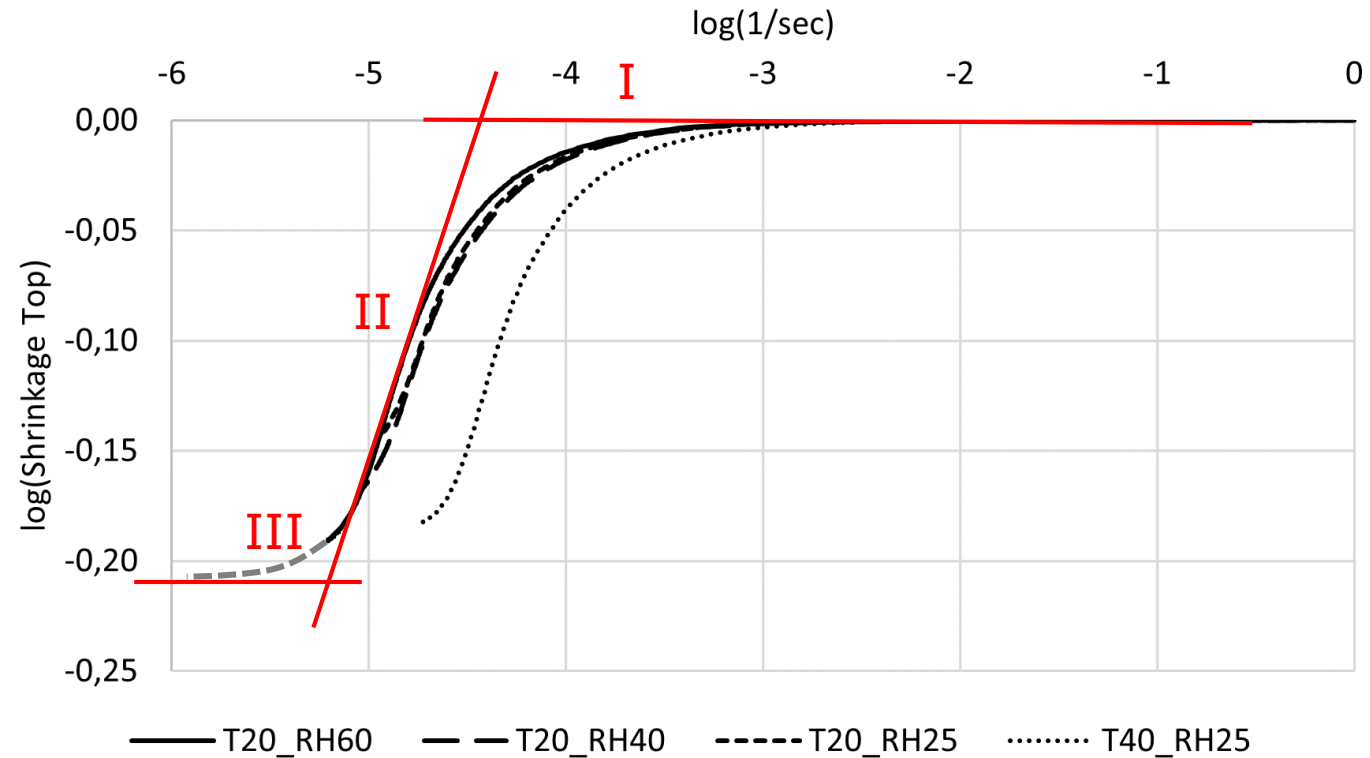
- Similar shrinkage at 20°C and RH25%, RH40%
- Shrinkage at 40°C much faster
- Similar magnitude of shrinkage



Results optical parameters

Shrinkage Top View

- different shrinking states
- Highest shrinkage rate in state II
- Ca. 90% of drying time is state II

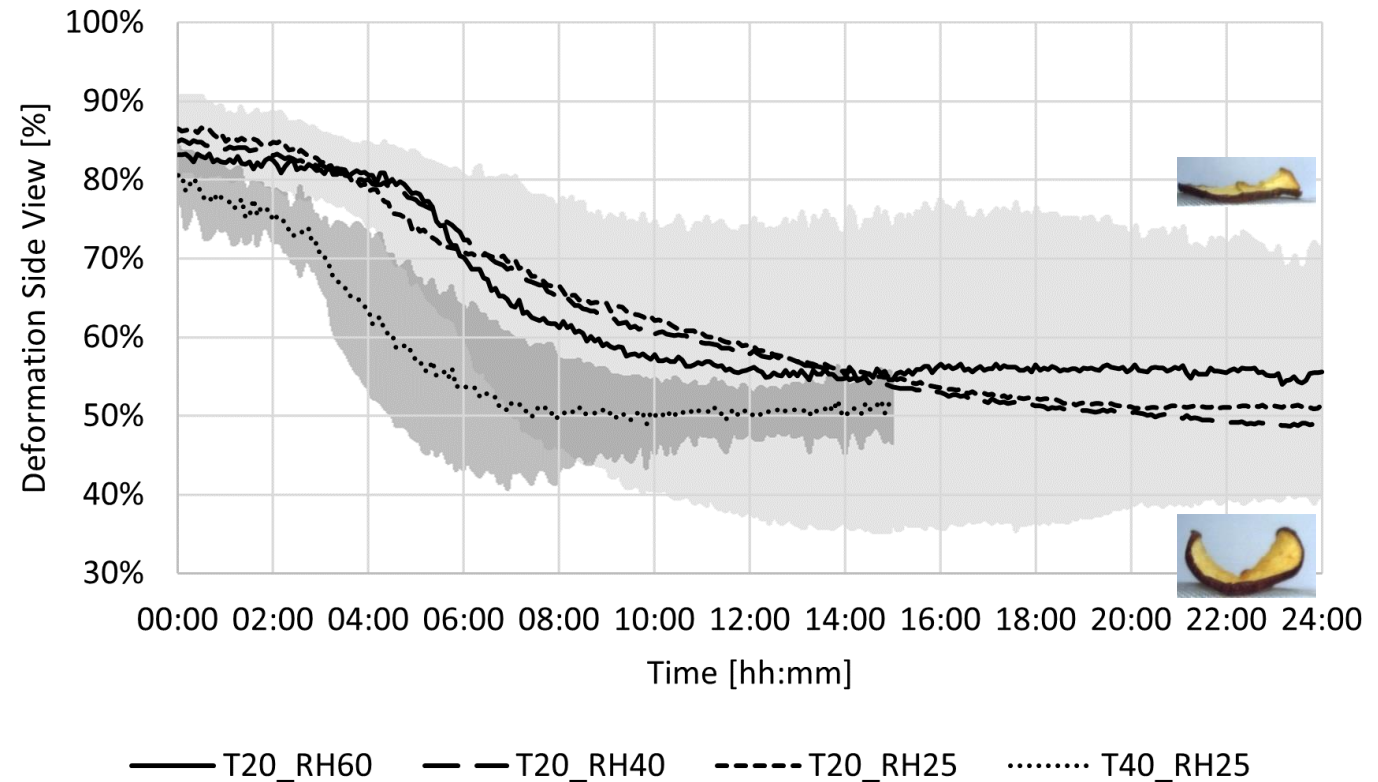


Results optical parameters

Deformation Side View

- Similar deformation at 20°C
- Strong fluctuation In deformation magnitude

[Demo Video Deformation Side View \(30sec\)](#)

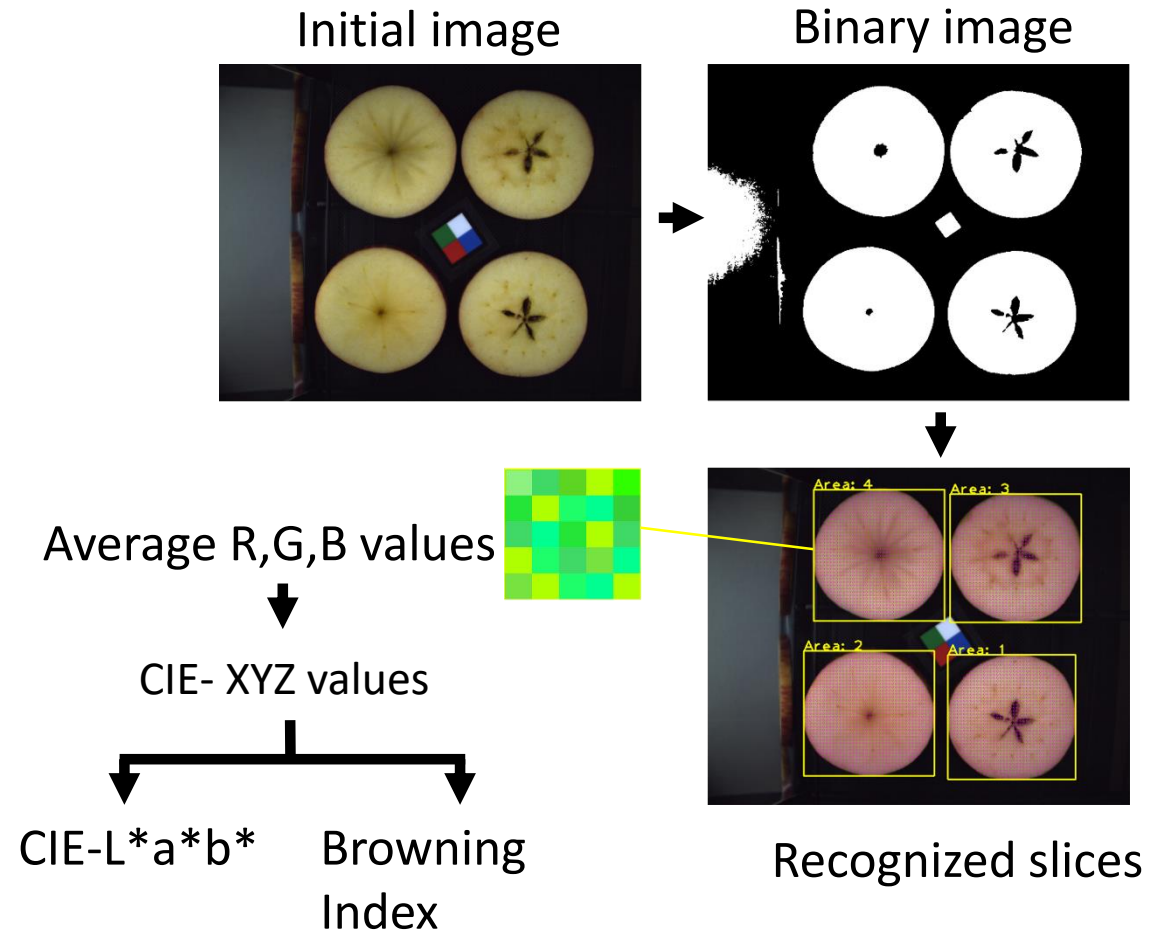


Optical Parameters (color alternation)

Measuring Principles

- Analyzed with Java Tool and OpenCV
- Readout and average of RGB values for each apple slice and each image
- Conversion to CIE-L*a*b* color space and Browning Index ^[3]

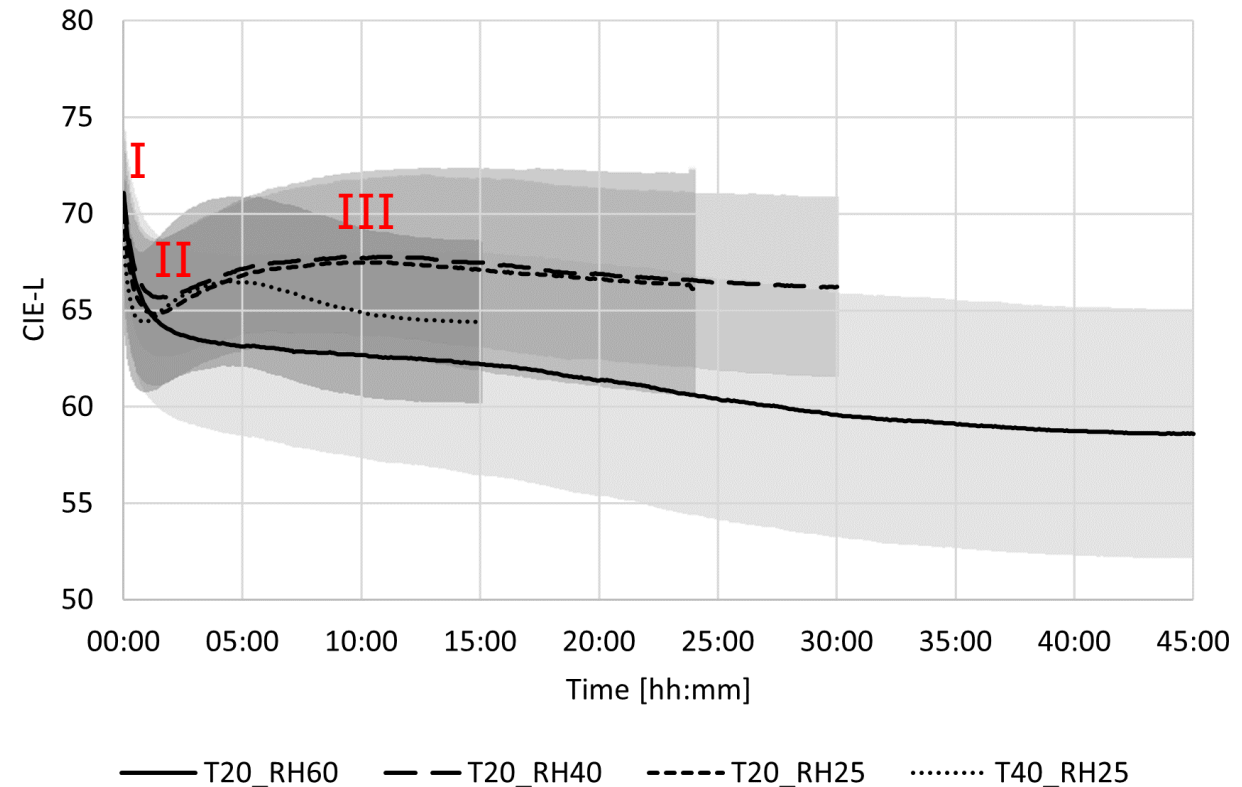
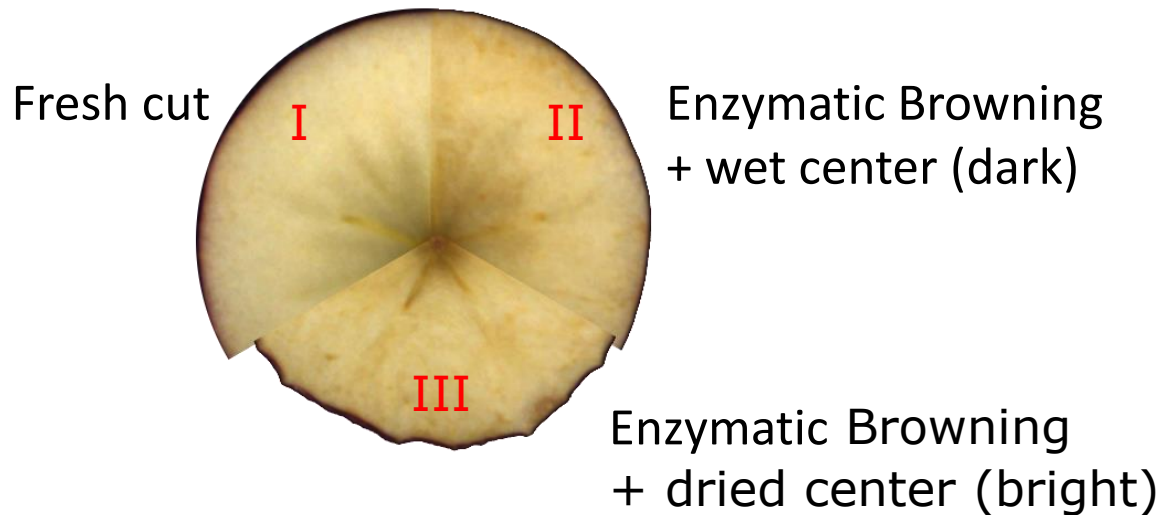
[Demo Video \(30sec\)](#)



Results optical parameters

Color CIE-L value (lightness)

- T20_RH40 and T20_RH25 similar
- Minimum after ca. 3-4h

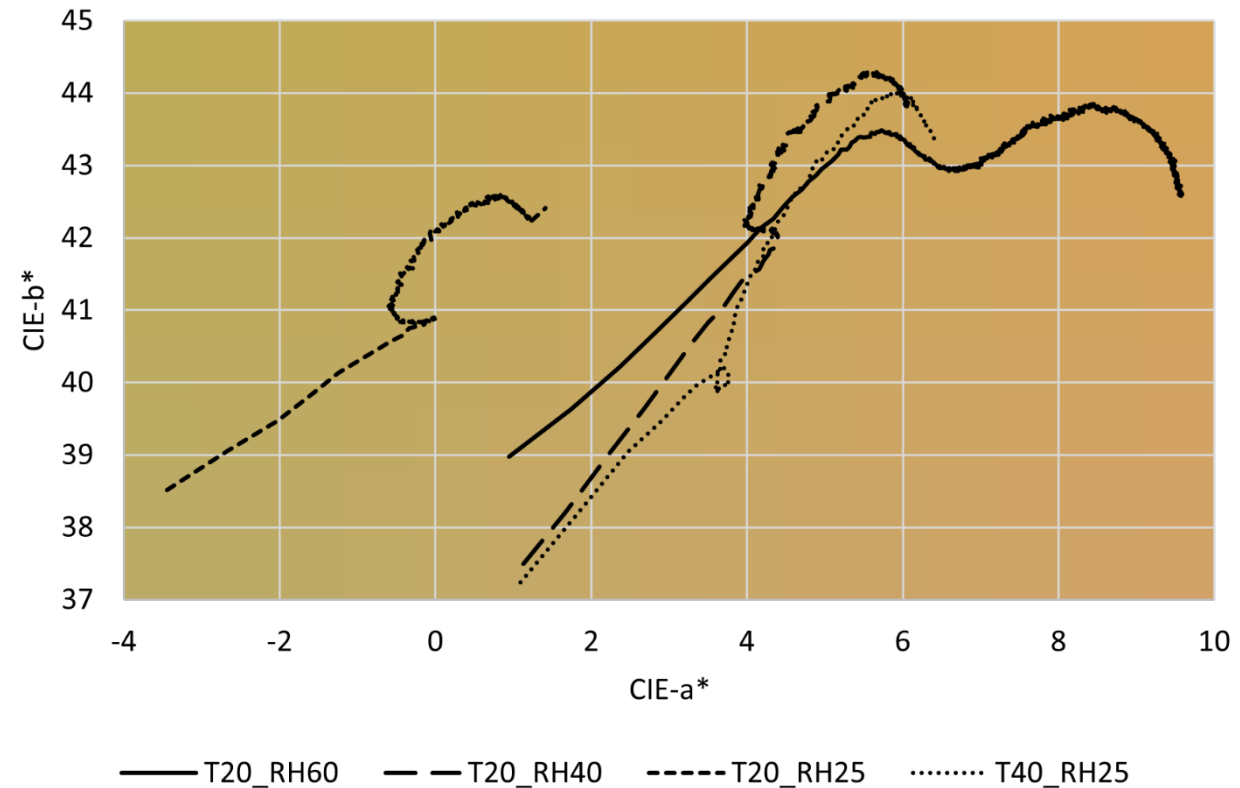


Results optical parameters

Color CIE-a and CIE-b value

- Biggest alternation within the first few hours

[Demo Video \(30sec\)](#)

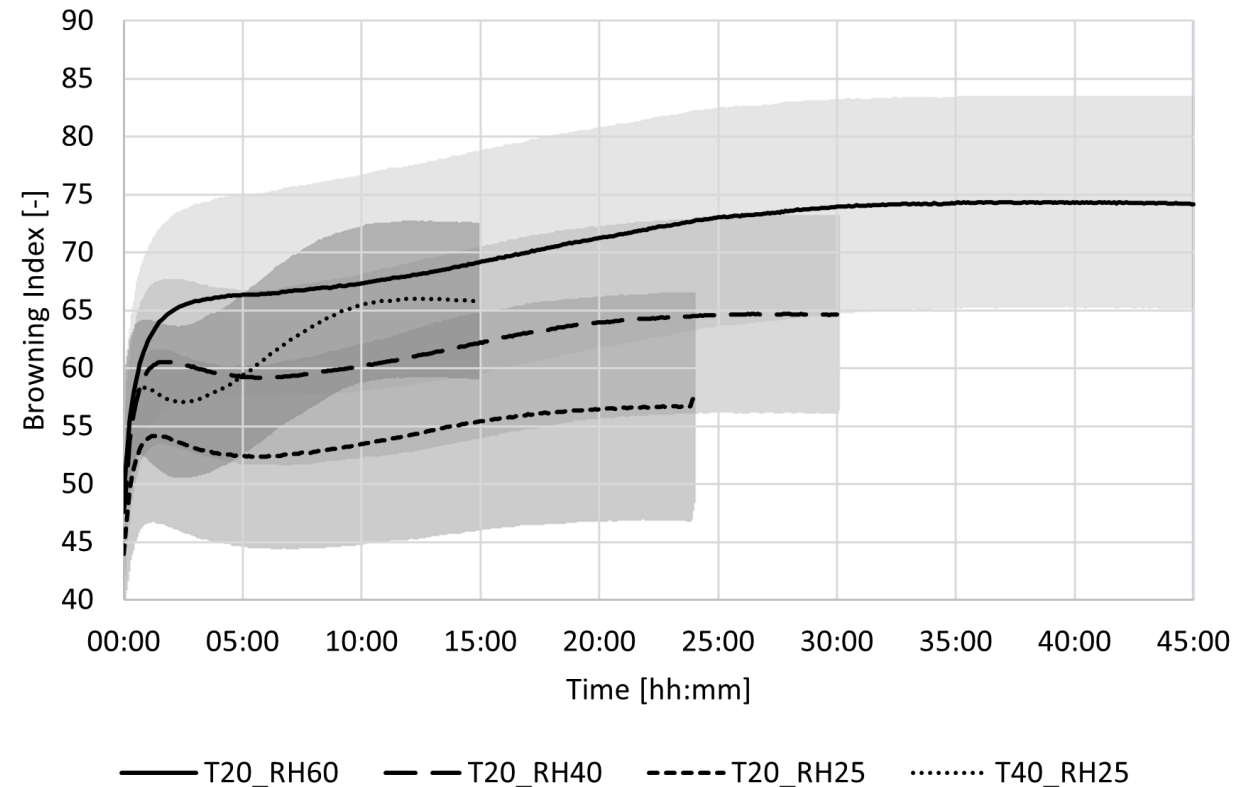


Results optical parameters

Color Browning Index

- Increases with humidity
- Minimum results from the CIE-L value
- Buera et al. [4]

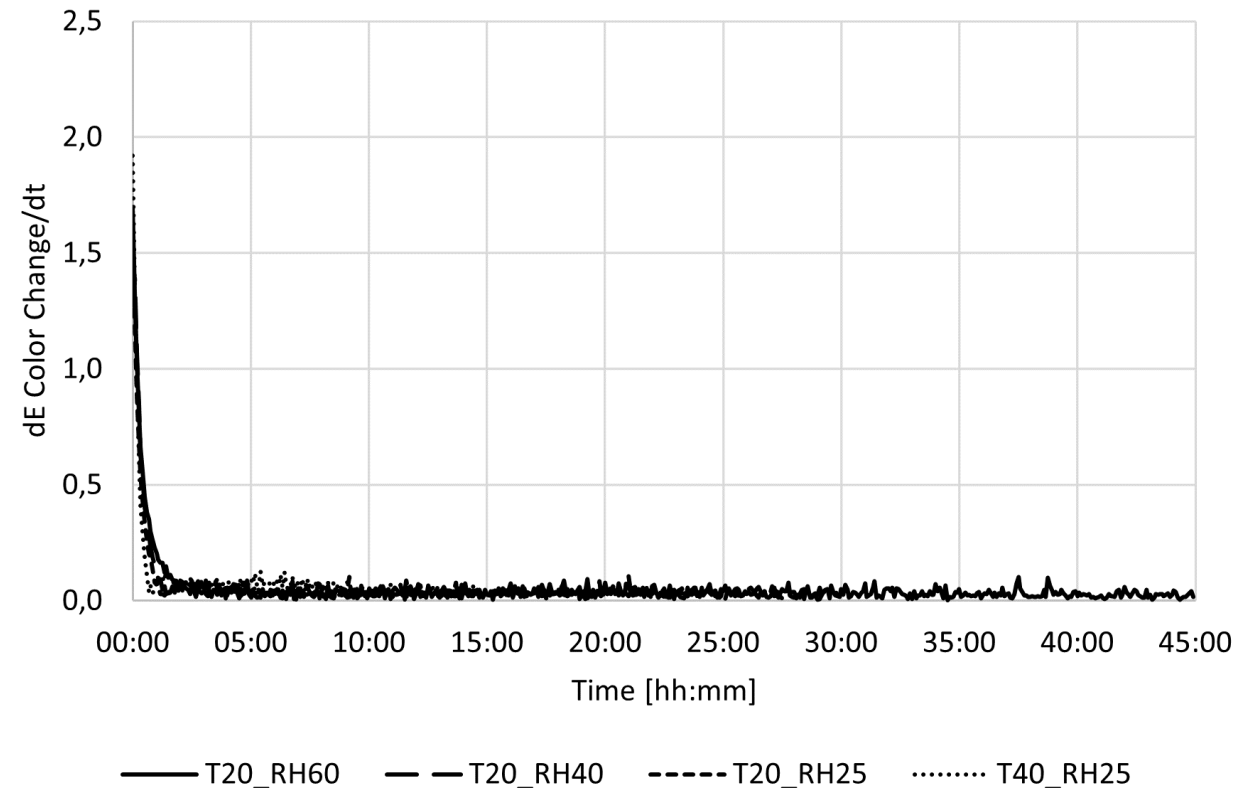
$$BI = \frac{(x_{D65} - 0,32)}{0,162} * 100$$



Results optical parameters

Color alternation rate

- All color alternation happened within the first 2-3 hours
- The drying process had no influence on the color change



Conclusion

- Apples were stored about 3 months → no exclude of storing influence
- Shape recognition works very precise and reliable (not only apples)
- Color measurement requires a very good image quality (Illumination conditions, camera settings, black level, white balance, color spaces, file format etc...)
- Optical analysis direct in LabVIEW → react on optical changes "on the fly"
- Smart drying programs with focus on product quality and/or energy aspects
- AI could be used to recognize drying states (e.g. if diffusion is main transport process then decrease temperature)

Outline 10: Improved drying strategies – Concept for Enthalpy controlled drying

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Concept of enthalpy controlled drying

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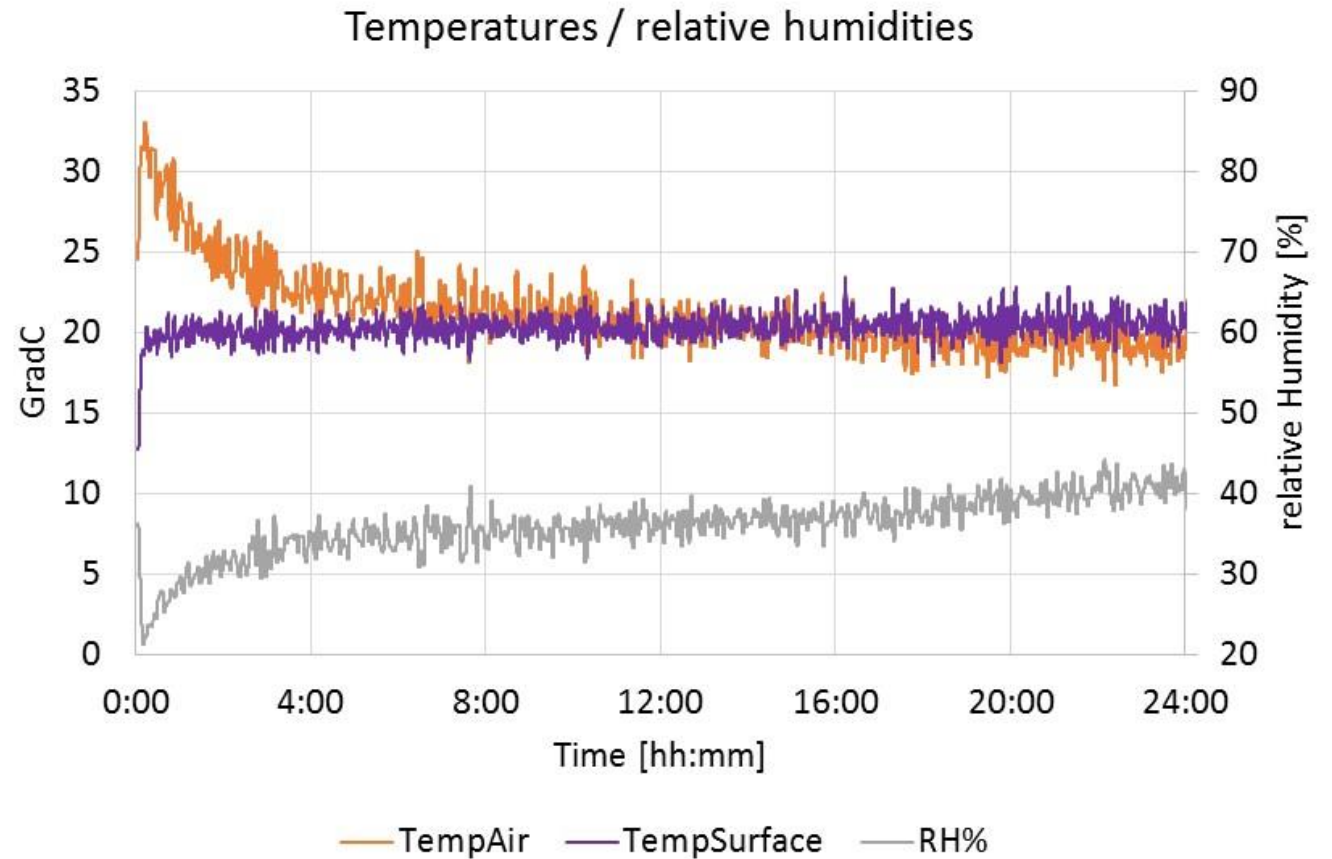
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First Results

Regulations

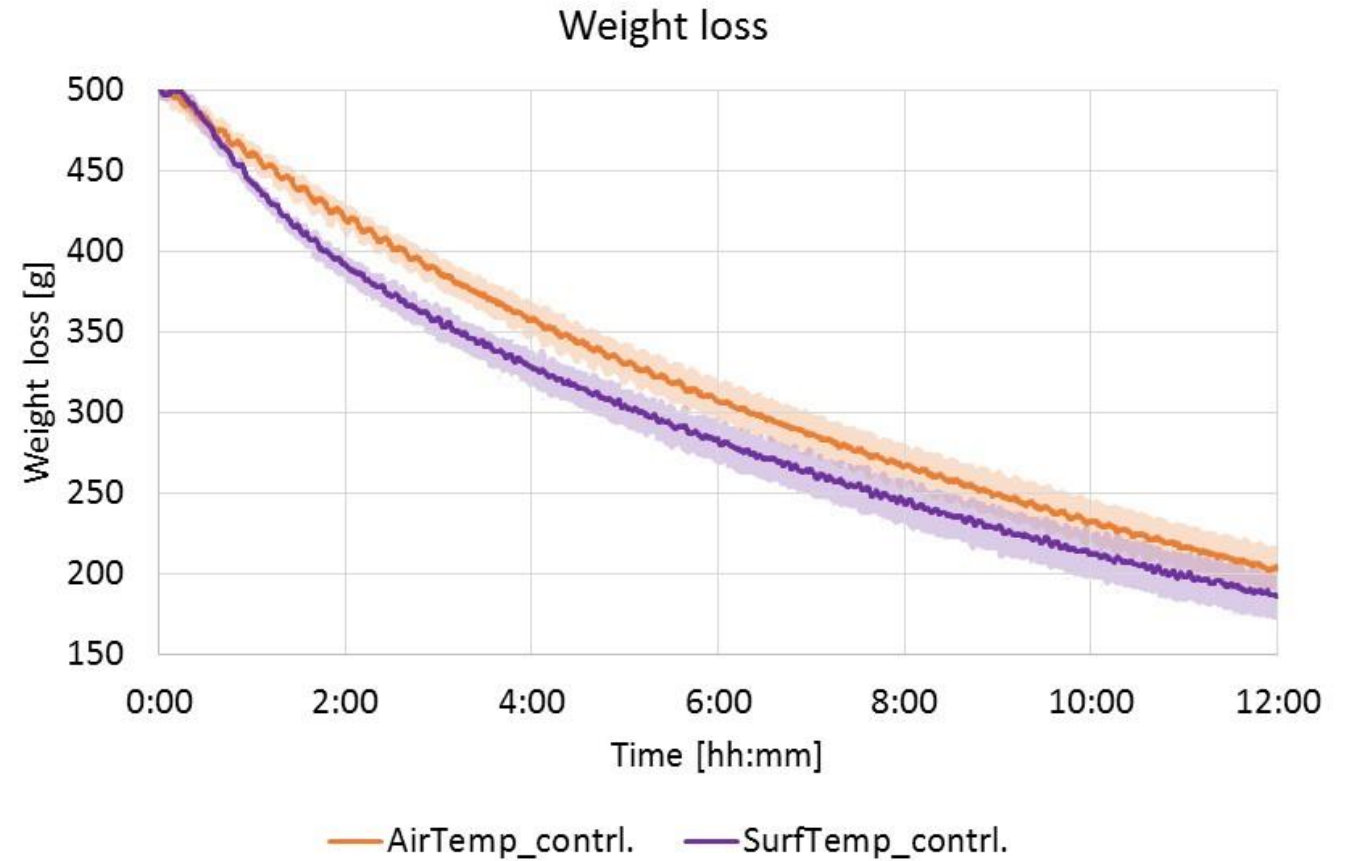
- Constant Surface Temp.
- No humidity regulation yet
- Fluctuations due to sensor uncertainties



First Results

Weight loss

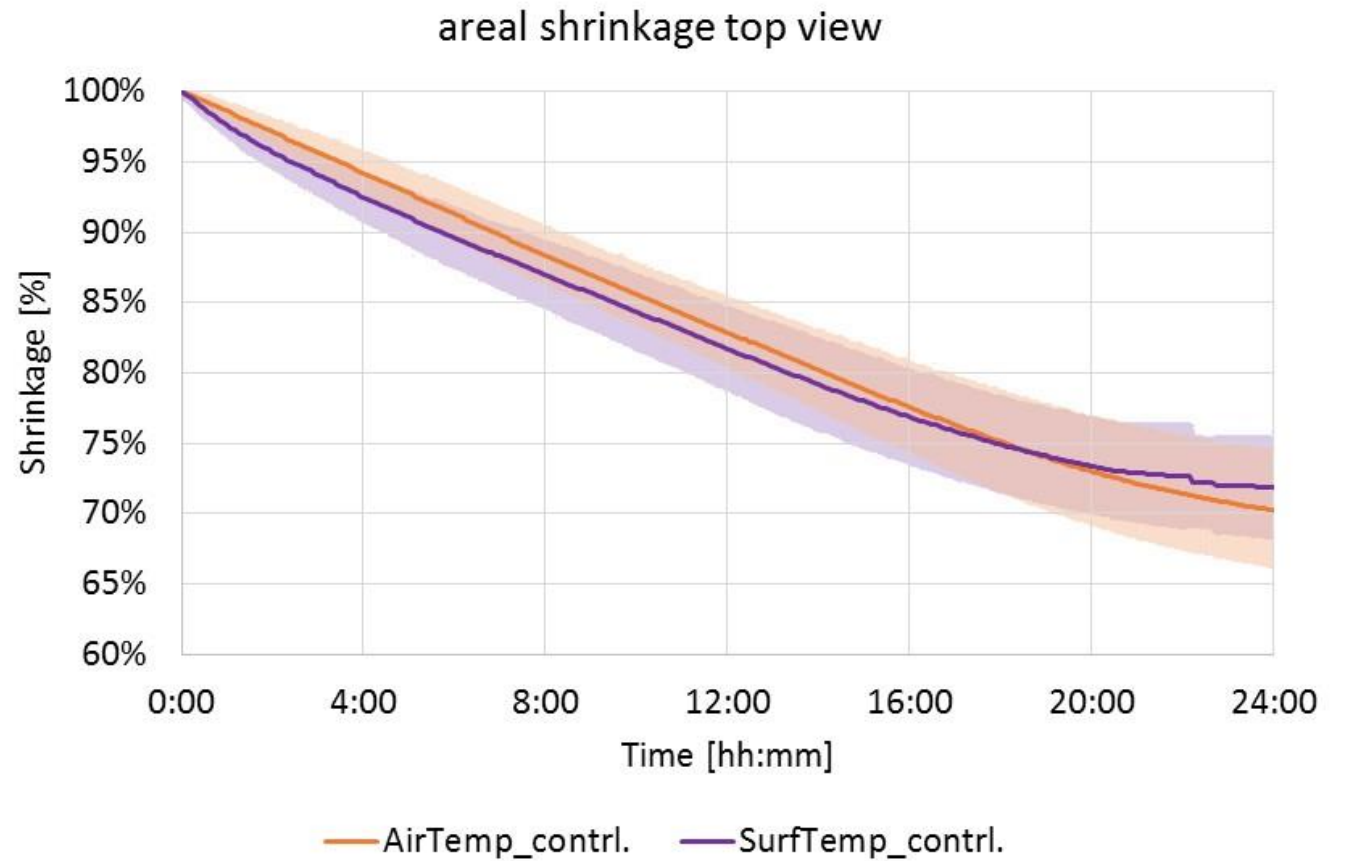
- Faster drying in the beginning due to higher temperature



First Results

Shrinkage Top View

- Results: average of 8 apple slices each
- Similar shrinkage progression



First Results

Browning Index

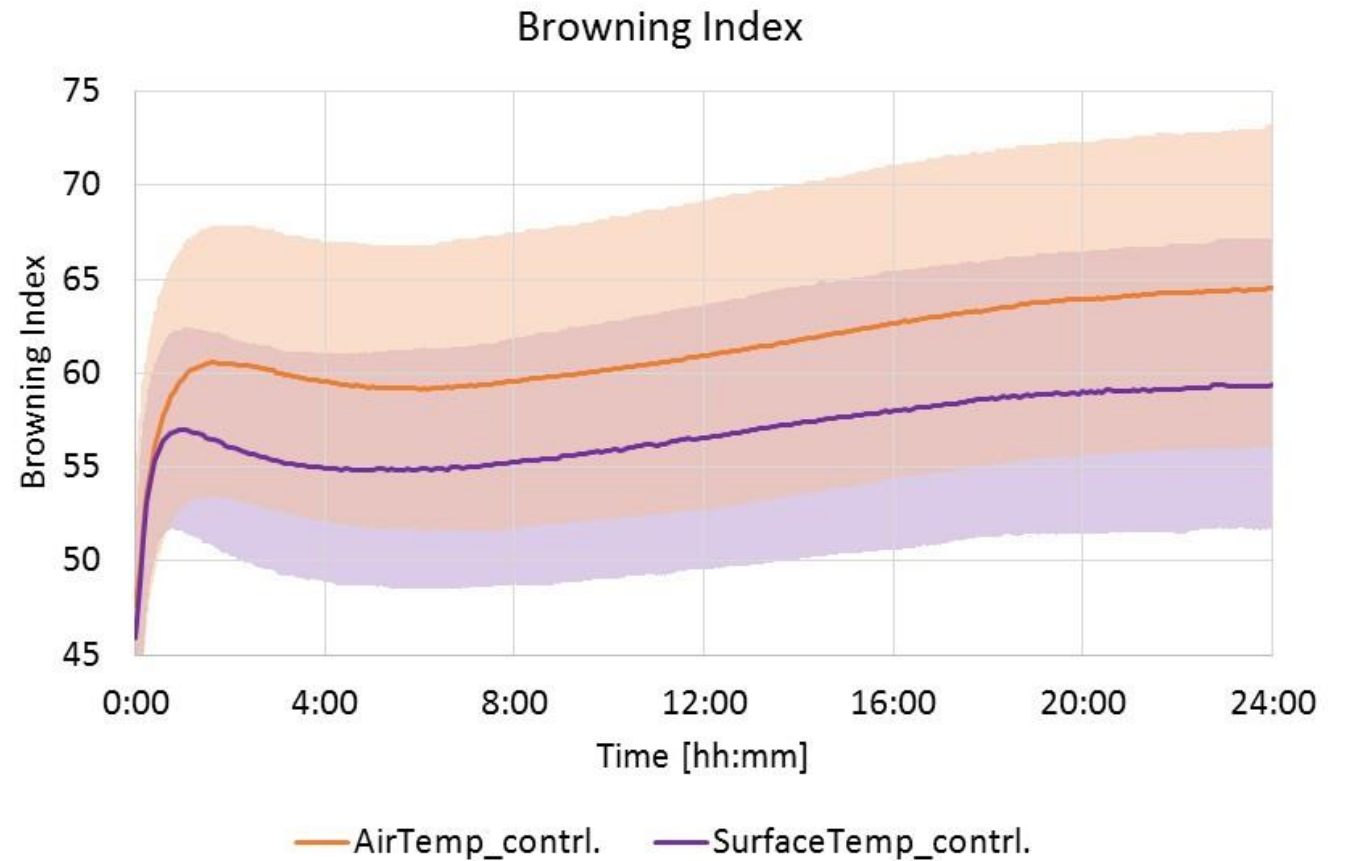
- average of 8 apple slices
- RGB → XYZ → $x = X/(X+Y+Z)$

$$BI = \frac{(x_{D65} - 0,32)}{0,162} * 100$$

BI=60



BI=55



Conclusion

- Improvements of the regulations
- More experiments
- Accelerate drying process
- No product damaging through exceeded surface temperature
- Positive influence on Vitamin C and color alternation [Chou and Chua 2003]
- Useful for sensitive drying products

References

1. **BEIGI, M., Energy efficiency and moisture diffusivity of apple slices during convective drying. Food Science and Technology, 2016. 36: p. 145-150.**
2. **Bradski, G., The OpenCV Library, Dr. Dobb's Journal of Software Tools, 2000. Opencv.org**
3. **al., B.e., Definition of colour in the non enzymatic browning process. Die farbe, 1986. 32: p. 318-322.**
4. **Hirschler, R., Whiteness, Yellowness and Browning in Food Colorimetry, in Color in Food: Technological and Psychophysical Aspects, M.d.P. Buera, Editor. 2016.**