Neutron radiography/tomography for visualising and quantifying the novel fruit pulp concentration process

”Solar Assisted Pervaporation”

Randi Phinney[1], Thijs Defraeye[2], Peter Vontobel[3], Petr Dejmek[1], Ingegerd Sjöholm[1] and Marilyn Rayner[1]

[1] *Department of Food Technology, Engineering and Nutrition,* **Lund University**, Lund, Sweden

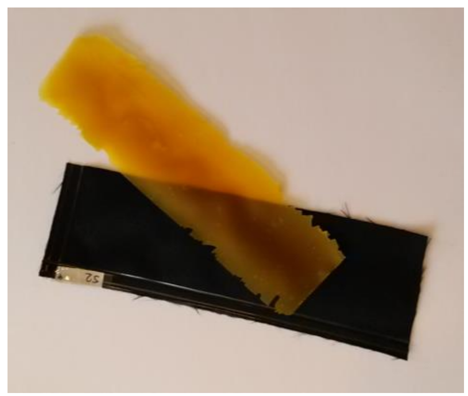
[2] *Multiscale Studies in Building Physics,* ***Empa****, Überlandstrasse 129, 8600 Dübendorf, Switzerland*

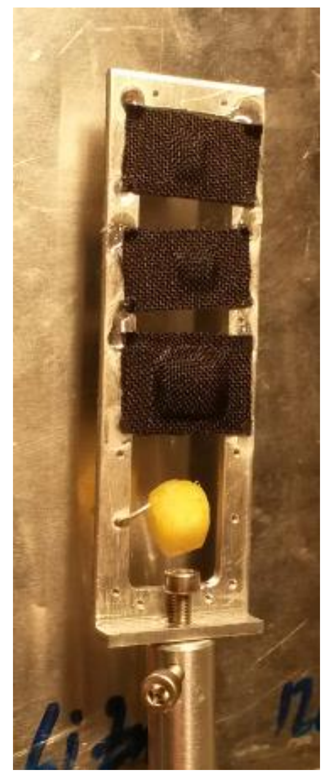
[3] ***Paul Scherrer Institut*** *(PSI), 5234 Villigen, Switzerland*

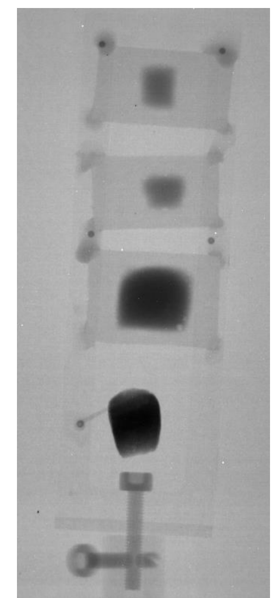
Key message

Neutron imaging is a promising technique for <u>quantifying</u>

Solar Assisted Pervaporation (SAP)





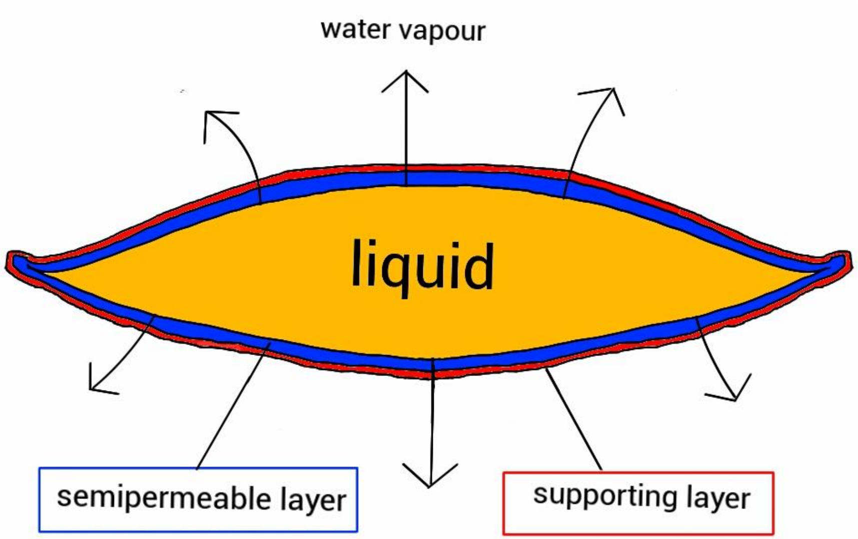


Outline

- What is Solar Assisted Pervaporation (SAP)?
- Aim
- Methods Explored
- Preliminary Results
- Main Findings and Limitations
- Future Work

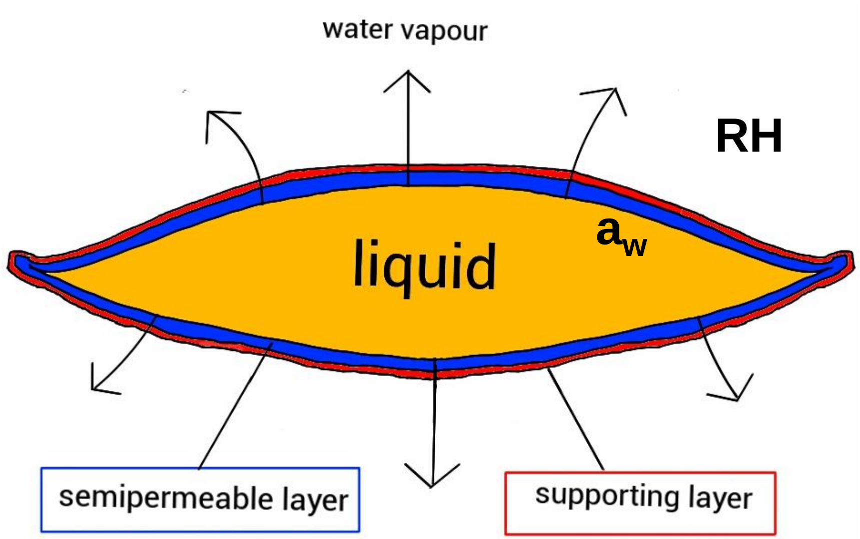
Solar Assisted Pervaporation (SAP)

- "Breathable" fabric pouch
- Permeable to water vapour but not liquid water
- Homogeneous hydrophilic



Solar Assisted Pervaporation (SAP)

- “Breathable” fabric pouch
- Permeable to water vapour but not liquid water
- Homogeneous hydrophilic



Driving force for mass transport: a_w – RH/100

Where can SAP be used?

Mozambique

Sweden

Almost anywhere...

Aim of the study

Test various neutron radiography/tomography setups to see which are compatible with SAP

Can we use neutron imaging to quantify internal mass transport and drying uniformity during SAP?

Collaborating partners

Empa
Materials Science and Technology

LUND UNIVERSITY

PAUL SCHERRER INSTITUT
PSI

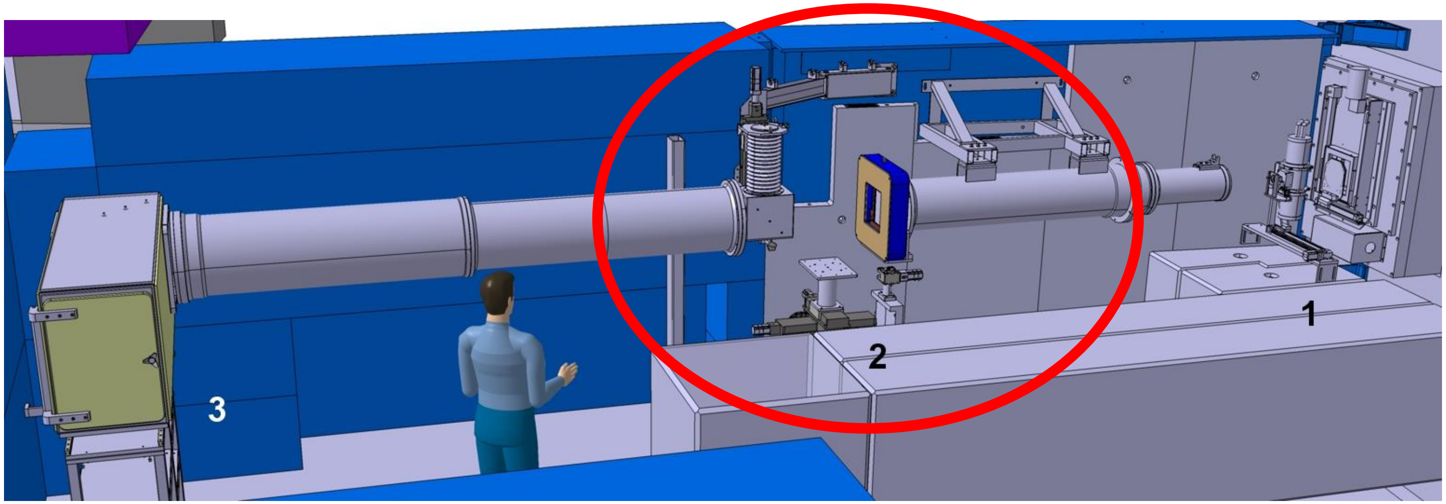
Paul Scherrer Institute

- Villigen, Switzerland

- Neutron source:
  - **SINQ (Swiss Spallation Neutron Source)**
    - » Continuous source
    - » Flux: 10^{14} n/cm^2/s

      - Beamline:
        - » **NEUTRA**
          - » Thermal neutron radiography station

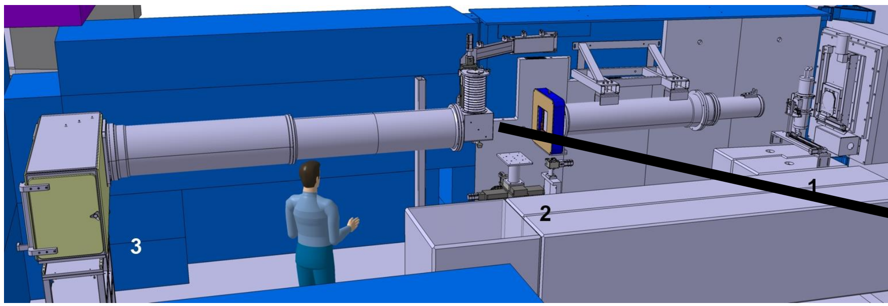
NEUTRA: NEUtron Transmission Radiography

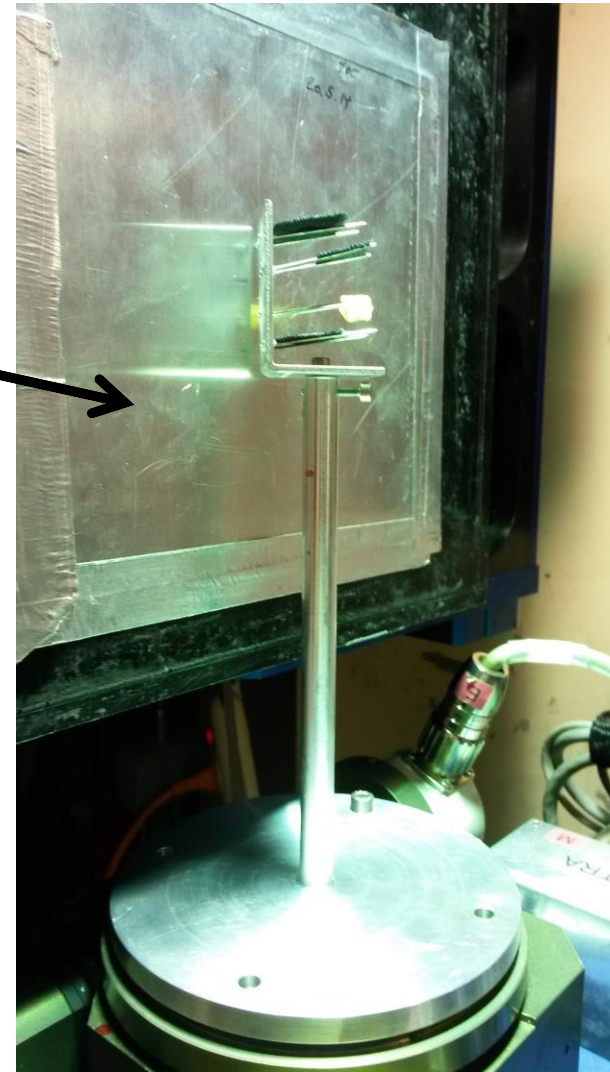


Neutron energy: 25 meV thermal Maxwellian spectrum
Neutron flux at sample position: >5 x 10^6 neutrons cm^{-2} sec^{-1} mA^{-1} (p-current)
Maximum field of view: 30 cm x 30 m

Image source: https://www.psi.ch/sinq/neutra/description

NEUTRA: NEUtron Transmission Radiography (PSI)





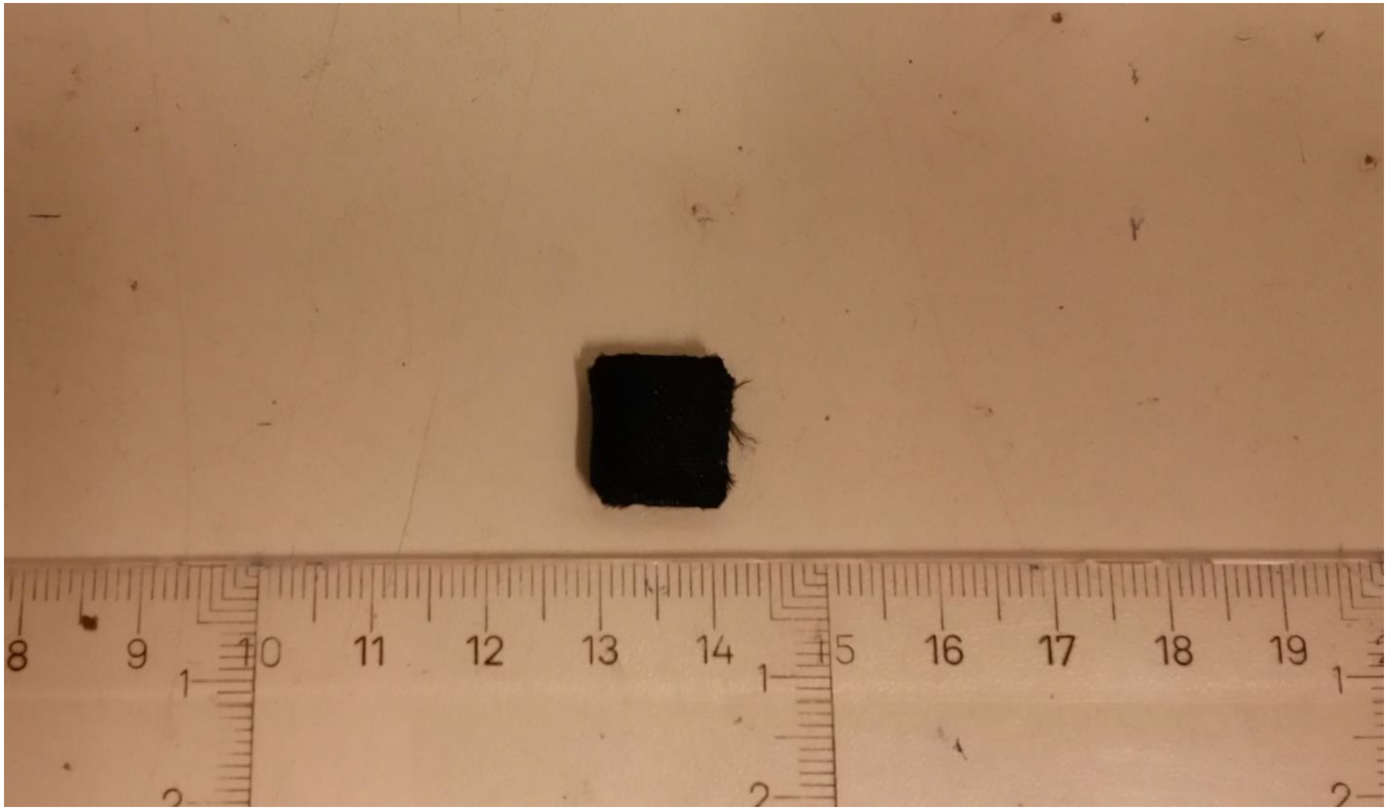
Methods Explored

Summary of Experimental Setups

Experiment	Bag orientation	Bag type	Irradiance (W/m^2)	Materials tested
1	horizontal	mini	80	solid apple (w and w/o bag), purée and juice
2	vertical	mini	210	solid apple (w and w/o bag), purée and juice
3	vertical	big	210	apple purée
4	vertical	column	210	apple purée and juice
5	vertical	column + D_2O	210	apple purée

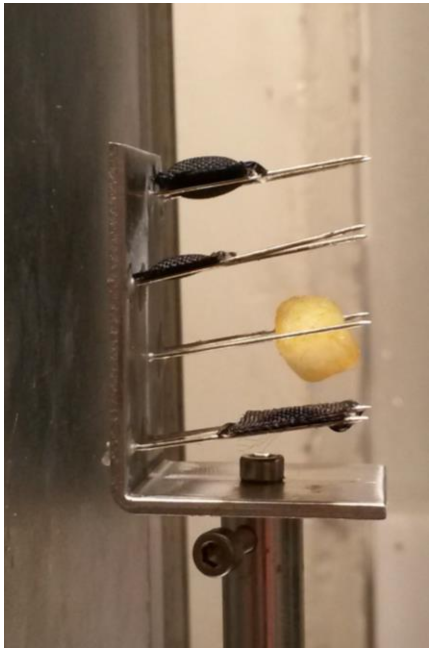
Apple: Organic Golden Delicious (94021) from Italy, purchased in Sweden

The Challenge



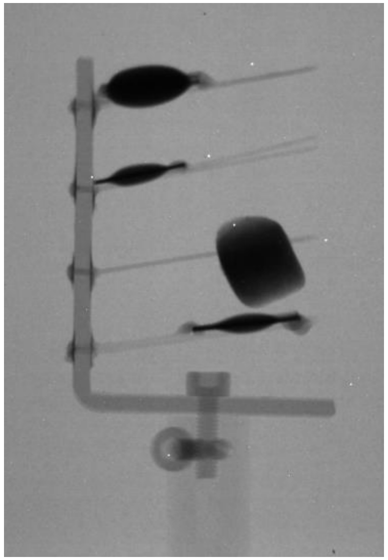
Spatiotemporal Tomography
“Mini” Bags (Horizontal)

Purpose: create a 3D reconstruction of the dehydration process for horizontal ”mini” bags 10 mm x 10 mm [L x W]



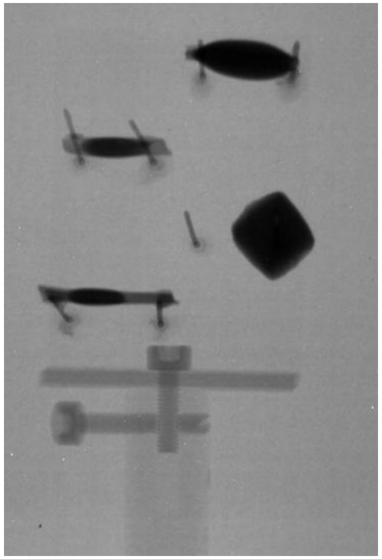
→

1



\+

2



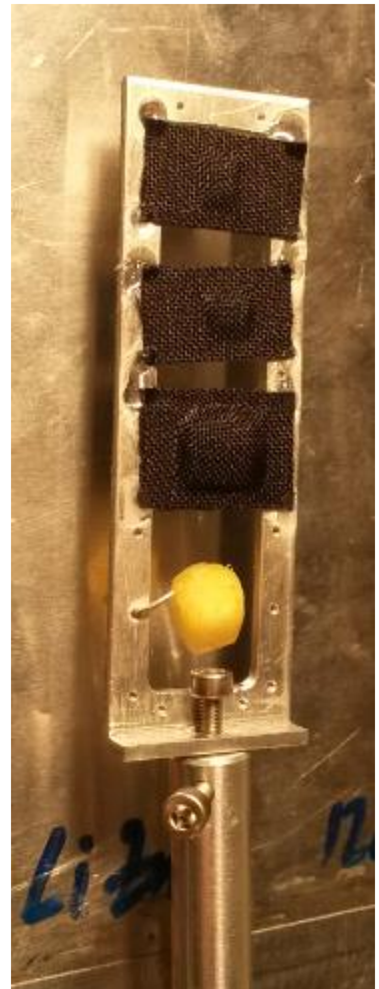
\+ …

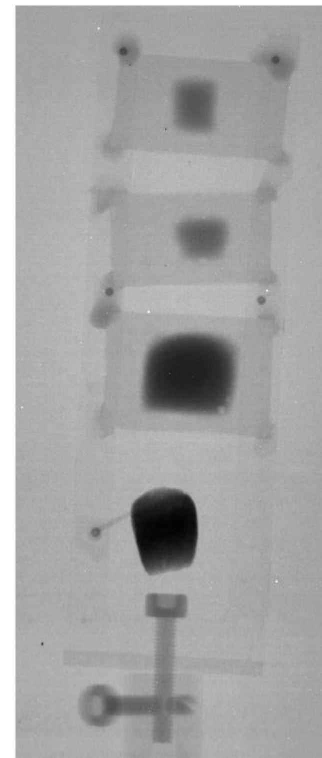
3

Radiography
”Mini” Bags (Vertical)

Purpose: visualise and quantify drying patterns in ”mini” vertical bags with:

- Apple purée [1]
- Apple juice [2]
- Solid apple (in bag) [3]
- Solid apple (no bag) [4]





1

2

3

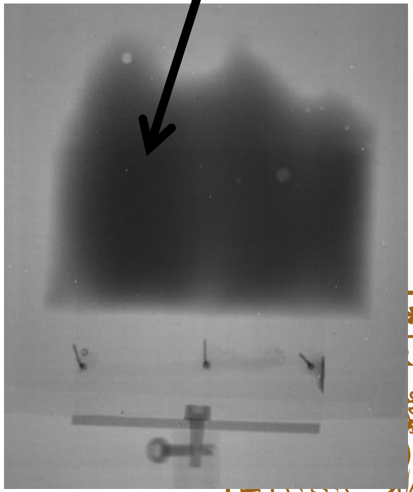
4

Radiography
”Big” Bag (Vertical)

Purpose: visualise and quantify drying patterns in a ”big” vertical bag with apple purée

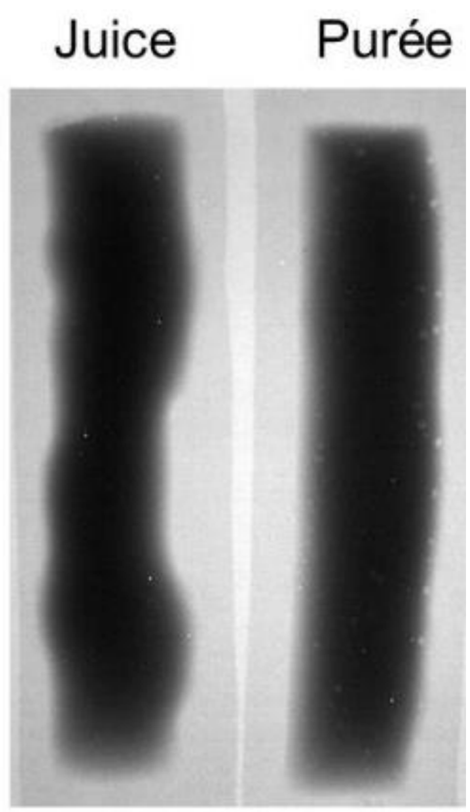
7 cm

Apple purée



Radiography
”Column” Bags (Vertical)

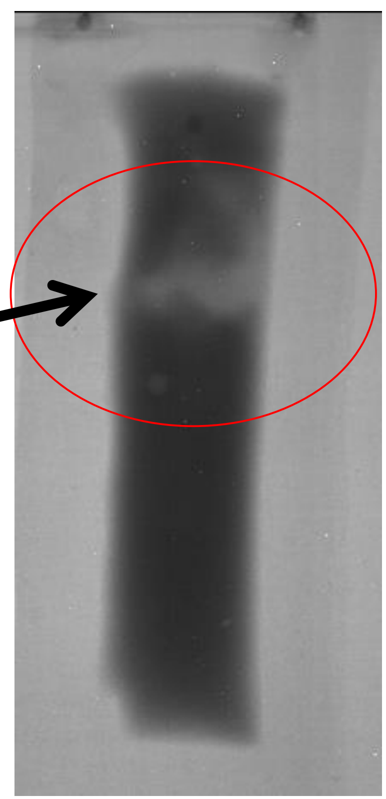
Purpose: visualise and quantify drying patterns in vertical column bags to compare apple purée vs. apple juice



Radiography
”Column” Bags (Vertical) with D_2O Injection

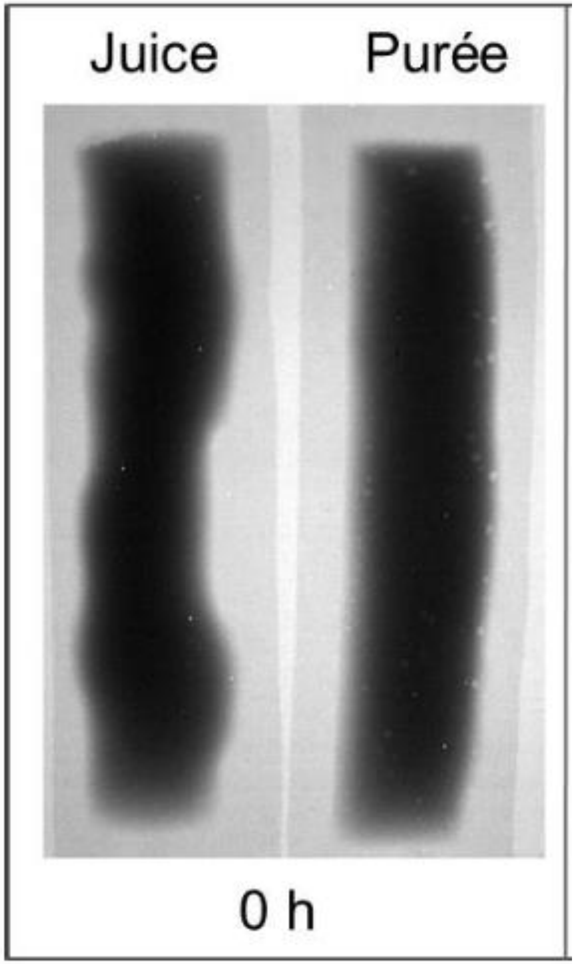
Purpose: to see if D_2O can be used to quantify mass transport inside the bags

D_2O

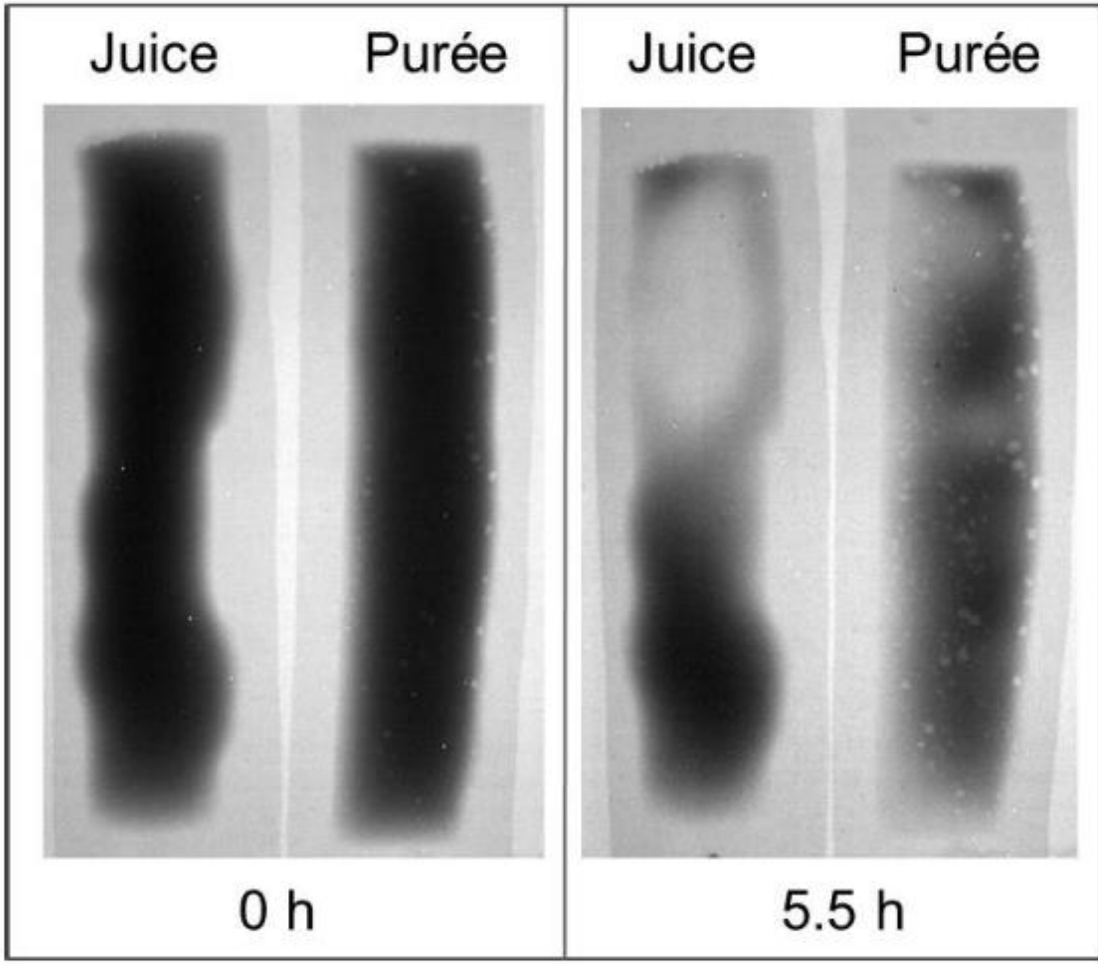


Preliminary Results

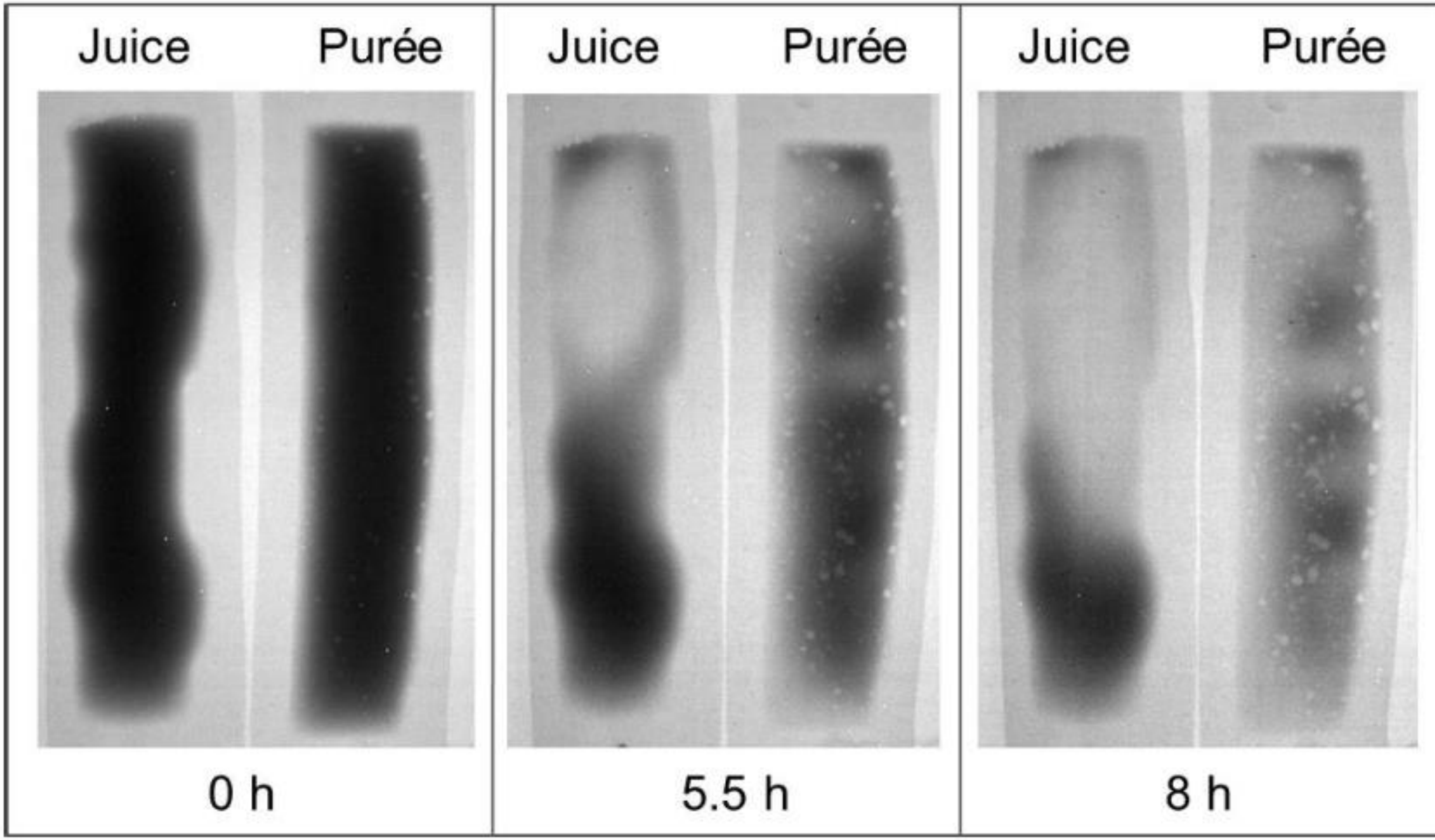
Vertical Radiography: Effect of viscosity on drying uniformity



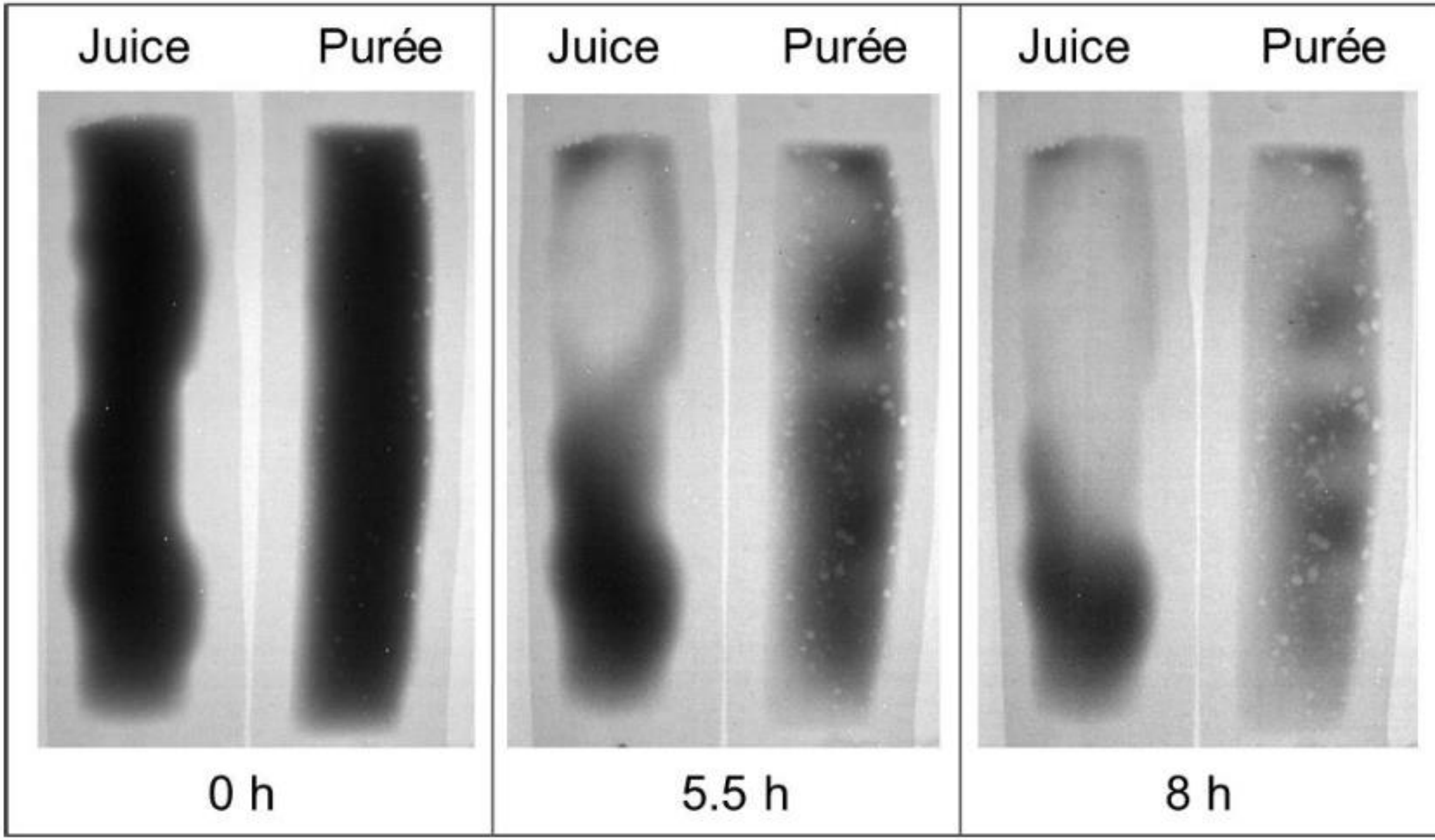
Vertical Radiography:
Effect of viscosity on drying uniformity



Vertical Radiography: Effect of viscosity on drying uniformity

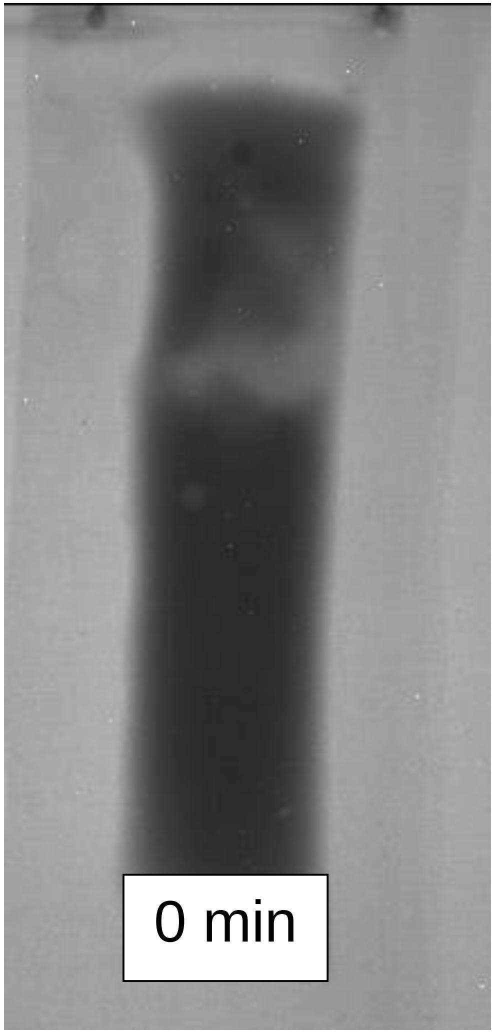


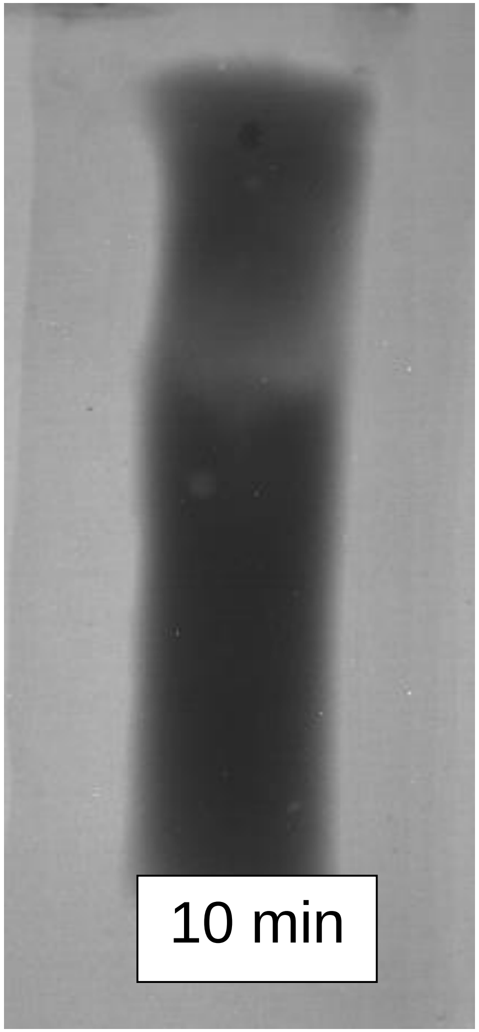
Vertical Radiography: Effect of viscosity on drying uniformity

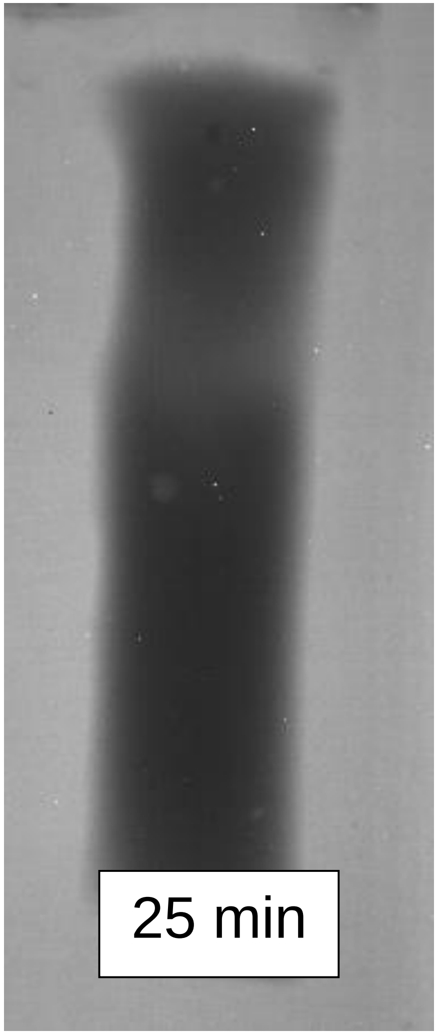


Local moist spots and uneven drying: food safety risk

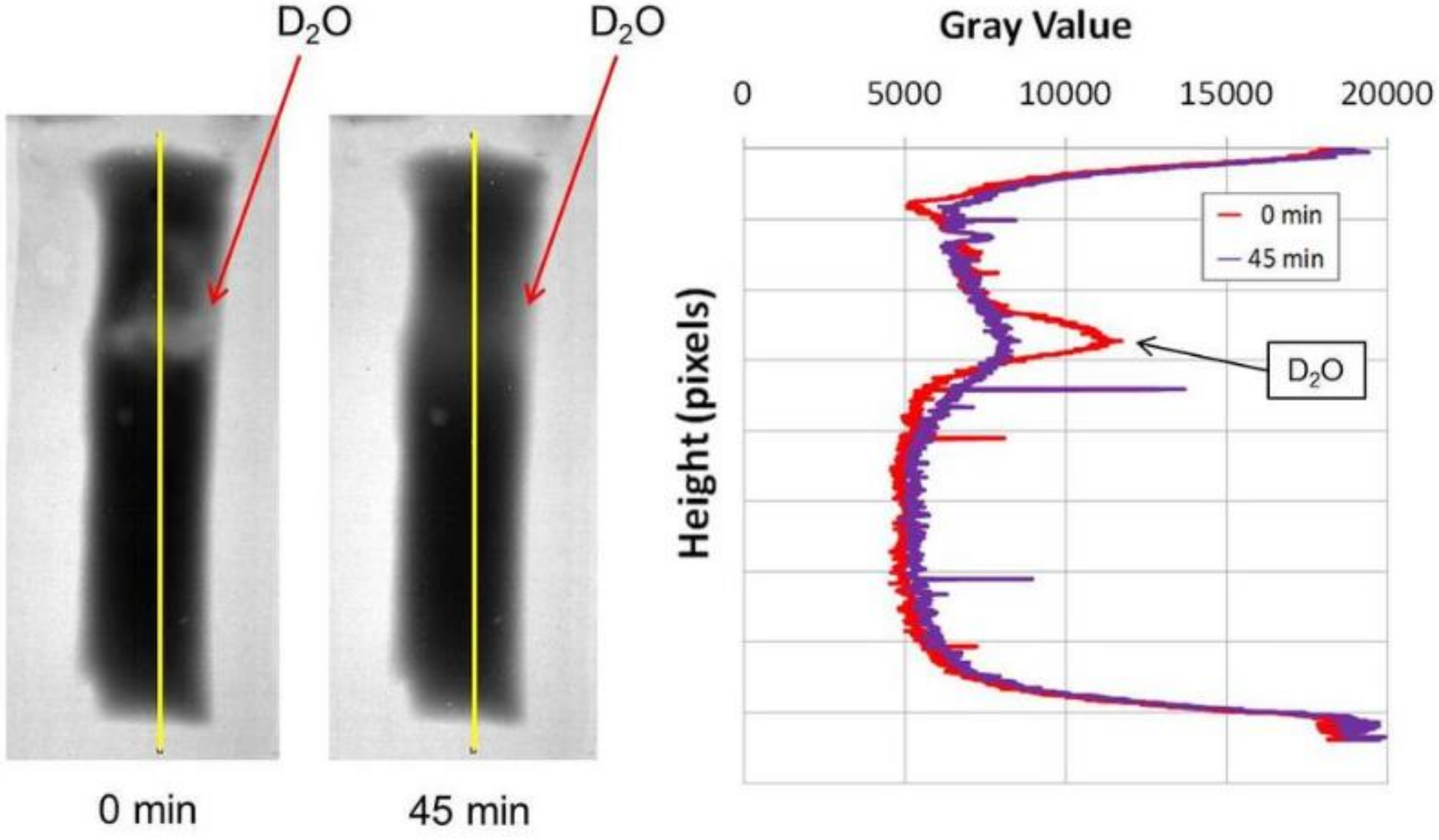
$D_2$0 Injection: diffusion-driven process







D_20 Injection: to quantify mass transport



Limitations of the setup

- 10 mm sample depth
  - Forced to use ”mini” horizontal bags
- Vertical setup: 15 x 15 cm Field of View
  - Smaller than real ”SAP” bag
- Hard to distinguish water from carbohydrates

Conclusions and Next Steps

- D_2O injection seems promising for visualising and quantifying mass transport inside the bag
  - Next step: calculate diffusion rates

- Local moist spots and drying heterogeneity can be identified
  - Next step: calculate local drying rates

Data from other experimental setups to be analysed

Future Work

Use a vertical setup with

1) purées of differing viscosity and
2) D_2O injections to:

   – validate a multiphysics model of the process
   – quantify internal mass transport
   – understand food safety risks with non-uniform drying

Acknowledgements

- Swedish Research Council (PhD Project Funding)
- Thijs Defraeye, Empa, Switzerland
- Peter Vontobel, PSI, Switzerland
- Petr Dejmek, Ingegerd Sjöholm and Marilyn Rayner (supervisors at the Department of Food Technology, Engineering and Nutrition)

Questions?