Drying research : from physical and biological mechanisms to breakthrough innovation

Cécile Le Floch-Fouéré, Luca Lanotte, Song Huang, Céline Sadek, Maheshchandra H Patil, Gwénaël Jan, Gaëlle Tanguy, Eoin G Murphy, Xiao Dong Chen, Romain Jeantet

Drying research

From physical and biological mechanisms to breakthrough innovation

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STLO : Science et Technologie du Lait et de l'Œuf
UMR 1253 Rennes

Context , Research topics , Strategy

- Massive growth of Infant milk formula (IMF) market
- Controlled properties, incorporation of live probiotics
- Environmental and costs concern

Understand the particle formation mechanisms

Identify the key parameters that rule the powder properties and evolution

Explore new technological concepts for technological breakthrough innovation

Consider simplified & controlled models (dairy colloids, bacteria)

Observe the phenomenon at different scales to make the study possible

Combine disciplines: from biology to soft matter and chemical engineering

Partnership to feed the scientific questions and identify technological outputs

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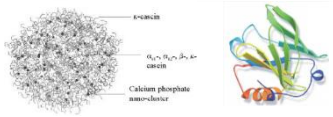
1. • ***Exploring particle formation to control IMF properties***

2. • ***Triggering the protection mechanisms to maximize survival of bacteria***

3. • ***Redesigning the process for the production of whey/permeate powders***

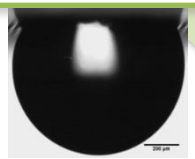
Strategy - Study of the drying process on multi-scales

Milk colloids



- Whey protein isolates (WPI)
- Micellar casein (MC)
- Single or mixed together

Single droplet 3D / 2D



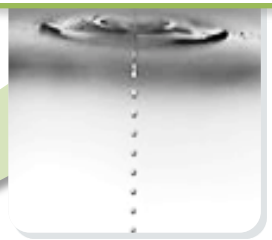
PARTICLE FORMATION

- **Control and study** the drying kinetics
- **Record** *in situ* deformation

Coupling methods

- **Mass balance**
- **Microscopy**
- **Rheology**

Mono-disperse droplets



PARTICLES PROPERTIES

- **Control** drying history
- **Get** homogenous samples
- **Analyze** physical properties

Spraying cone of droplets

SCALE UP

- **Validate** on an industrial scale
- **Control** powder properties

Protein signature in the course of drying

Langmuir 29 **(2013)** 15606 - 15613

Drying Technol 32 **(2014)** 1540 - 1551

Food Hydrocolloids 48 **(2015)** 8 - 16

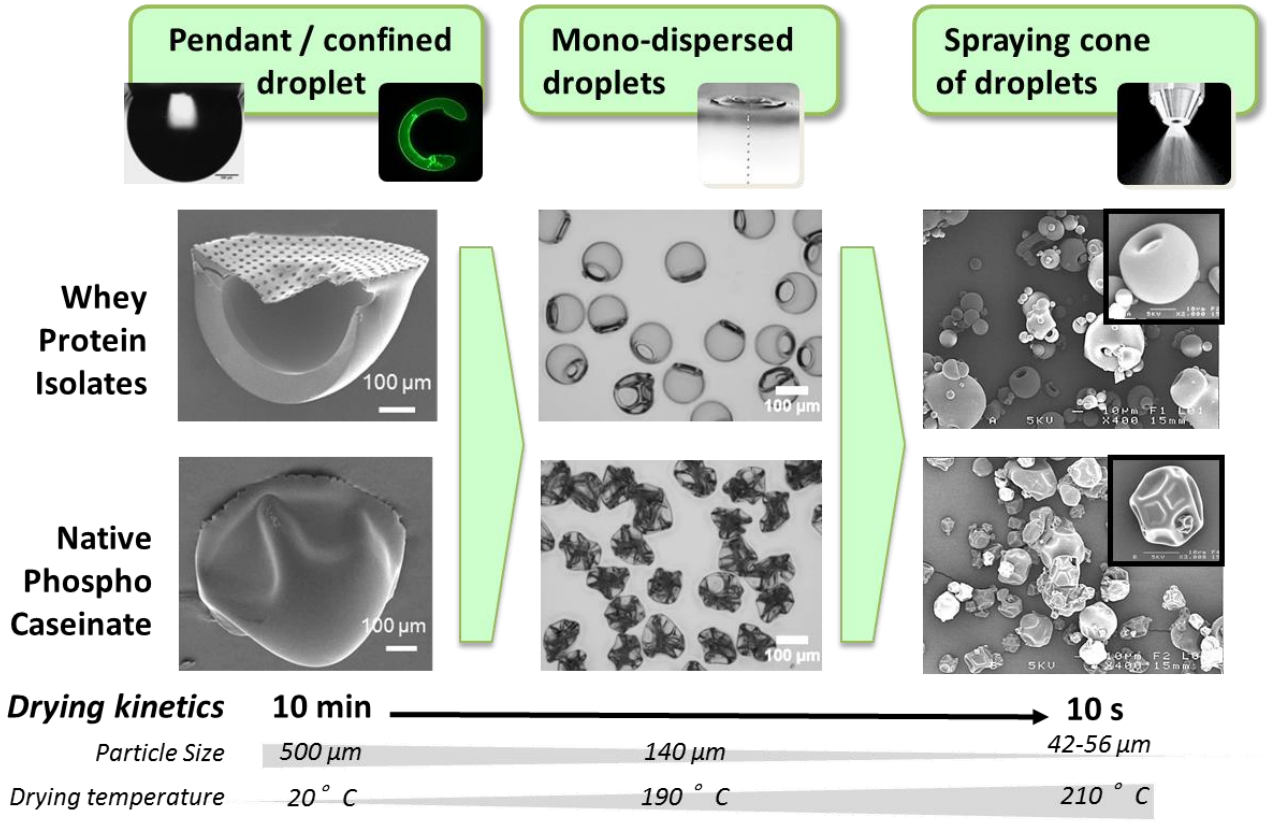
Food Hydrocolloids 52 **(2016)** 161 -166

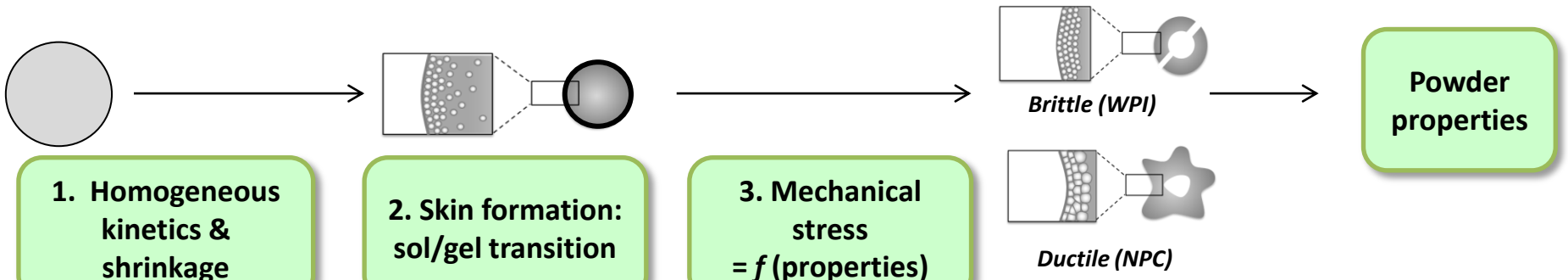
Colloids and Surfaces A 553 ***(2018)*** *20-27*

Colloids and Surfaces A 620 ***(2021)*** *126560*

Foods 11 ***(2022)*** *562*

Specific signatures of WP and MC proteins governing the particle formation / shape and properties, regardless of the drying kinetics

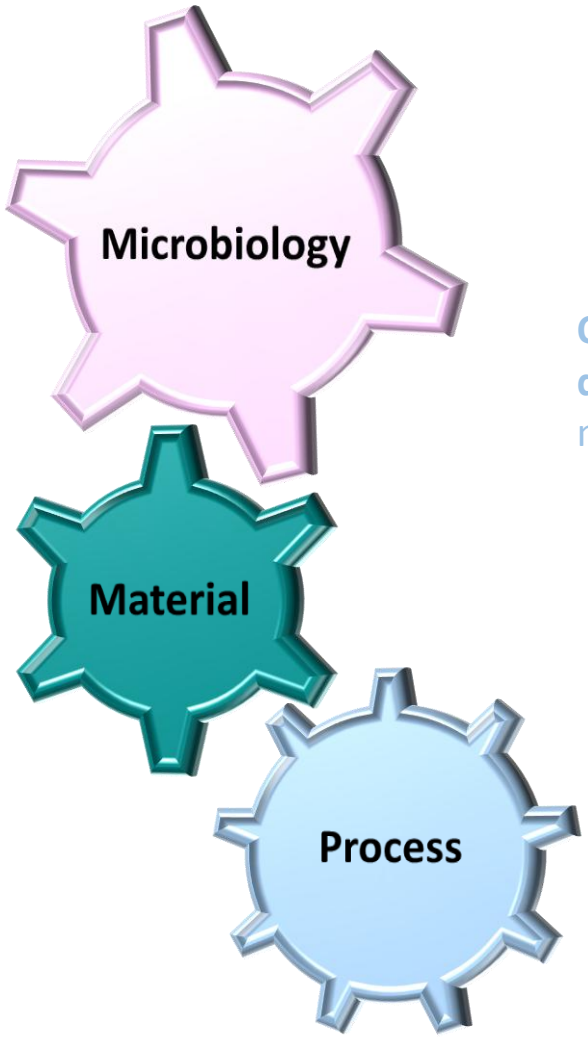


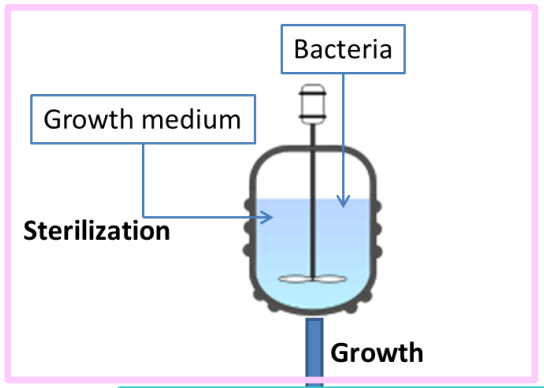


2.

- ***Triggering the protection mechanisms to maximize survival of bacteria***

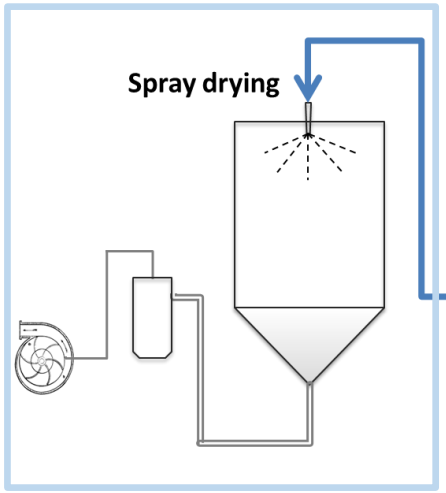
Strategies in probiotics drying research

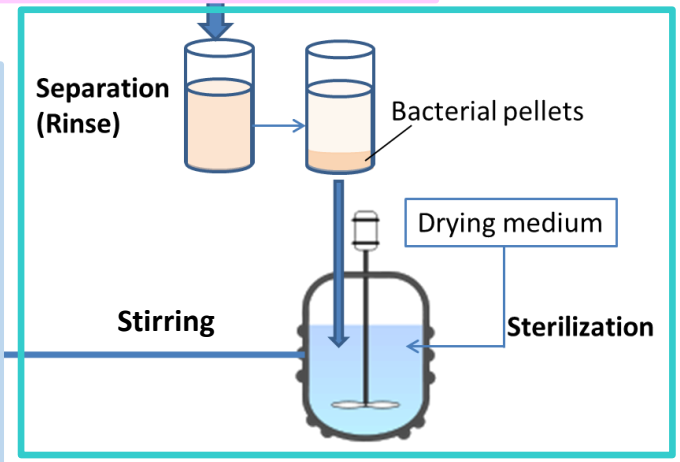




Resistant strain selection, Cross-protection *via* sublethal stresses, etc.

Optimize/moderate drying conditions: multistage, belt, etc.





Protective food grade constituents: Carbohydrates, proteins, polymers, minerals

Coupling strategies to improve probiotics viability?

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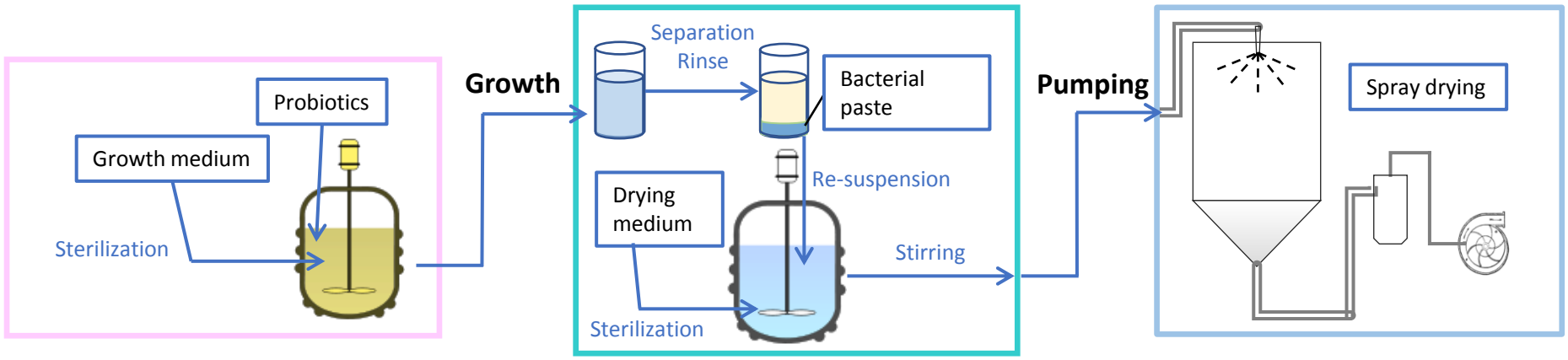
A coupled approach for a novel process



Concentrated 2-in-1 (*Growth & Drying*) Medium

Food grade materials
Carbohydrates
Proteins
Polymers
Minerals

Cross-protection

Sublethal osmotic

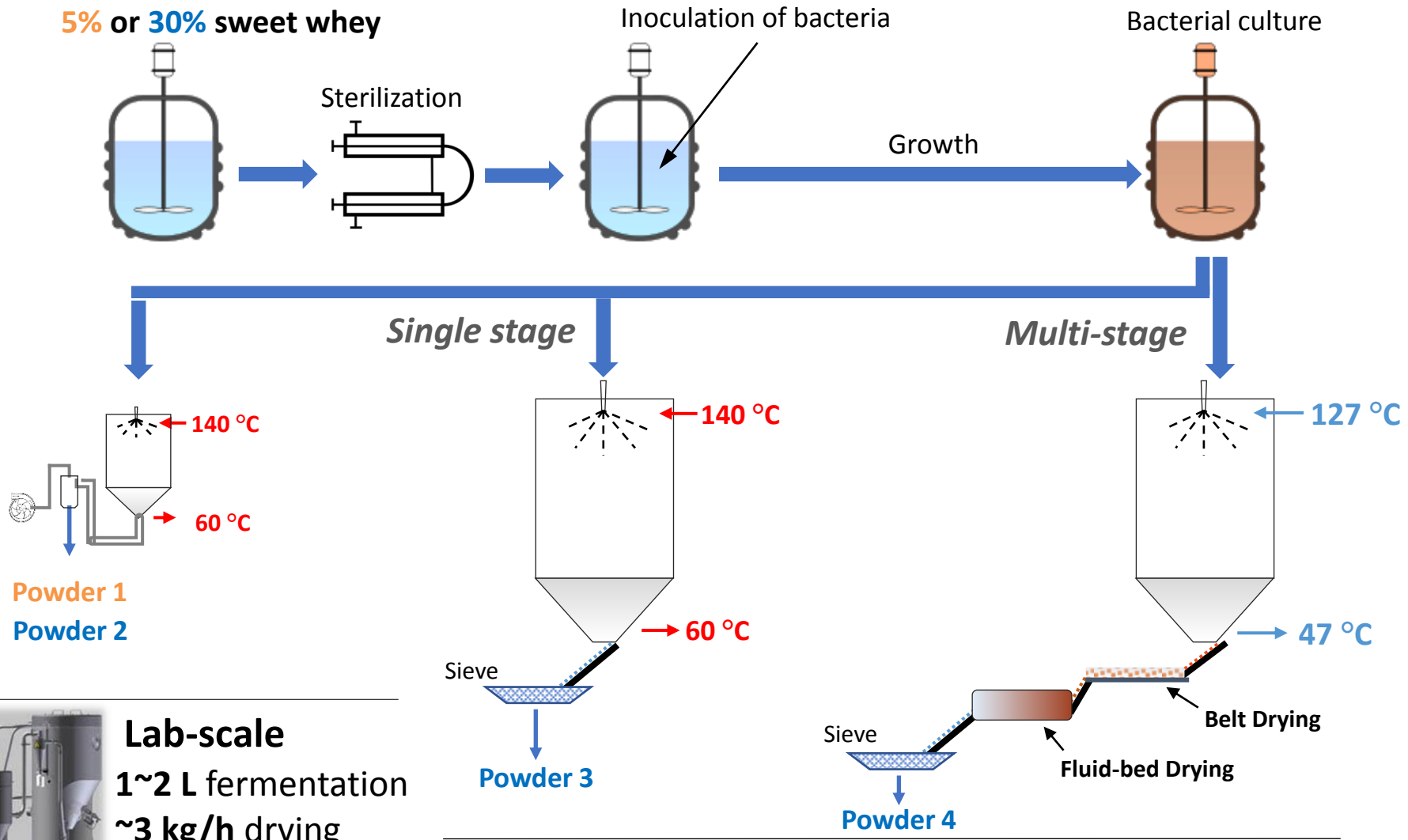
Stress Tolerance

Multi-stage drying

Pre-concentration

Lower θ / Energy savings

Drying bacteria at different scales



Lab-scale

1~2 L fermentation

~3 kg/h drying

Pilot-scale BIONOV

500 L fermentation

~100 kg/h drying

J Food Eng 196 (2017) 11 - 17

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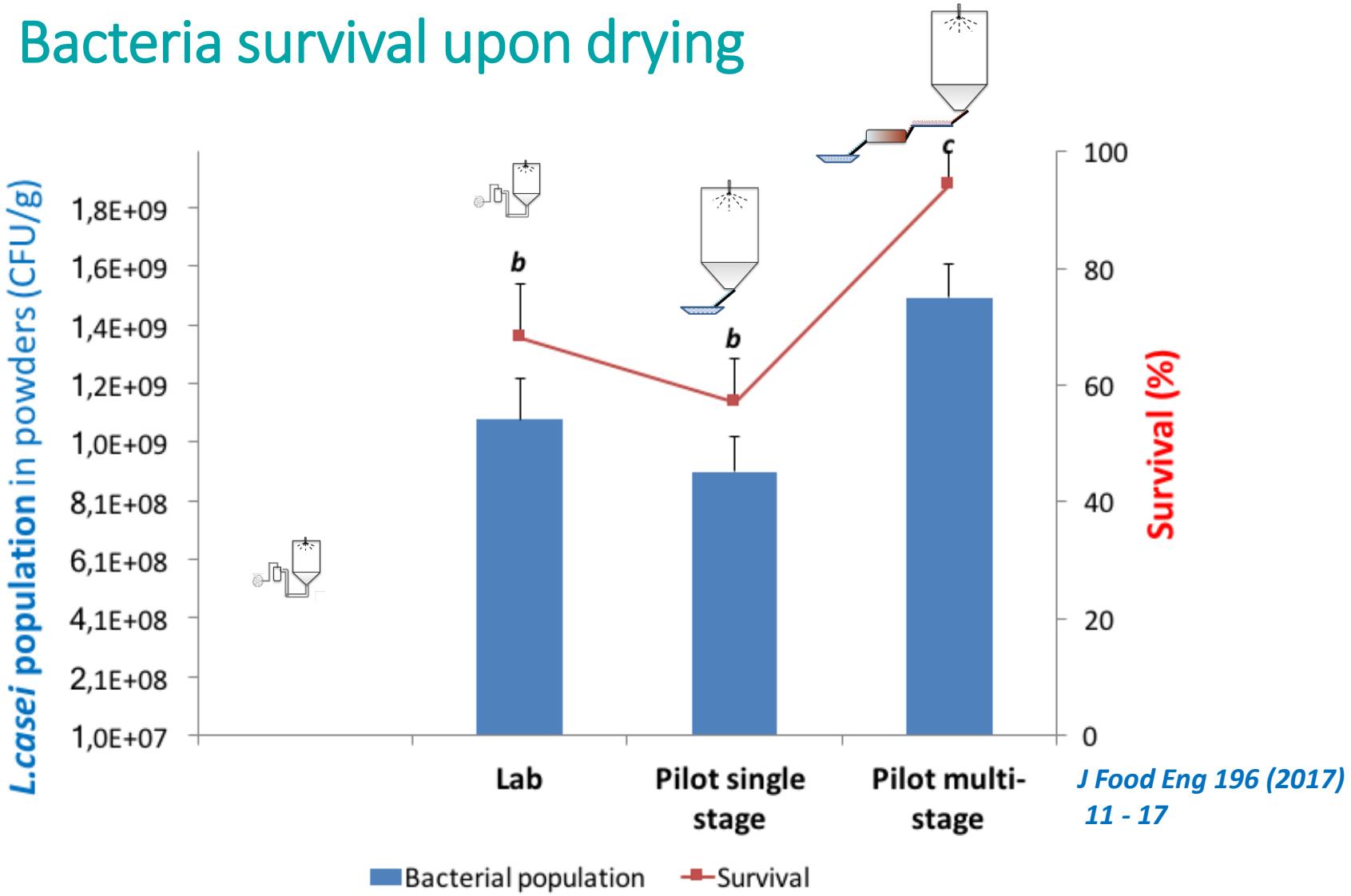
Bacteria survival upon drying



J Food Eng 196 (2017) 11 - 17

Acquired cross protection with multi stage scheme provides 100% survival
⇨ Patented process EP 15 306465.4 - 1357

3.

- ***Redesigning the process for the production of whey/permeate powders***

Current bottlenecks in whey/permeate powder production

Liquid whey or permeate

Concentration 6 > 60 % DM

Falling-film evaporators

Batch crystallization

Spray drying 60 > 97% DM

Multi stage dryer

Whey or permeate powder

SEC (kJ.kg^{-1} water)

418 kJ.kg^{-1} ← x 10 → **5256 kJ.kg^{-1}**

⍰ concentrate DM, but limiting viscosity / pumping and spraying

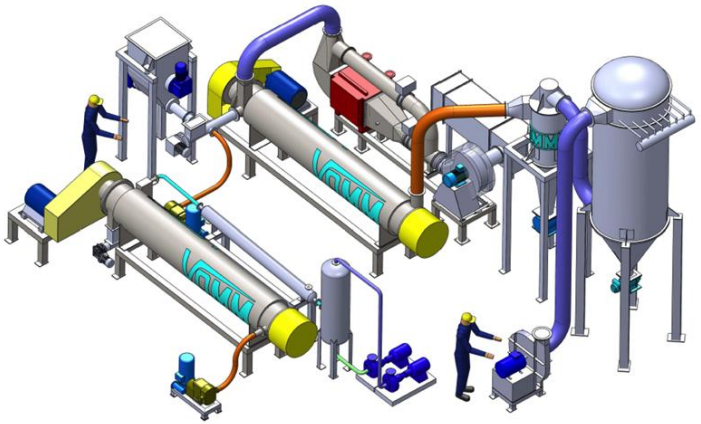
55% of the overall energy for less then 10% of the water removed

Innovative process based on thin-film rotary evaporator where viscosity is controlled by a vigorous mechanical treatment that maintains a fluid flowing state at high DM

Patented PST : a new process for whey/permeate powder

Liquid whey or permeate → **Concentration** 6 > 60 % DM → **Batch crystallization** → ~~Spray drying 95 – 97% DM~~

Falling-film evaporator



Super-concentration 60 > 80 % DM

2 Thin-film horizontal rotary evaporators

VOMM

Granulation

Final drying 88 > 97 % DM

Recirculation rate 1:1

Whey or permeate powder

Whey or permeate powder

Feasibility of PST process at pilot scale:

* Satisfactory properties of the resulting powder
* Energy savings estimation range from 10 to 30%
* Building savings estimated at 40%

Patent EP 15752957.9 - 1358 **(2015)**
Innov Food Sci Emerging Technol 41 **(2017)** 144 -149

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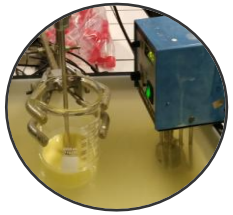
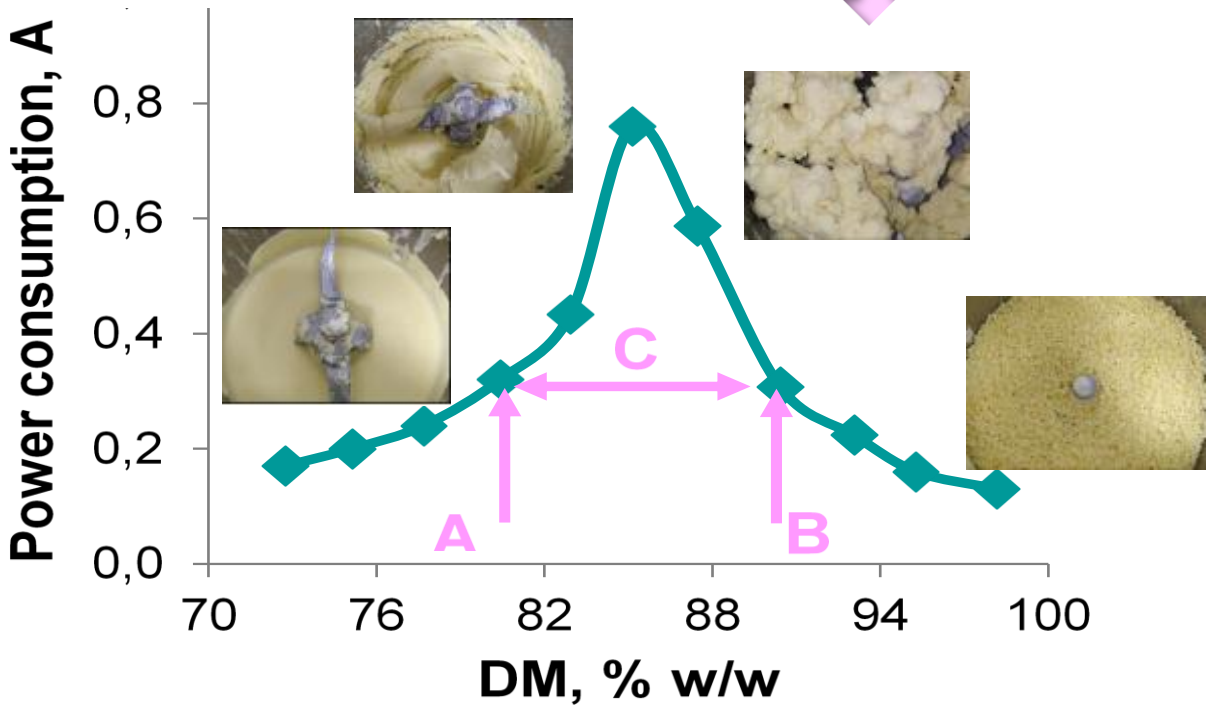
Limiting factors of superconcentration & granulation process

Development of a lab-scale model to mimic the PST process

0,1 µm MicroFiltration Permeate (MFP) at 30 % DM

Concentration 30 > 60 % DM → **Batch crystallization** → **Super-concentration** 60 > 80 % DM → **Granulation** → **Final drying** 88 to 97 % DM





A reliable protocol to identify,
*** crucial parameters of the superconcentration-granulation process**
*** the influence of composition on product-process interactions**

A:maximum surconcentration; B:minimum recirculation rate for granulation; C:Highly cohesive phase

Conclusion and perspectives

Take-home messages

- **Colloid properties conditions the skin formation and properties**
- **Tuning compatible solutes accumulation to enhance bacterial survival**
- **PST process control relies on cohesive phase understanding**

Extensive work on IMF formulation is needed in future

- **Process determines powder properties**
- **Conditions particle intrinsic features, then powder properties**
- **Enhances probiotics survival during drying and in the dry state**

Research strategy to overcome industry challenges

- **Address simultaneously hygienic / nutritional / environmental issues**
- **Identifying the mechanisms at small scale, scale up needed**
- **Multidisciplinary approach is mandatory: physics / biology / medical**

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THANK YOU FOR YOUR ATTENTION

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