IFPRI International Fine Particle Research Institute — LIBio Laboratoire d'Ingénierie des Biomolécules — Université de Lorraine — SIReNa

A multiscale study of powder reconstitution phenomena

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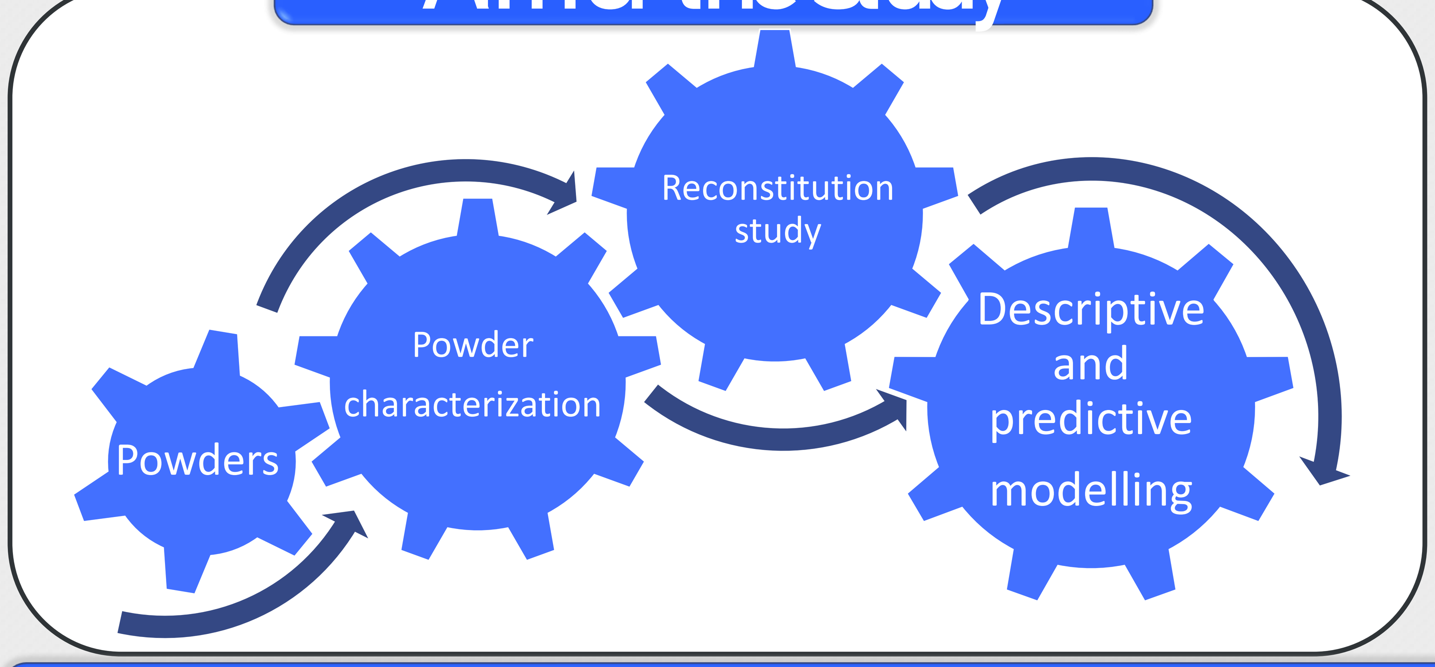
Aim of the study



Introduction

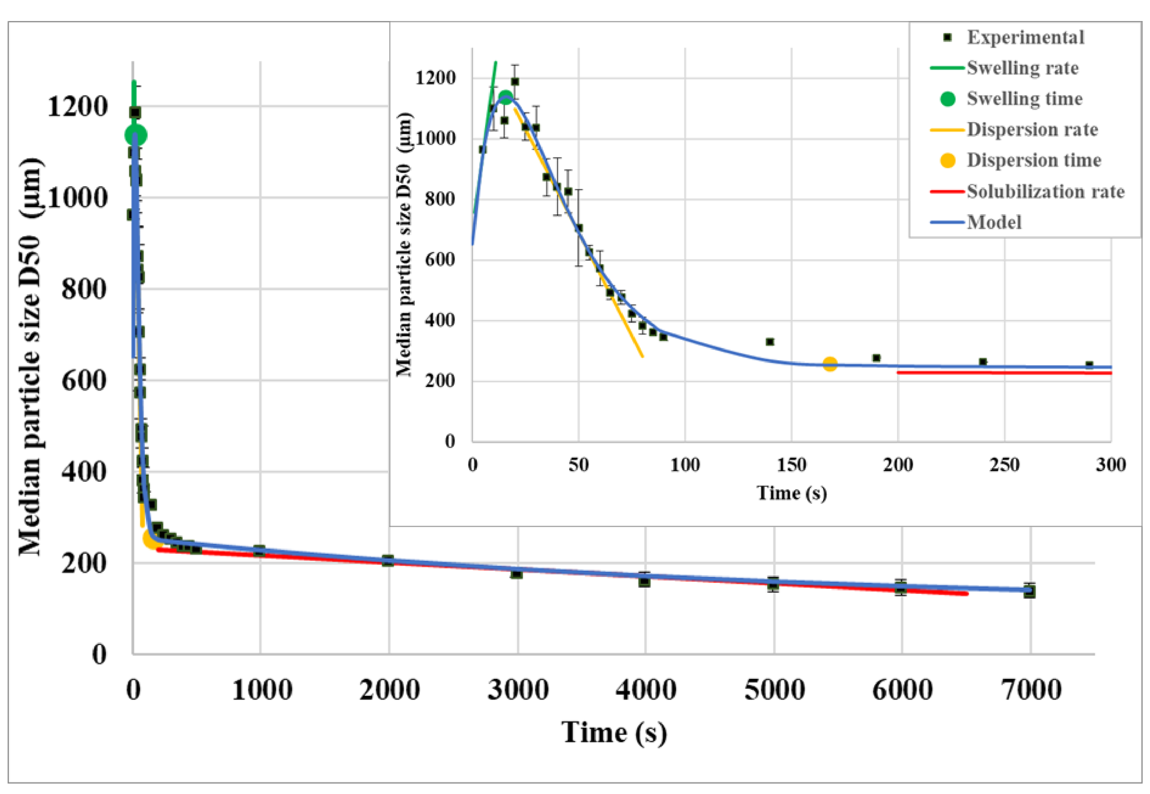
The reconstitution properties of powders depend on the raw material and the production process, as they influence the structure and composition of powder surface, the particle size distribution, etc. In order to determine the impact of these factors on powder reconstitution, a multitude of analytical characterizations is necessary to enable semi-empirical modelling of the reconstitution phenomena and the prediction of reconstitution times in agitated vessels.

The third part of the PhD work consisted in the descriptive modelling of reconstitution profiles of a large variety of food powders and the predictive modelling of reconstitution times from powder physicochemical characteristics.

Descriptive modelling of reconstitution kinetics

This semi-empirical model, allowing the description of the kinetics of reconstitution followed by laser granulometry, consisted in representing the evolution of the median particle size during the main stages of reconstitution (from swelling to solubilization) in the form of first-order indicial responses, which made it possible to access kinetic information about each reconstitution step.

Example of instant mashed potatoes



- $t_{swelling} = 10.7\ s;$
- $t_{dispersion} = 196.1\ s;$
- $t_{reconstitution} = 1\ 177.7\ s;$
- 82.47 µm.s^{-1} swelling rate;
- -12.58 µm.s^{-1} dispersion rate;
- -0.021 µm.s^{-1} solubilization rate.

A_0 = 481.67 µm; A_1 = 1 669.67 µm; A_2 = 116.35 µm; τ_0 = 8.89 s; τ_1 = 35.71 s; τ_2 = 2 771.89 s; R^2 = 0.98.

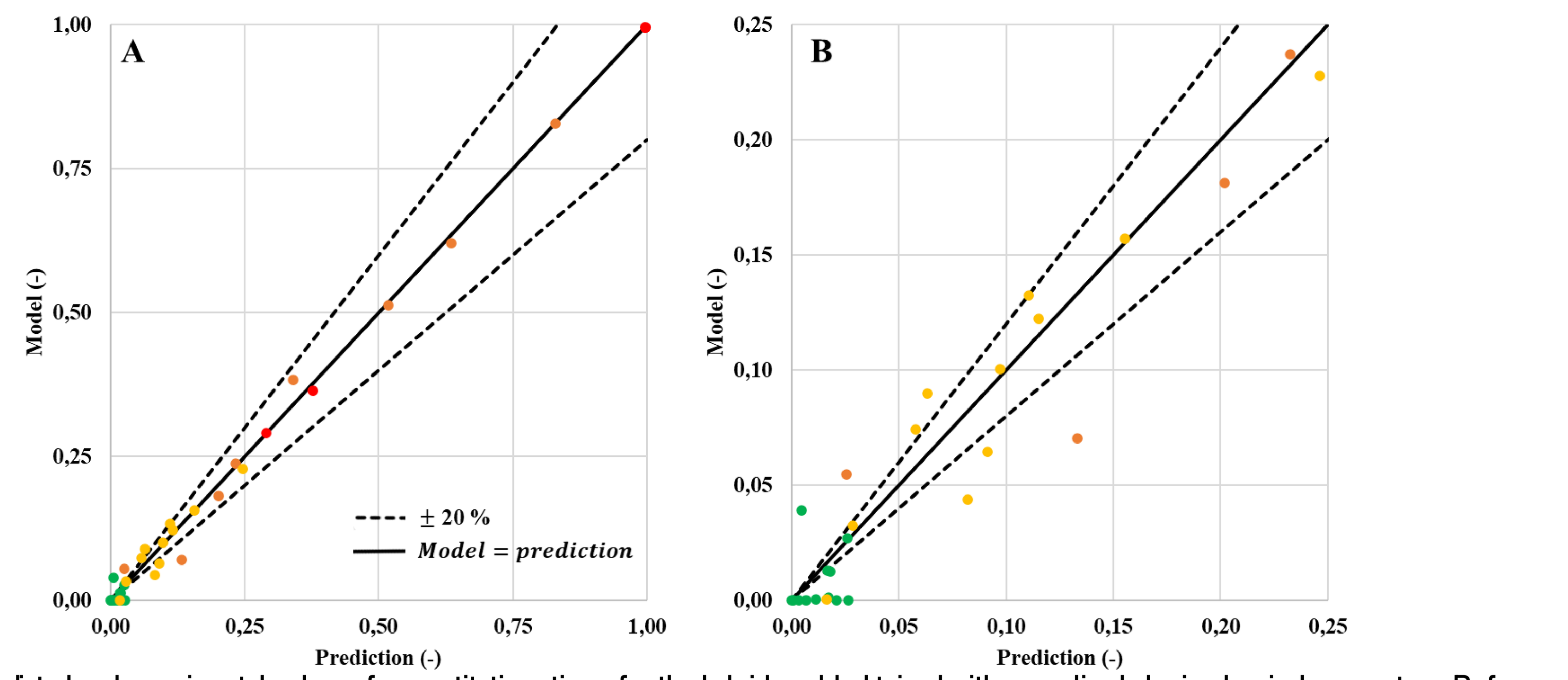
Dry particle size — Swelling — Dispersion — Solubilization

$$D50(t) = D50_0 + A_0\left(1 - e^{\frac{-t}{\tau_0}}\right) - A_1\left(1 - e^{\frac{-t}{\tau_1}}\right) - A_2\left(1 - e^{\frac{-t}{\tau_2}}\right)$$

The obtained semi-empirical descriptive model made it possible, using statistical methods (Pearson coefficients), to identify the impact of the physicochemical parameters of eight powders (the kinetics obtained for the other powders could not be modeled given their instantaneity or complexity) on the durations and rates of the various stages of reconstitution.

Predictive modelling of reconstitution times

This model, aiming at predicting, from the most influential physicochemical properties, the reconstitution time of the powders under the reference mixing conditions used in the first part of the PhD work was developed using empirical models of classical form (multilinear regression, monomial model) or improvements to these models based on normalized values of physicochemical properties. A hybrid model combining power and exponential laws was the best predictive model.



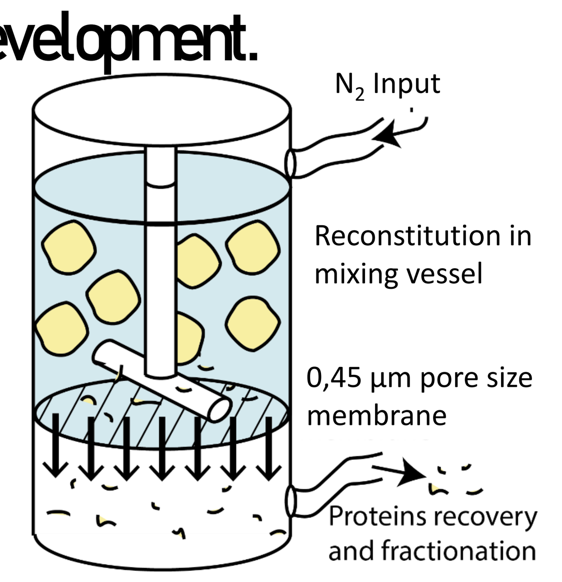
A- comparison of predicted and experimental values of reconstitutions times for the hybrid model obtained with normalized physicochemical parameters. B- focus on normalized reconstitution times between 0 and 25 %. Color corresponds to the powder classification deduced from year 1: green, good (short wetting and short reconstitution), yellow: decent (long wetting and short reconstitution), orange: mediocre (short wetting and long reconstitution), and red: poor (long wetting and long reconstitution).

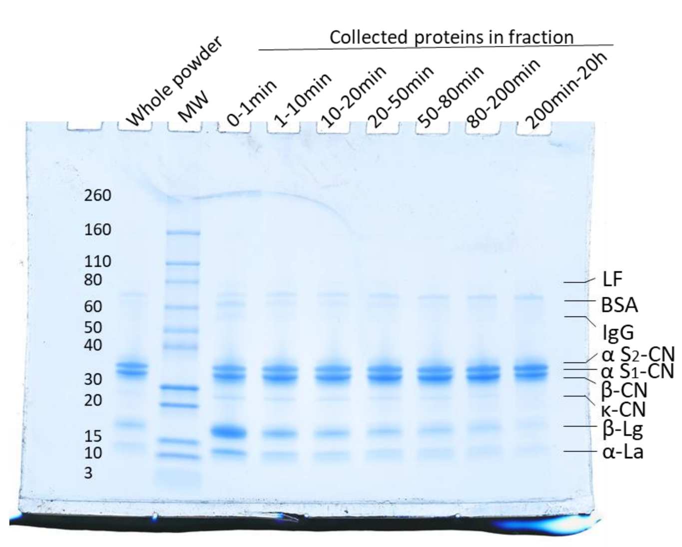
$$t_{reconstitution} = 0.97 \times Proteins^{0.60} \times Lipids^{0.40} \times e^{Carbohydrates \times -7.48} \times e^{Sugars \times -13.11} \times Fibers^{0.11} \times e^{Minerals \times -28.87} \times a_w^{2.56} \times e^{H_2O\ \% \times 5.79} \times e^{C/O \times -5.79} e^{C-C/C-other \times -5.28}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

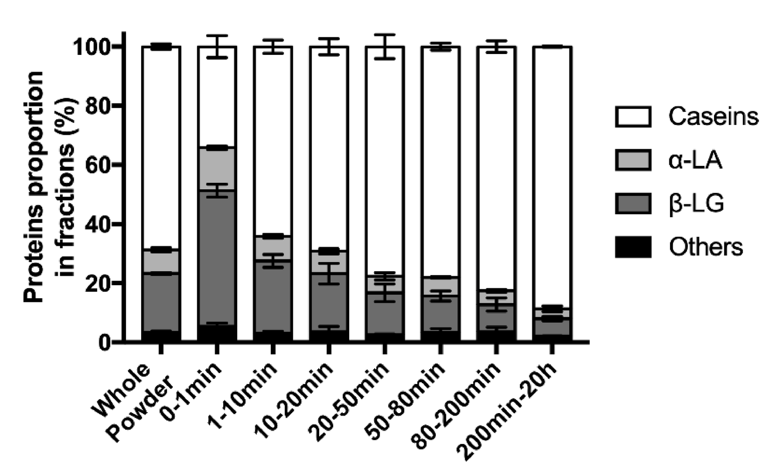
The predictions of reconstitution time remained underestimated for most powders of the green group (good wettability and reconstitutability), which highlighted that some physicochemical parameters that are very influent on reconstitution time may be missing. Moreover, investigated powders did not permit to have sufficiently intermediate values of predictors (such as carbohydrates, sugars, and minerals contents), impairing the ability of models to correctly evaluate their individual influence.

Method development: reconstitution of powder components from surface to bulk

A method to fractionate dairy powder proteins, depending of their location within particles (either at particle surface or in the particle core) was developed during powder reconstitution. This fractionation method is based on the passage through a 0.45 µm pore size membrane of components released during powder reconstitution. Dairy proteins were then identified by SDS-PAGE. Presented results correspond to a milk protein powder taken as reference for method development.







- Isolation, detection and quantification of molecules depending on their location within particles
- Prediction tool for powder reconstituability

Conclusion

Reconstitution descriptive and predictive modelling :

- A semi-empirical model allowing the description of the kinetics of reconstitution followed by laser granulometry was developed. The impact of powder physicochemical parameters on the durations and rates of the various stages of reconstitution were identified. Published in Chemical Engineering Science https://doi.org/10.1016/j.ces.2022.117440.
- A predictive model was developed, the predictions were satisfactory except for short reconstitution times (under 5 min). All the results will be made available to all IFPRI members promptly.

Perspectives

4th year by Arnaud Paul (post-doc – LIBio) :

A method developed for dairy powders will be used to follow components solubilization during powder reconstitution. Powders from "year one" will be tested with this method to screen components location from surface to bulk.