Possibilities for monitoring product quality and adjustment of drying conditions

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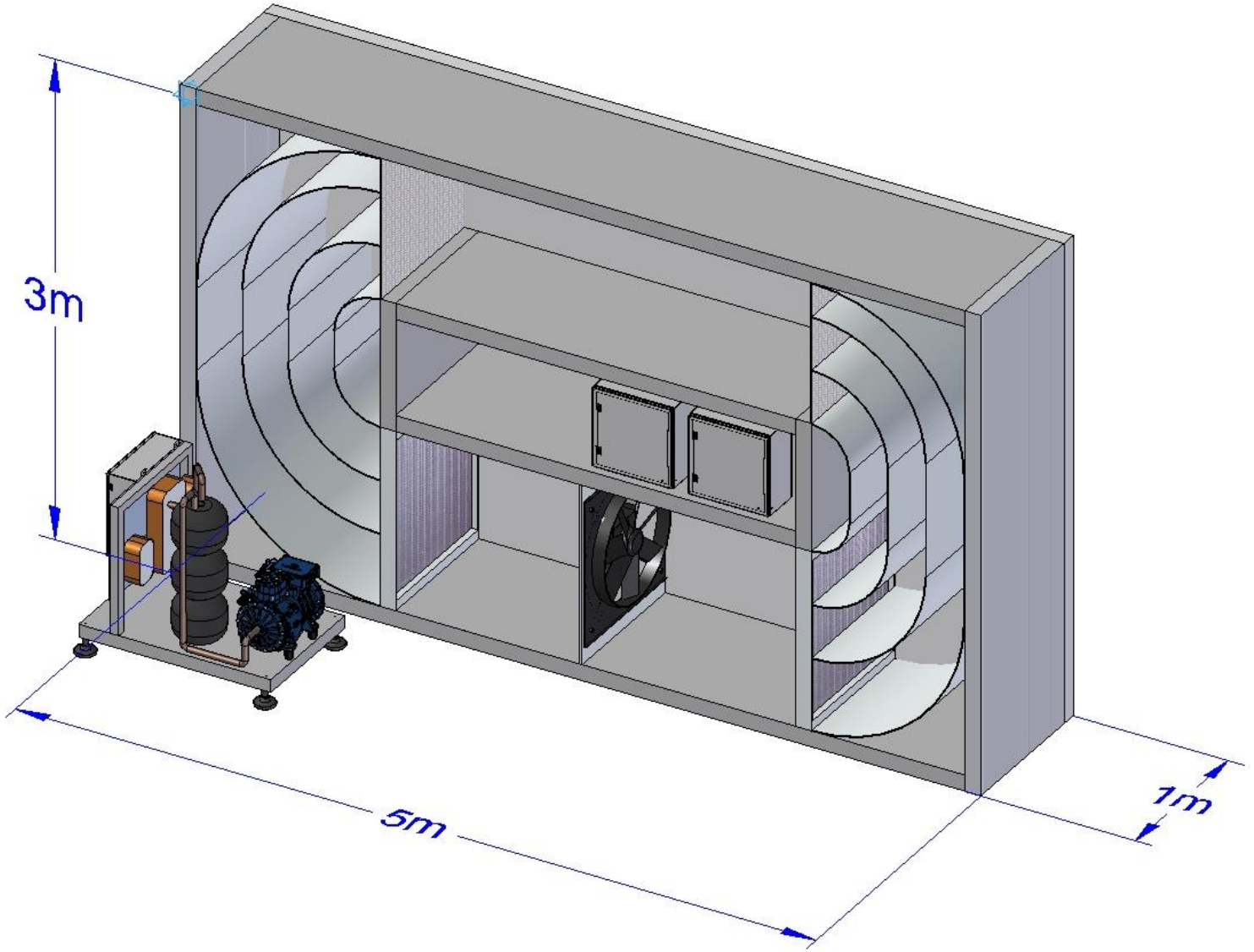
Initial Situation

Possible settings

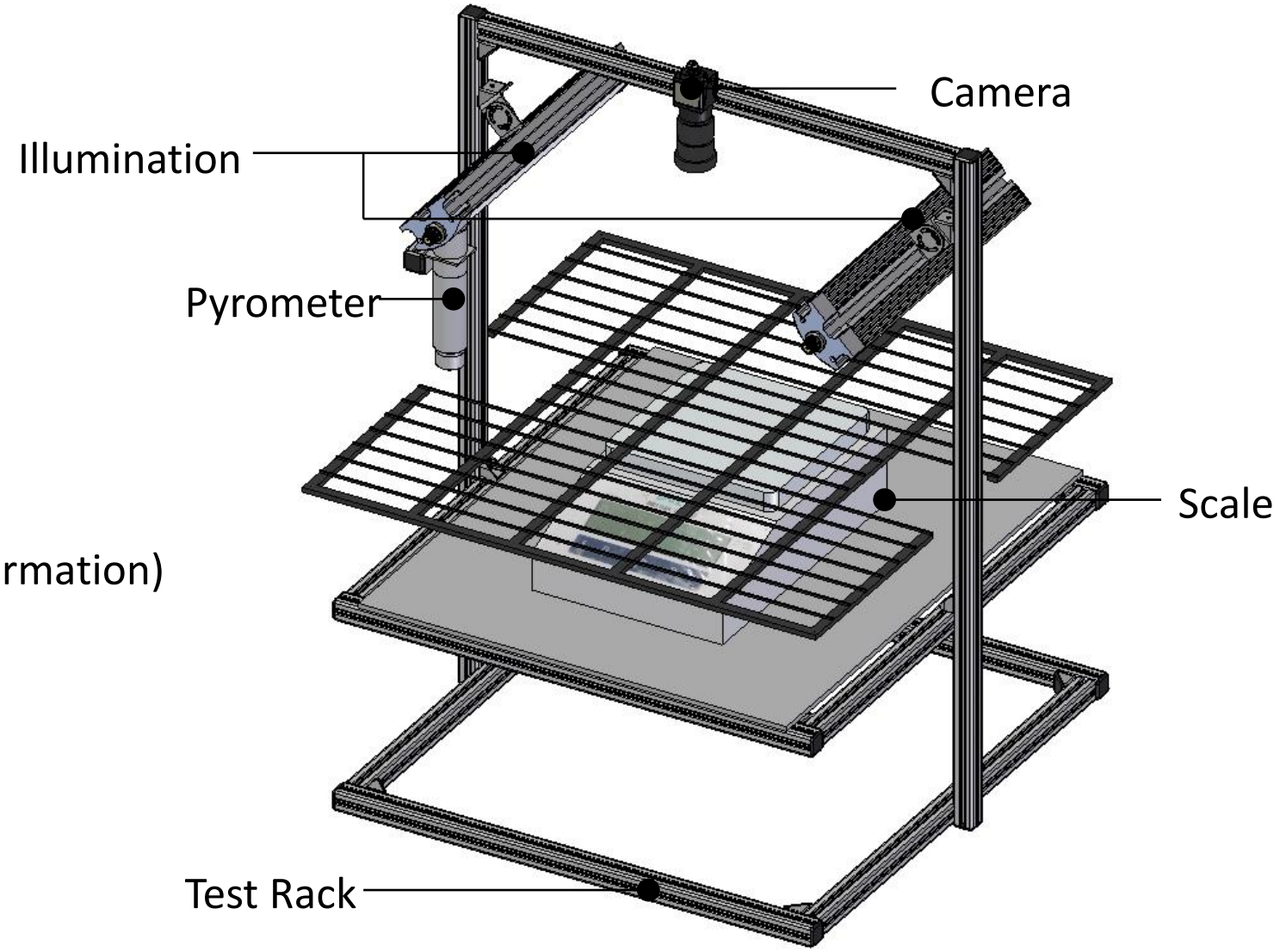
- Set temperature
- Set air velocity
- Set glycol temperature
- Record of Temperature
- Record of relative Humidity
- Record of Air Velocity



Modifications

New sensors

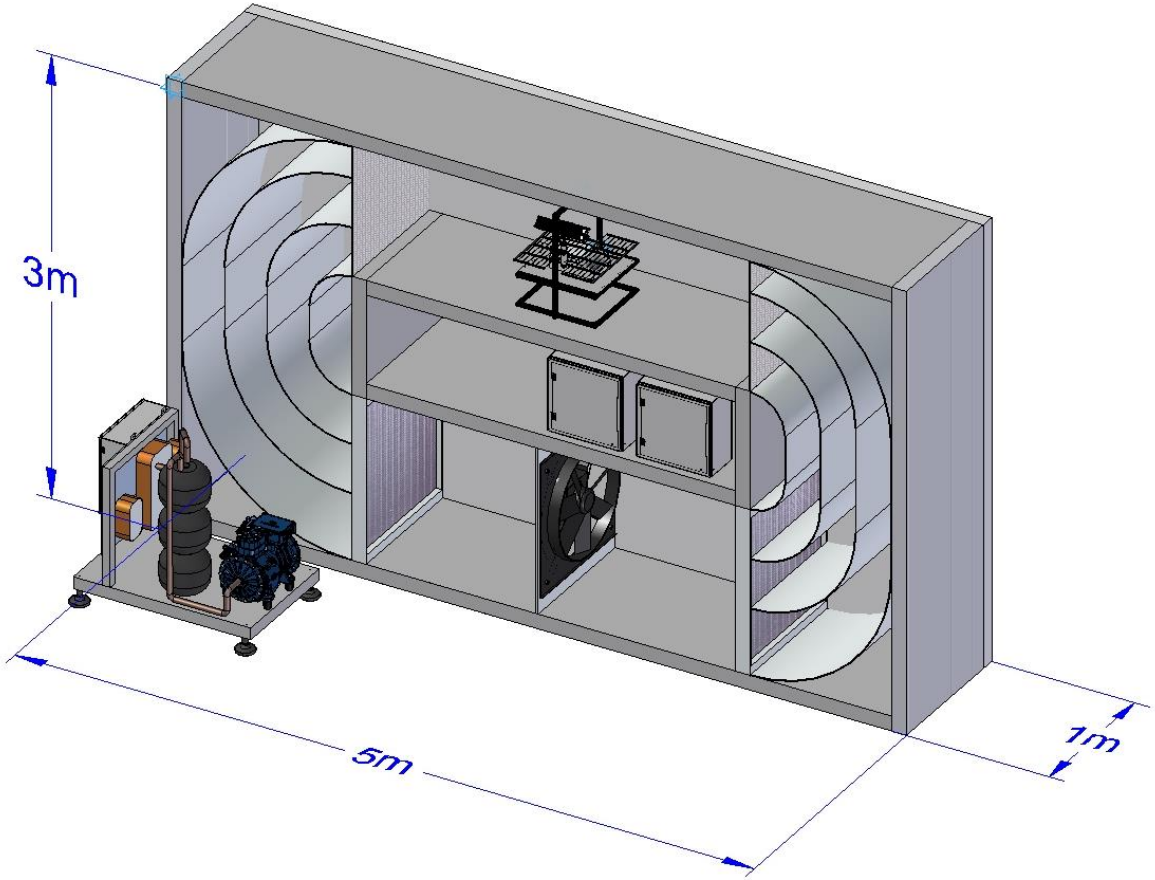
- Scale (drying kinetics)
- Pyrometer (surface temperature)
- Camera system with illumination
  (color alternation, shrinkage and deformation)



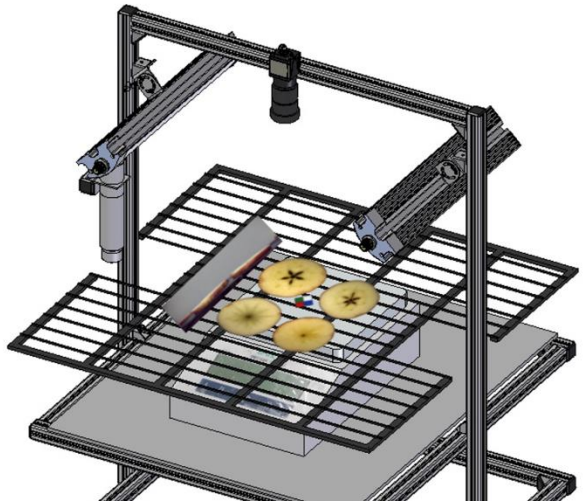
Modifications

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



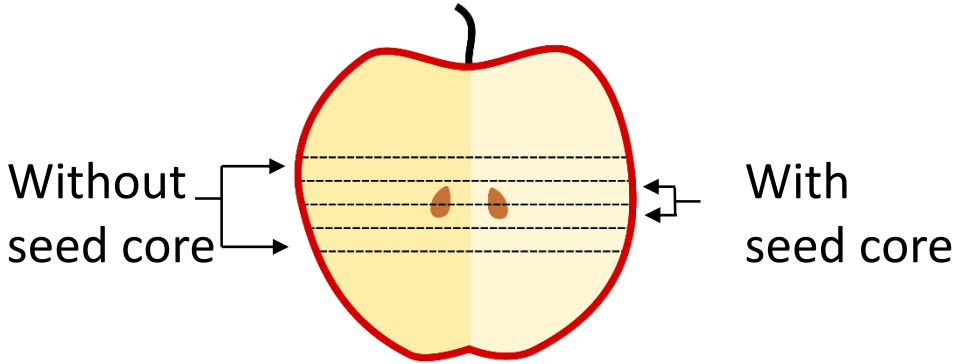
Experiments setup



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

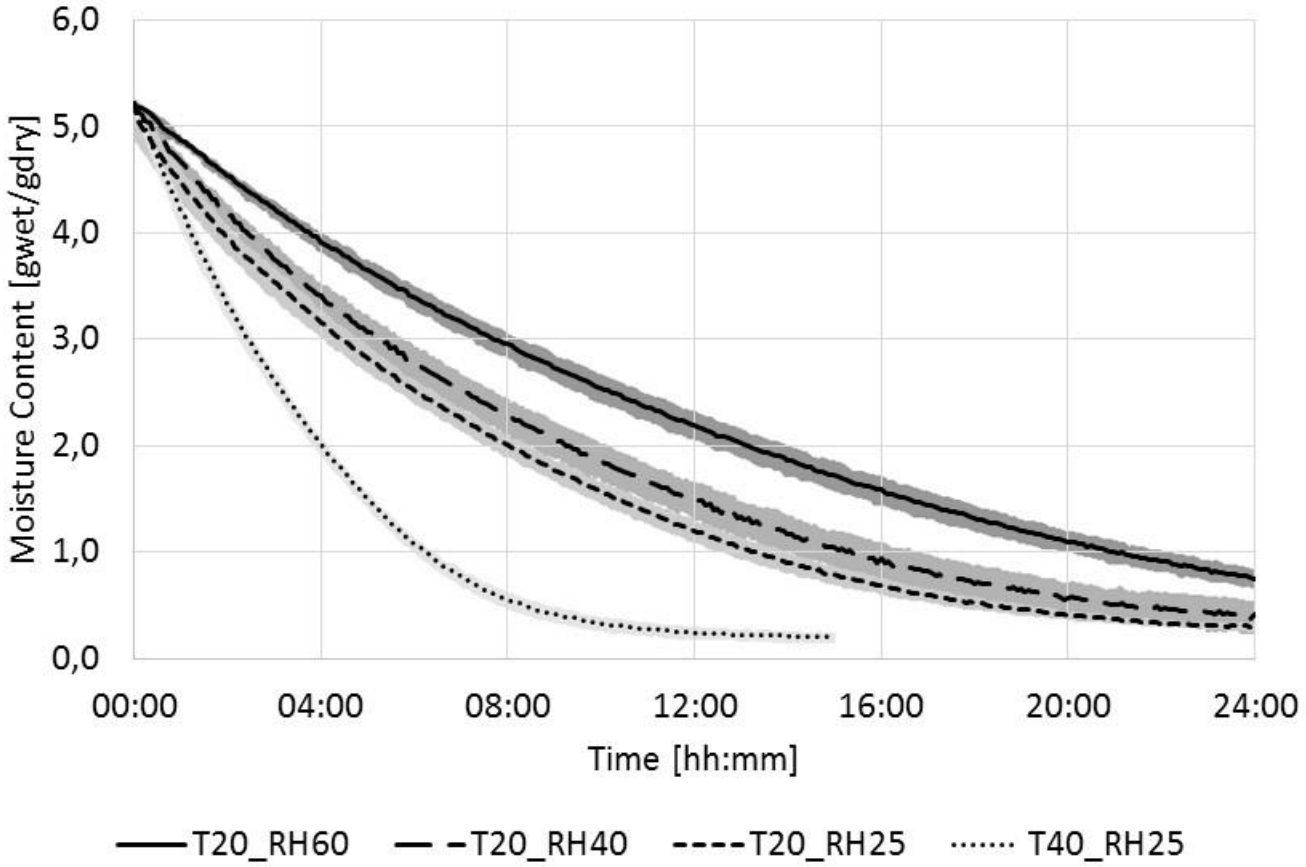
Test name	Temp. dry air	Rel. humidity	Air velocity
T20_RH60	20 GradC	60%	1,5m/s
T20_RH40	20 GradC	40%	1,5m/s
T20_RH25	20 GradC	25%	1,5m/s
T40_RH25	40 GradC	25%	1,5m/s



Results drying kinetics

Moisture Ratio

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

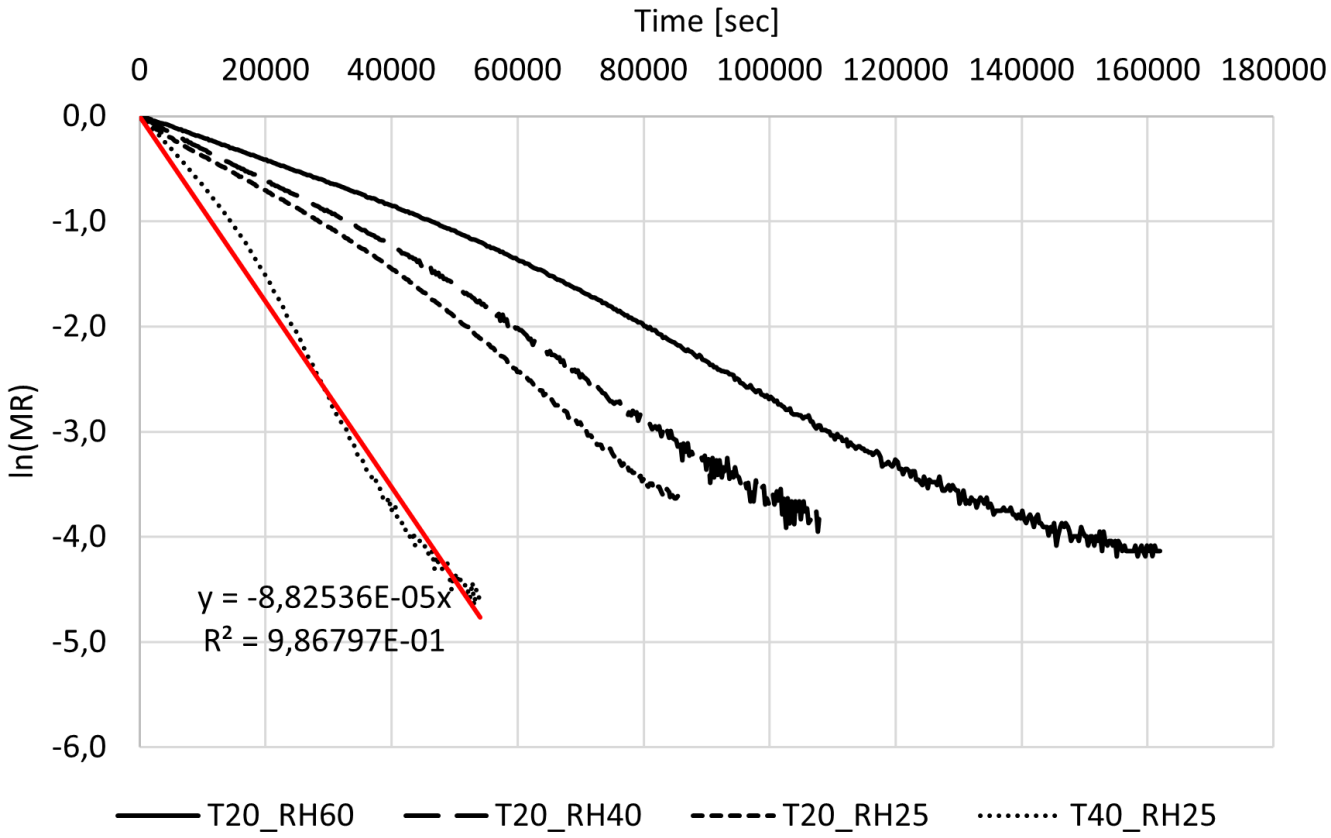


Results drying kinetics

Effective Diffusivity [1]

	D_{eff} [m²/s]
T20_RH60	2,7E-10
T20_RH40	3,6E-10
T20_RH25	4,1E-10
T40_RH25	8,9E-10

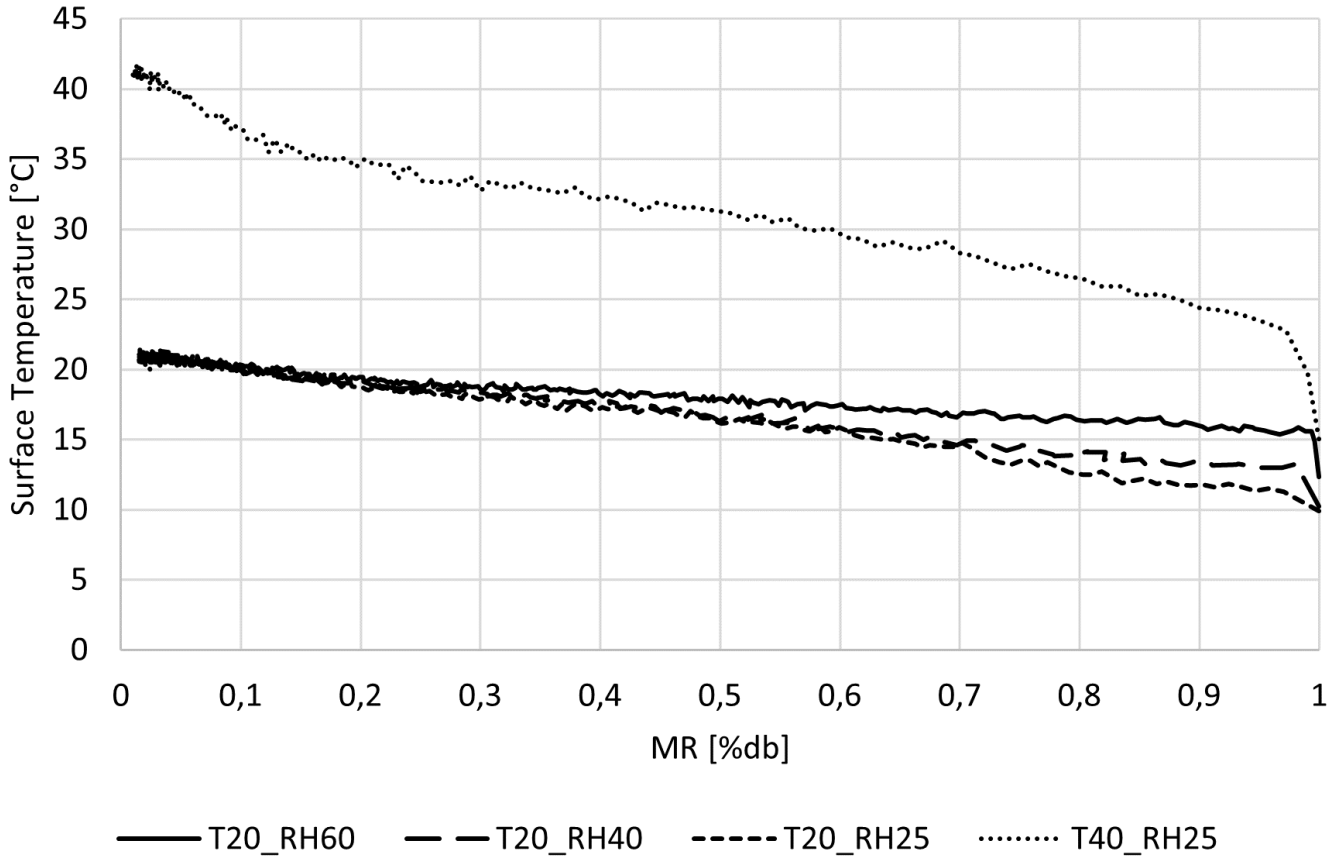
$$D_{eff} = -\left(\frac{4(\frac{thickness}{2})^2}{\pi^2}\right) * (slope\ of\ line)$$



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)

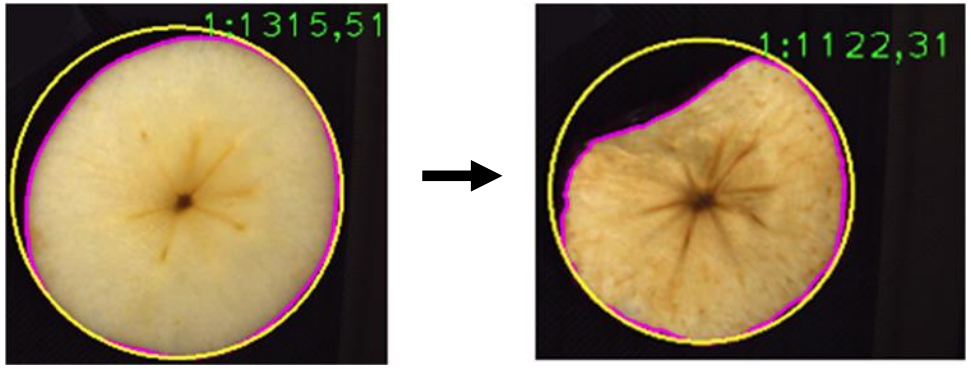
Measuring Principles

- 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

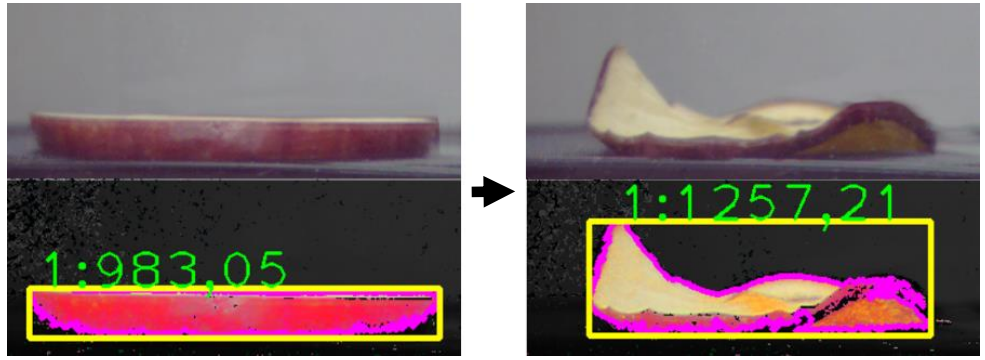
Demo Video Top View(30sec)

Demo Video Sidelong View (30sec)

Top view, circle as reference shape



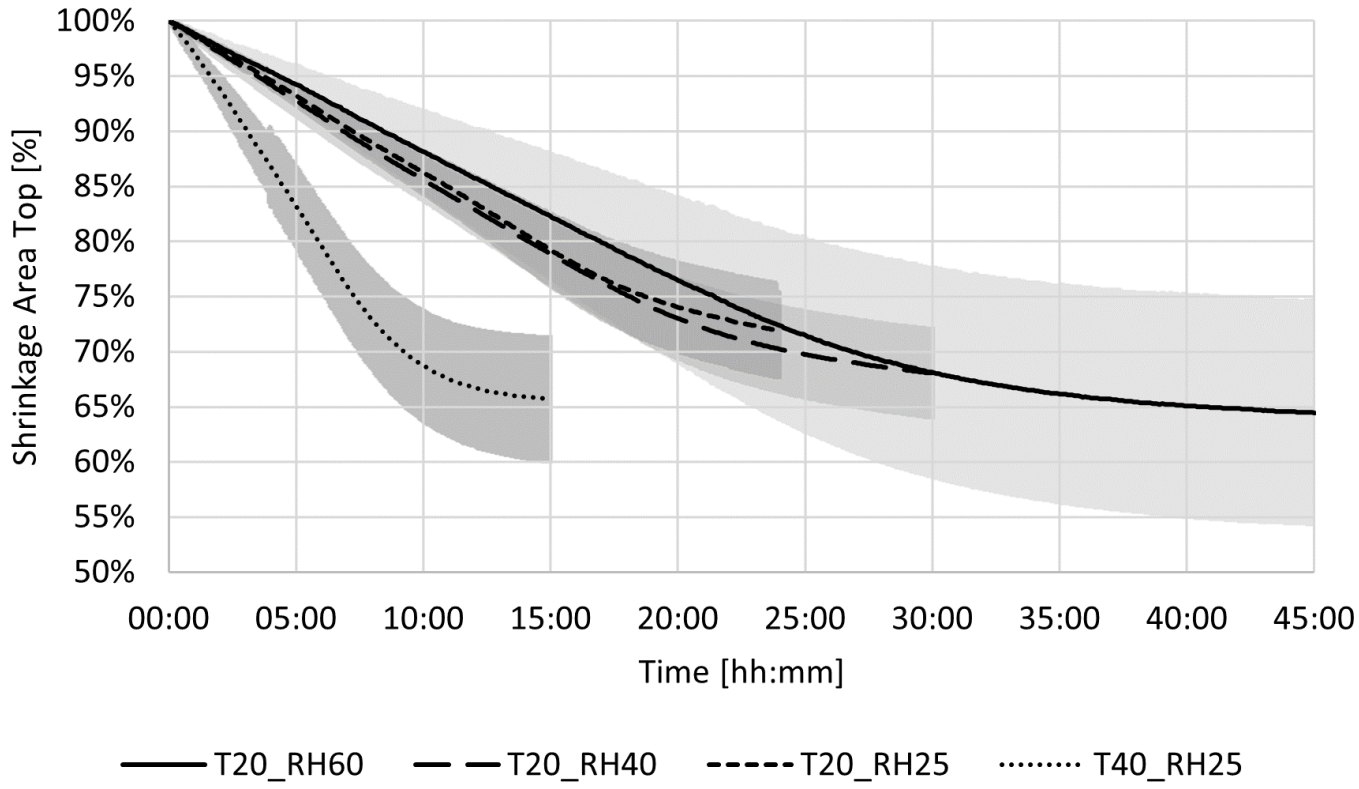
Sidelong view, rectangle as reference shape



Results optical parameters

Shrinkage Top View

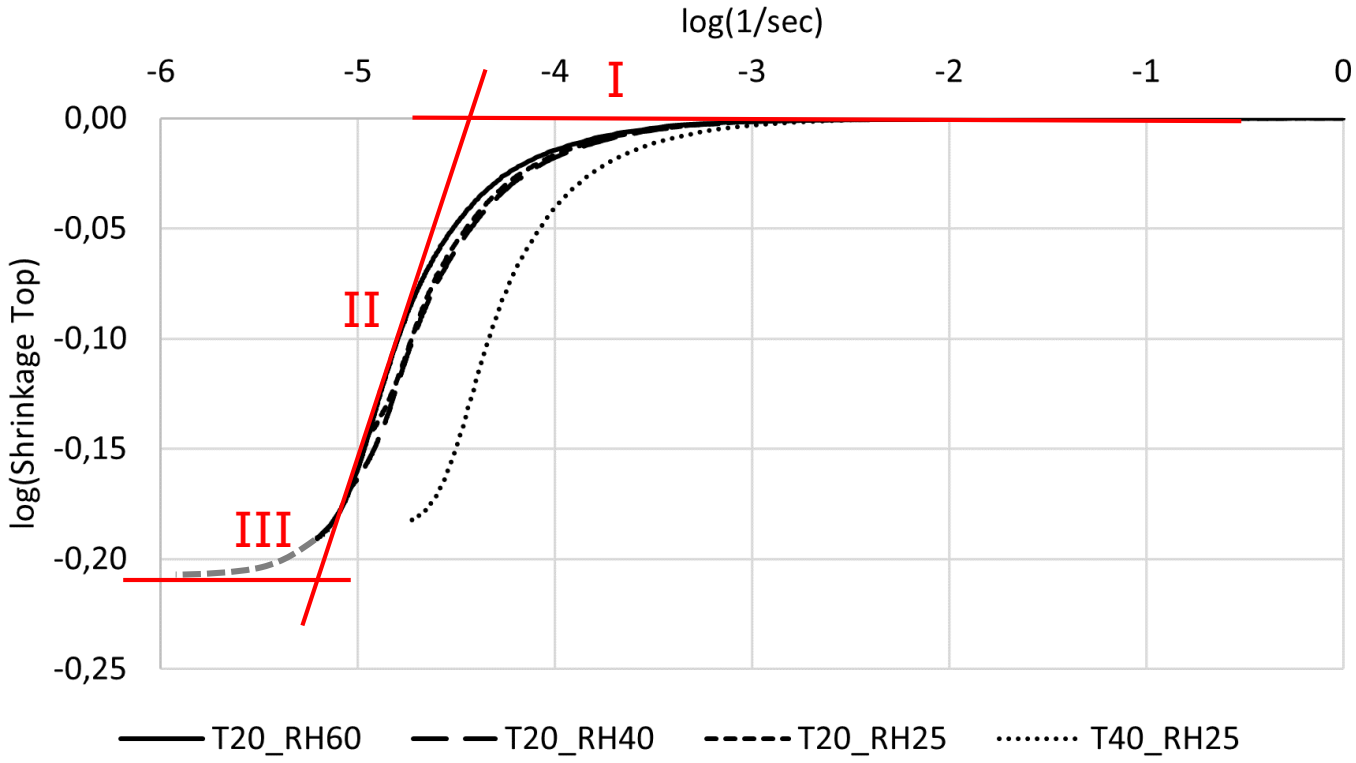
- Similar shrinkage at 20°C and RH25%, RH40%
- Shrinkage at 40°C much faster
- Similar magnitude of shrinkage



Results optical parameters

Shrinkage Top View

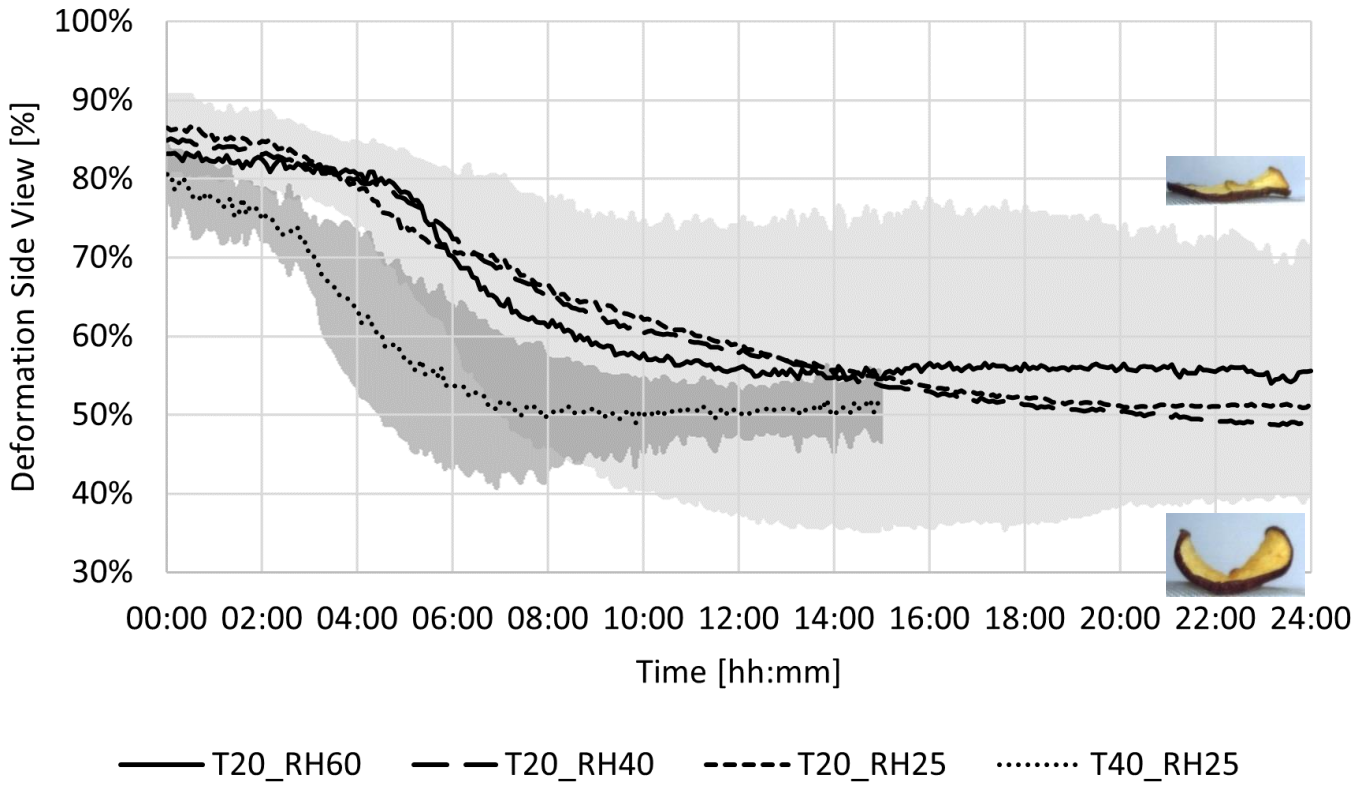
- different shrinking states
- Highest shrinkage rate in state II
- Ca. 90% of drying time is state II



Results optical parameters

Deformation Side View

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



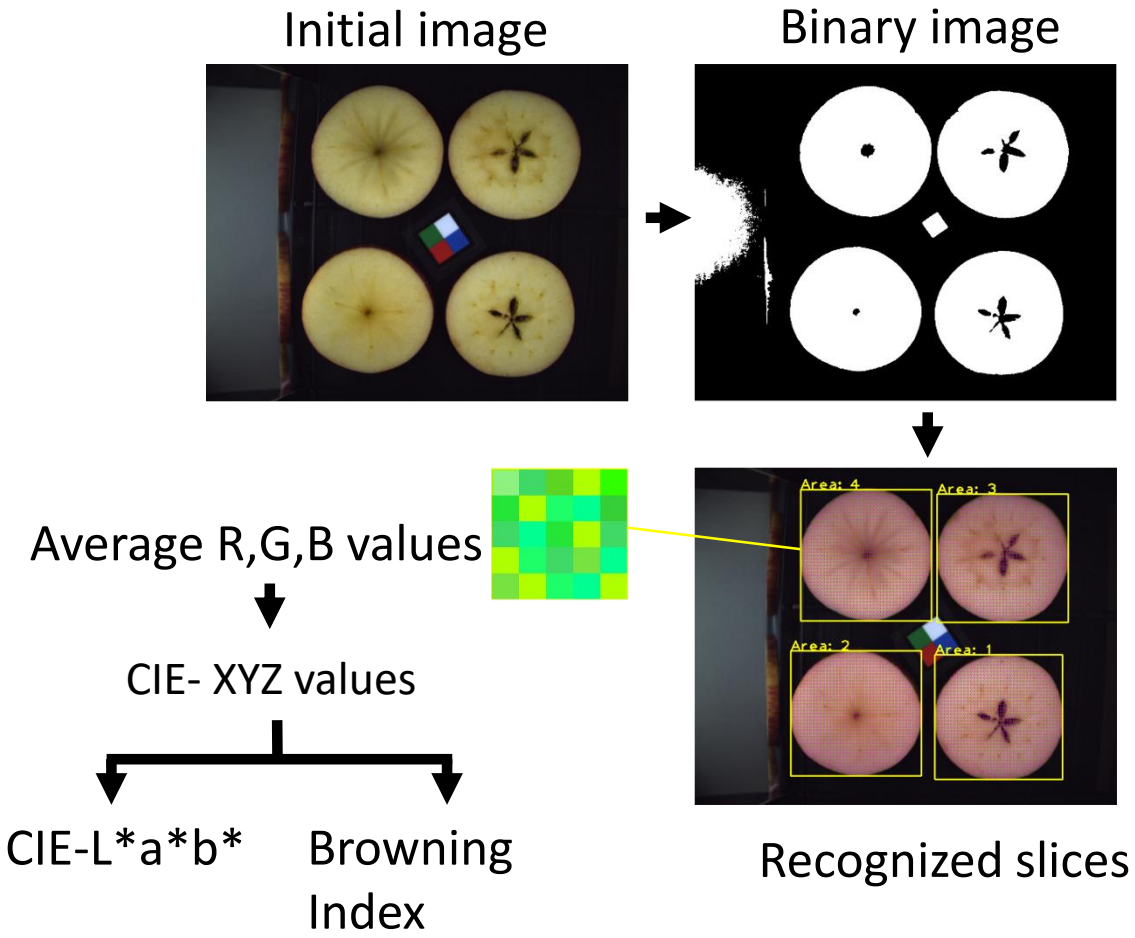
Demo Video Deformation Side View (30sec)

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]

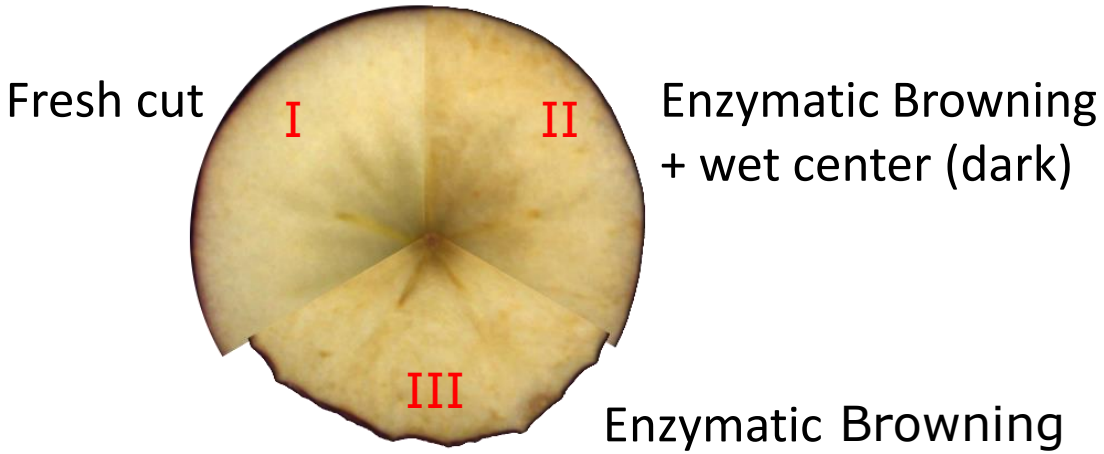
Demo Video (30sec)

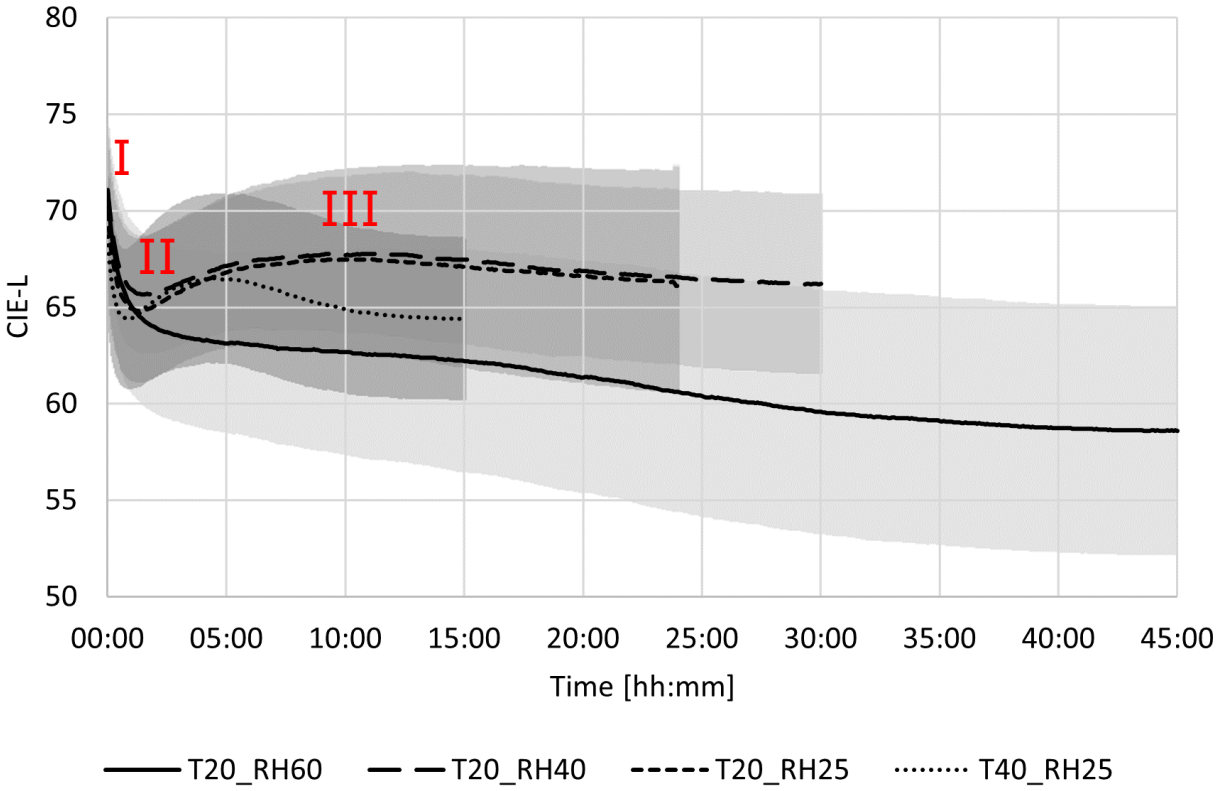


Results optical parameters

Color CIE-L value (lightness)

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



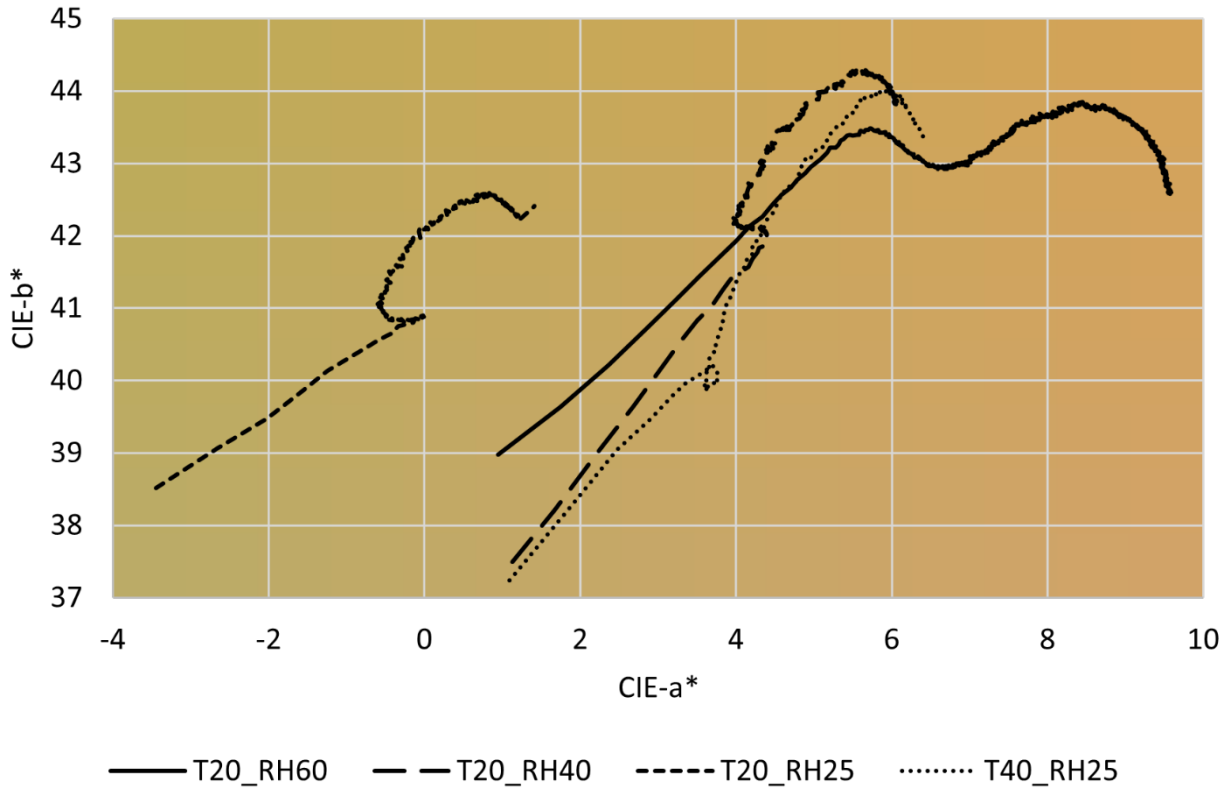


Results optical parameters

Color CIE-a and CIE-b value

- Biggest alternation within the first few hours

Demo Video (30sec)

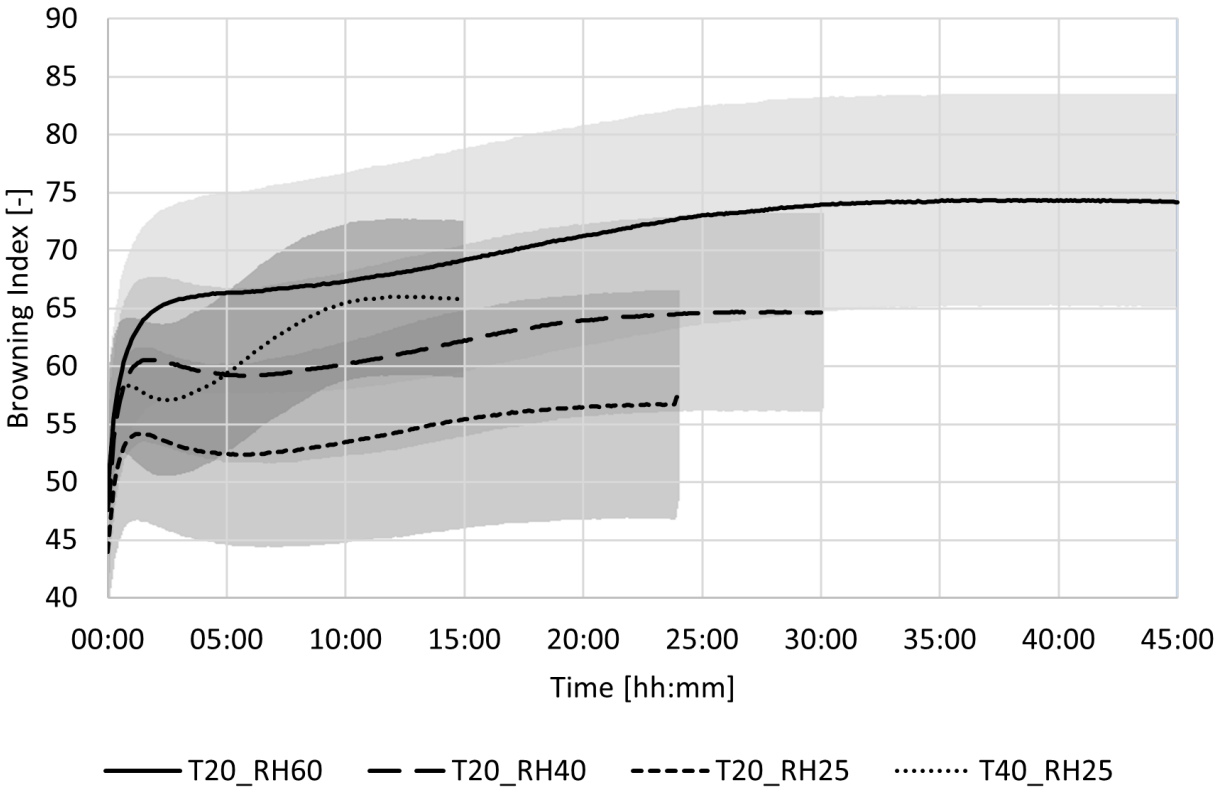


Results optical parameters

Color Browning Index

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

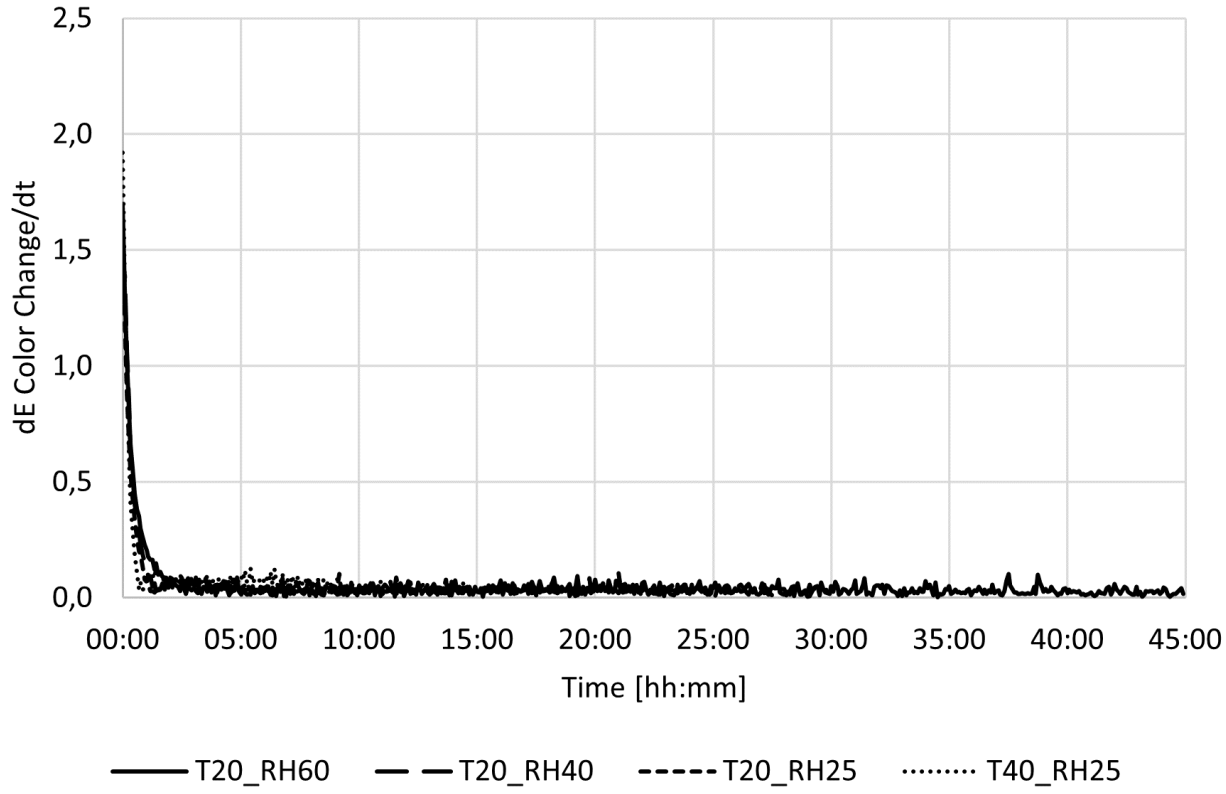
$$BI = \frac{(x_{D65} - 0{,}32)}{0{,}162} * 100$$



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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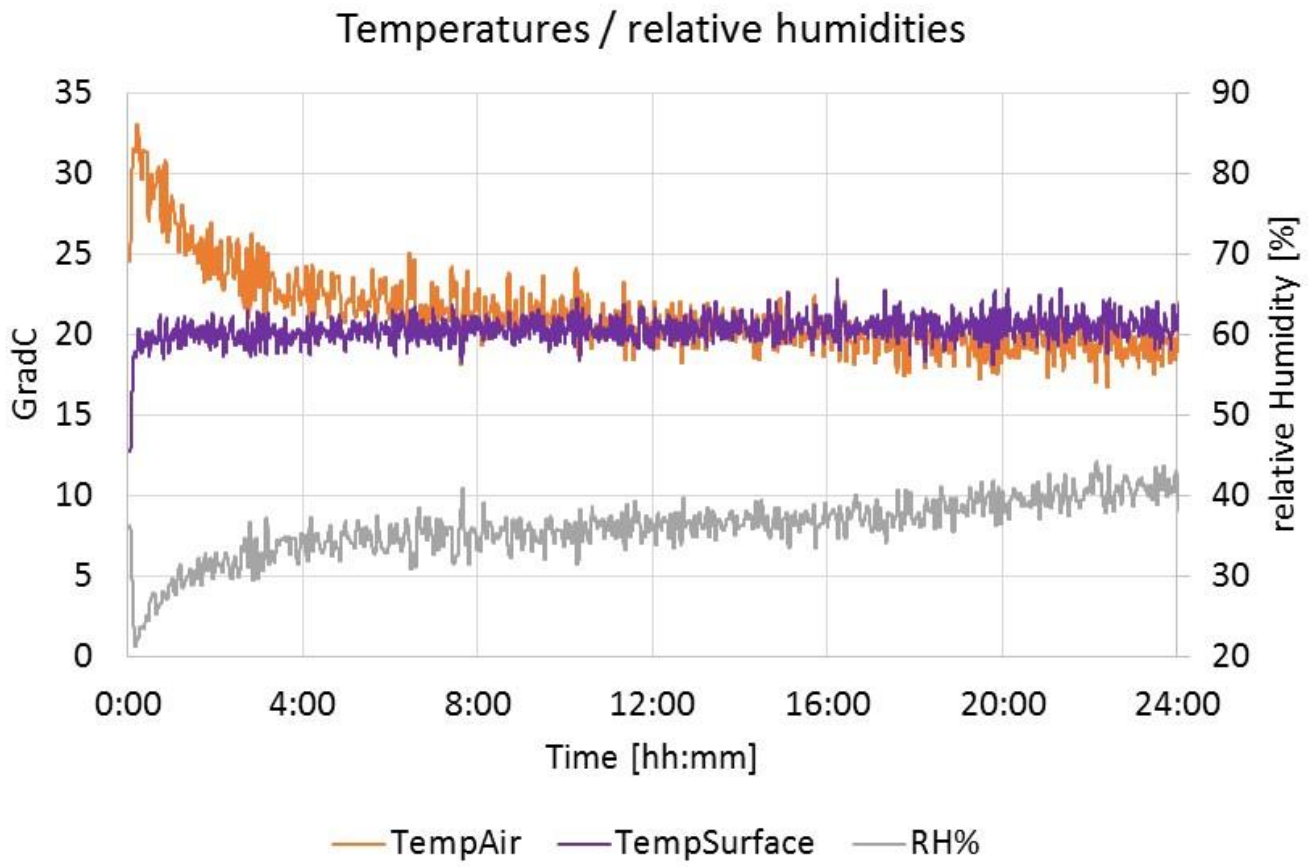
First Results

Regulations

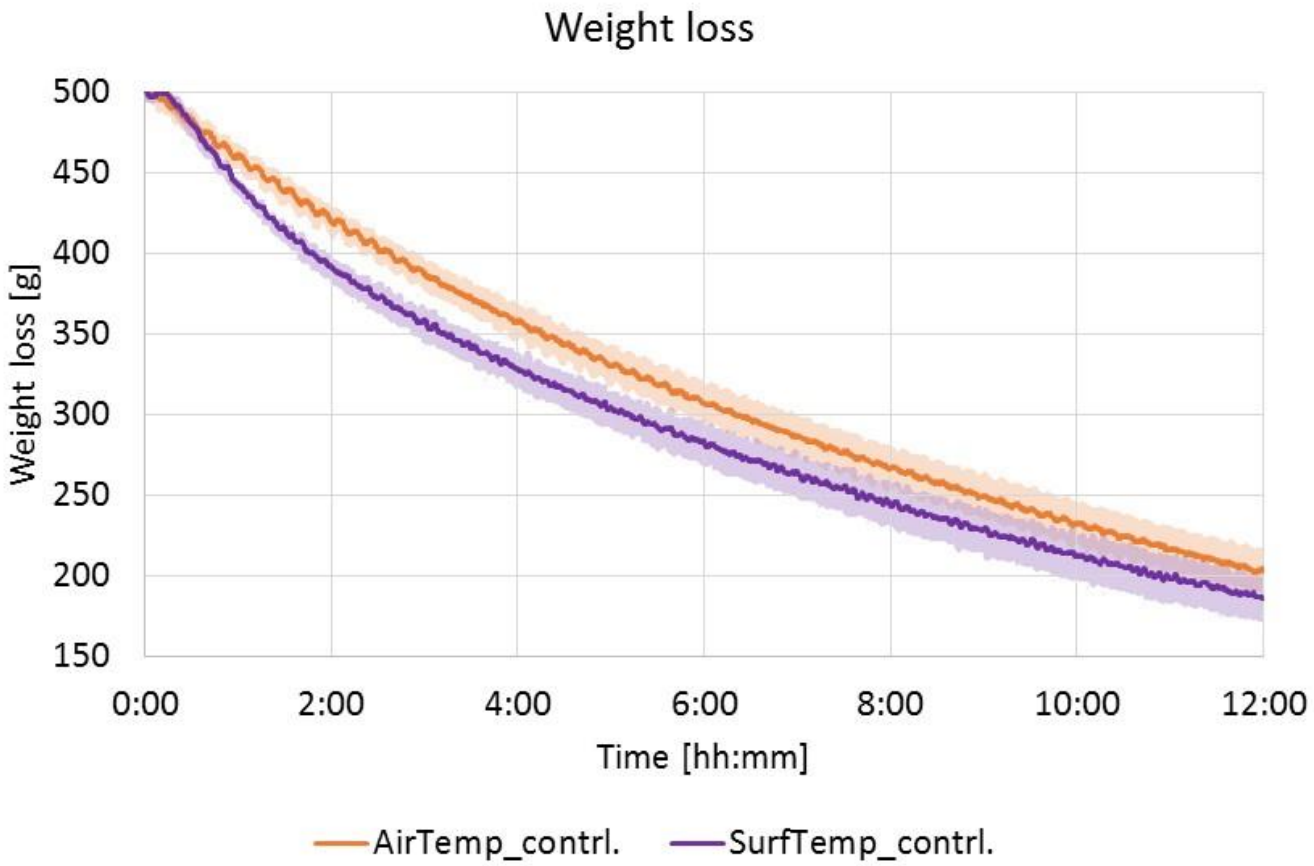
- Constant Surface Temp.
- No humidity regulation yet
- Fluctuations due to sensor uncertainties



First Results

Weight loss

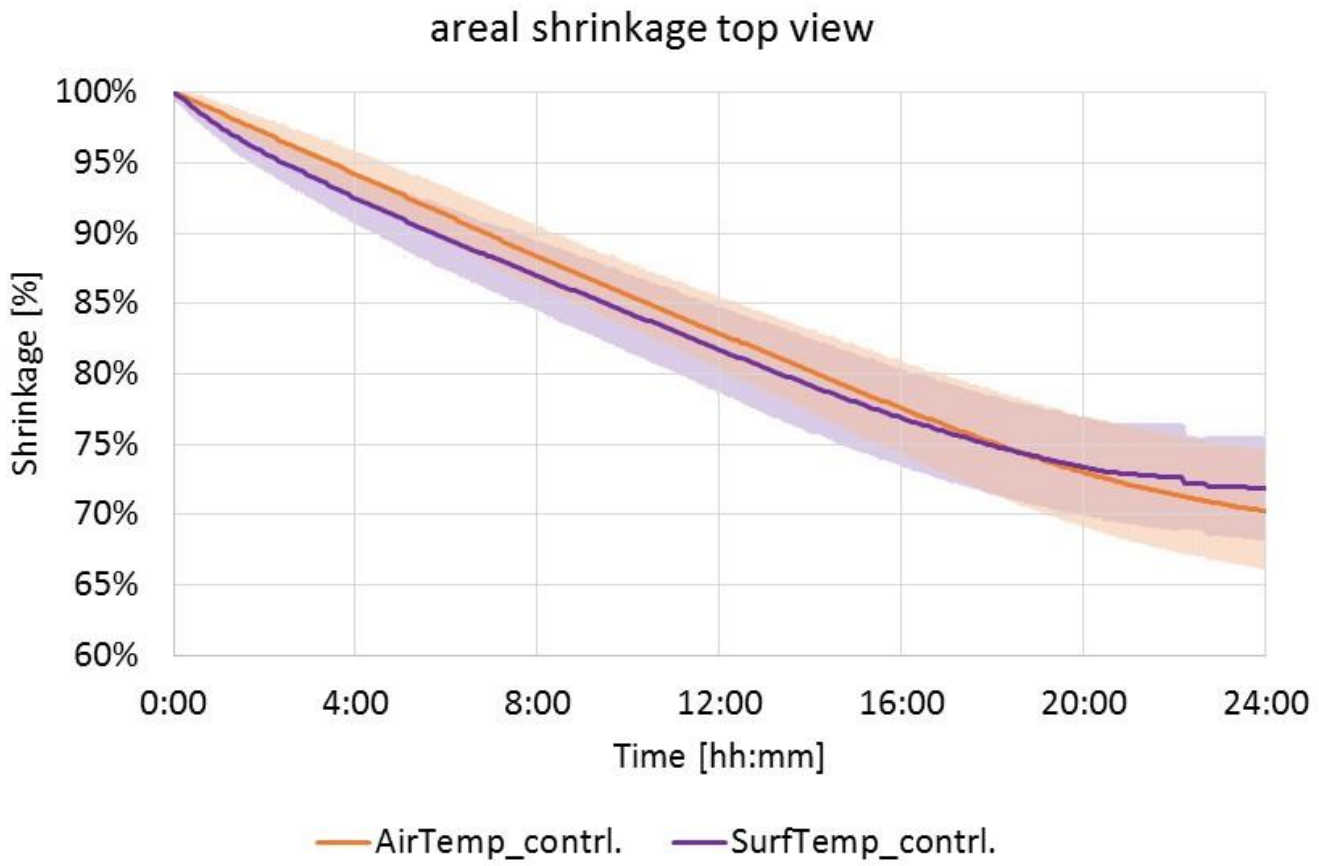
- Faster drying in the beginning due to higher temperature



First Results

Shrinkage Top View

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



First Results

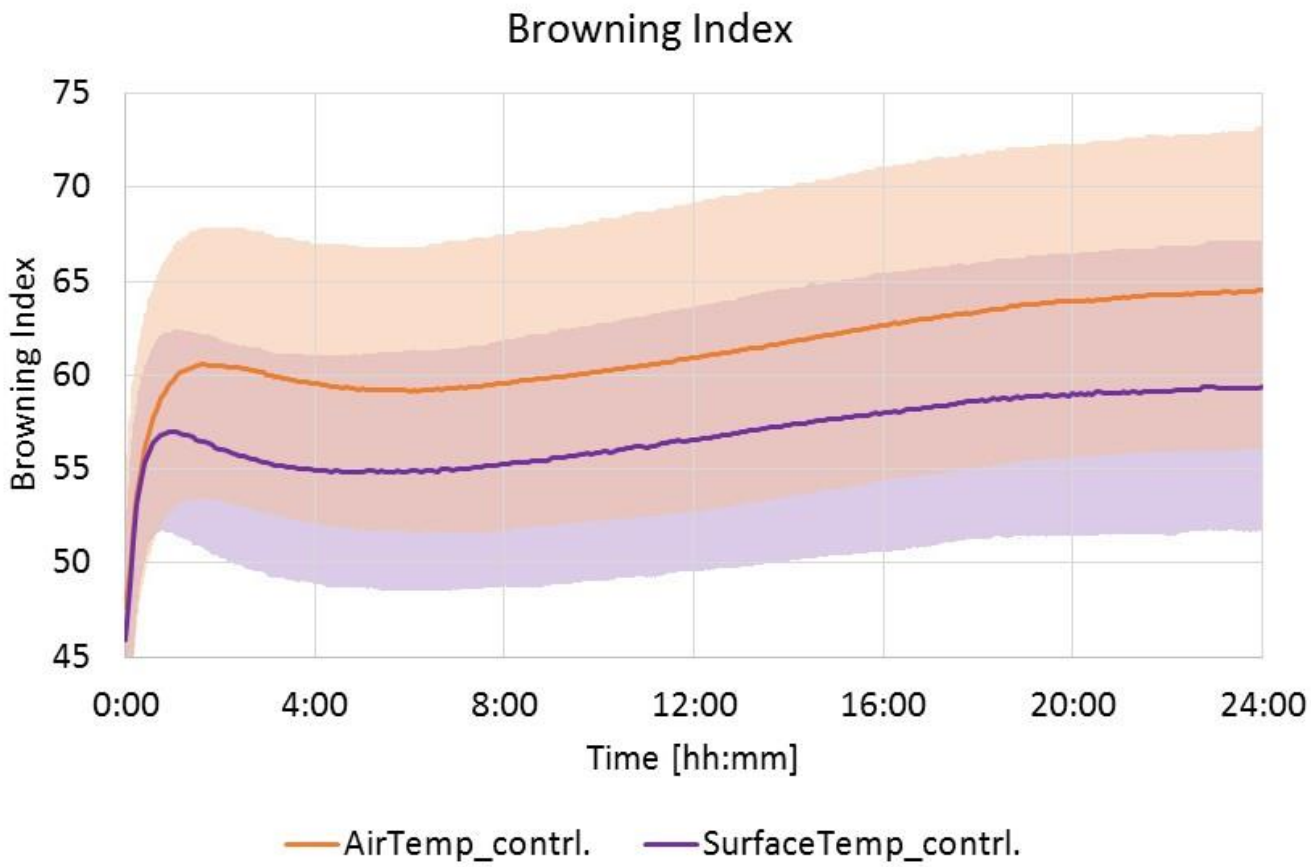
Browning Index

- 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.