



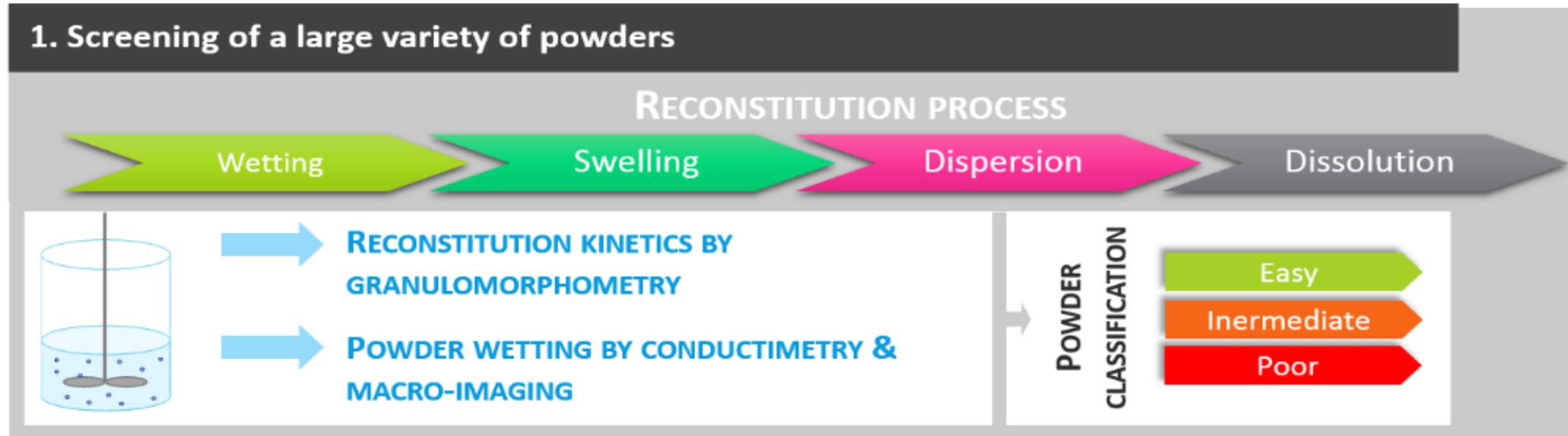
A MULTISCALE STUDY OF POWDER RECONSTITUTION

Claire GAIANI, Jennifer BURGAIN & Jeremy PETIT

Tristan FOURNAISE (PhD) & Arnaud PAUL (Post Doc)

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PLANNING OF PHD WORK AND ACHIEVED DELIVERABLES



Year 1 (January 2019 – January 2020)

- Powders classification according to their reconstitution behavior 
- First statistical correlations between the various powder characteristics and their reconstituability ranking 

PLANNING OF PHD WORK AND ACHIEVED DELIVERABLES

Year 1 (January 2019 – January 2020): Take-home message

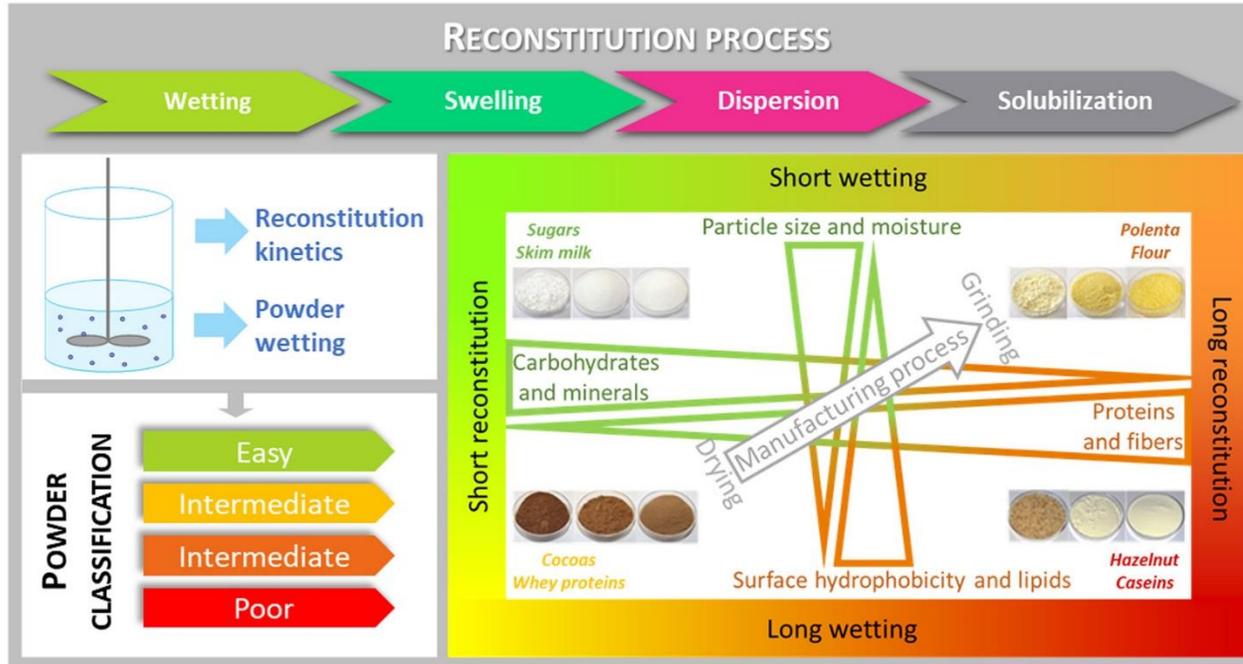
Physicochemical characteristics of powders were correlated with the wetting and reconstitution times of 36 food powders by principal component analysis (PCA). Four powder categories were identified based on wetting and reconstitution times.

Green group: short wetting and reconstitution times.

Yellow group: long wetting time and short reconstitution time.

Orange group: short wetting time and long reconstitution time.

Red group: long wetting and reconstitution times.



Powder classification according to their reconstitution behavior :

- **Long reconstitution times** are linked to the powder manufacturing process (powders obtained by milling of solid materials led to poorer reconstitution behavior than spray-dried powders), low sugar and high protein contents in the powder bulk.

- **Long wetting times** are associated to high particle surface hydrophobicity, small median particle size, as well as high fat contents in the powder bulk.

PLANNING OF PHD WORK AND ACHIEVED DELIVERABLES

Year 1 (January 2019 – January 2020): Take-home message

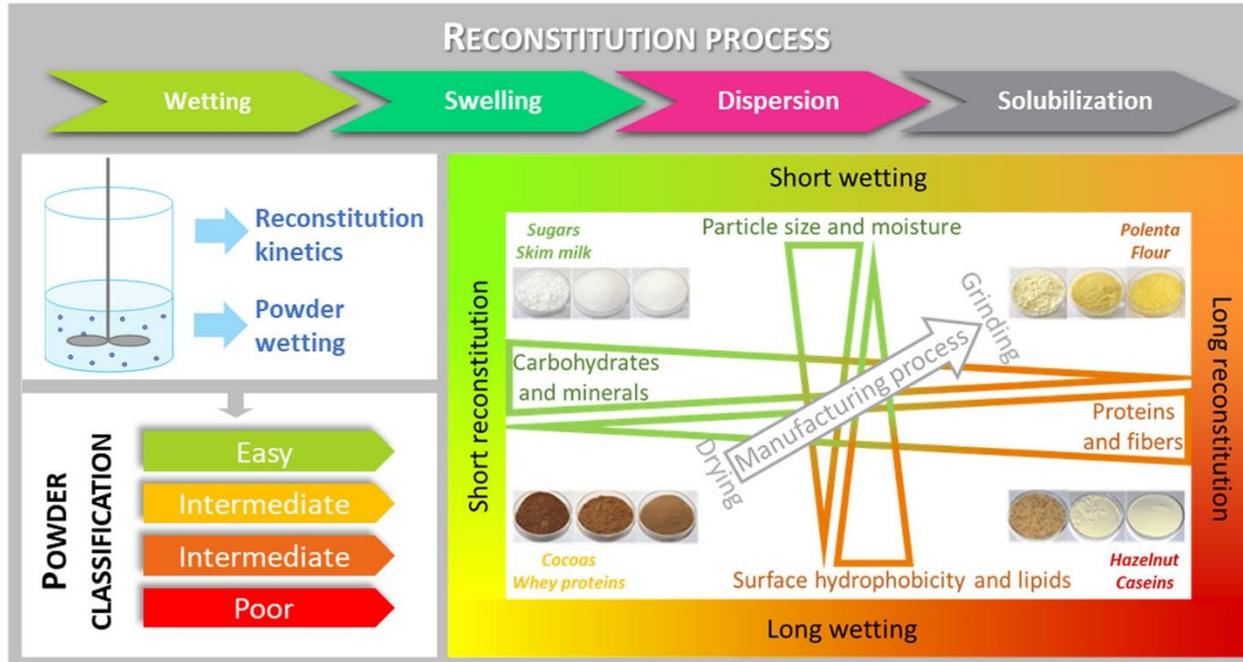
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Powder Technology

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Main powder physicochemical characteristics influencing their reconstitution behavior

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PLANNING OF PHD WORK AND ACHIEVED DELIVERABLES

2. Surface composition (micro & molecular scale)

Selection of representative powders from each class of reconstitutability

SUGAR COATING

SURFACE MAPPING

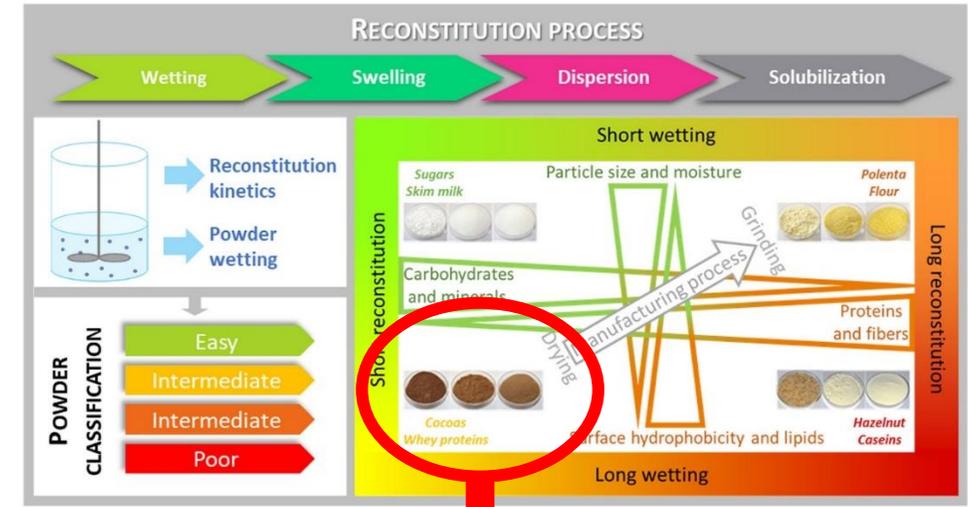
Atomic force microscopy (AFM):
topography, chemical forces, nanoindentation

SURFACE COMPOSITION

X-ray photoelectron spectroscopy (XPS):
surface elemental composition

POWDER CLASSIFICATION

- Easy
- Intermediate
- Intermediate
- Poor



Focus on powders of poor wettability and easy reconstituability (whey protein powder)

Year 2 (January 2020 – January 2021)

- Surface modifiers impact (covered surface fraction, distribution at the particle surface, minimal quantity necessary to improve wetting, etc.)
 - Surface chemical mapping and nanoindentation to establish correlations with powder wettability
- Year 4 (work of Arnaud Paul)

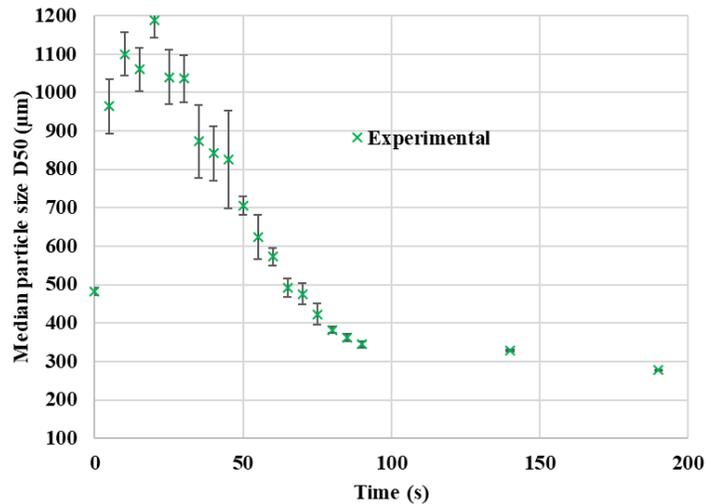


PLANNING OF PHD WORK AND ACHIEVED DELIVERABLES

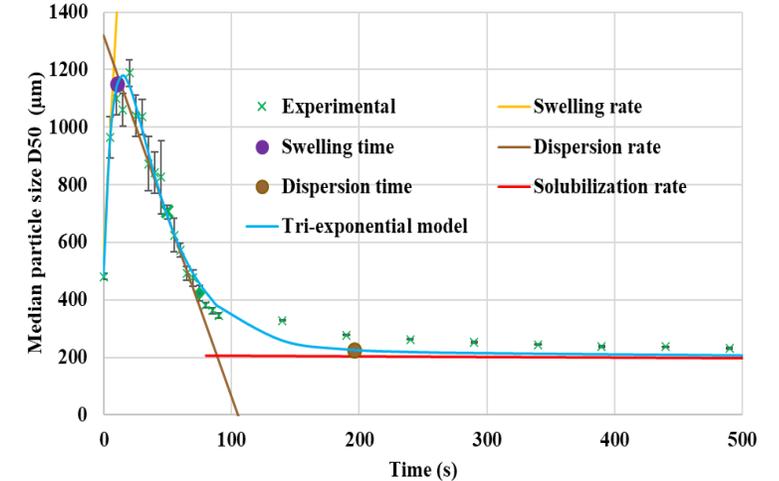
Year 3 (January 2021 – January 2022)

3. Development of descriptive and predictive models for the reconstitution of powders

- Fitting of reconstitution kinetics followed by granulometry 



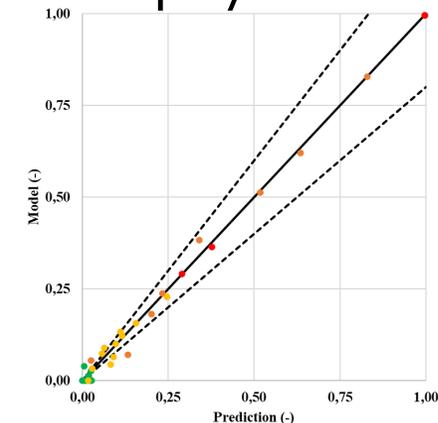
Semi-empirical approach



- Empirical models able to predict reconstitution times from powder physicochemical characteristics 

- Physicochemical properties of powders
- Reconstitution time obtained by conductimetry (year 1)

Empirical approach



PLANNING OF PHD WORK AND ACHIEVED DELIVERABLES

Year 3 (January 2021 – January 2022): Take-home message

Chemical Engineering Science 252 (2022) 117440



Contents lists available at [ScienceDirect](#)

Chemical Engineering Science

journal homepage: www.elsevier.com/locate/ces



Descriptive modelling of food powders reconstitution kinetics followed by laser granulometry



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^b Institut Universitaire de France (IUF), France

A B S T R A C T

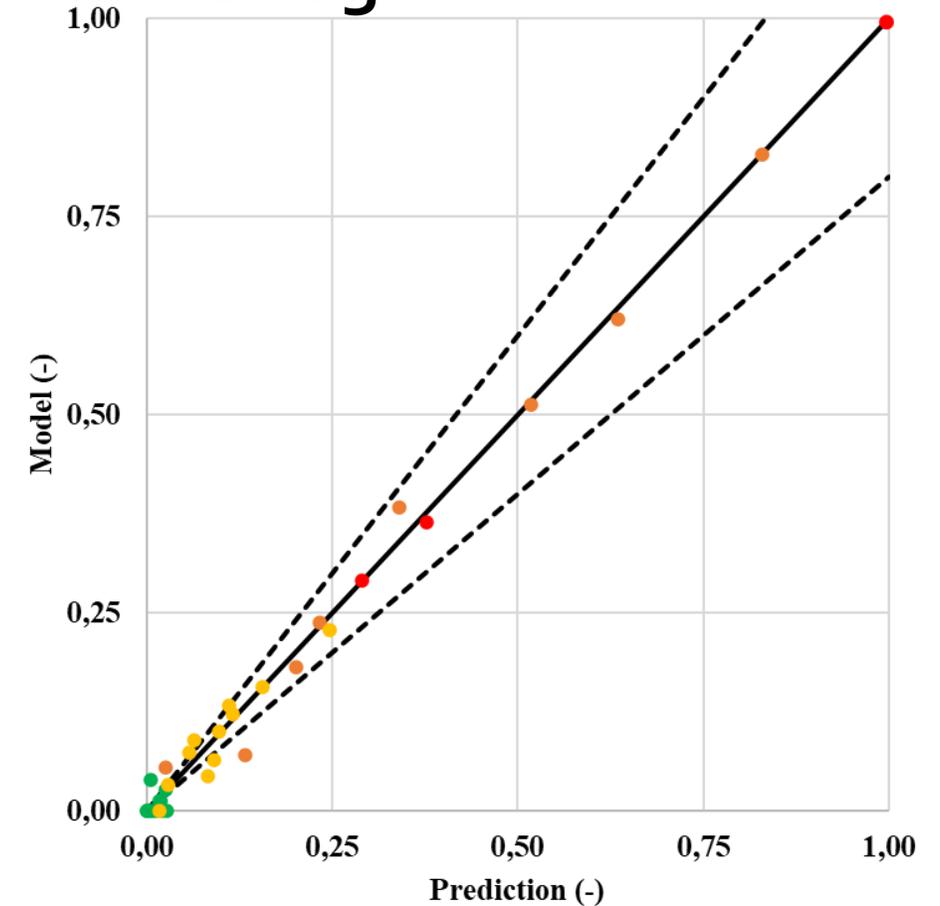
Reconstitution kinetics of various food powders in fixed mixing conditions were followed by laser granulometry. Obtained reconstitution profiles were fitted using a sum of first-order indicial responses. This descriptive modelling approach allowed linking each of the main reconstitution steps (swelling, dispersion, and solubilization) to a single first-order indicial response and characterizing their kinetics. Initial, maximal, and final median particle sizes; swelling, dispersion, and solubilization durations and rates; as well as an overall reconstitution time, were calculated from model parameters. This descriptive modelling approach was not successful for instant powders or powders composed of several major components having well different kinetics for the same reconstitution steps. The durations and rates of reconstitution steps were correlated with physicochemical properties of investigated powders in order to evidence the most influencing properties on food powders reconstitution: contents in lipids, sugars, fibers, and water, surface hydrophobicity, and mostly median particle size at dry state.

- Development of a descriptive modelling approach for the reconstitution kinetics followed by granulometry: from swelling to solubilization steps using a single equation
- Identification of swelling, dispersion and solubilization durations, as well as rates for each reconstitution step
- Identification of the impact of the main physicochemical parameters of powders on each reconstitution step

PLANNING OF PHD WORK AND ACHIEVED DELIVERABLES

Year 3 (January 2021 – January 2022): Take-home message

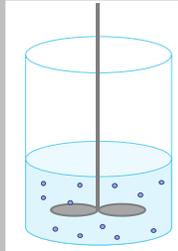
- The best predictive modelling approach developed for the reconstitution time, using a set of normalized powder physicochemical properties and a hybrid model mixing power and exponential laws was satisfactory for short, intermediate, and long reconstitution times, but the prediction failed for powders with very short reconstitution times (less than 5 min).
- The limitations of this kind of empirical models seem to have been reached.



$$t_{reconstitution} = 0.97 \times Proteins^{0.60} \times Lipids^{0.40} \times e^{Carbohydrates \times -7.48} \times e^{Sugars \times -13.11} \\ \times Fibers^{0.11} \times e^{Minerals \times -28.87} \times a_w^{2.56} \times e^{H_2O \% \times 5.79} \times e^{C/O \times -5.79} e^{C-C/C-other \times -5.28} \times D50^{0.32} \\ \times e^{span \times -3.11} \times e^{Aerated density \times 4.34} \times Sphericity^{2.72} \times Convexity^{-2.19} \times Aspect ratio^{-0.59}, R^2 = 0.99$$

1. Screening of a large variety of powders

RECONSTITUTION PROCESS



RECONSTITUTION KINETICS BY GRANULOMORPHOMETRY

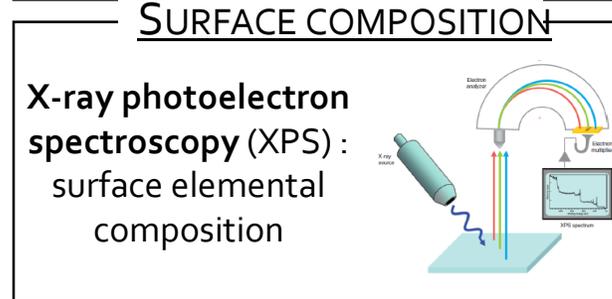
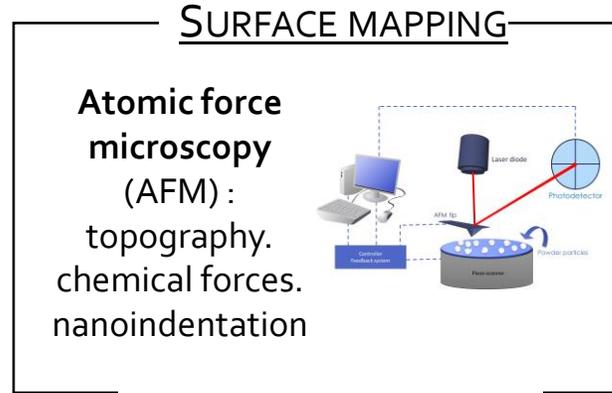
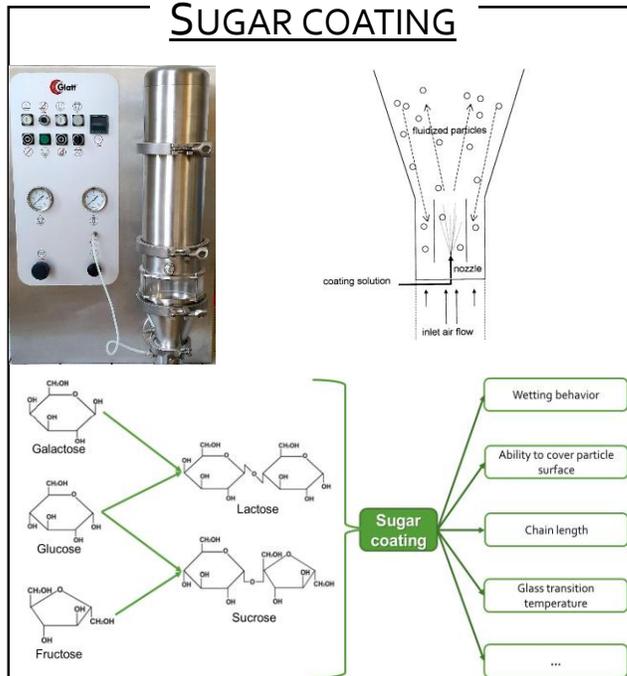
POWDER RECONSTITUTION STEPS BY CONDUCTIMETRY & MACRO-IMAGING

POWDER CLASSIFICATION



2. Surface composition (micro- & molecular scale)

Selection of representative powders from each class of reconstitutability



MOLECULES PARTICLES POWDERS

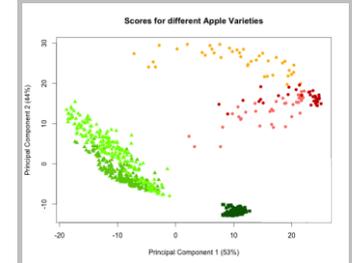
Nano-Micro-Macro

MULTISCALE STUDY

Semi-empirical model



Experimental data from years 1 & 2



3. Development of a reconstitutability index, in order to predict reconstitution times

NEXT STEPS IN YEAR 4

Year 4 (January 2022 – January 2023)

Tristan FOURNAISE PhD defense (July 4th, 2022)

Jury members:

- Marco RAMAIOLI: INRAE, University of Paris-Saclay
- Guillaume DELAPLACE: INRAE, University of Lille
- Jennifer BURGAIN: University of Lorraine
- Julien DUPAS: Nestlé (IFPRI)



Thèse

Présentée et soutenue publiquement pour l'obtention du
titre de DOCTEUR DE L'UNIVERSITÉ DE LORRAINE

Mention : Procédés Biotechnologiques et Alimentaires

Par Tristan FOURNAISE

Sous la direction de Pr. Claire GAIANI

et Dr. Jérémy PETIT

Étude multiéchelle des phénomènes de reconstitution
de poudres issues d'agroressources

Multi-scale study of the phenomena of reconstitution
of powders from agroressources

Date de soutenance : 04/07/2022

Membres du jury :

Directrice de thèse :	Pr. Claire GAIANI	Université de Lorraine, Nancy
Co-directeur de thèse :	Dr. Jérémy PETIT	Université de Lorraine, Nancy
Président du jury :		
Rapporteurs :	Dr. Marco RAMAIOLI	INRAE, Université de Paris-Saclay
	Dr. Guillaume DELAPLACE	INRAE, Université de Lille
Examineurs :	Dr. Jennifer BURGAIN	Université de Lorraine, Nancy
	Dr. Julien DUPAS	Nestlé, Lausanne

Arnaud PAUL (year 4)

Supervision: Jeremy PETIT, Jennifer BURGAIN, Claire GAIANI



PhD, focused on food biochemistry

Bachelor / Master degree (2009 - 2014) :
Biochemistry and molecular biology

PhD (2014 - 2018) :

Biochemistry, molecular biology, cellular biology

Postdoc experiences (2018 - 2022) :

Food science, milk powder, food biochemistry

THANK YOU FOR YOUR ATTENTION !

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