



Coupling phenomenological model of expansion with mechanical model of starchy products extrusion (Projet AIC 'QualExp' 2013-2015)

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Coupling **phenomenological model** of **expansion** with **mechanical model** of starchy products **extrusion**: AIC-QualExp (2013-2015)

Magdalena KRISTIAWAN (BIA-MC2)

Problème d'application INCOM : **Couplage/Réduction de modèles**

Partners

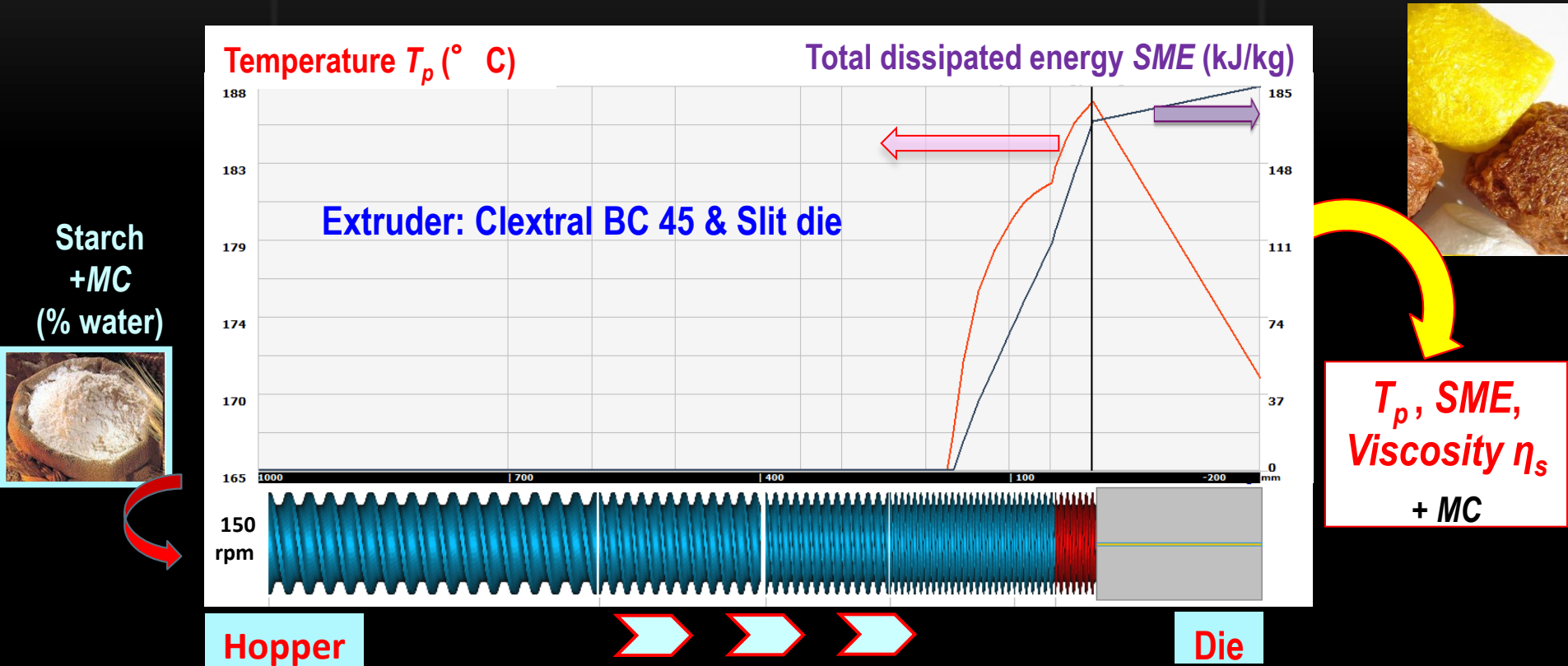
- INRA: M. Kristiawan, K. Kansou, G. Della Valle (BIA); A. Ndiaye (I2M)
- CEMEF: B. Vergnes
- SCC: C. David

Examples of application

- **Innovative starchy foods**, with modulated shape and digestibility
- Starch based **shape memory biopolymers** for medical devices

Coupling between expansion and 1D mechanical **Ludovic®** models

(Logiciel d'Utilisation de **DOubleVis**
Corotatives)

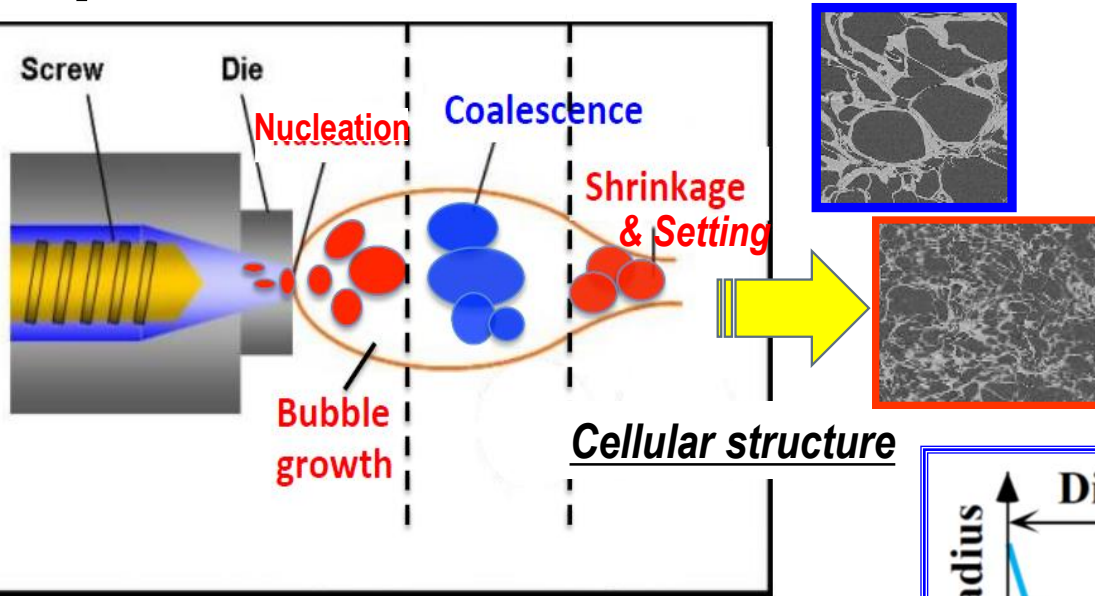


« Ludovic®'s output variables at die exit = input of expansion model »

« New Ludovic outputs = macro & cellular structure of foams »

Context : Expansion by extrusion

Acquisition of texture



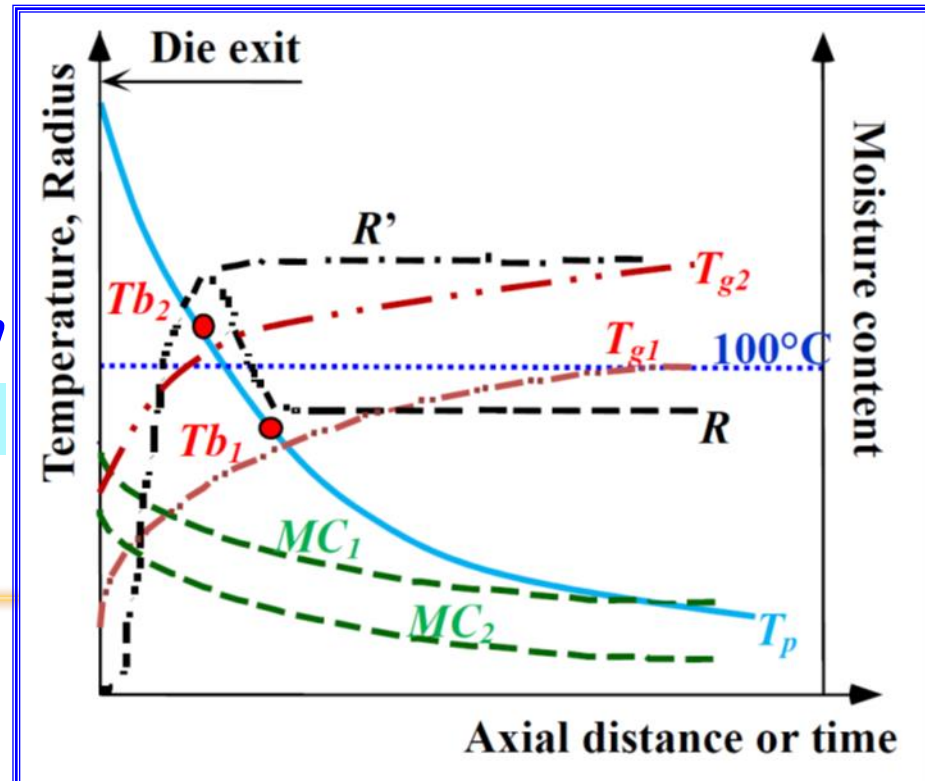
Deterministic models:

- Unsatisfactory
- Complex $\leftrightarrow$ Ludovic®

State diagram

The bubble growth stops at $T_p \geq T_g + 30^\circ \text{C}$

MC = product water content
 T_g = glass transition temperature
 T_p = product temperature
 R = bubble radius



Methods and Resources

Phenomenological modeling of **bubble growth** in a **viscoelastic** biopolymer matrix **in the transition state from rubbery to solid phase**.

Macro & micro structure = f (Water%, T_p , C , SME kWh/t, shear & elongational viscosities)

Approach

- 1) Validation of Ludovic[®] extrusion simulation for starchy products
➤ Ludovic[®]'s **output variables** at die exit = input of expansion model
- 2) Collection & Representation of knowledge (scientific)
➤ *Concept map*
- 3) Establishment of phenomenological models of expansion
➤ **Model validation on more complex starchy products**
- 4) Relation between anisotropy and cellular structure (fineness)
- ← 5) **Coupling between expansion & Ludovic[®] models: INRA & SCC**

Ongoing Achieved

Output variables

- Macrostructure (360 data, maize starches)

Volumetric Expansion Index (VEI)

$$VEI \approx \frac{\text{melt density}}{\text{foam density}}$$

Radial Expansion Index (SEI)

$$SEI = \frac{\text{foam cross section}}{\text{die cross section}}$$

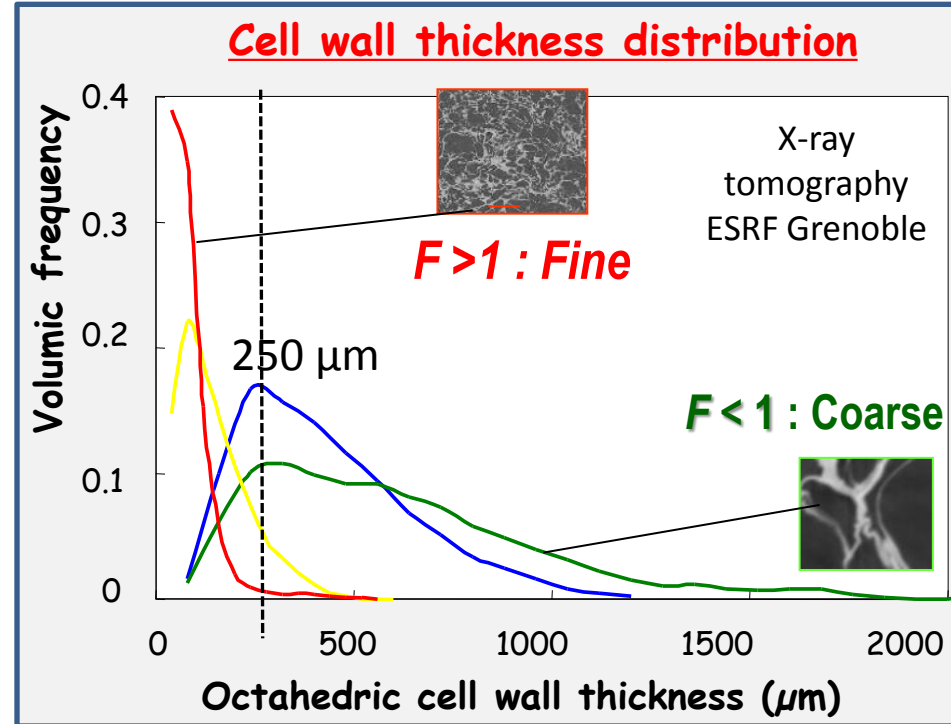
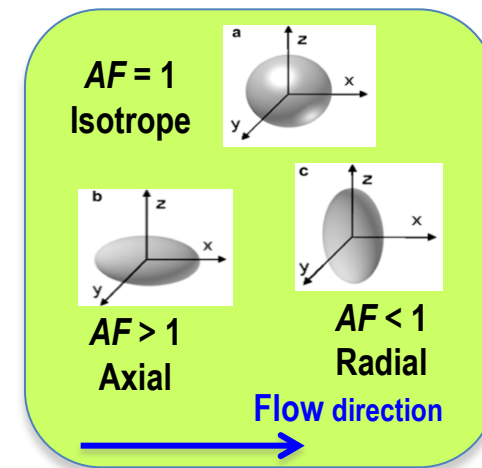
Anisotropy Factor (AF)

$$AF = \frac{VEI}{SEI^{3/2}}$$

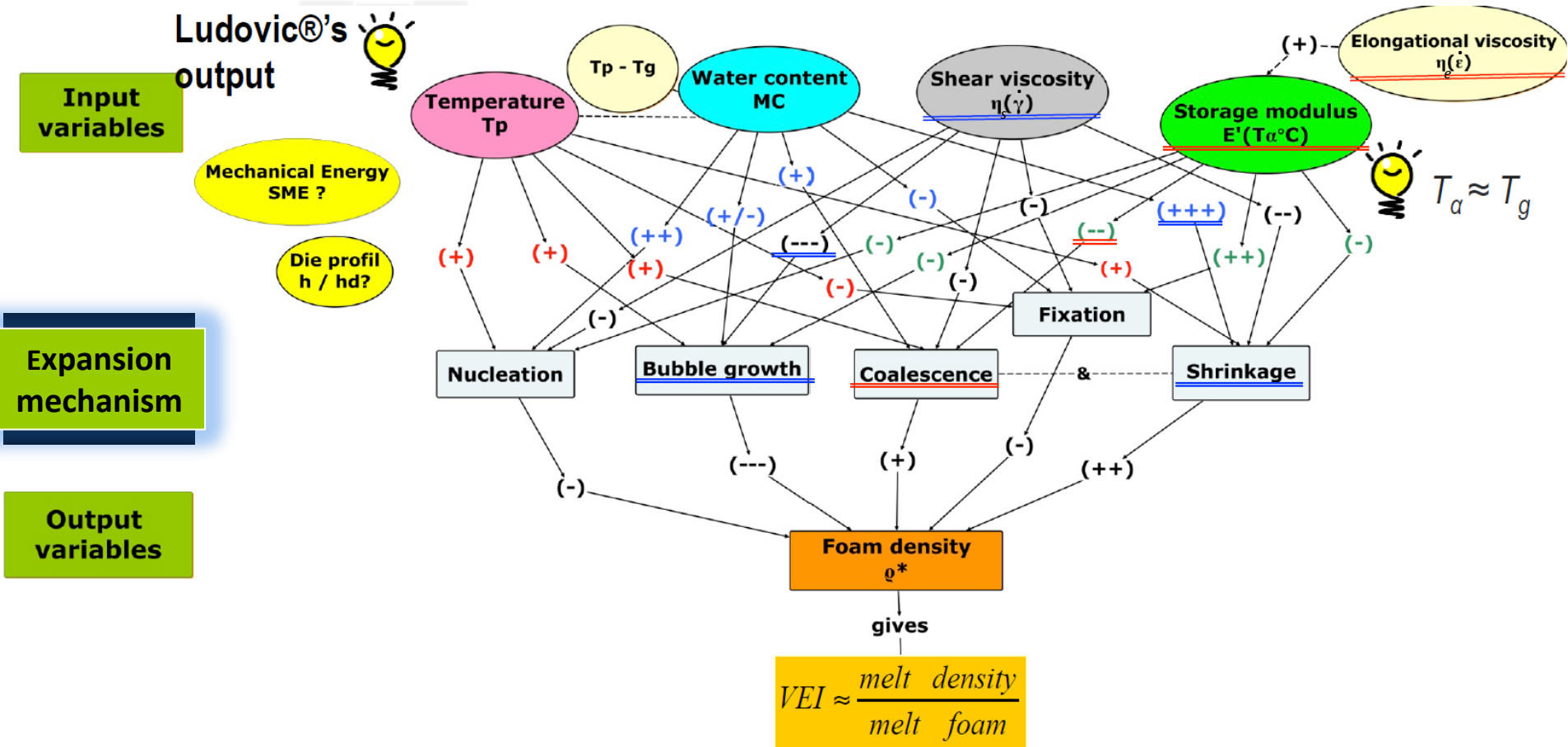
- Microstructure: Cellular Fineness (F)

$$F = \sqrt{\frac{\frac{\pi 250}{C} \frac{\sigma^2}{\delta} + \frac{\pi 1}{C} \frac{\sigma^2}{\delta}}{2}}$$

MCS = Mean cell size (mm)
MWT = Mean wall thickness (μm)



Concept map: Phenomenological model of expansion



$$VEI \approx [MC]^x \otimes [T_p]^y \otimes [\eta(\dot{\gamma})]^z \otimes [E'(T_g)]^t$$

General expansion model: $SEI = \alpha. (\eta/\eta_0)^n$

$E' = \text{storage modulus}$

$$a = b_0 (MC / MC_0)^{b_1} (Tp / Tp_0)^{b_2} (SME / SME_0)^{b_3} (E' / E'_0)^{b_4} (h / h_d)^{b_5}$$

$$n = b_6 + (MC / MC_0)^{b_7} + (Tp / Tp_0)^{b_8} + (SME / SME_0)^{b_9} + (E' / E'_0)^{b_{10}} + (h / h_d)^{b_{11}}$$

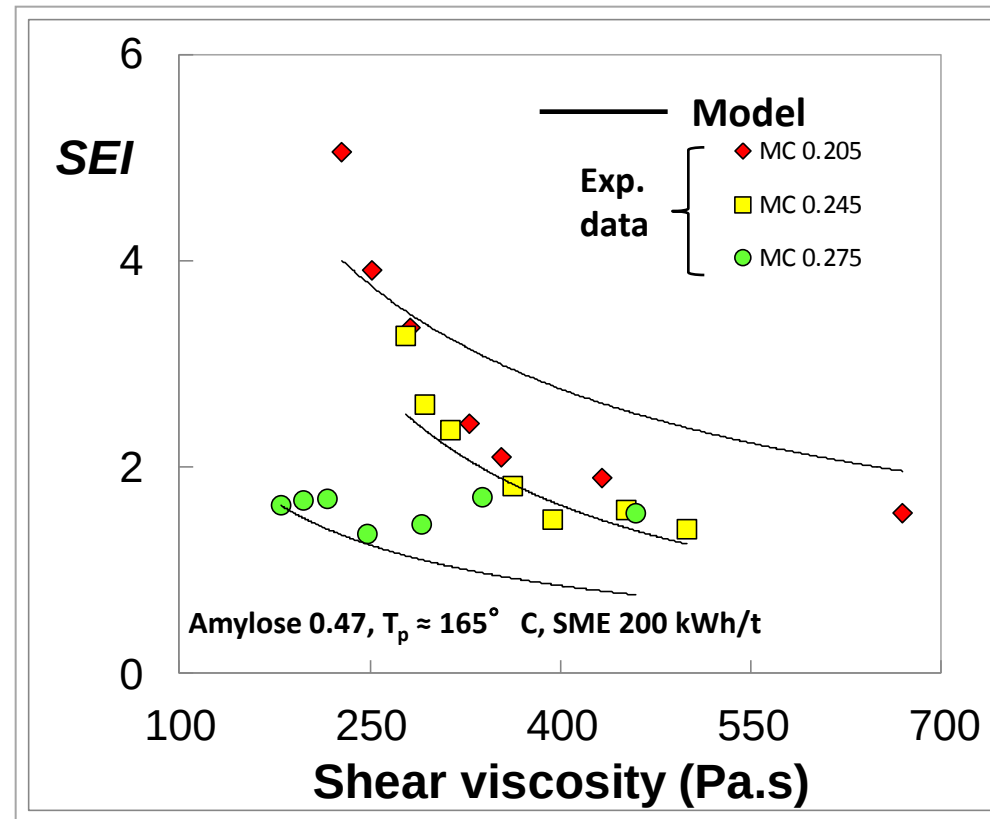
$R^2 \text{ adj} = R^2 = 0.78; ddf = 348$

Significativity of model parameters

a	b_0	constant	
	b_1	MC water	---
	b_2	$T_p \text{ } ^\circ \text{C}$	-
	b_3	SME	-
	b_4	$E'(T_g)$	++
	b_5	h/h_d	+
n	b_6	constant	
	b_7	MC water	-
	b_8	$T_p \text{ } ^\circ \text{C}$	-
	b_9	SME	n.s.
	b_{10}	$E'(T_g)$	n.s.
	b_{11}	h/h_d	n.s.

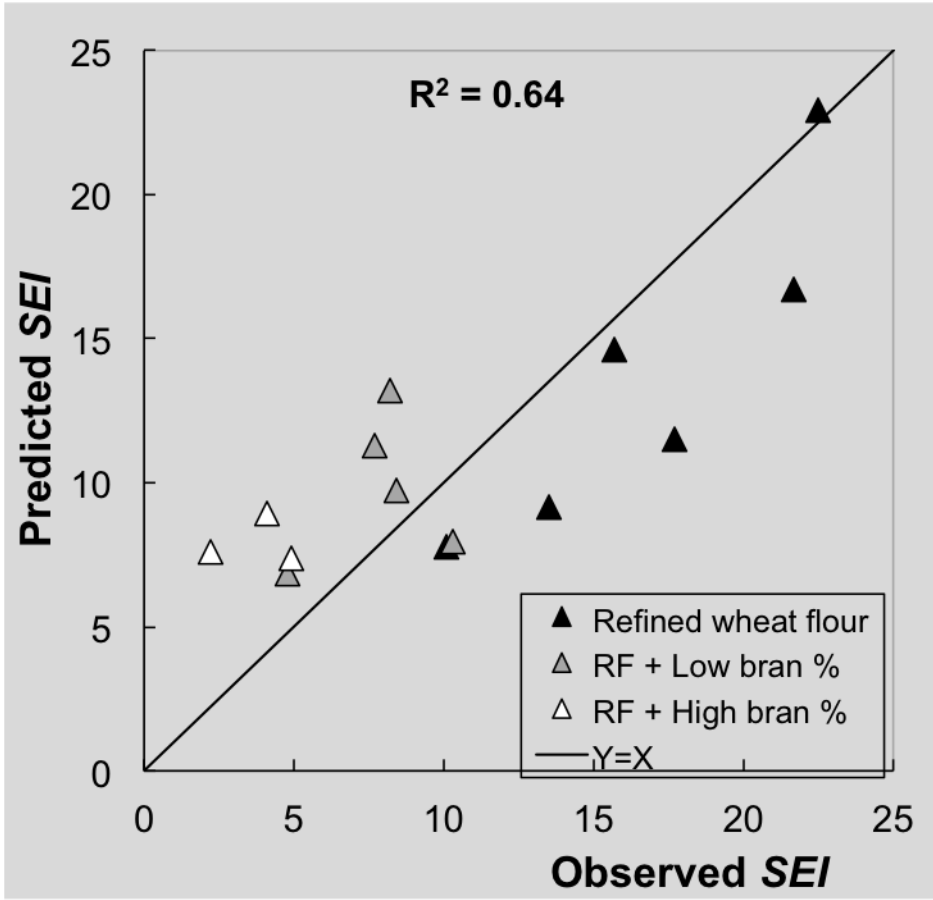
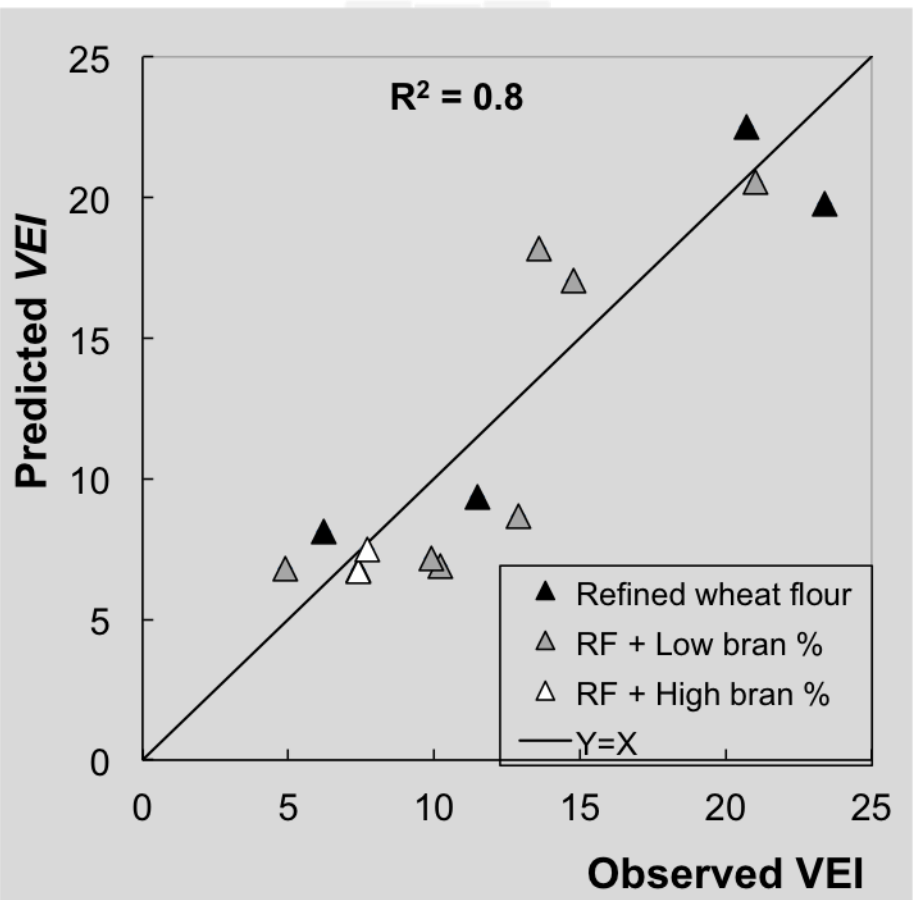
--- or +++ = most significant

Computing the effect of
water content on SEI



Model validation

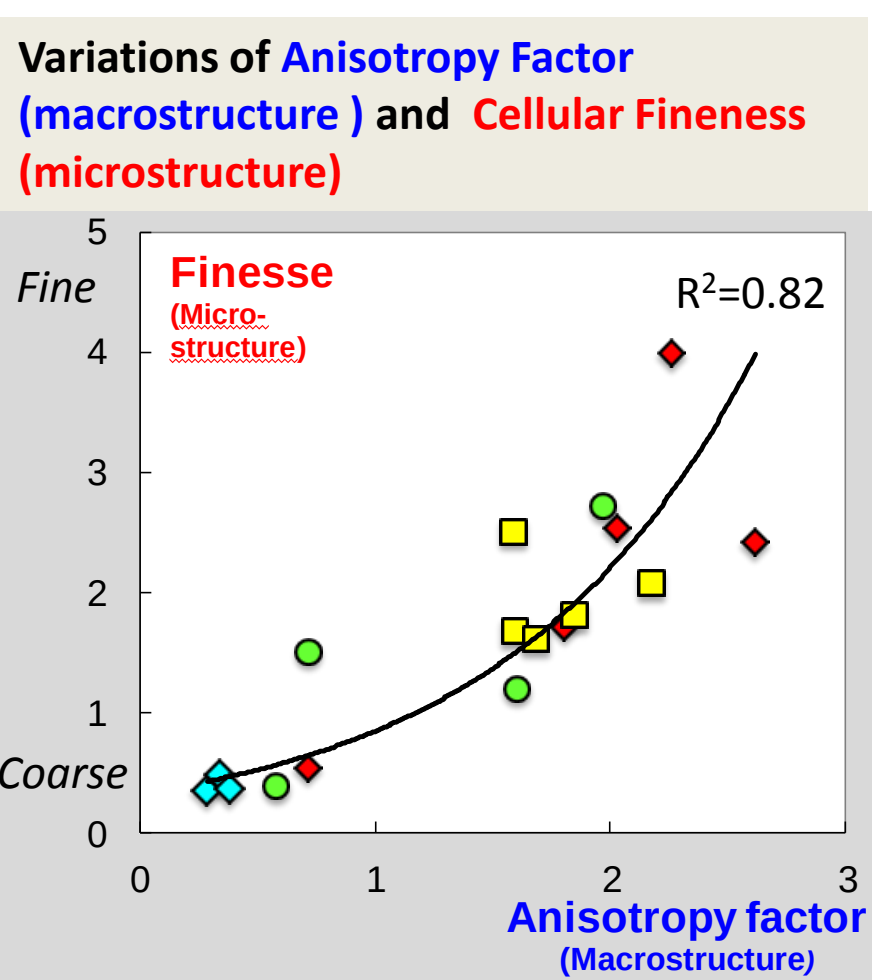
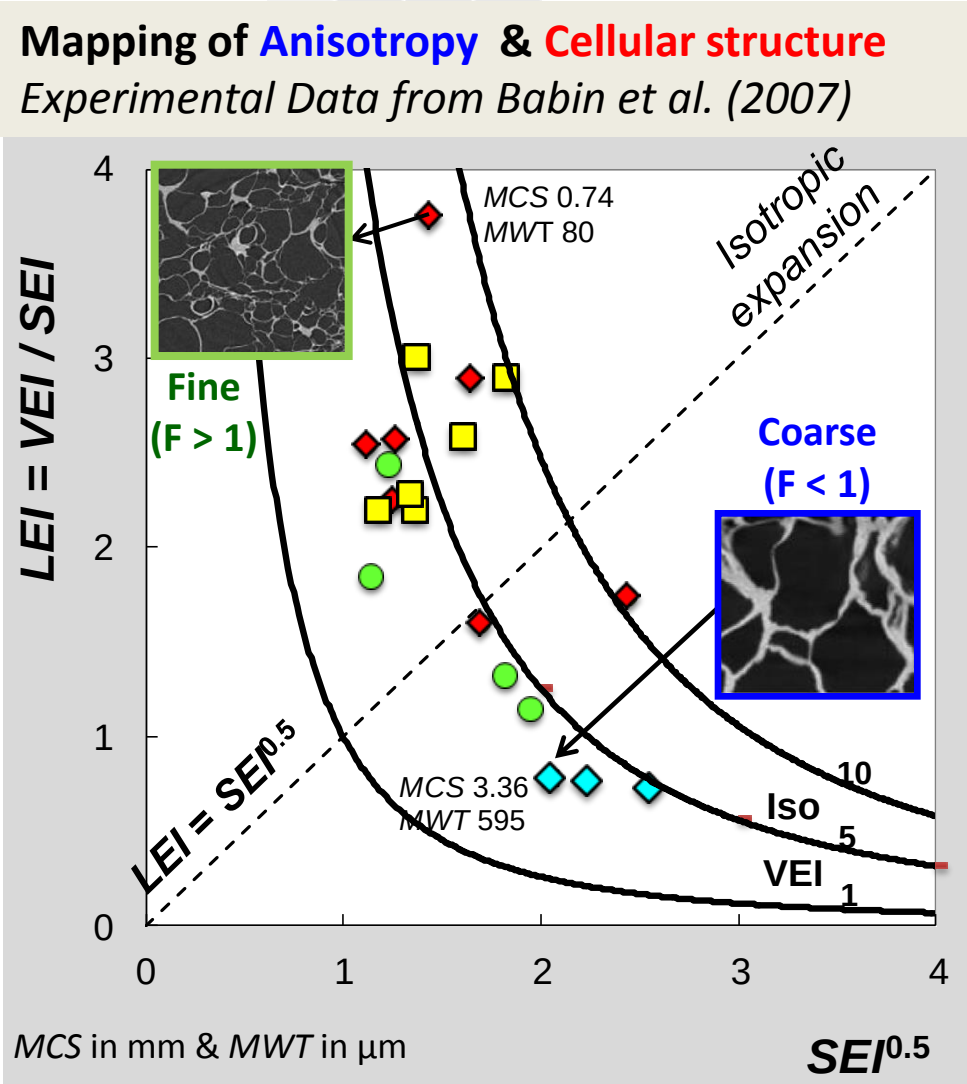
Application of expansion model to experimental data from literatures
(including **Rheological behavior***) of wheat flour with bran (Robin et al., 2011)



***Difficult to find in the literature**



Anisotropy & cellular structure: from macro to micro-scale



Axial expansion (LEI) is more favorable to finer cells

The higher AF , the finer the cellular structure.



Conclusions

- A robust model for starch expansion by extrusion has been established, thanks to the integration of scientific knowledge and experimental data
- Cell fineness was modeled from computed anisotropy factor, providing a link between micro and macroscopic scales

Ongoing & Perspective

- Coupling mechanical model of extrusion (Ludovic®) with phenomenological model of expansion
 - ✓ The new Ludovic®'s outputs: Macro and cellular structures of foams
- Extending the domain of application of the model and the software

Dissemination

Articles

Modeling of starchy melts expansion by extrusion (A review).

Trends in Food Sci. & Tech (**submitted**).

A phenomenological model of starch expansion by extrusion.

Rhéologie (**accepted**); Food & Bioprocess Tech. (**in prep.**)

Congress

Annual European Rheology Conference (**AERC**), April 2014, Karlsruhe. Poster.

Congrès du Groupe Français de Rhéologie (**GFR**), October 2014, Grenoble. Oral.

Annual European Rheology Conference (**AERC**), April 2015, Nantes. Oral.

International Congress on Engineering and Food (**ICEF**), June 2015, Québec. Poster.

American Assc. Cereal Chemists Int. (**AACCI**), October 2015, Minnesota. Poster/Oral?

Symposium

Ludovic Club, March **2014**, Lyon. Analysis of the expansion phenomenon during the extrusion process: Experiments and model. Oral.

Ludovic Club, March **2015**, Grenoble. Modeling starch expansion by twin screw extrusion. Oral.



Thank you for your attention

Discussion....

