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Multi-scale exploration of the drying dynamics of dairy colloids

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HAL Authorization



Multi-scale exploration of the drying dynamics of dairy colloids

Doctoral student :
Rui Ouyang

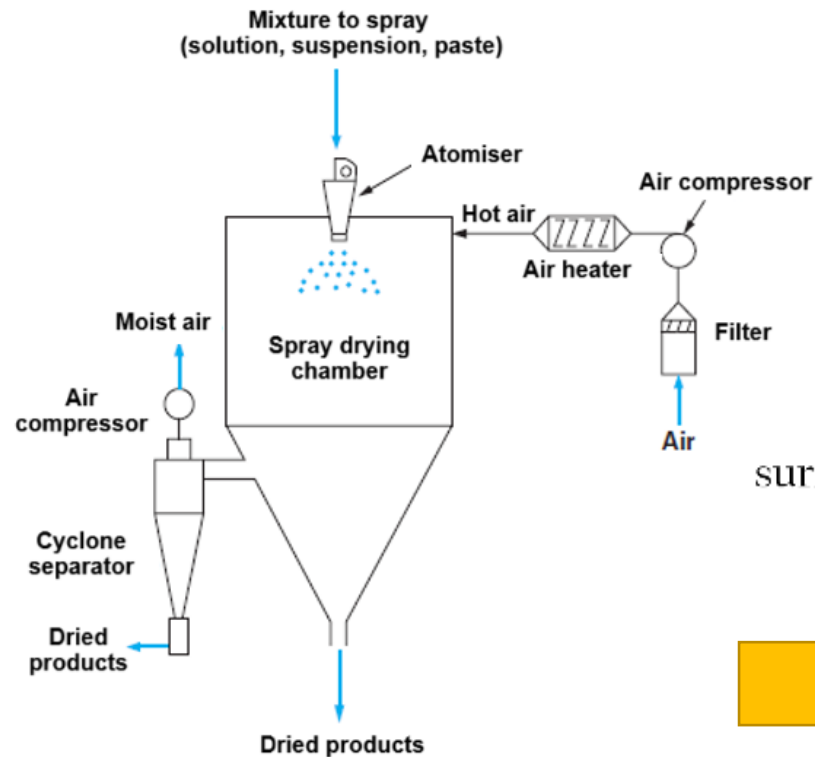
Supervisors :
Cécile Le Floch-Fouéré
Luca Lanotte

Co-supervisors :
Ludovic Pauchard (FAST, Orsay)
Kévin Roger (LGC, Toulouse)

➤ Scientific Background

Why do we care about drying proteins ?

Spray drying



Powder properties

Caking



Flowability



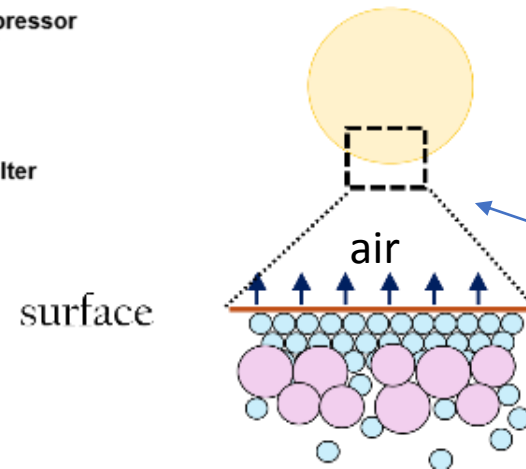
Storage



Rehydration



SKIN FORMATION
SOL/GEL TRANSITION



Powder surface structure



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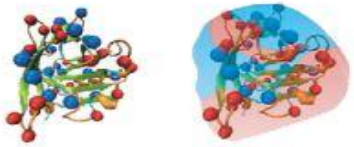
➤ Research Strategy

Simplification of complex systems

❑ Whey proteins (WPI)

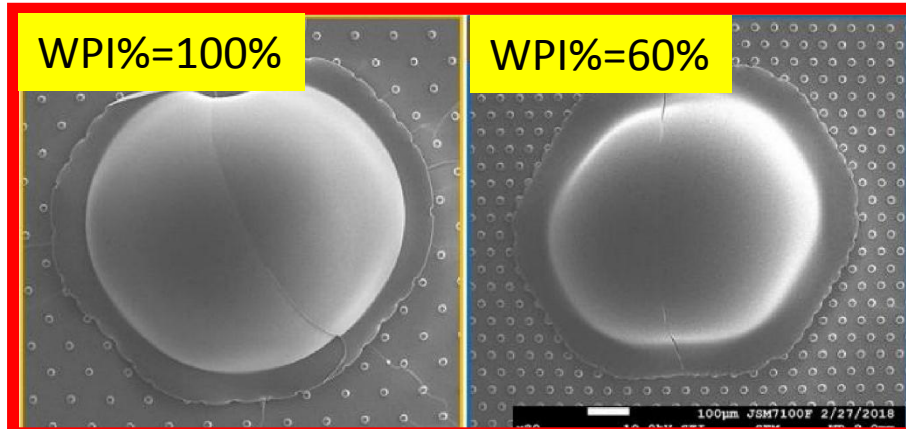
convex smooth surface

Charges in β -Lactoglobulin

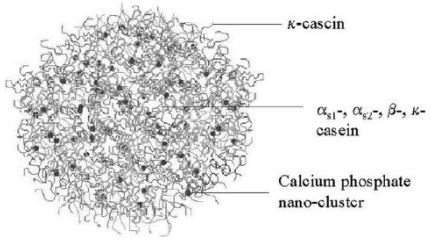


Yohko, 2012

Rigid globular structure,
D \approx 10-20 nm

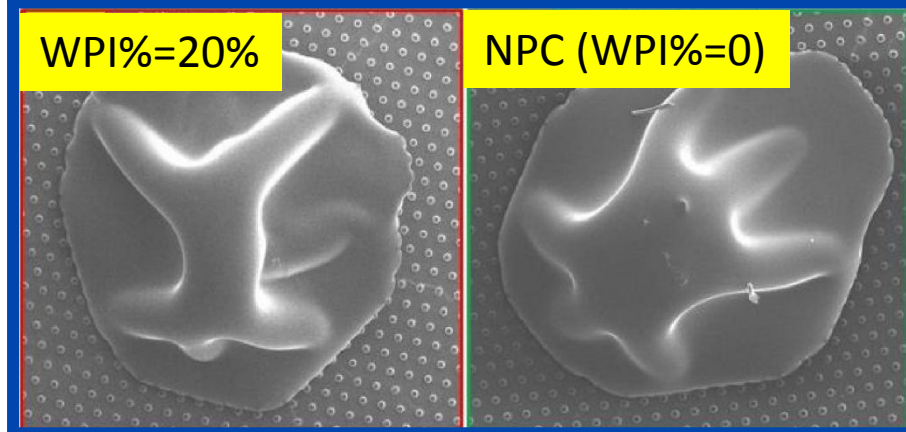


❑ Casein micelles (NPC)



Holt & Horne, 1996

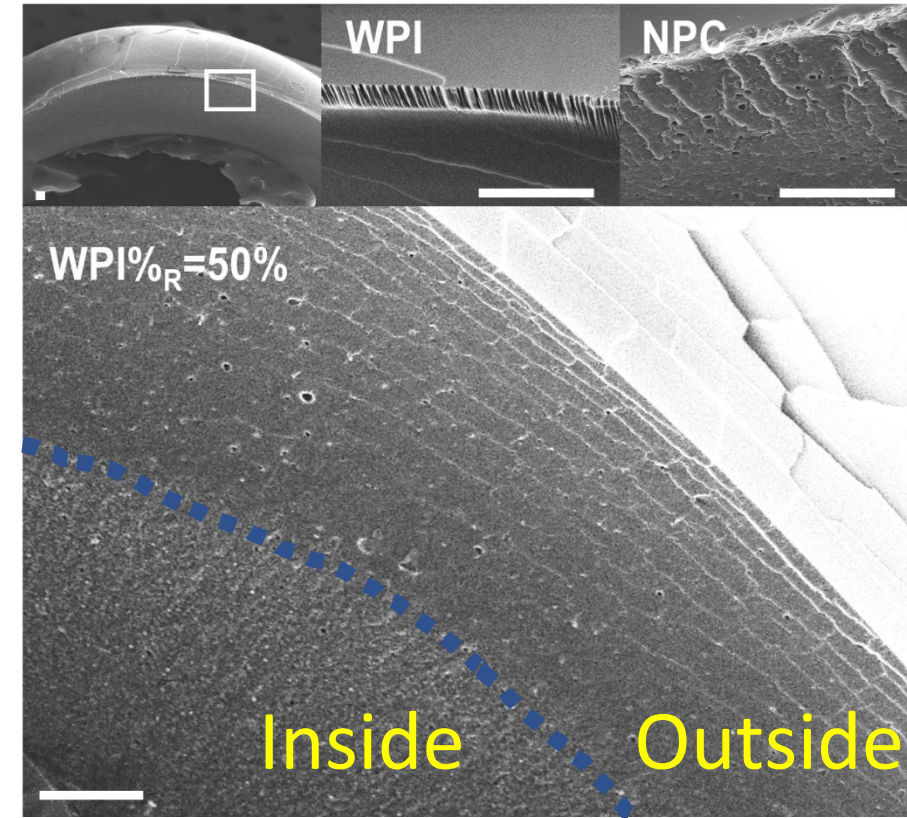
Micellar,
deformable & hydrated structure,
D \approx 100-300 nm



Wrinkled skin; Buckling

Lanotte et al., 2018

Small on Top



Stratification

Yu et al., 2021

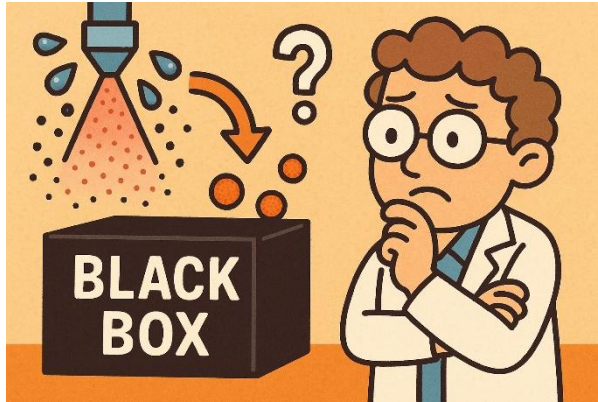


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➤ Research Strategy

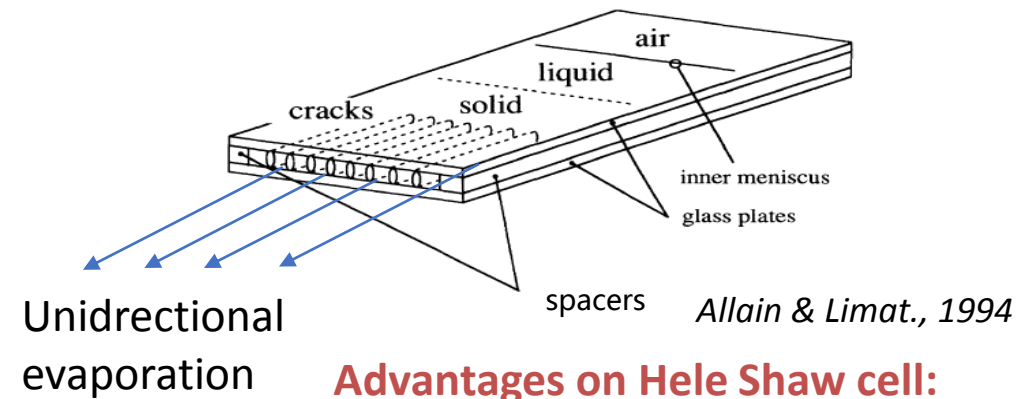
“Black box”



Limits on an industrial scale:

- *Fast drying kinetics*
- *Heterogeneity of samples*
- *Costs of large scale trials*

Directional drying device



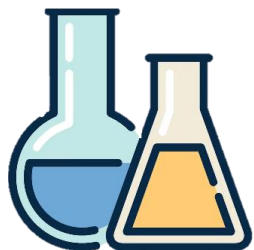
Advantages on Hele Shaw cell:

- *Slow & controllable kinetics*
- *Homogeneous film*
- *Simple & repeatable system*
- *Real-time observation*
- *Low costs*

➤ Materials & Methods

Experimental conditions:
 Temperature ≈ 20 °C
 Relative humidity = 60 %

Dairy Colloidal dispersions (12 wt%)



- Whey Protein Isolate (WPI)
 - Final dispersion: ~9% (v/v)
 - Size : 8–30 nm
 - pH ≈ 6.8 at 20 °C
- Native Phosphocaseinate (NPC)
 - Final dispersion: ~38% (v/v)
 - Size : 108–300 nm
 - pH ≈ 6.8 at 20 °C

Le Floch-Fouéré et al., 2019

- Mix of WPI/NPC

– Theoretical volume fraction φ as a function of the WPI% ($WPI\% = \frac{m_{WPI}}{m_{solute}}$):

WPI %	0%	20%	50%	80%	100%
φ_p	0.38	0.33	0.26	0.17	0.09
φ_{WPI}	-	0.01	0.04	0.07	0.09

Yu et al., 2021



➤ Materials & Methods

Morphological evolution & Drying kinetics

Experimental conditions:
Temperature $\approx 20\text{ }^{\circ}\text{C}$
Relative humidity = 60 %



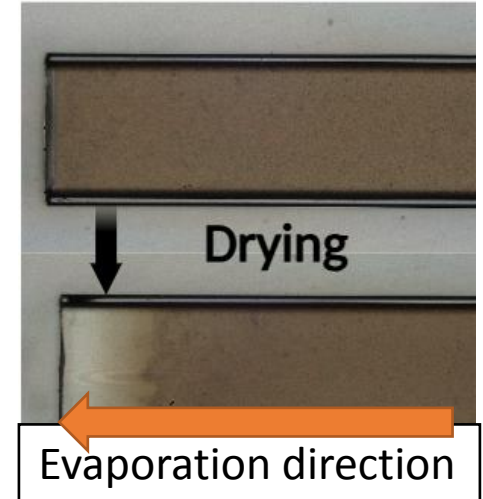
Unidirectional drying cell

Width = $1000\text{ }\mu\text{m}$;
Gap height = $100\text{ }\mu\text{m}$



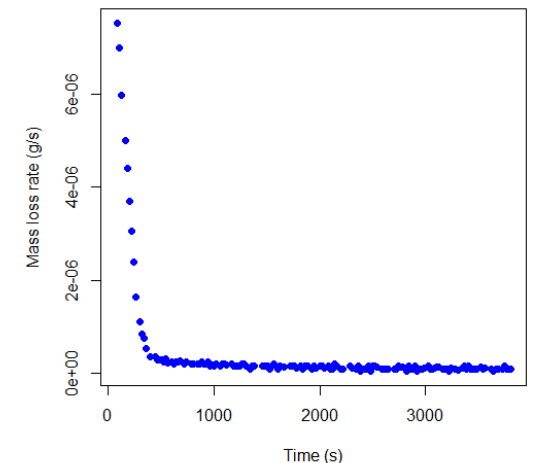
- Microscopic Monitoring
 - Digital Microscope: Keyence
 - Focus : X100

Morphological evolution



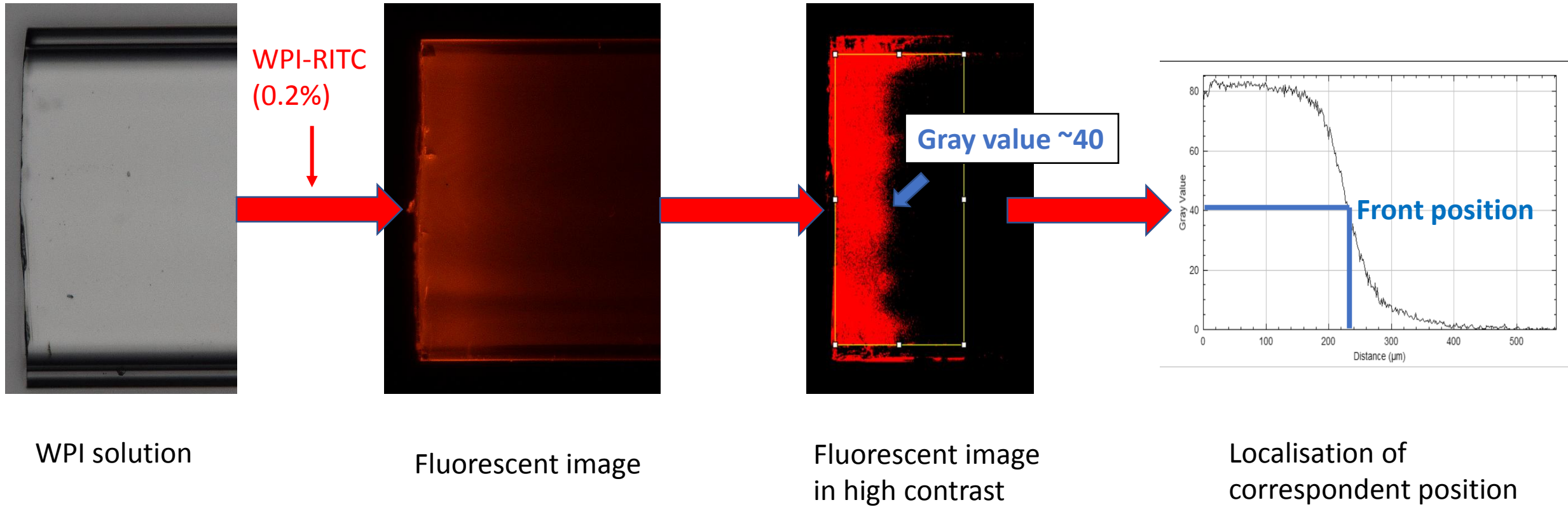
- Drying kinetics
 - Micro balance: Radwag
 - Precision : $1\text{ }\mu\text{g}$

Drying kinetics curve



➤ Materials & Methods

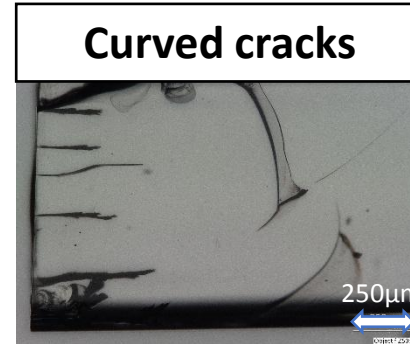
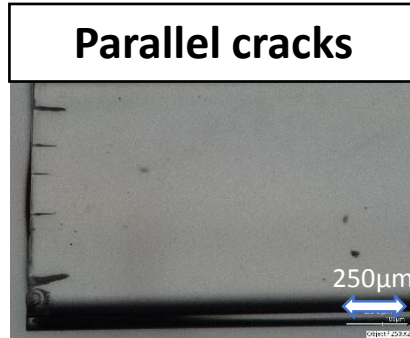
How to know the position of drying front



➤ Results & Discussion

Morphological evolution

WPI%=100%
(NPC=0%)



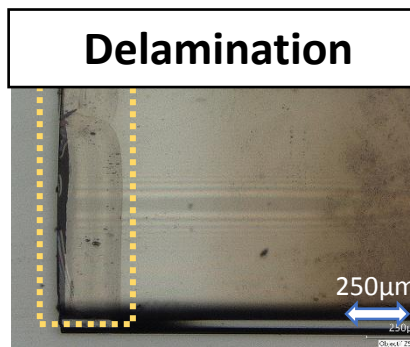
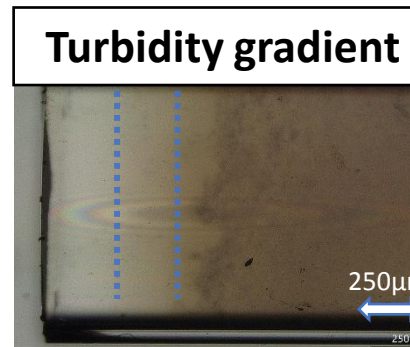
Cracks → Brittle

WPI%=50%
(NPC=50%)



Double properties
Heterogeneity

WPI%=0%
(NPC=100%)



Delamination (no crack)
→ Ductile

Drying beginning

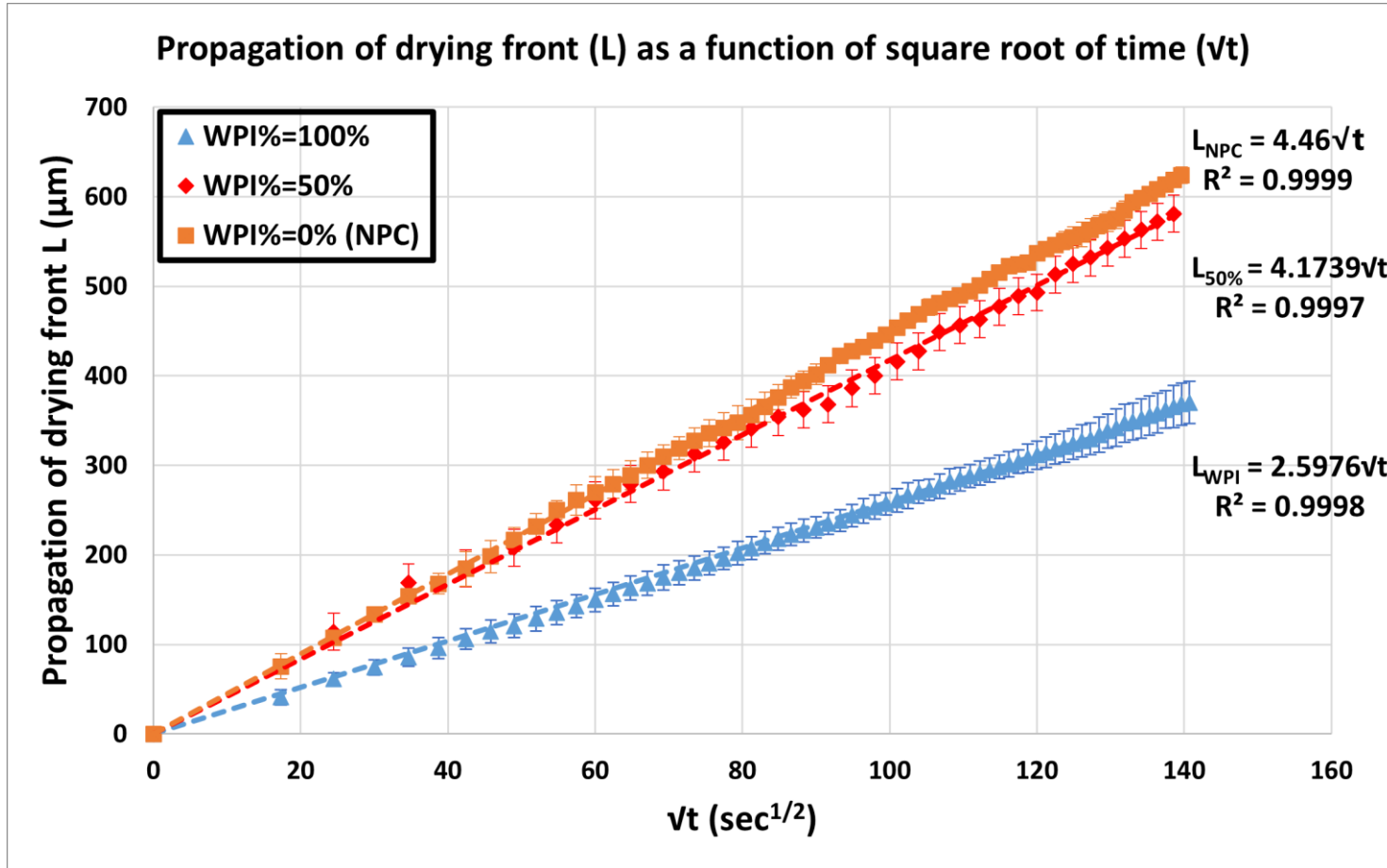
6h

24h

Time

➤ Results & Discussion

Morphological evolution during 6h



Diffusive regime

Small colloid (radius < 15 nm)

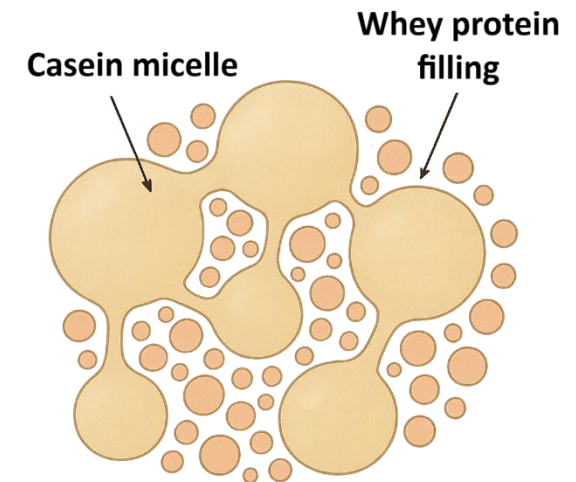
Lidon & Salmon, 2014



Microgel
(deformation & deswelling)

Roger & Crassous, 2021

Mixed protein network



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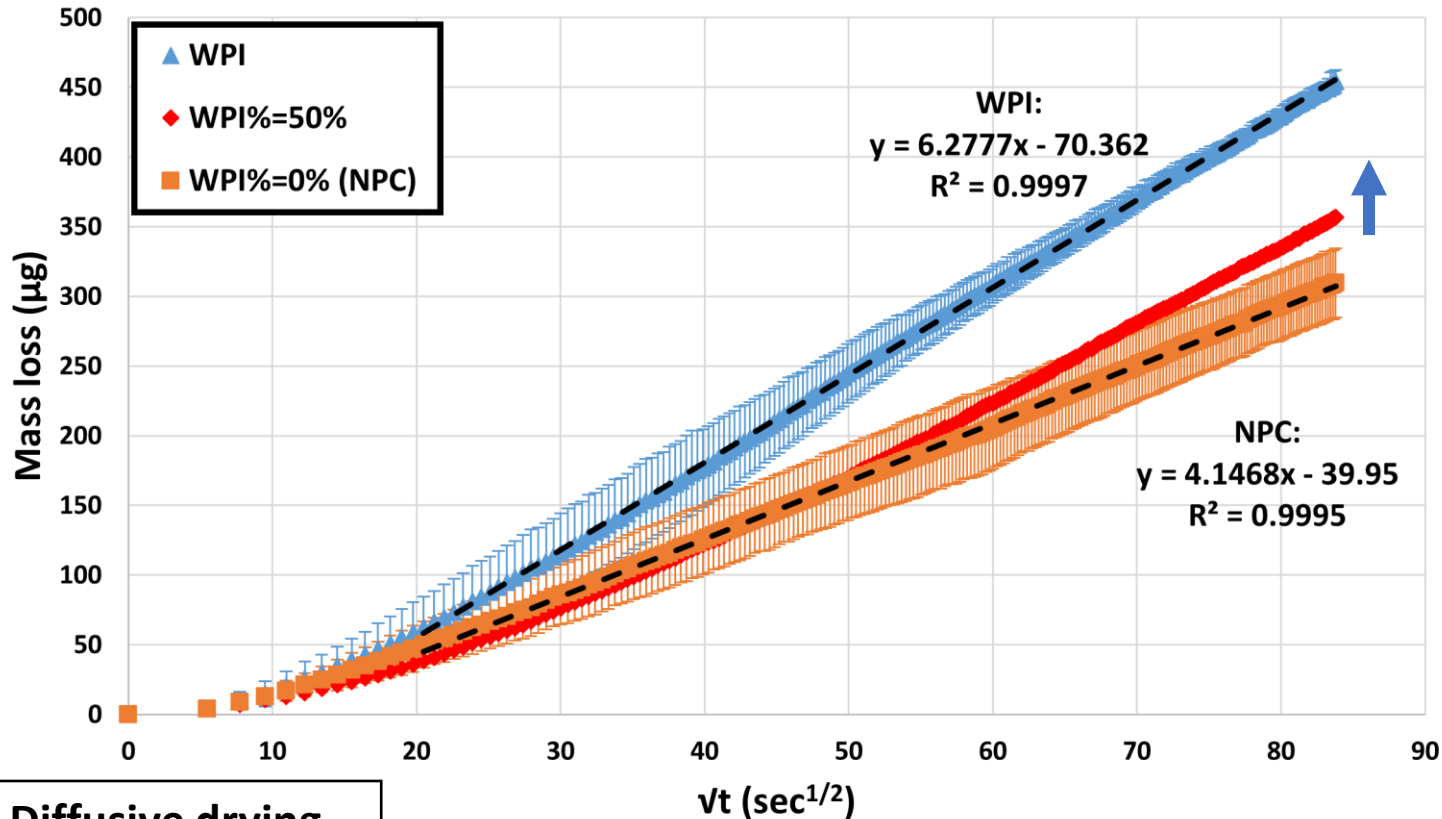
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➤ Results & Discussion

Drying kinetics during 2h

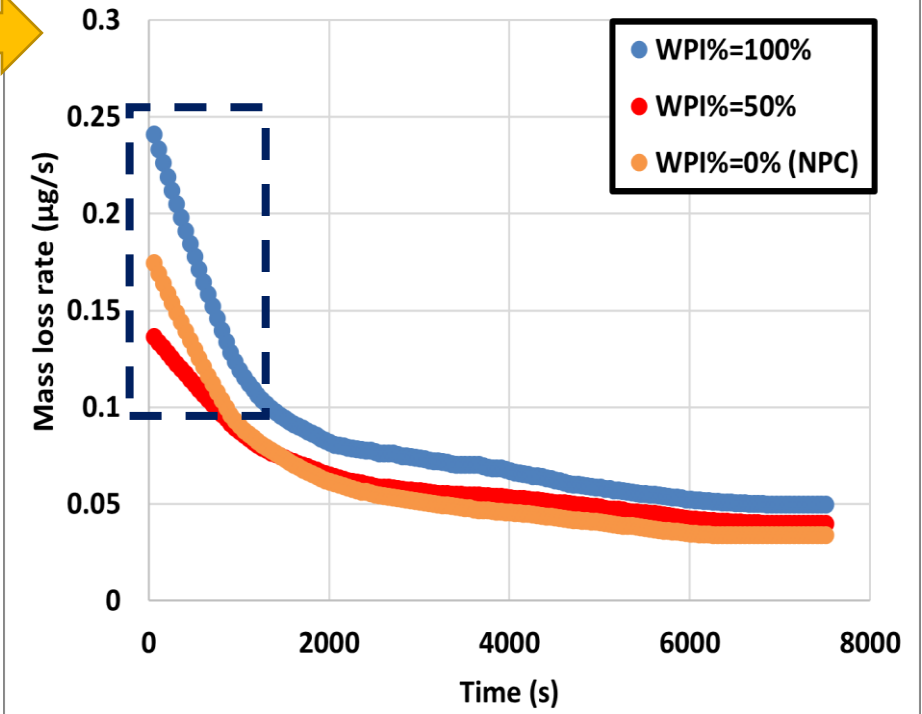
$$J_i [\mu\text{g/s}] = \frac{m_i - m_{i+1}}{\Delta t}$$

Mass loss as a function of square root of time



Diffusive drying

Rapid drying → Slower drying → Constant drying



Hypothesis :
Faster formation of mixed protein layer at air/water interface ?



> Conclusions

Drying dynamics of dairy colloids

Methodology

Unidirectional drying cell

Morphology

- Cracking
- Delamination



- Brittle
- Ductile

Drying kinetics

Diffusive drying of individual dairy colloid in a moderate condition



Complexed interaction between whey protein and casein micelle to explore

➤ Perspectives





Thank you for your attention !