August 11, 2017
Berne, Switzerland

Verarbeitungsmethoden und ihre ernährungsphysiologische Bedeutung

Welche Bedeutung hat die Wahl der Technologie / der Methoden für die Gesundheit?

Laboratory of Food Process Engineering

Erich J. Windhab

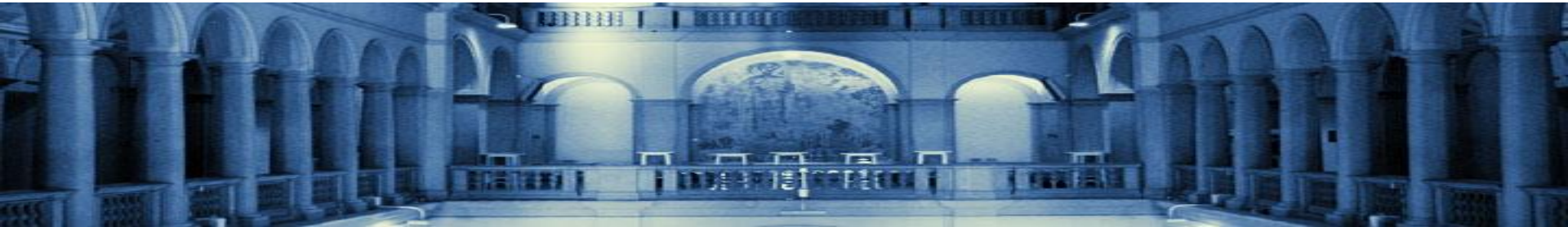
IFNH

INHALT

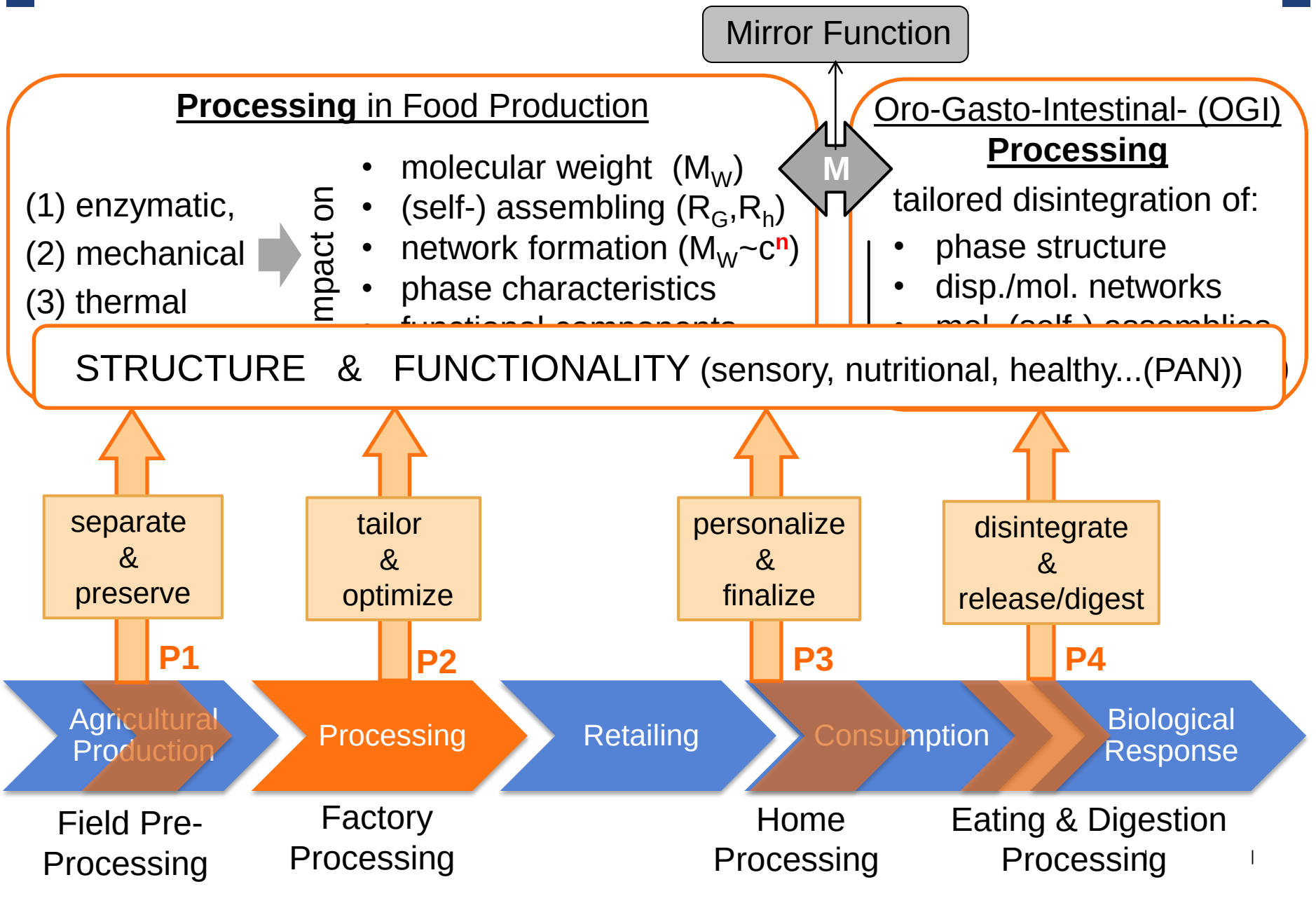
Verarbeitungsmethoden und ihre ernährungsphysiologische Bedeutung

Welche Bedeutung hat die Wahl der Technologie / der Methoden

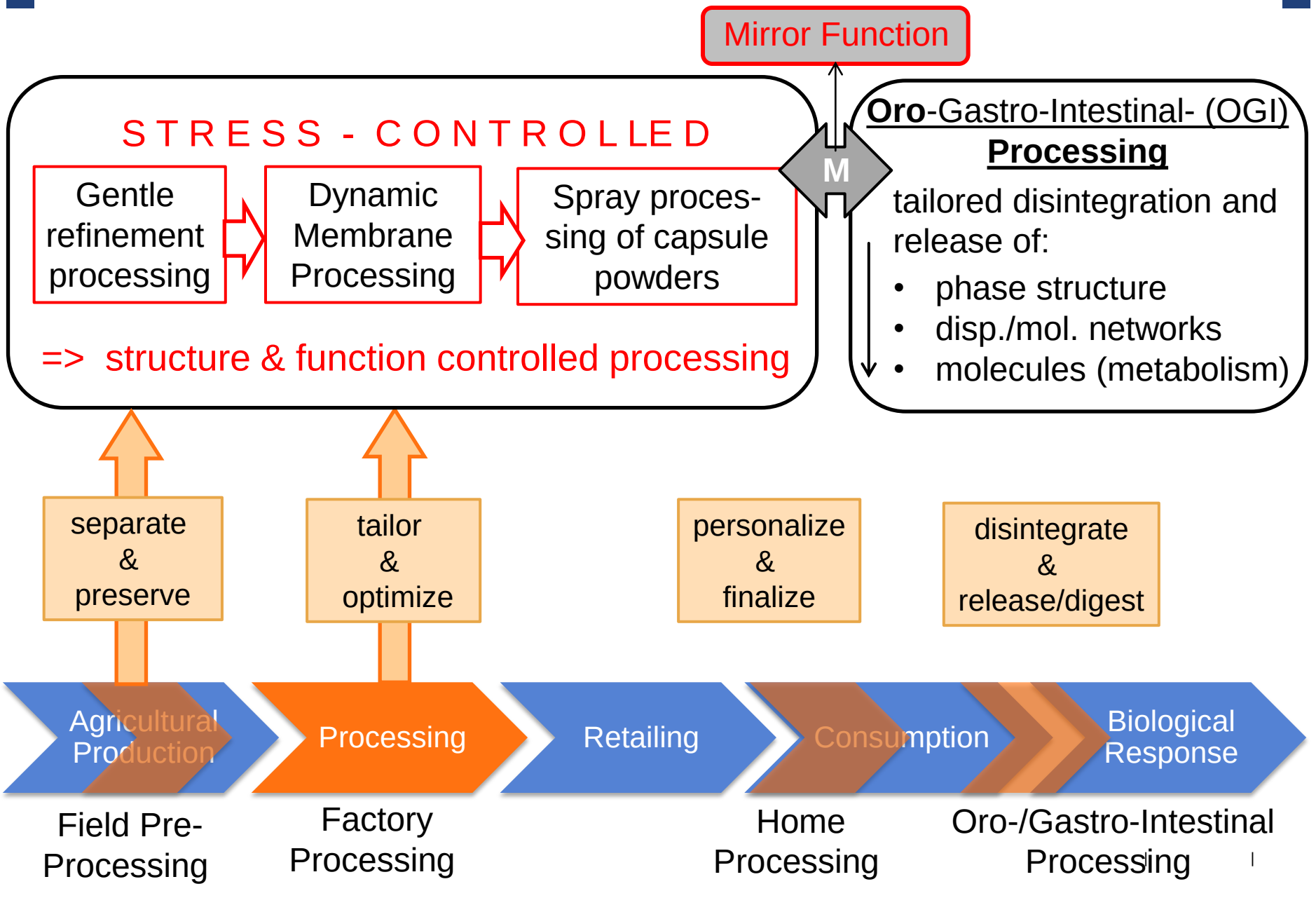
1. Beispiele Funktionlität erhaltender / erzeugender neuer Verarbeitungsverfahren entlang der Lebensmittel Wertschöpfungskette
   - 1.1 Erntenahe Vorverarbeitung: **Rubbery Vermahlung** von Samenkernen
   - 1.2 Fabrik Verarbeitung:
     - 1.2.1 Dynamische **Membran-Strukturierung** von Doppelemulsionen
     - 1.2.2 **Sprühbasierte** Erzeugung von funktionalisierten **Kapselpulvern**
   - 1.3 Küchen-Verarbeitung: **Additive Verfahren** zur Personalisierung
2. Oro-Gastro-Intestinale Lebensmittel Struktur-Disintegration und Freisetzung sensorisch und ernährungsphysiologisch relevater Funktionalitäten
3. Zusammenfassung / Ausblick



1. Processing along the Food Value Chain



1. Processing along the Food Value Chain



Processing in Food Production

(1) enzymatic,
(2) mechanical
(3) thermal

impact on

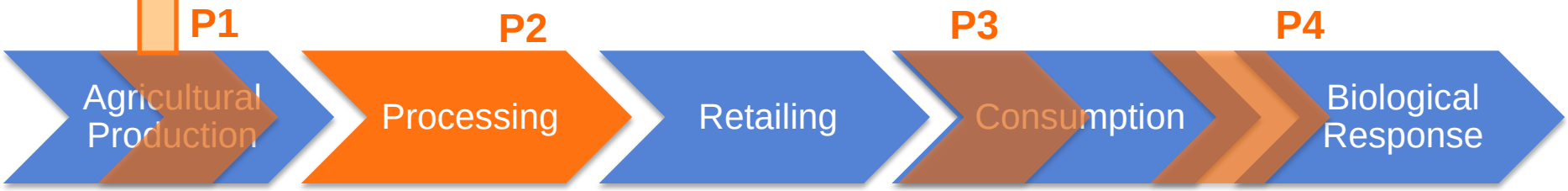
- molecular weight (M_W)
- (self-) assembling (R_G,R_h)
- network formation (M_W~c^n)
- phase characteristics
- functional components
- macrostruct./morphology

EXAMPLE 1:

Rubbery milling of gallactomannan seeds

here:
locus bean gum (LBG)
or guar gum (GG)

separate & preserve



ZIELSETZUNG:

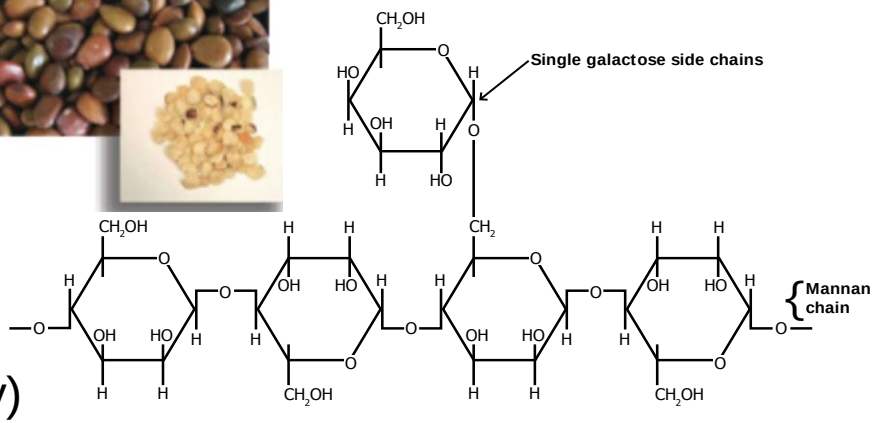
Erhalt natürlicher Funktionalität durch schonende jedoch effiziente Zerkleinerung im „erweichten“ (gummiartigen= rubbery) Zustand

1.1

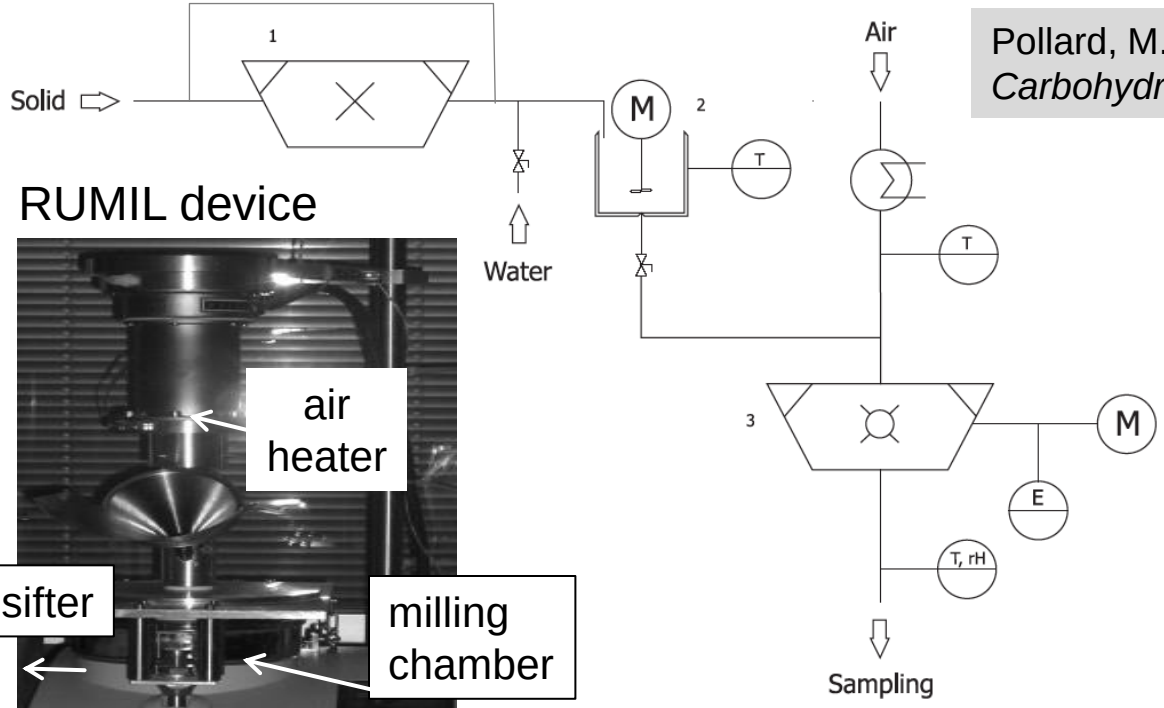
Rubbery Milling / Refining

Rubbery Milling (RUMIL)
of Locust Bean Gum (LBG)

Low galactose content of LBG leads to low solubility at cold dissolution temperatures

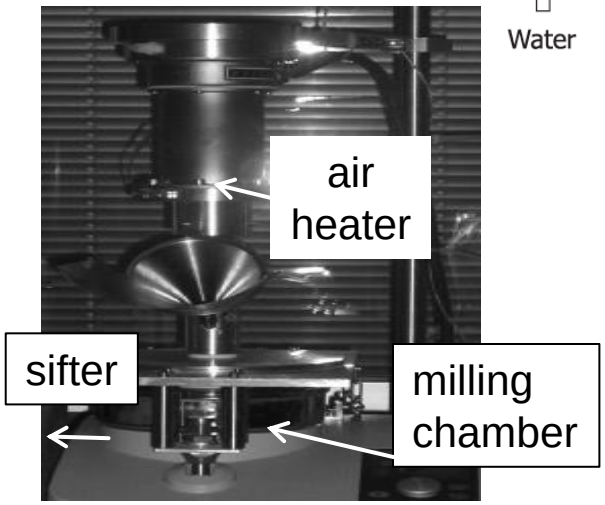


- NEW: up to 78% H_2O in seed (rubbery)
- Conventional: 10-12% H_2O in seed (glassy)

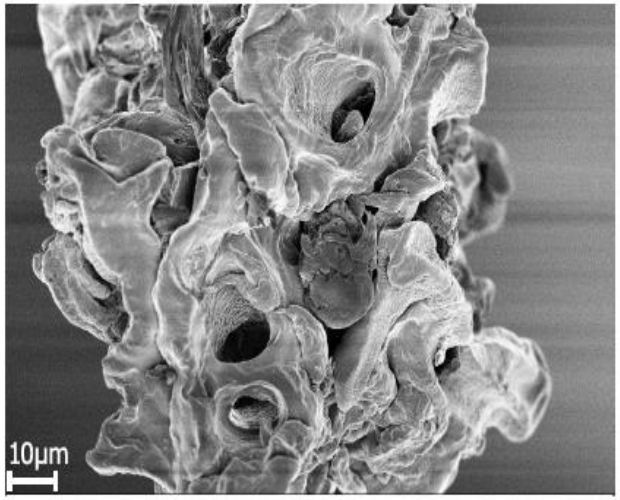


Pollard, M., Fischer P., and Windhab, E.J. (2011); *Carbohydrate Polymers*, 84, 550-559.

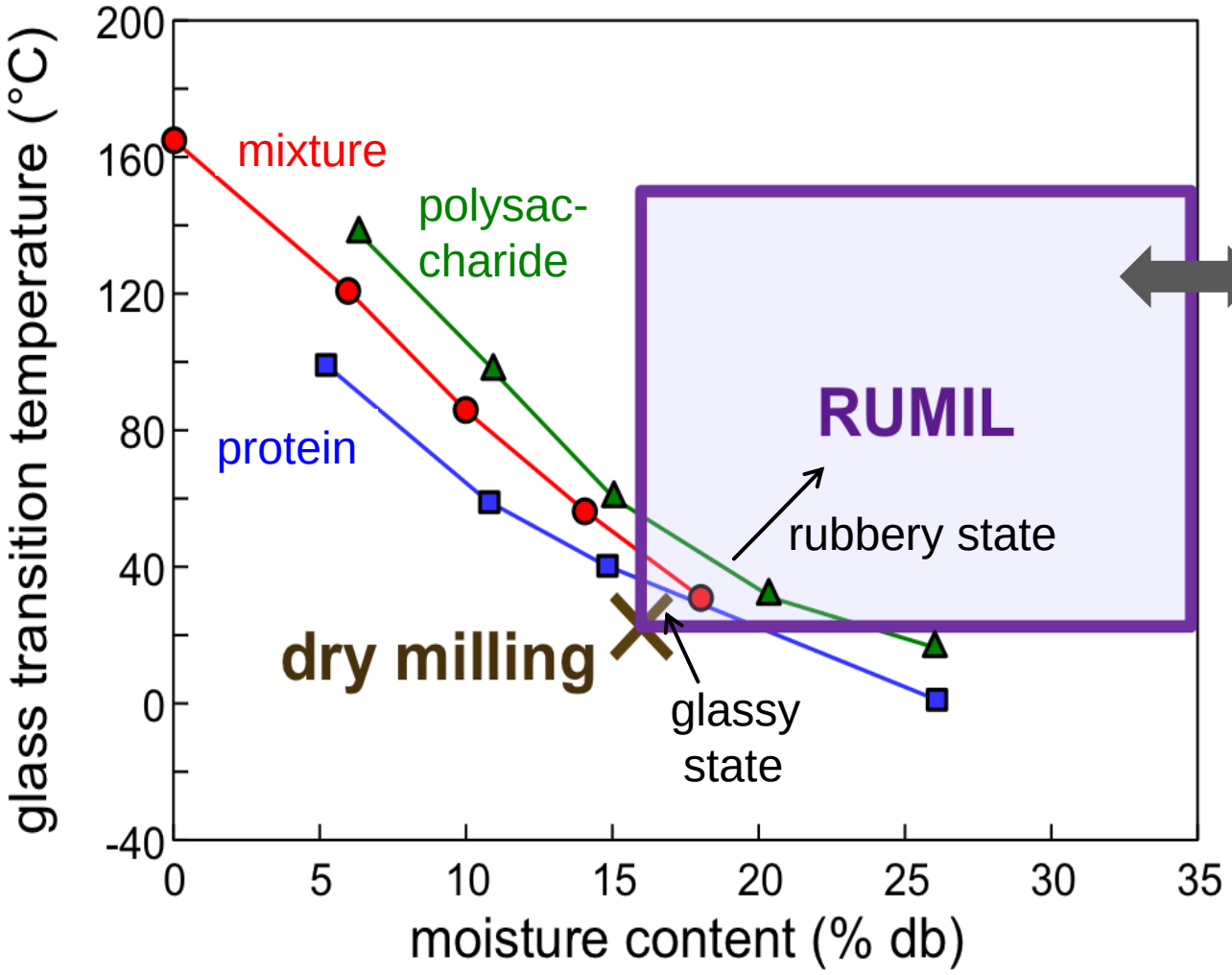
RUMIL device



LBG product powder particle



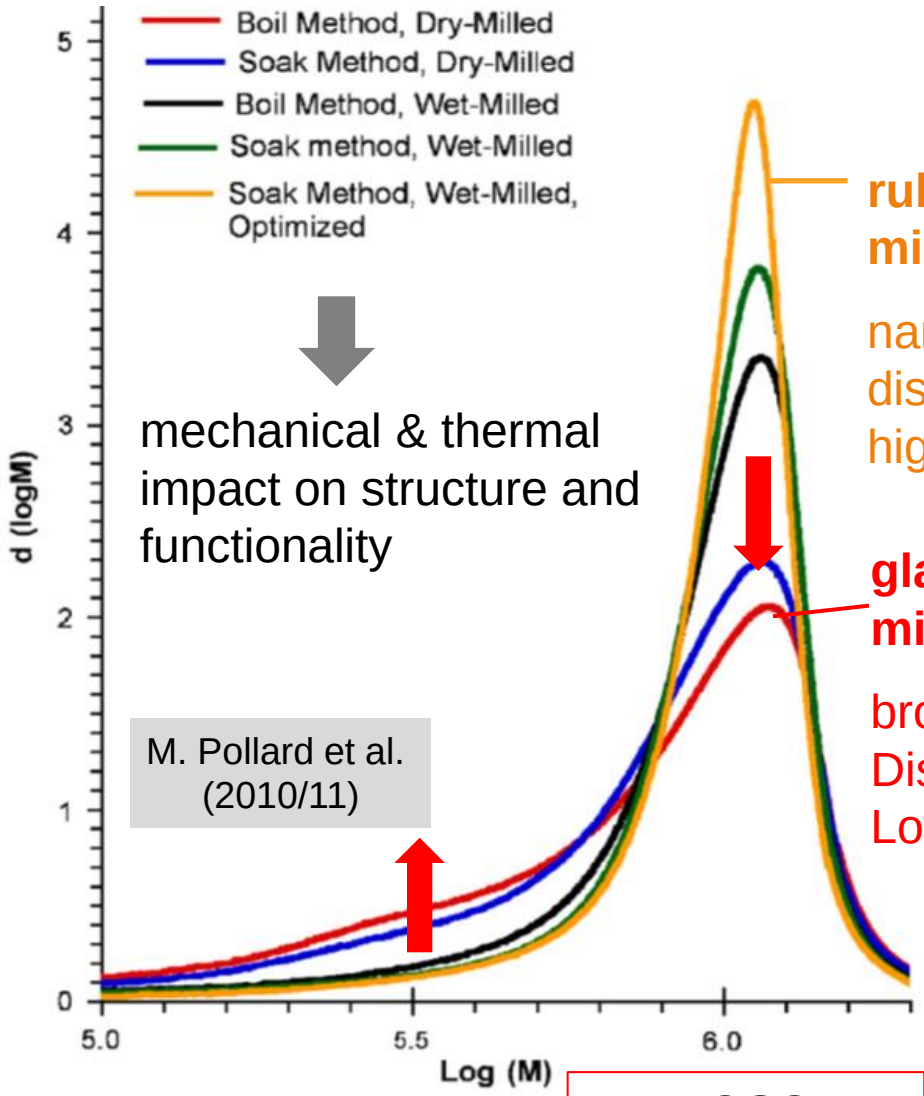
Rubbery Milling (RUMIL)



Gentle structure disintegration:

- reduced mole-cular damage (breaking stress reduction)
- meso-porous particle structure (convective re-drying effect)

Process effects on LGB structure (mol. mass Distribution & particle porosity)



mechanical & thermal impact on structure and functionality

M. Pollard et al. (2010/11)

rubbery-milled:

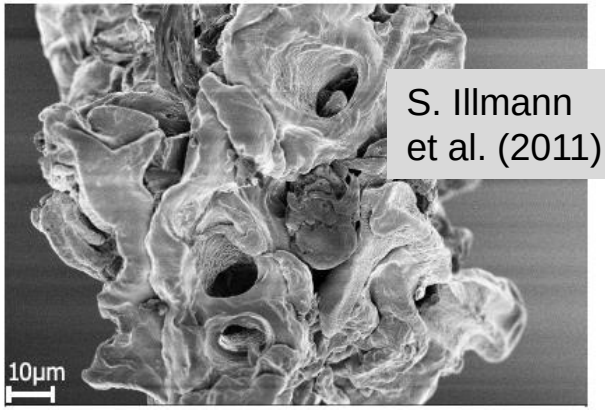
narrowest distribution highest M_w

glassy (dry)-milled:

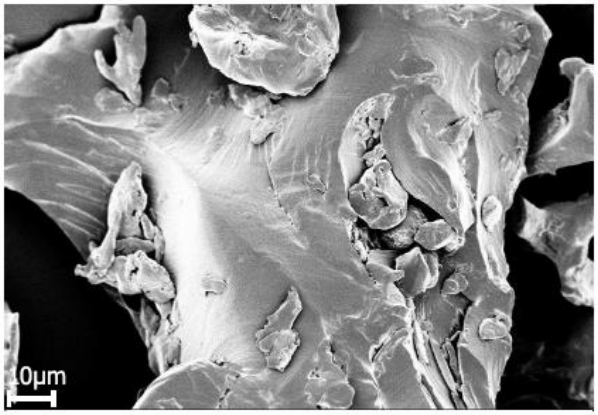
broadest Distribution Lowest M_w

MIKROSCALE

novel RUMIL product

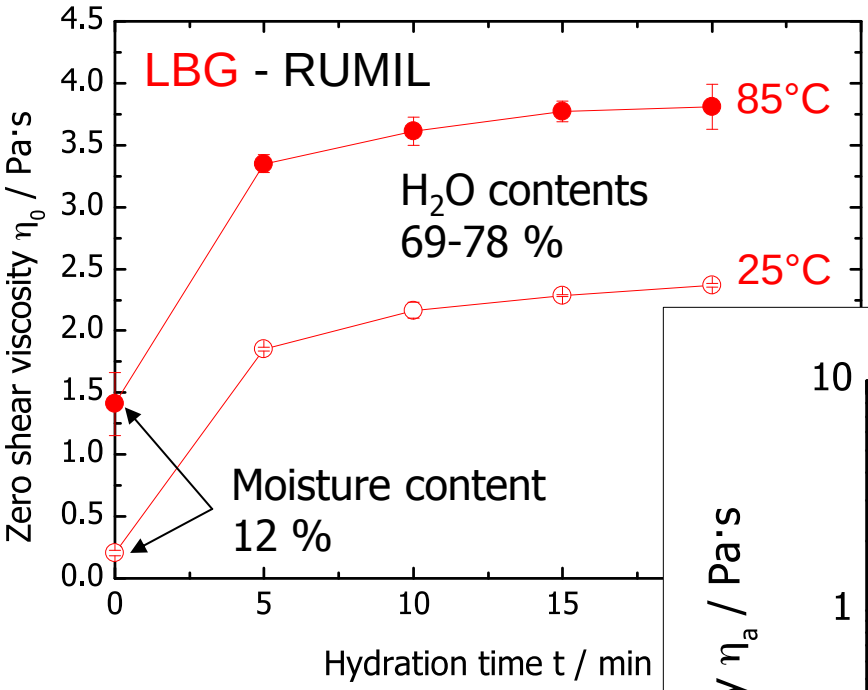


S. Illmann et al. (2011)



commercial product

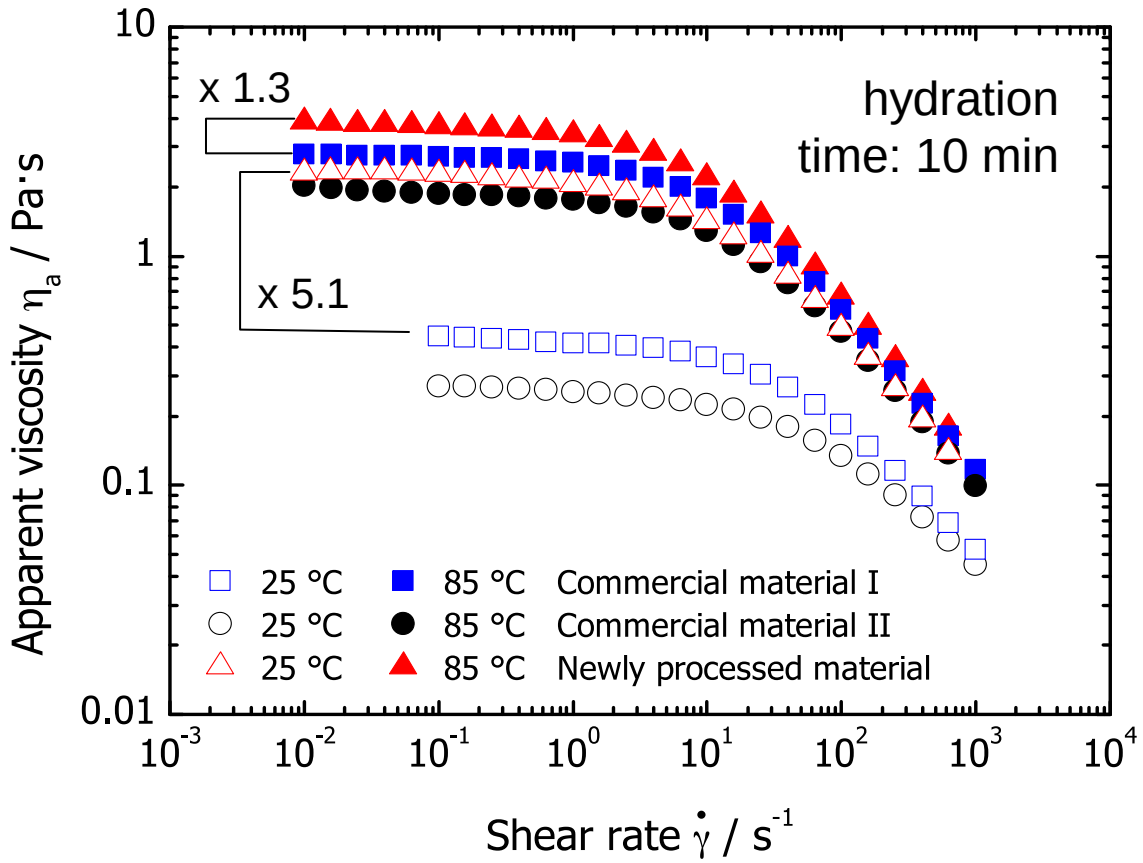
MAKROSCALE



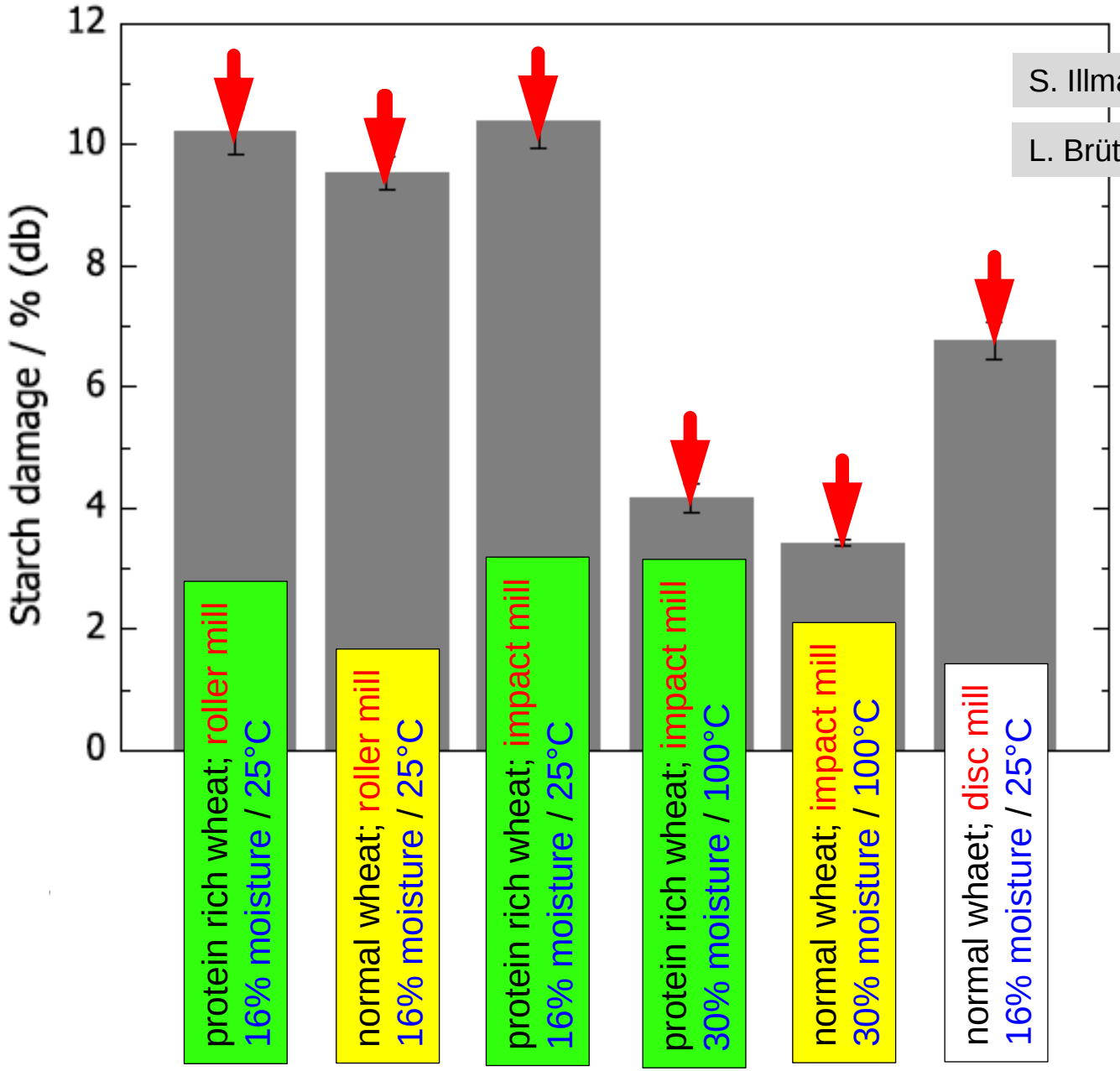
⇒ network disentanglement instead of molecular rupture

significant increase of shear viscosity when milling in the rubbery state at H2O content of ≥ 30-ca. 80%

LBG – RUMIL / LBG commercial



1.1 Rubbery Milling of wheat grains (starch damage impact)



S. Illmann et al. (2011)

L. Brütsch et al. (2014)

Processing in Food Production

(1) enzymatic,
(2) mechanical
(3) thermal

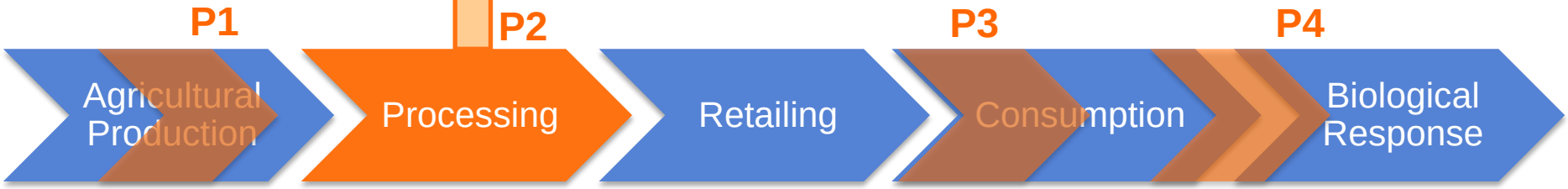
impact on

- molecular weight (M_W)
- (self-) assembling (R_G,R_h)
- network formation (M_W~c^n)
- phase characteristics
- functional components
- macrostruct./morphology

EXAMPLE 2 :

Generation of Multiple Capsule suspension by dynamic membrane dis-persing

tailor & optimize



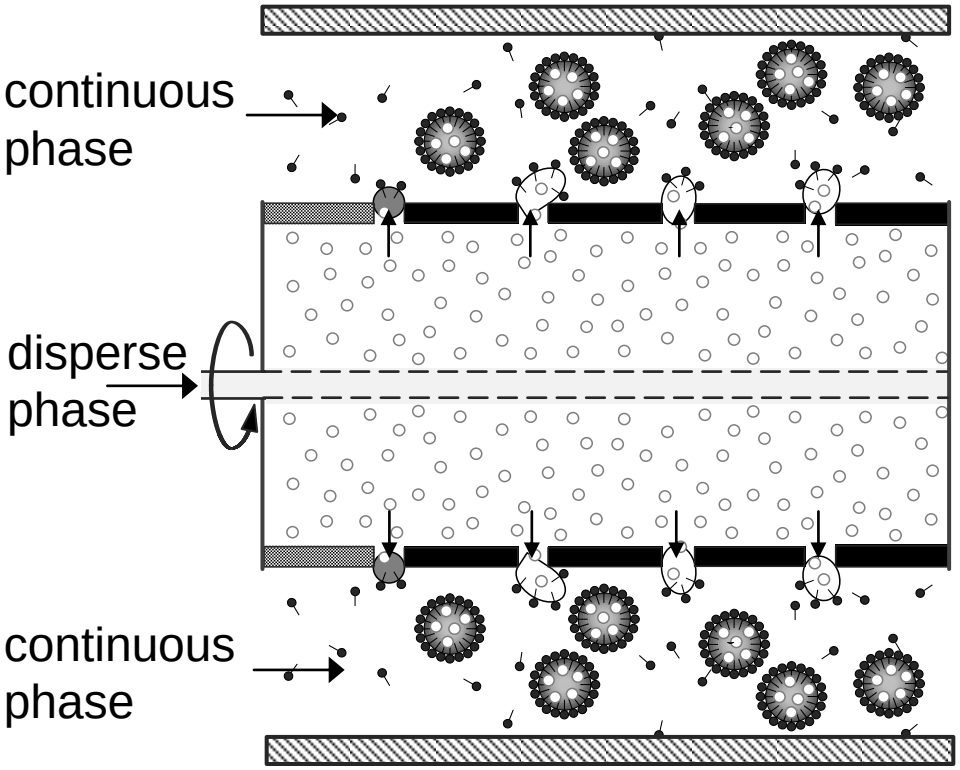
Zielsetzung:

Einstellbare Tropfen/Kapseldurchmesser
und - Durchmesserverteilung

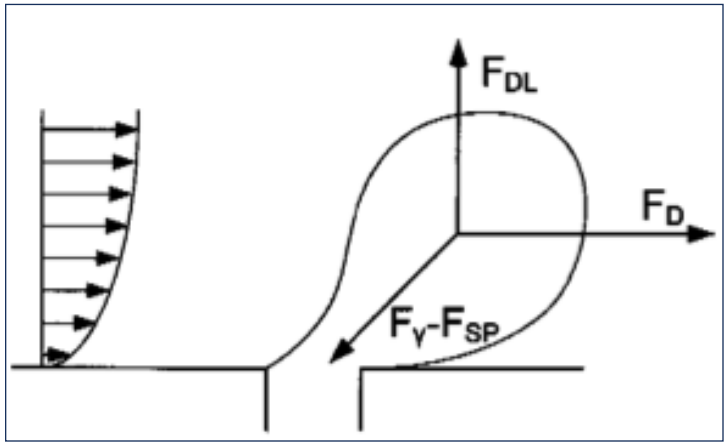
1.2.1

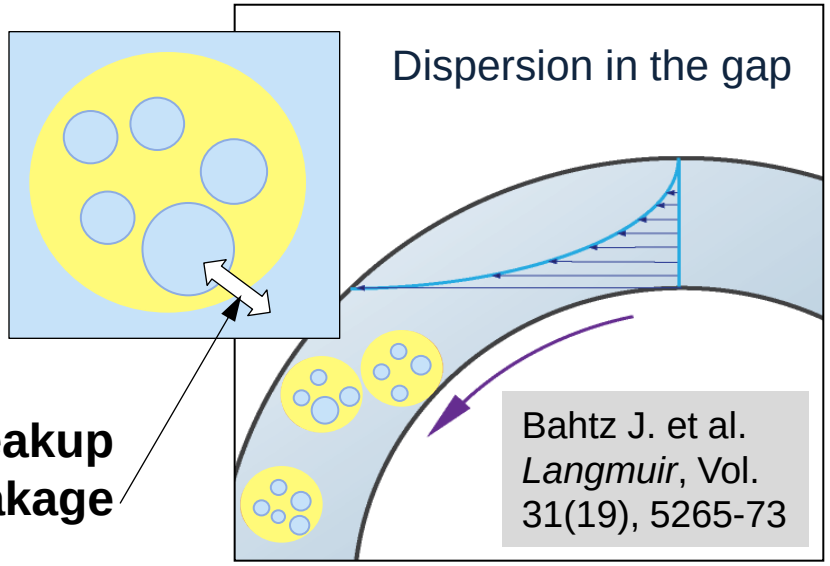
Dynamic Membrane Structuring

Dynamic Membrane Emulsification (mechanically most gentle in dripping mode)



drop detachment from the membrane

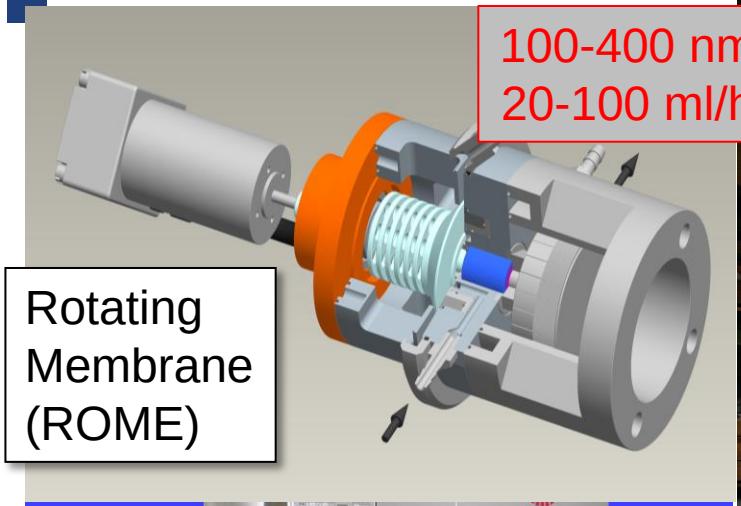




- Gentle emulsification
- **BUT:** Higher structure sensitivity with higher water loads

Breakup
Leakage

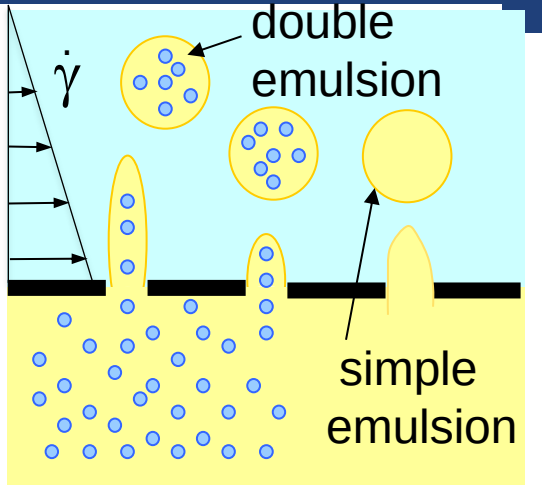
1.2.1 Dynamic membrane structuring



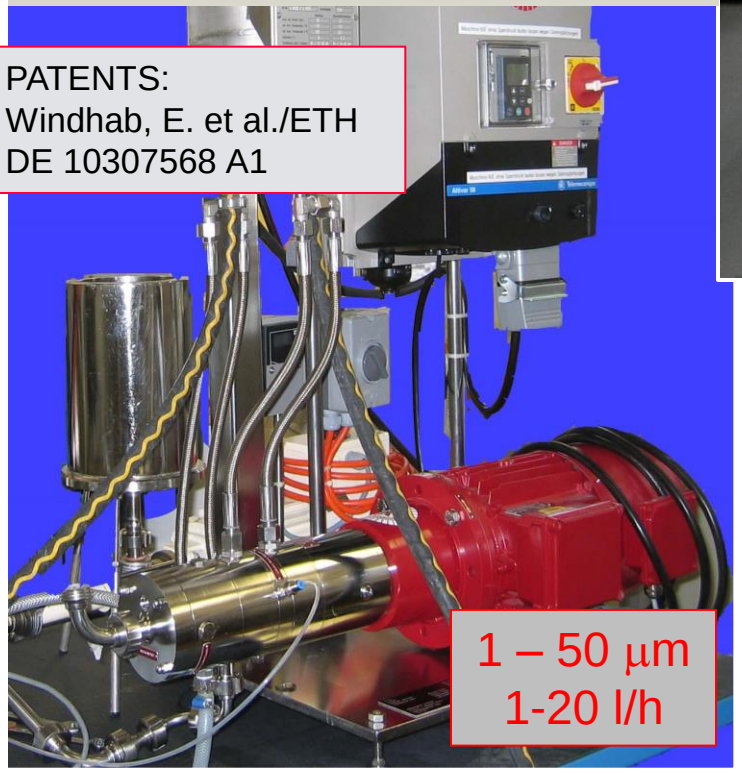
100-400 nm
20-100 ml/h

Rotating Membrane (ROME)

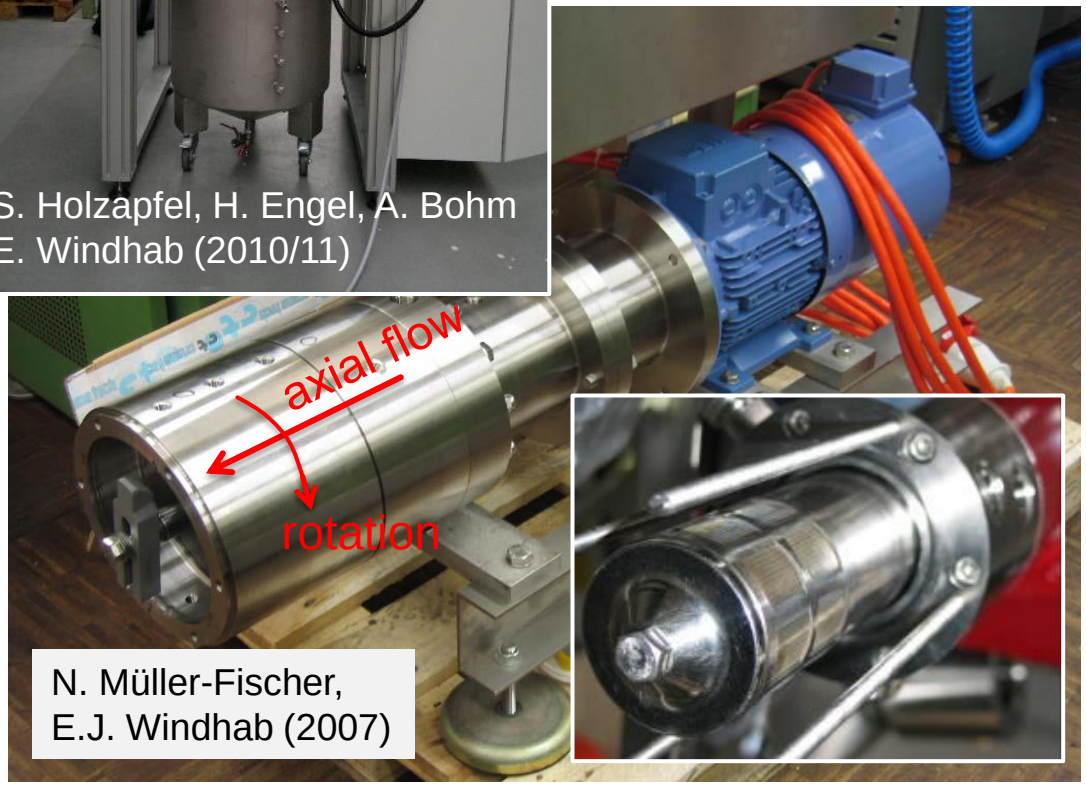
S. Holzapfel, H. Engel, A. Bohm
E. Windhab (2010/11)



PATENTS:
Windhab, E. et al./ETH
DE 10307568 A1

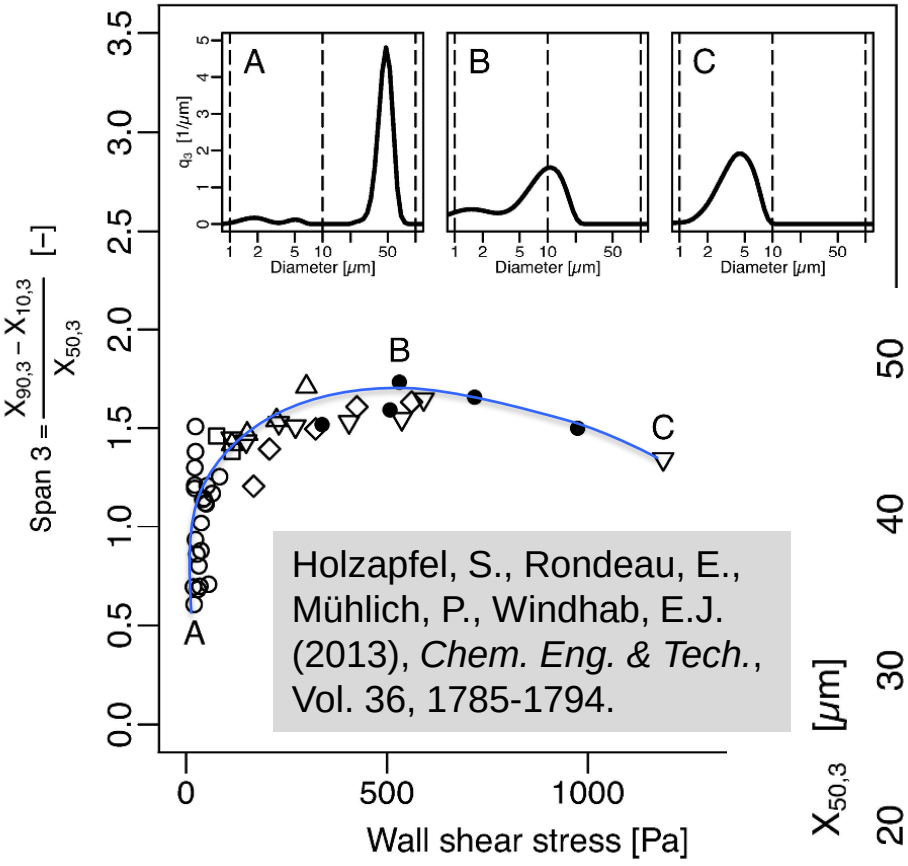


1 – 50 µm
1-20 l/h



N. Müller-Fischer,
E.J. Windhab (2007)

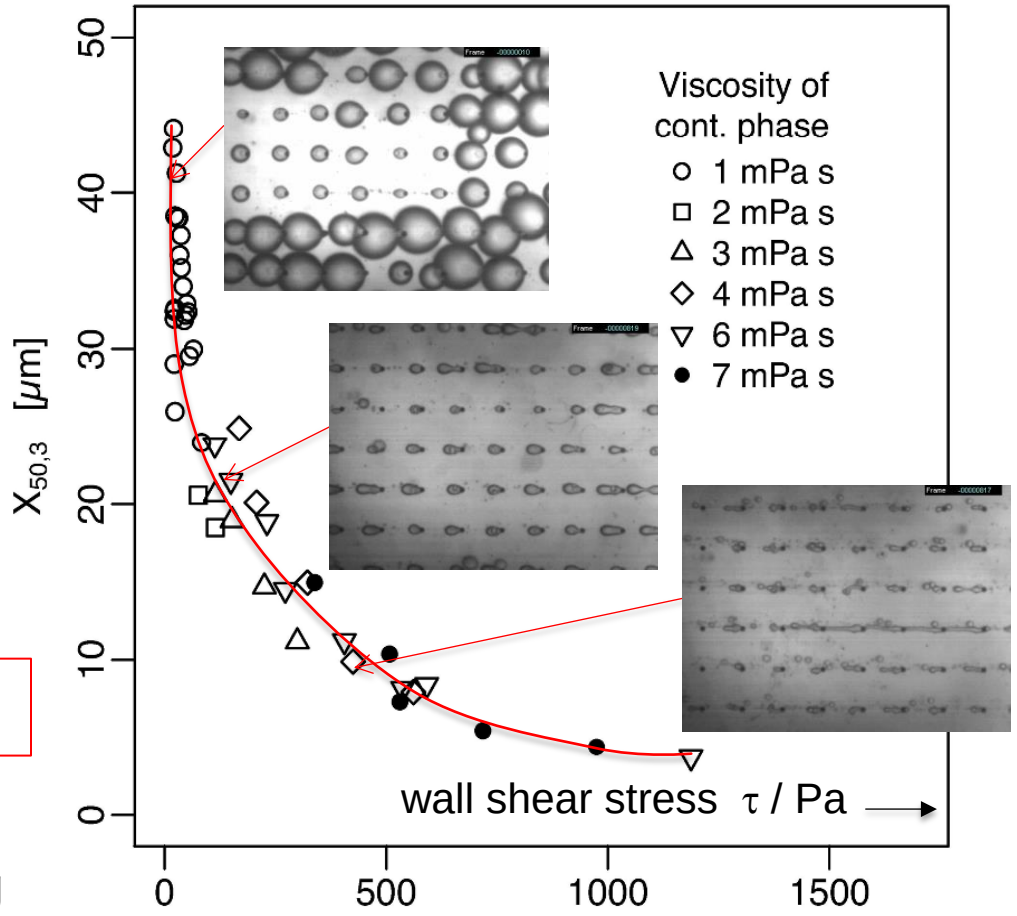
1.2.1 Dynamic membrane structuring



Holzapfel, S., Rondeau, E., Mühlich, P., Windhab, E.J. (2013), *Chem. Eng. & Tech.*, Vol. 36, 1785-1794.

o/w emulsion (Hydrioil with hydrated Alcylesthers (C12, C14) in water by Polyglycol 35000 s, from Clariant)

here: pore size 5 μm



Applicable for:
Nano-
Ultra-
Micro-
Membranes in
dispersing / encapsulation processing

$$d_{drop}/d_{pore} = K\,\tau^{-\alpha}$$

Processing in Food Production

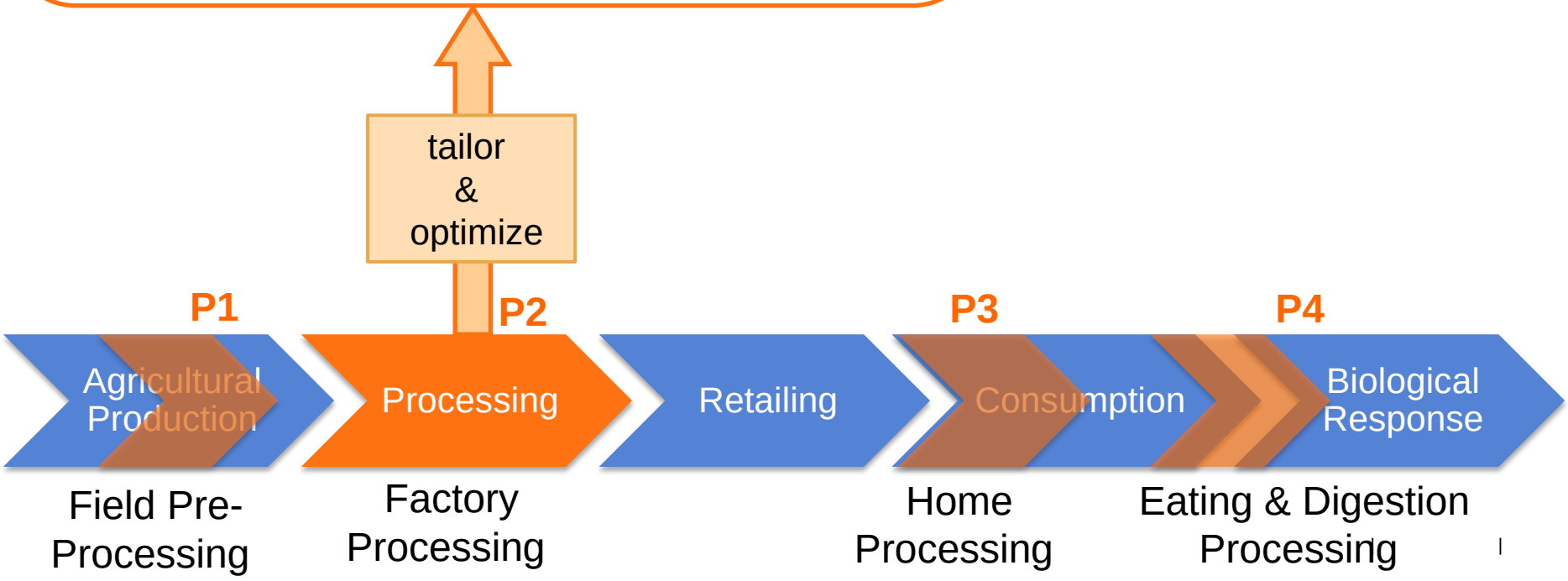
(1) enzymatic,
(2) mechanical
(3) thermal

impact on

- molecular weight (M_W)
- (self-) assembling (R_G,R_h)
- network formation (M_W~c^n)
- phase characteristics
- functional components
- macrostruct./morphology

EXAMPLE 3 :

Stress-controlled spray-processing of of multiple emulsions powders for encapsulation of functional components FCs)



Zielsetzung:

Erhalt/Einstellung der Mikro- und Makrosruktur (disperse Grössenverteilungen und Phasenverteilungen)

1.2.2

Stress-controlled spray processing

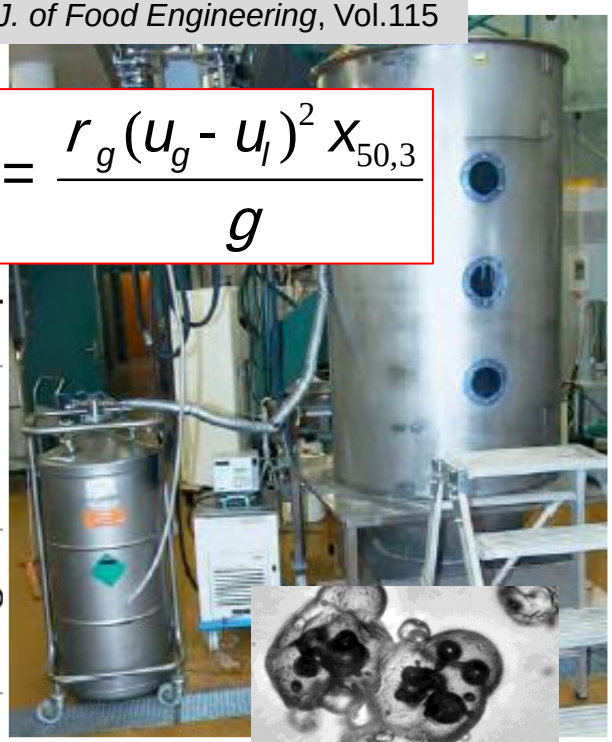
Gentle spray processing

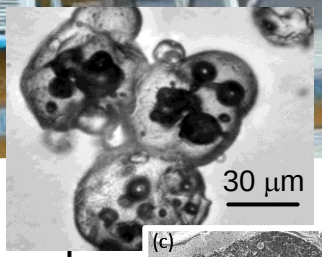
for functional multi-capsule structure preservation

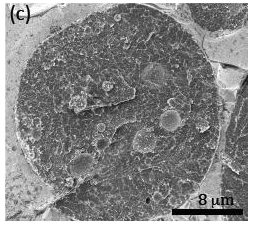
Dubey, B., Windhab, E.J (2013)
J. of Food Engineering, Vol.115

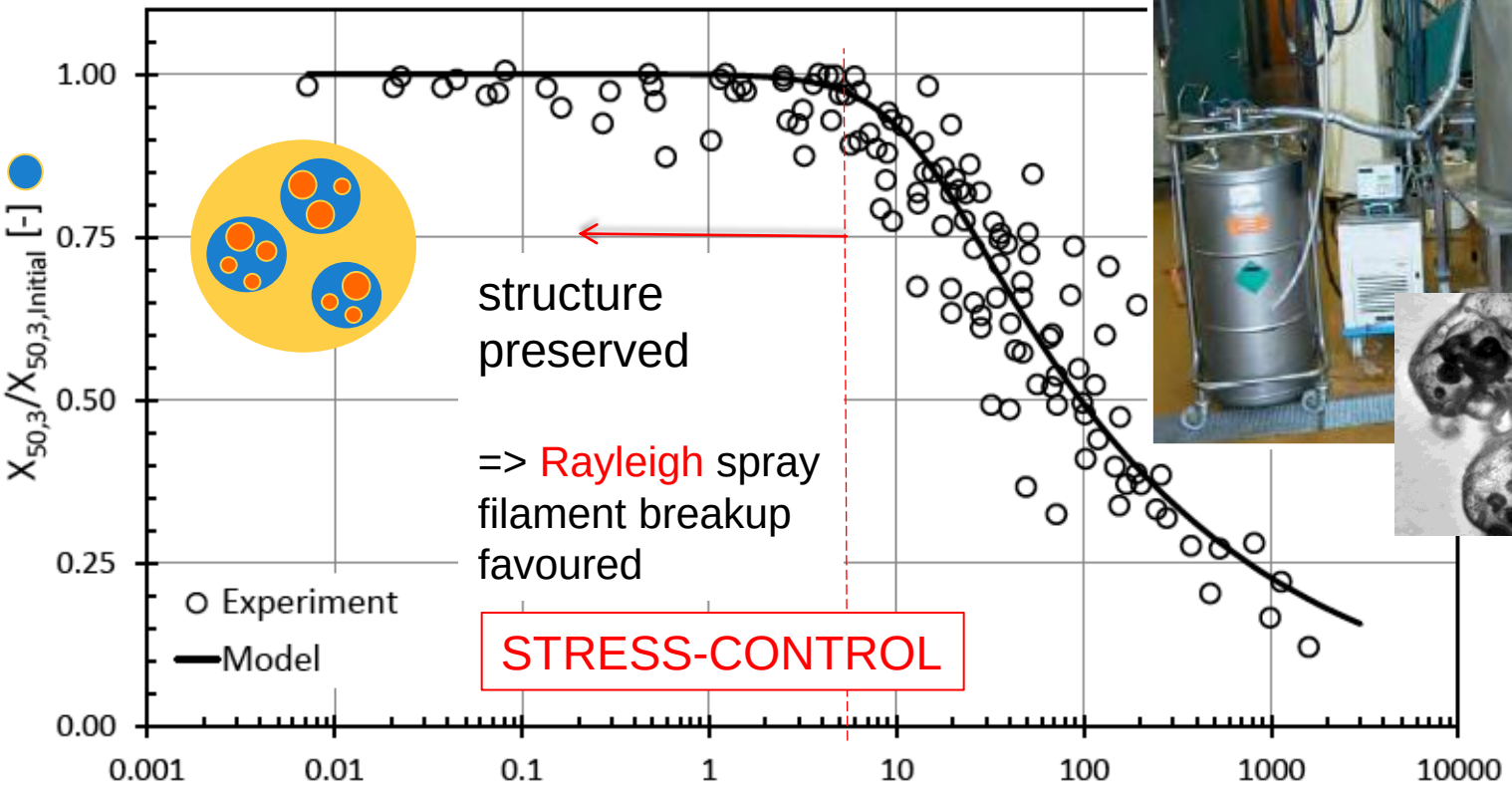
$$x_{50,3} / (x_{50,3})_0 = \left[1 + (m We_{g,drop})^2\right]^n$$

$$We_{g,drop} = \frac{r_g (u_g - u_l)^2 x_{50,3}}{g}$$

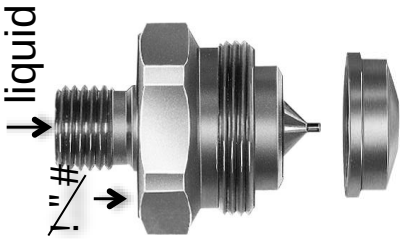


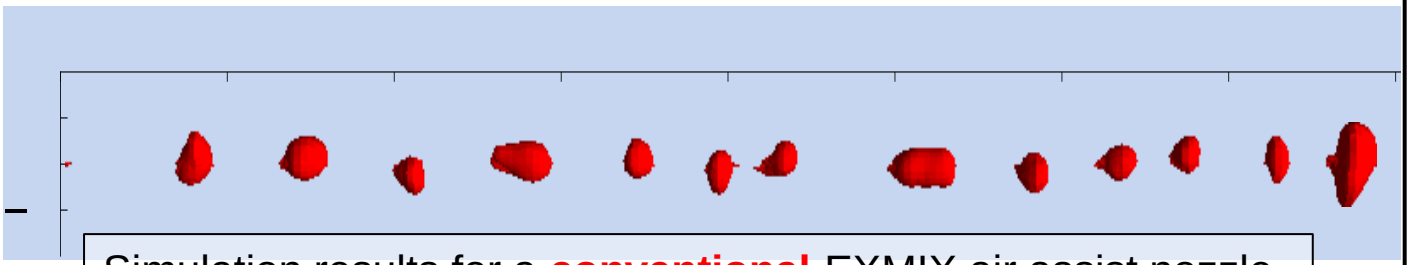






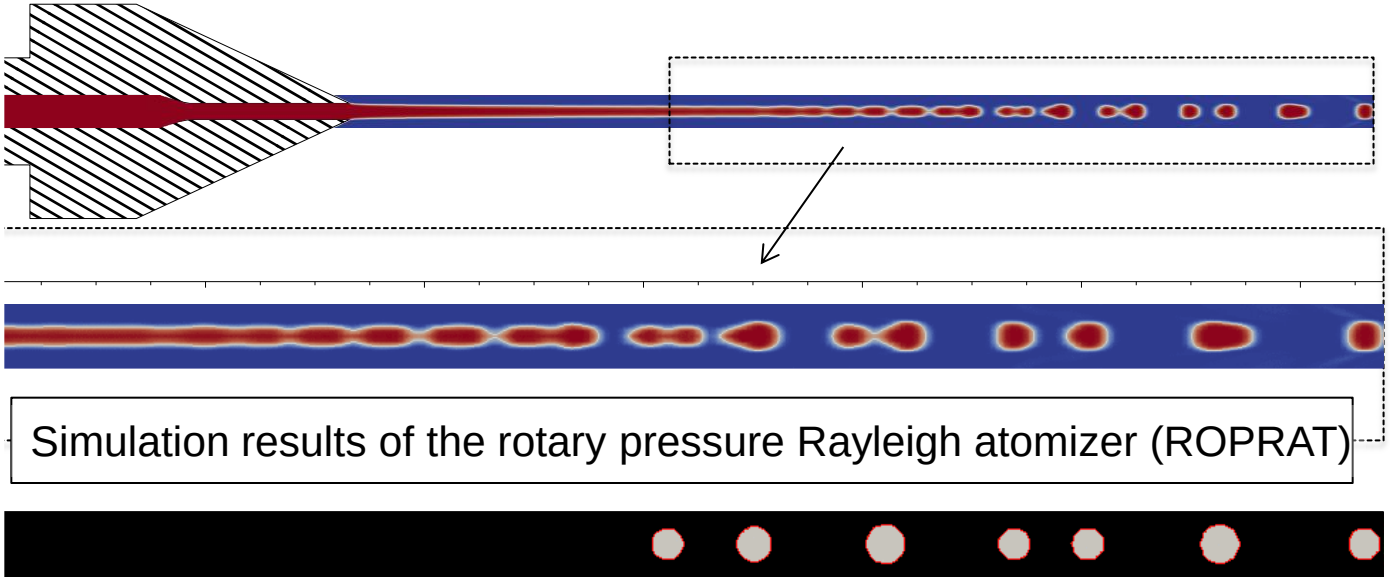
$We_{g,Drop} / \lambda$ → $\lambda = \eta_{O/W1} / \eta_{W2}$





Simulation results for a **conventional** EXMIX air assist nozzle

W. Case et. al.(2014)

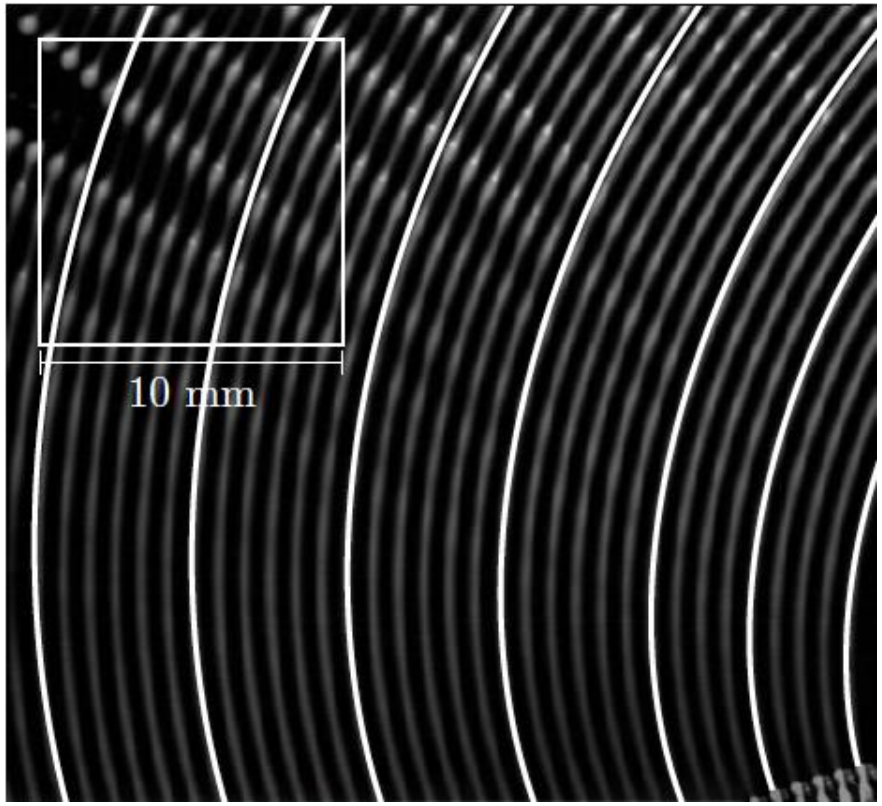


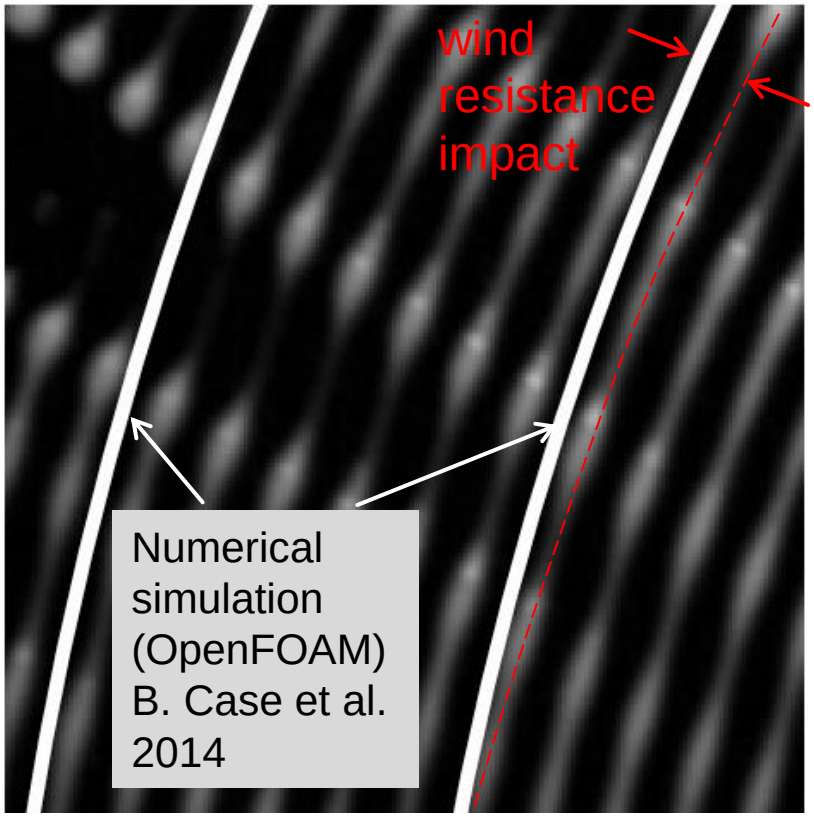
Simulation results of the rotary pressure Rayleigh atomizer (ROPRAT)

NEW Rotary Pressure RAYLEIGH Atomizer (ROPRAT)
n = 5000 rpm, p = 5 bar

Experimental prototype testing results (ROPRAT)

Spray filament trajectories (pressure assisted rotary spray)





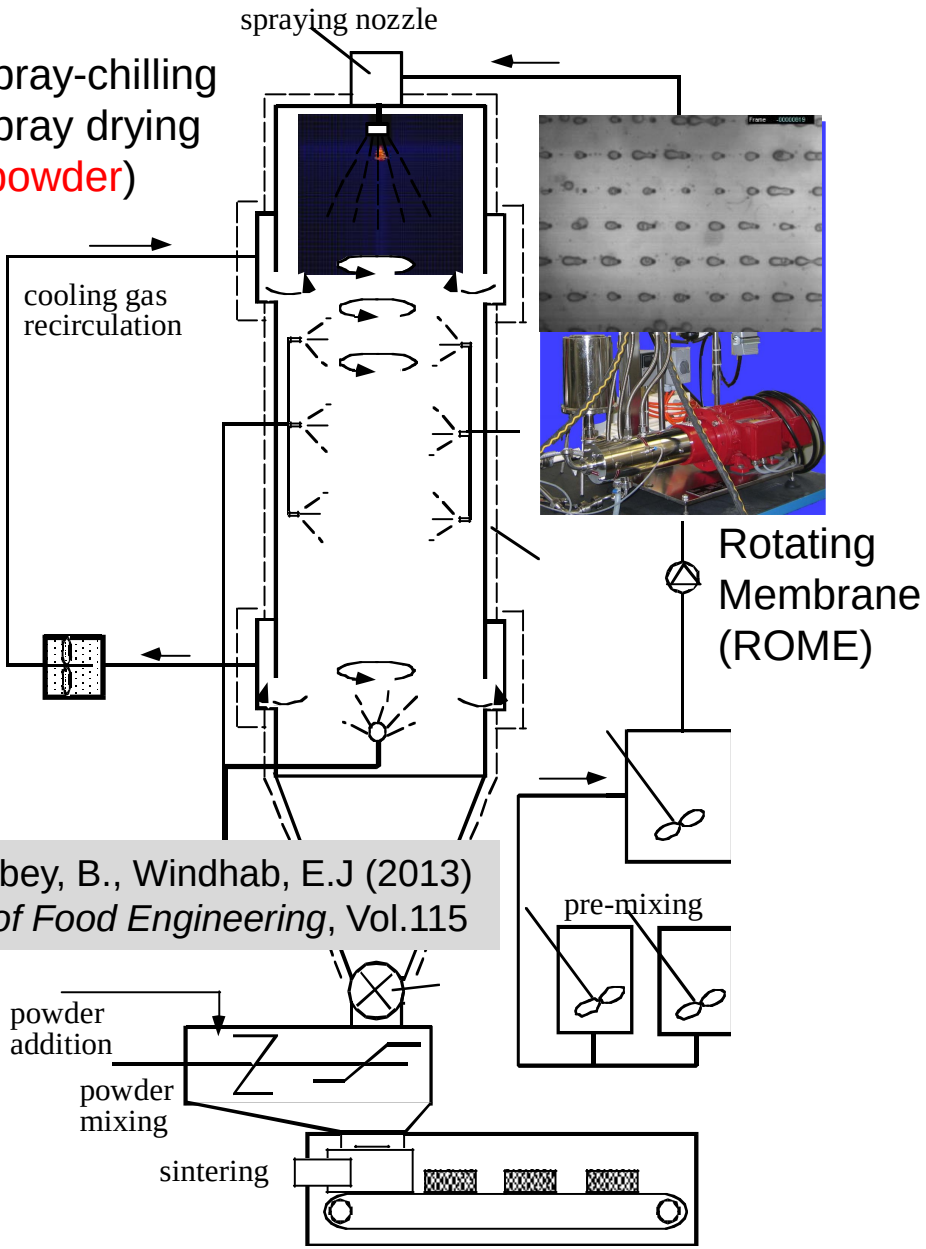
After tension term relaxing,trajectories calculated from :

$$X(T) = \frac{T}{\mathrm{Rb}} \sin\left(\frac{T}{\mathrm{Rb}} - \theta\right) + (T+1)\cos\left(\frac{T}{\mathrm{Rb}} - \theta\right)$$

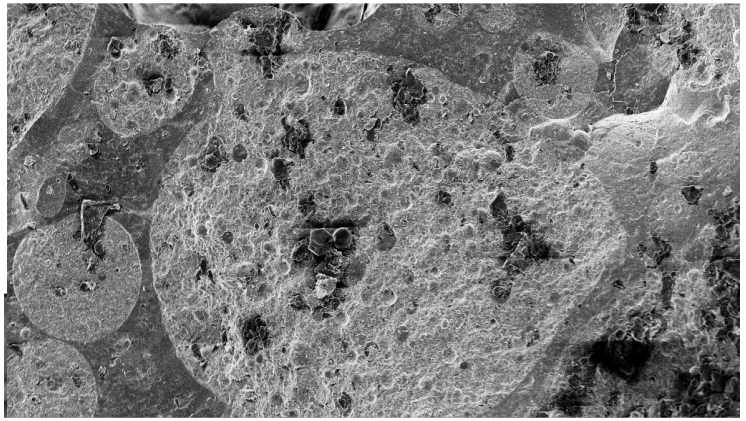
$$Y(T) = \frac{T}{\mathrm{Rb}} \cos\left(\frac{T}{\mathrm{Rb}} - \theta\right) - (T+1)\sin\left(\frac{T}{\mathrm{Rb}} - \theta\right)$$

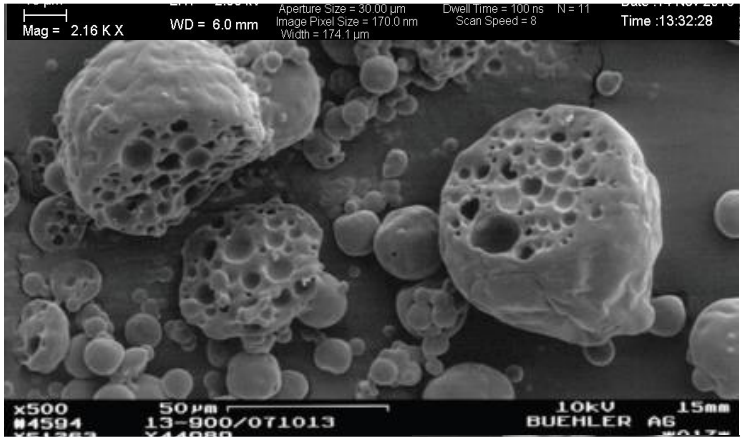
1.2.2 Stress-controlled spray processing

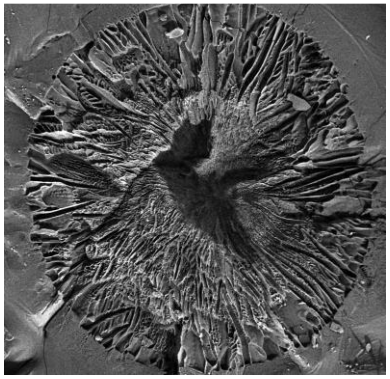
spray-chilling
spray drying
(powder)

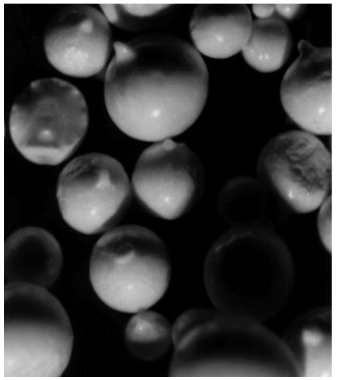


Dubey, B., Windhab, E.J (2013)
J. of Food Engineering, Vol.115



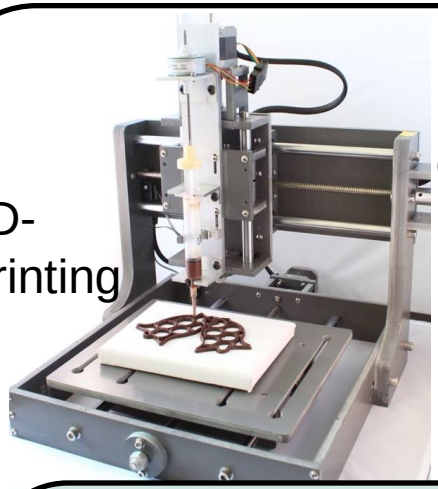




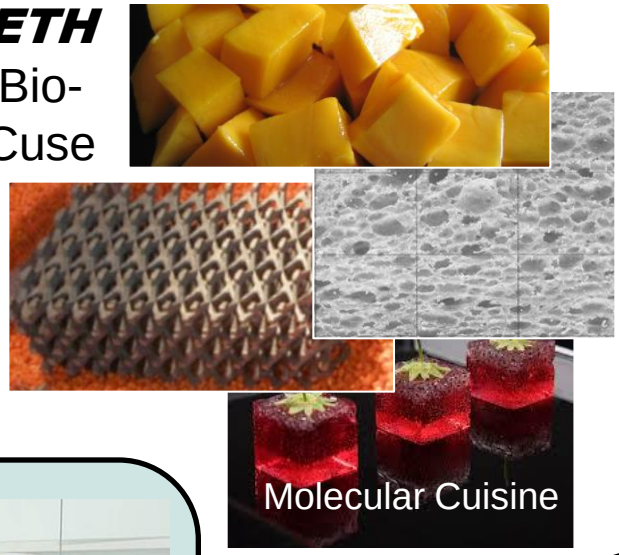


1.3. Home processing: Additive manufacturing based

3D-Printing



ETH Bio-Cuse



personalize & finalize

EXAMPLE(s) 3:

1. Multi-scale extrusion Including Micro-extrusion (3D-Printing)
2. ETH-BioCUSE (for functional powder systems)

+

3. MoleCuisine aspects

+

4. Kitchen Robotics

P3

P4

Agricultural Production → Processing → Retailing → Consumption → Biological Response

Field Pre-Processing

Factory Processing

Home Processing

Eating & Digestion Processing

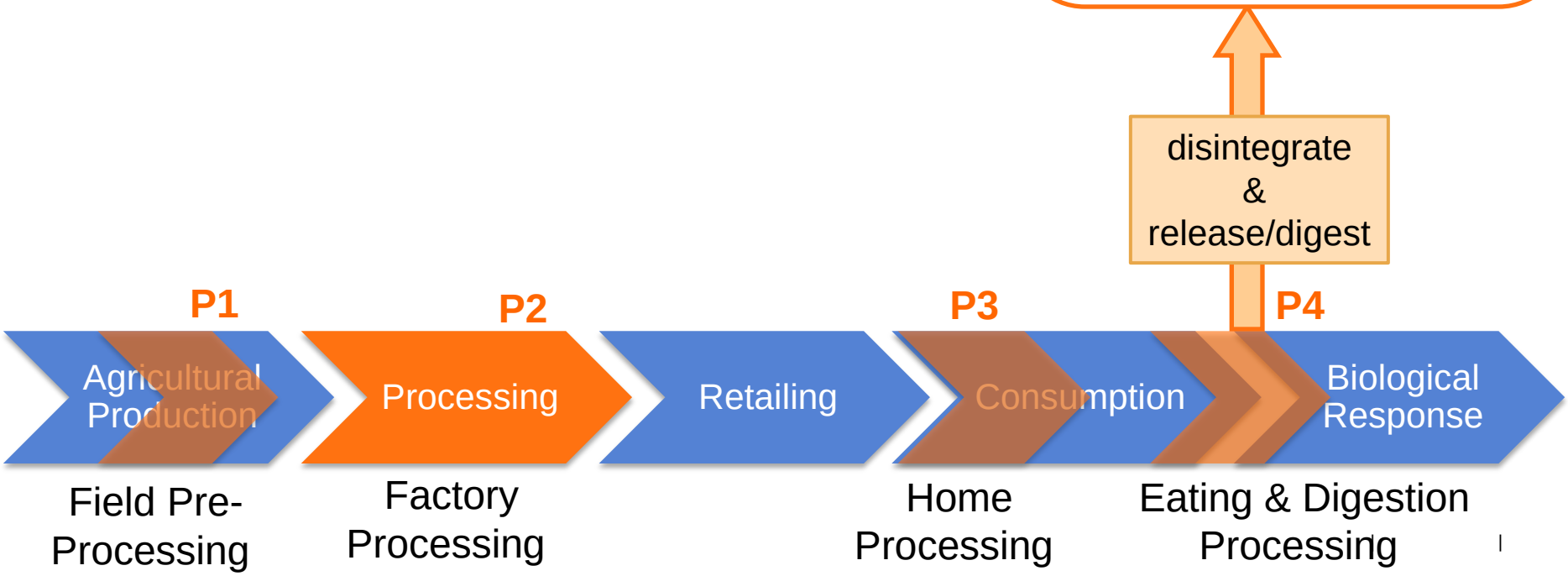
EXAMPLE 4:

Oro-Gastro-Intestinal disintegration of food structure and release of sensory / nutritive function(s)

Oro-Gasto-Intestinal- (OGI) **Processing**

tailored disintegration of:

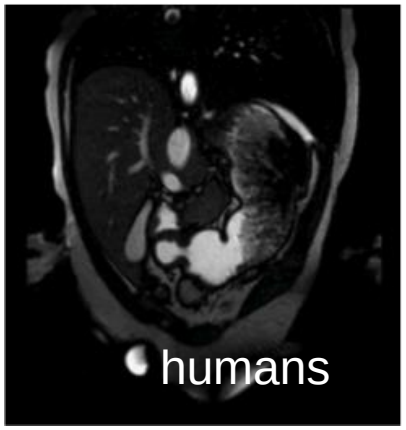
- phase structure
- disp./mol. networks
- mol. (self-) assemblies
- molecules (metabolism)



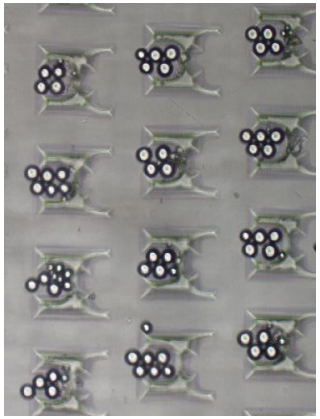
2. Oro-Gastro-Intestinal Processing

HERE: Interplay of disperse fat capsule structure with physiological dynamics - in **fat or protein digestion** (+ release of encapsulated micronutrients)

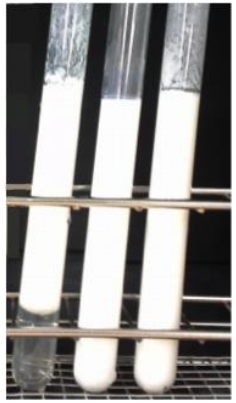
in vivo studies



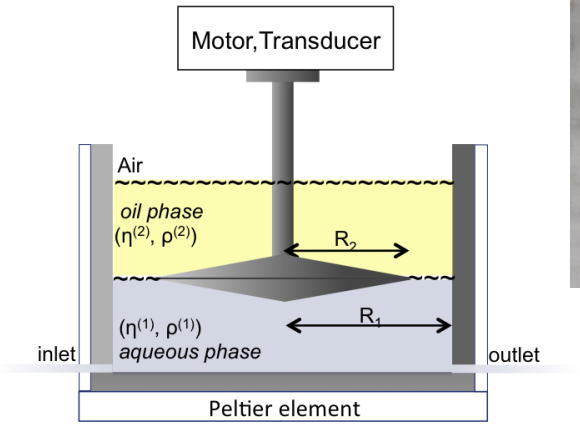
In vitro studies of capsules (novel microfluidics)



bulk phase structuring and analysis



Emulsion drop Interface – layer design

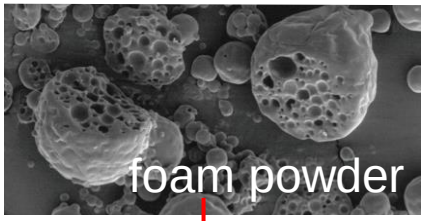


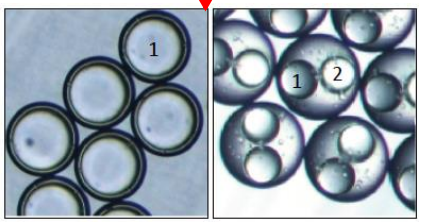
Analysis on multiple length, time and complexity scales

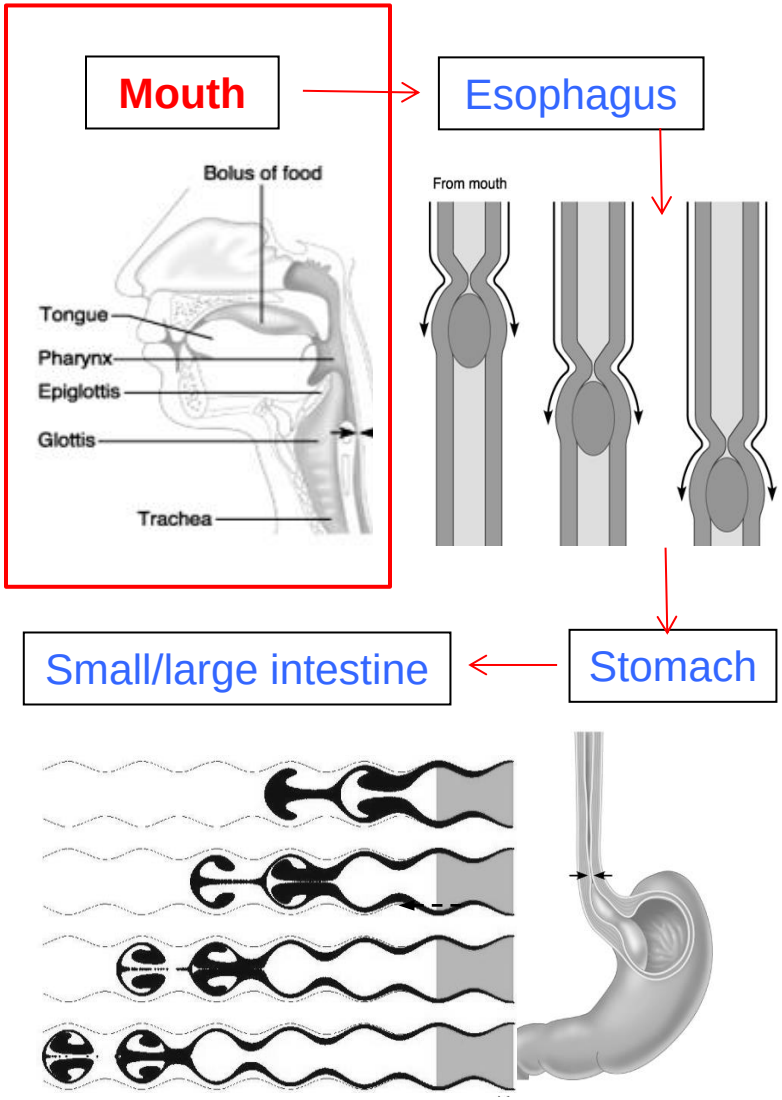
rats

2. Oro-Gastro-Intestinal Processing

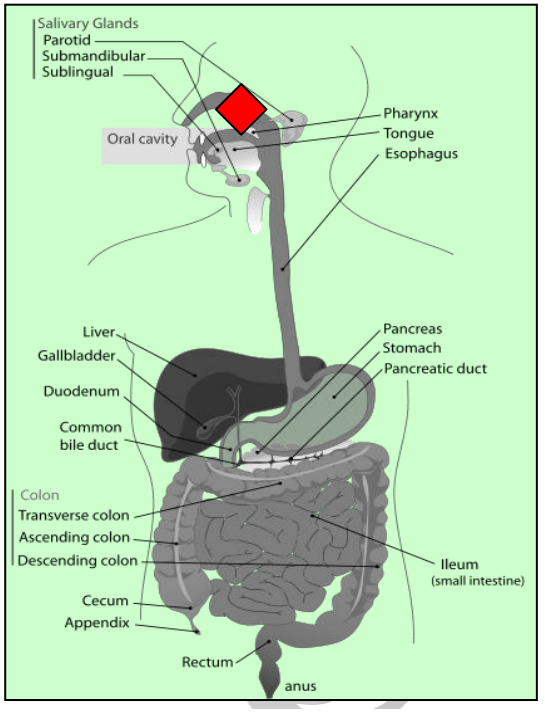
Digestion = Disintegration + Transport + Reaction







A. Leger, (2004)

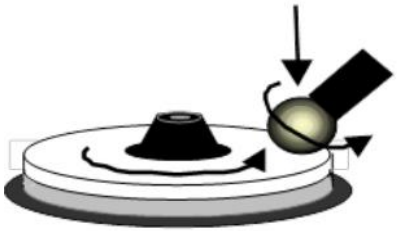


controlled release of functional molecule (◆):

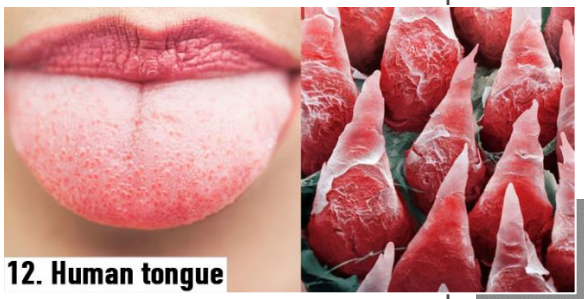
- site
- kinetics
- metabolic functionality (incl. bioavailability)

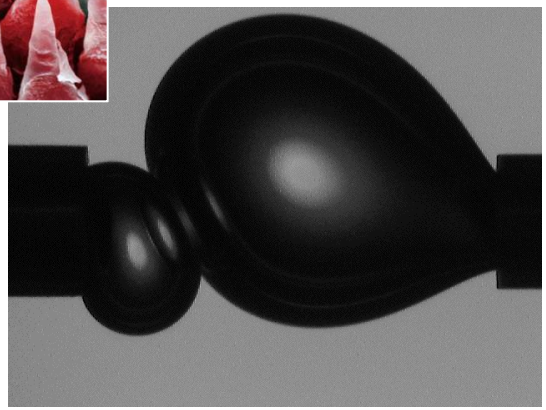
Stribeck - curves

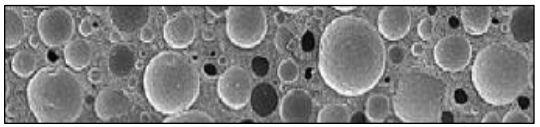
- 0.9% **fat** / ice cream mix
- 2.7% **fat** / ice cream mix
- 6.4% **fat** / ice cream mix
- 3.0% fat / ice cream mix **foam** with $\phi_V \approx$ 50 vol.% air

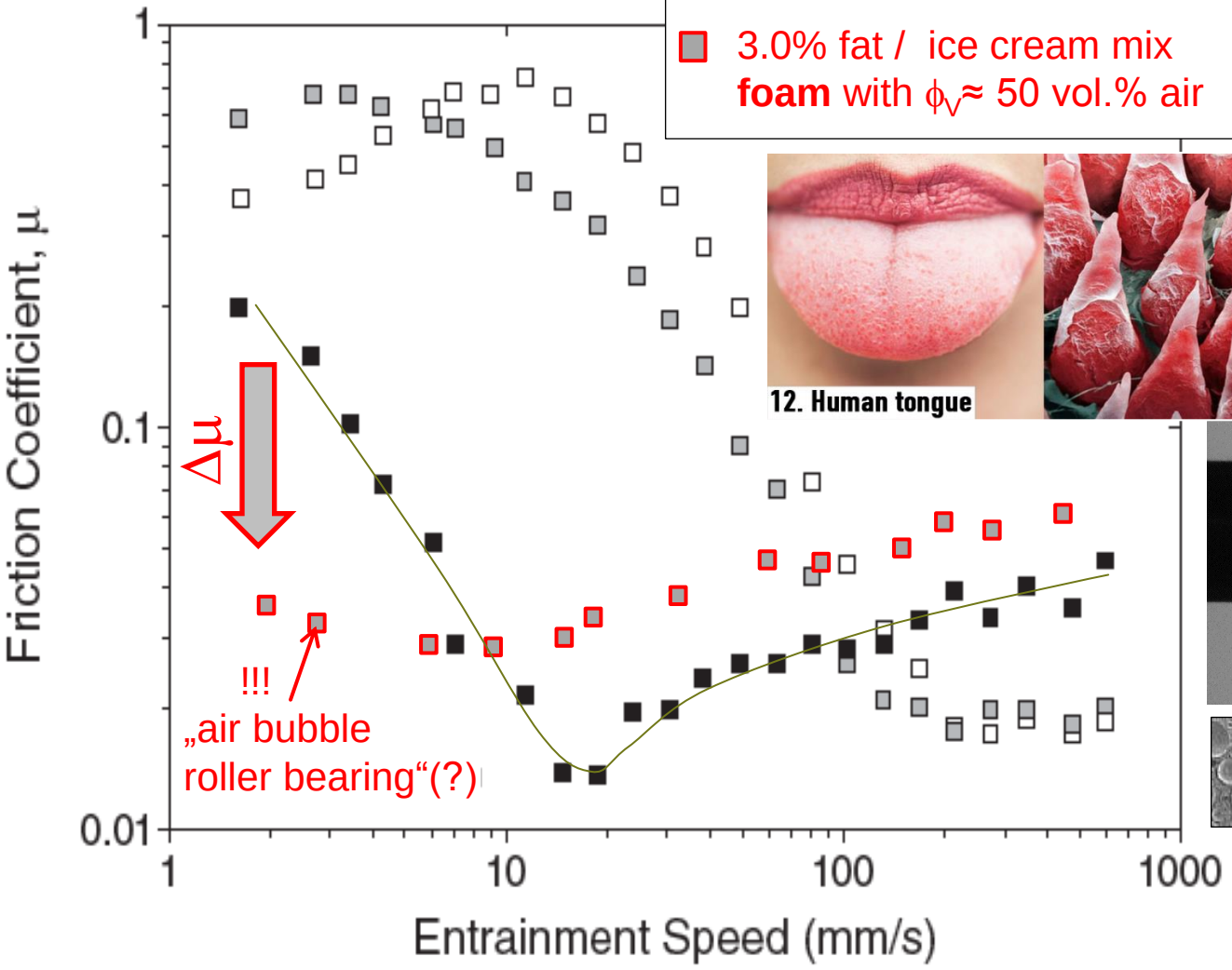


Soft-Tissue-Tribology
(sliding soft body on soft tissue substrate)



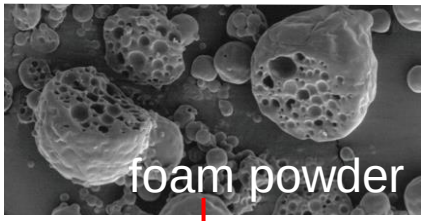


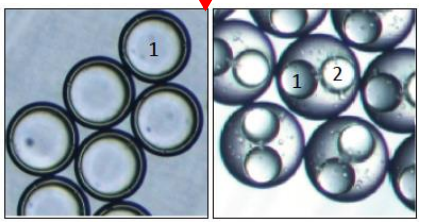


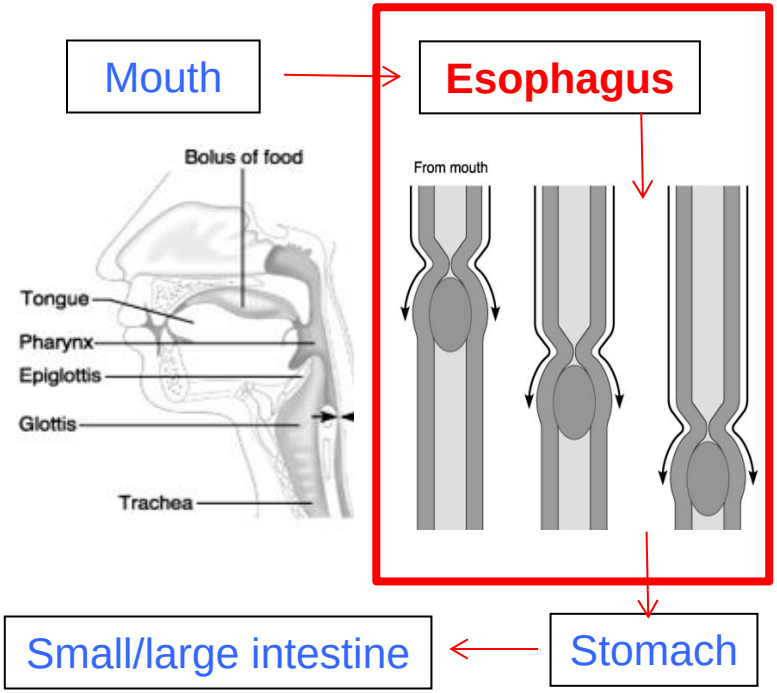


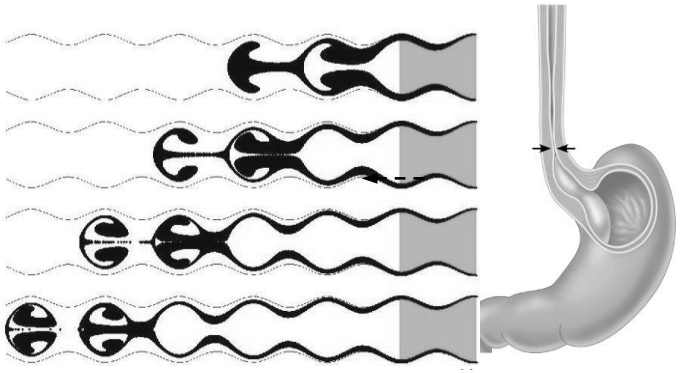
2. Oro-Gastro-Intestinal Processing

Digestion = Disintegration + Transport + Reaction

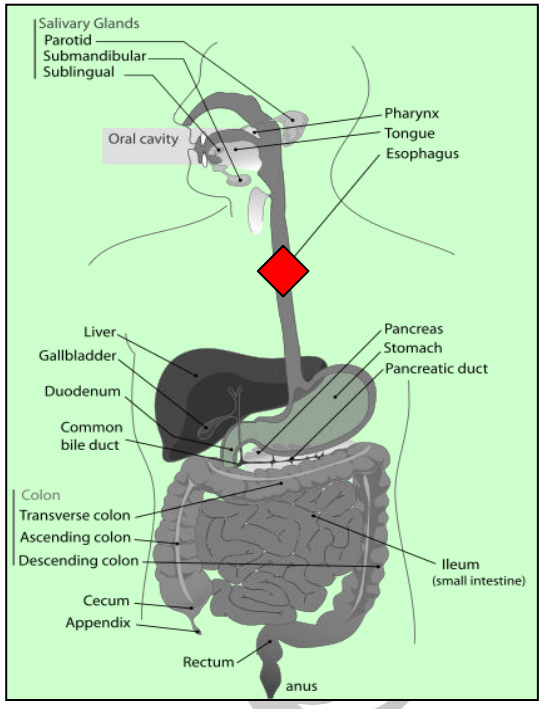








A. Leger, (2004)



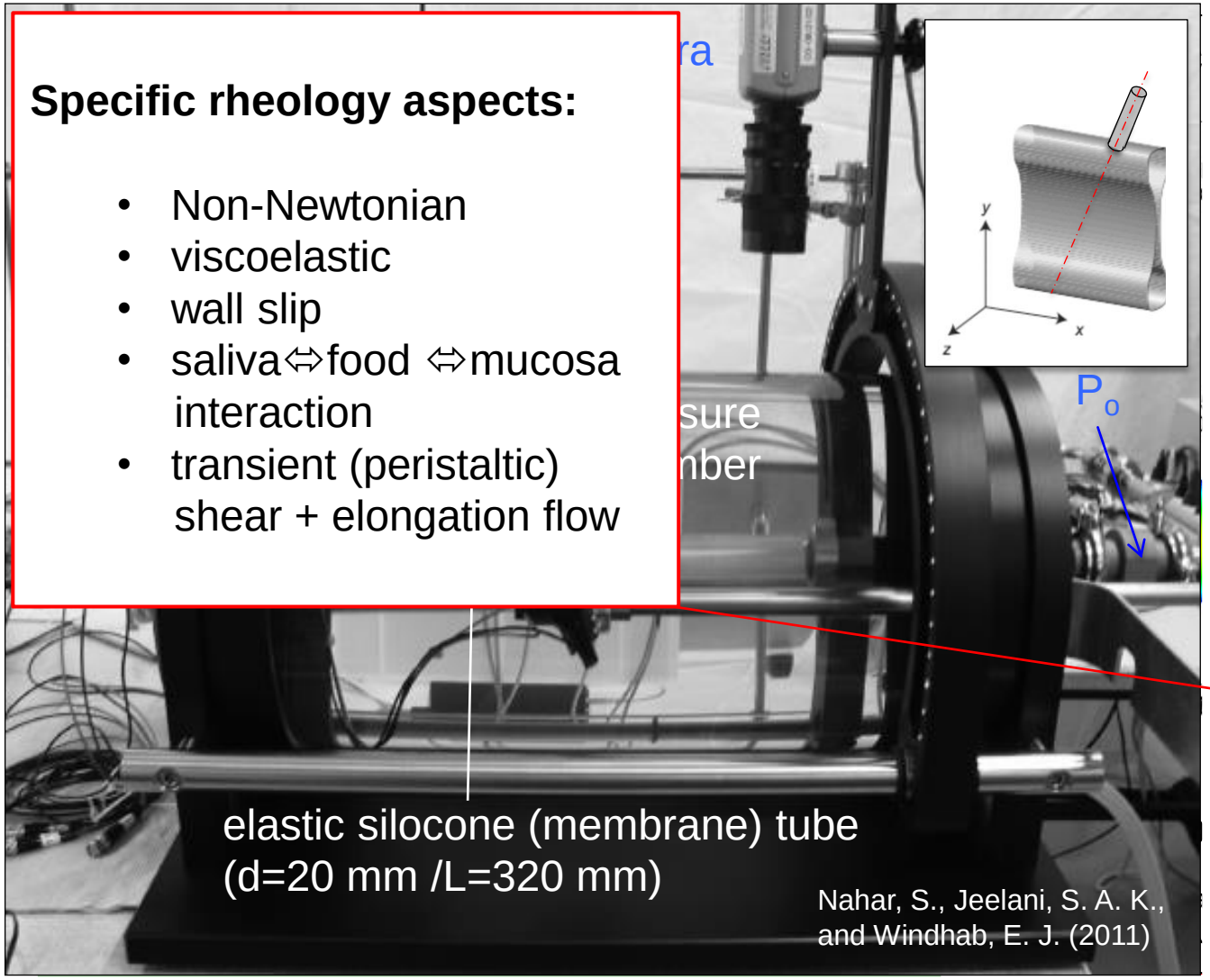
controlled release of functional molecule (◆):

- site
- kinetics
- metabolic functionality (incl. bioavailability)

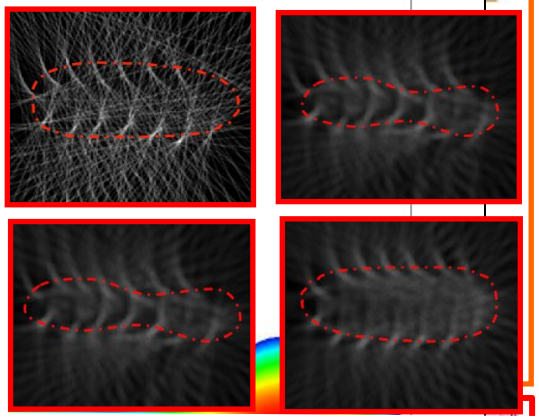
Experimental (Ultrasound-Doppler) velocity field measurements and Simulation of esophageal non-Newtonian (shear - thinning) fluid flow

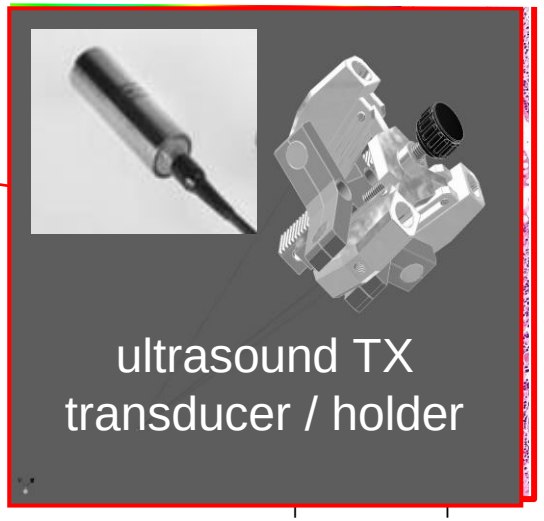
Specific rheology aspects:

- Non-Newtonian
- viscoelastic
- wall slip
- saliva⇔food ⇔mucosa interaction
- transient (peristaltic) shear + elongation flow



collapsing tupe deformation states

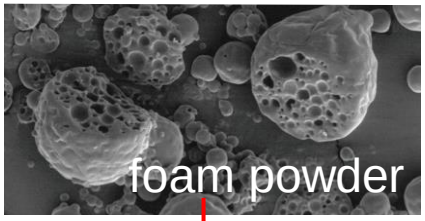


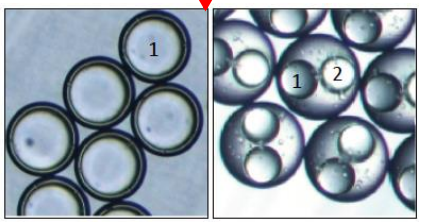


ultrasound TX transducer / holder

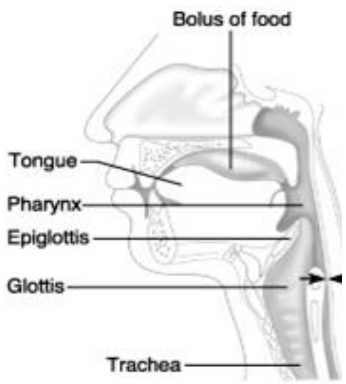
2. Oro-Gastro-Intestinal Processing

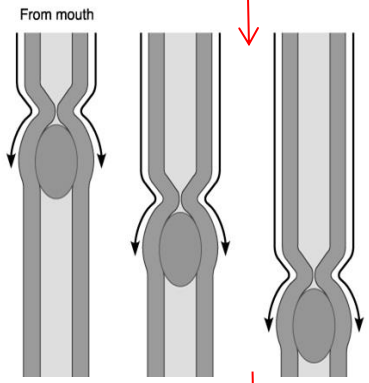
Digestion = Disintegration + Transport + Reaction



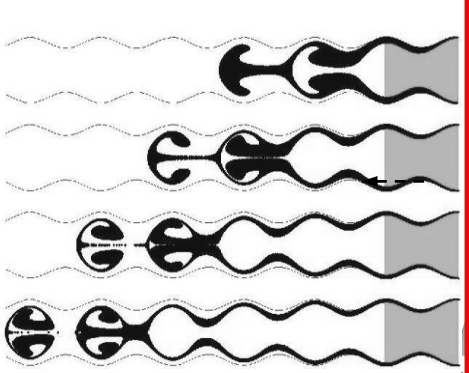


Mouth → Esophagus

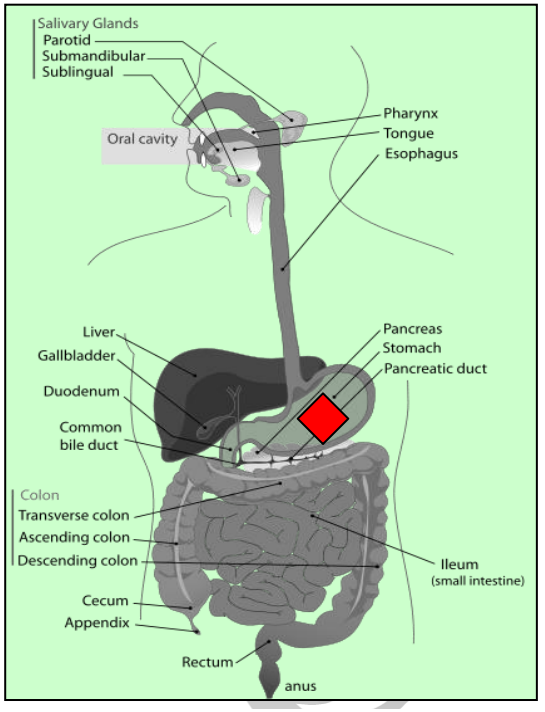




Small/large intestine ← **Stomach**



A. Leger, (2004)



controlled release of functional molecule (◆):

- site
- kinetics
- metabolic functionality (incl. bioavailability)

2. Oro-Gastro-Intestinal Processing

$\dot{\varepsilon}_{max} \approx 3.0 – 5.0$ 1/s
$\Delta t \approx 10$ s
$\varepsilon_{H,max} \approx 3.7$

$Ca_c \approx 0.05 / 0.2$
in uniaxal / planar elongational flow
at $\lambda \approx 0.07$
(model myonnaise)

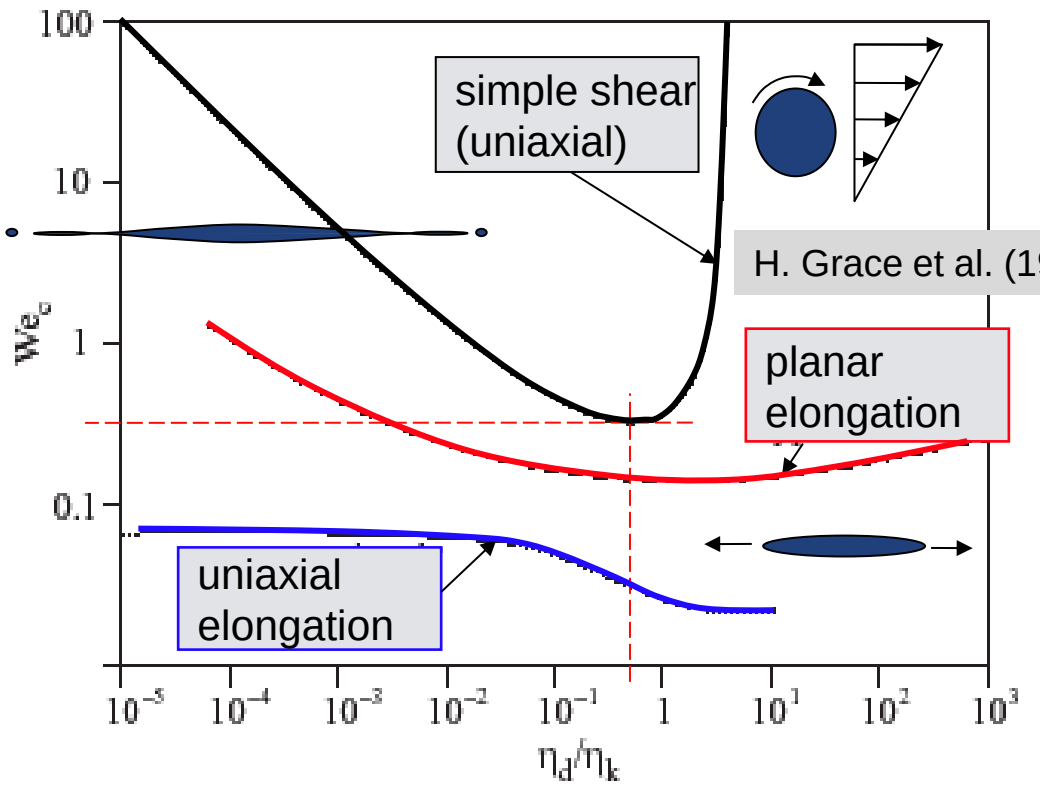
$\Rightarrow x_{max} \approx 5 - 20$ µm
assumption: steady state

O/W – emulsion:
(model mayonnaise)

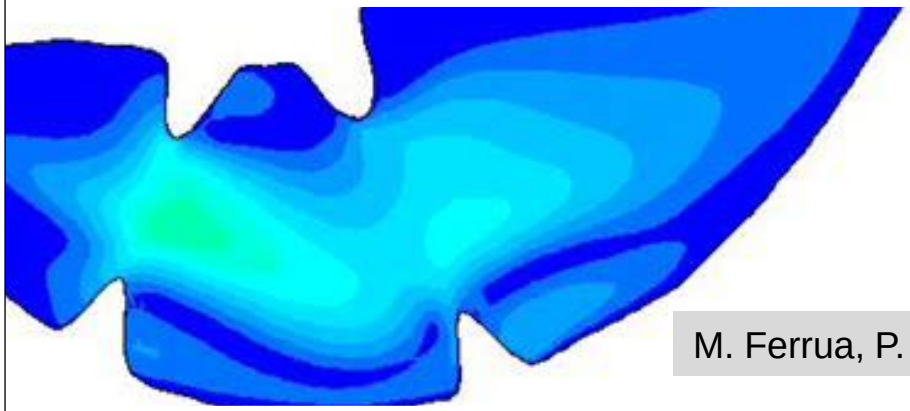
with $\eta_{+chyme,\gamma} \approx 0.5$ Pas
$\eta_{+chyme,\varepsilon} \approx 1.5$ Pas

assumption: elevated η,
$\sigma = 50$ mN/m

E. Windhab et. al. (2013)

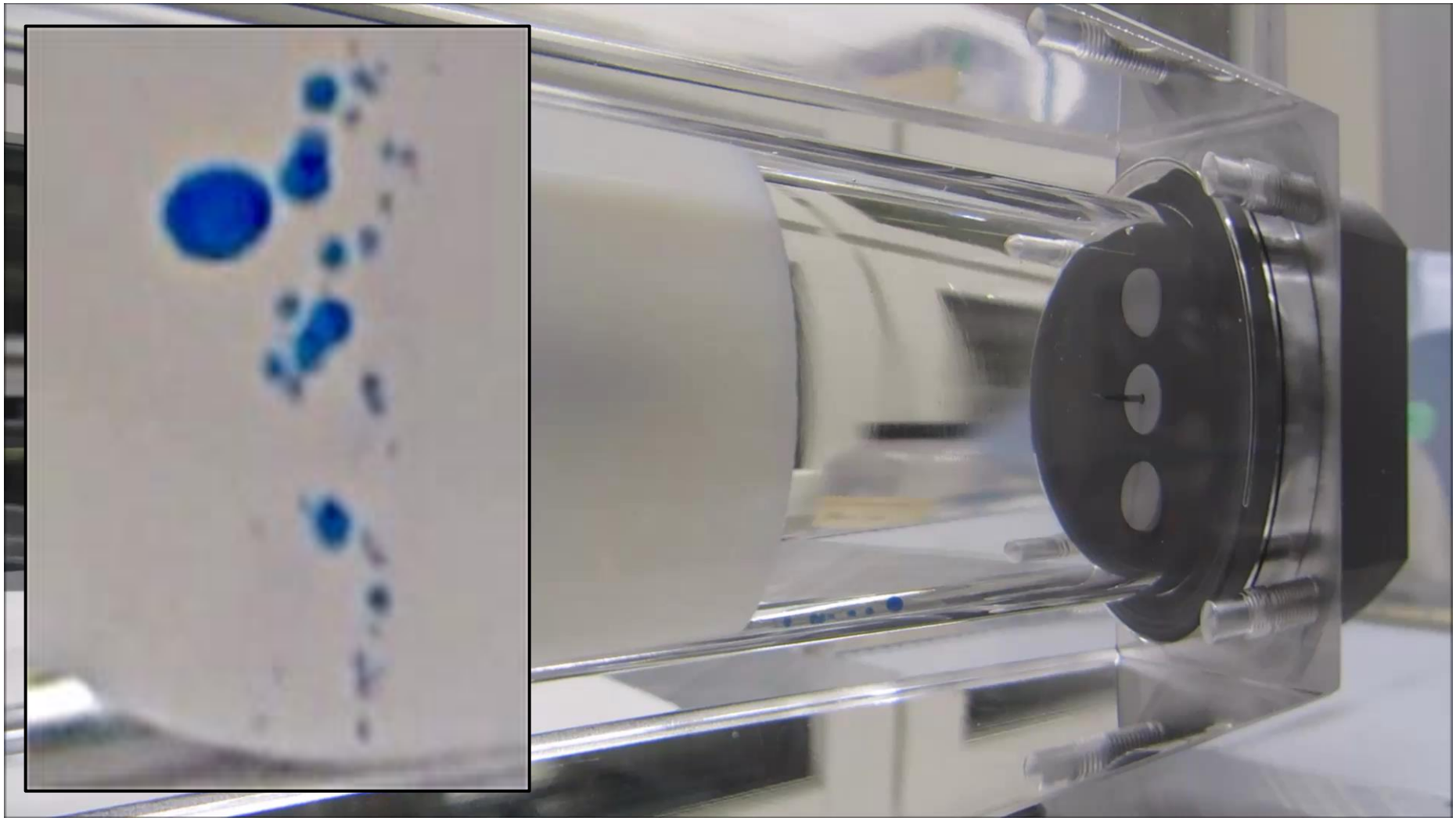


H. Grace et al. (1956)



M. Ferrua, P. Singh (2010)

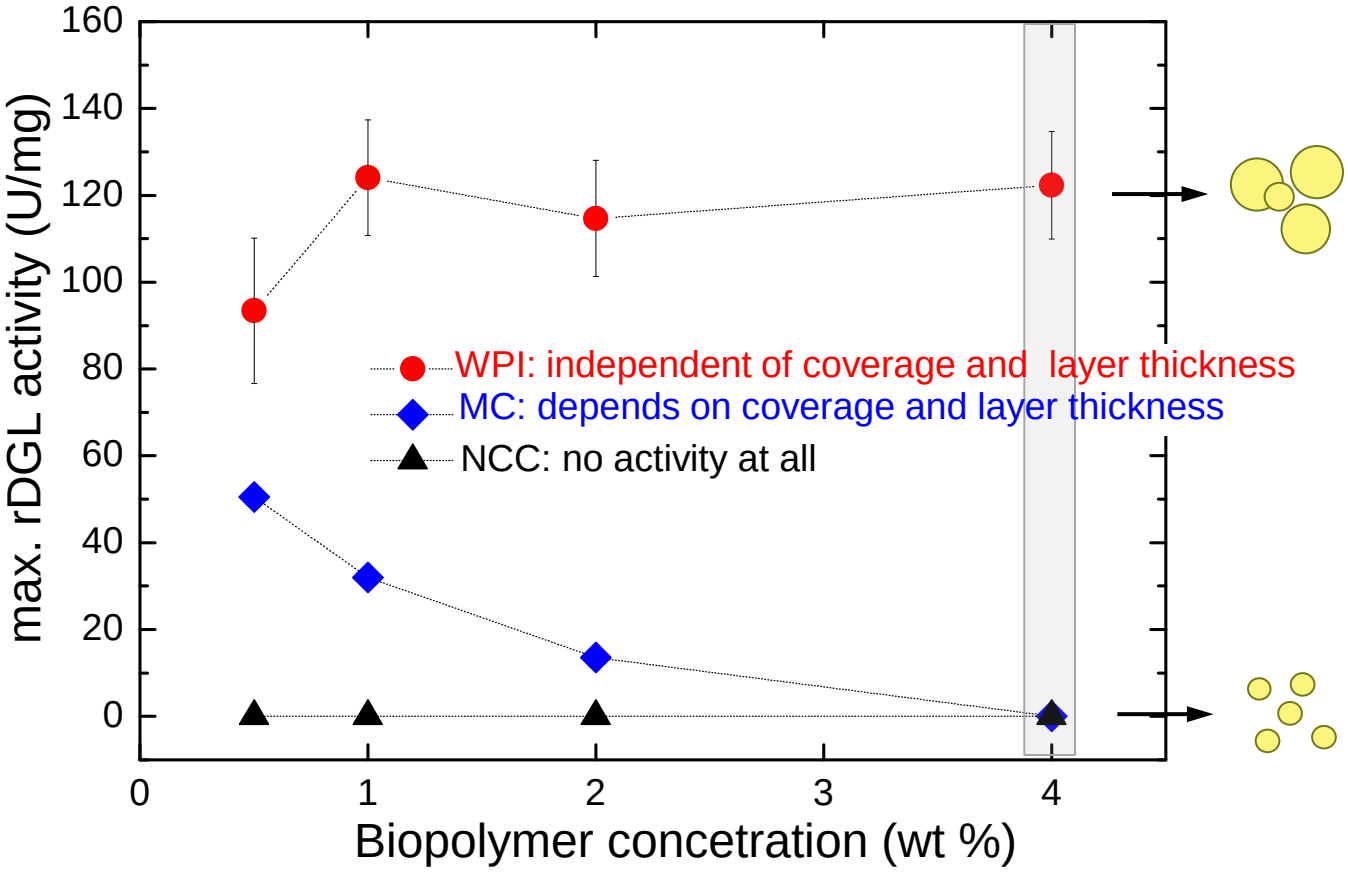
2. Oro-Gastro-Intestinal Processing

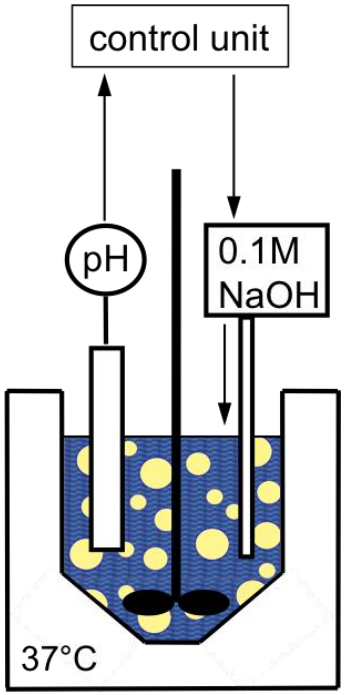


Mechanical human stomach model – Antrum wave dispersing experiments

Gastric lipolysis influenced by biopolymer type

(after 30 min. treatment time)

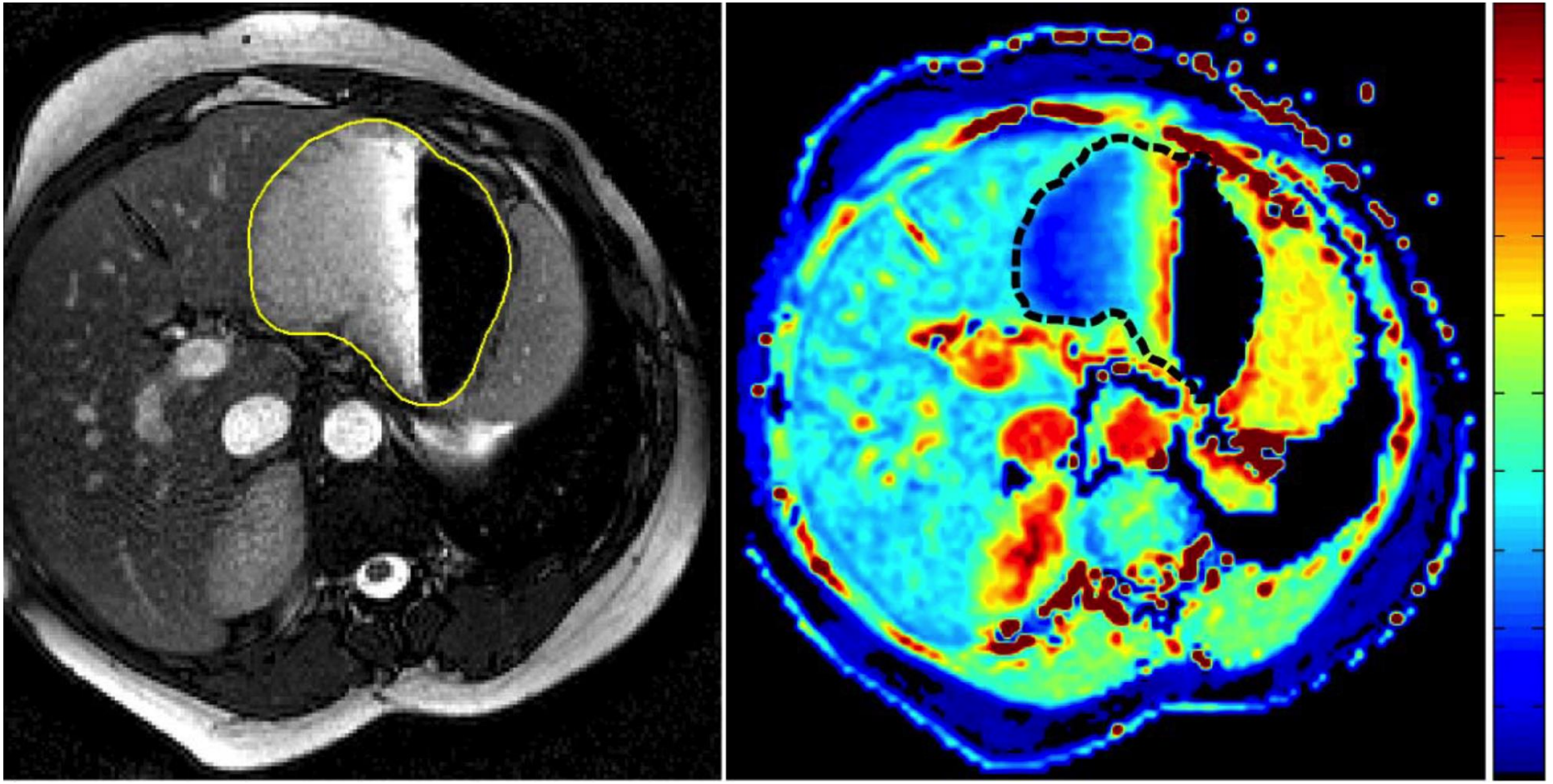




rDGL: recombinant dog gastric lipase

Gastric pre-digestion and emulsion re-structuring (e.g. oil droplet coalescence) have a major impact on gastric emptying, satiety and further duodenal fat digestion => gastric fluid mechanics + biochemistry => electrostatics interaction of interfaces and bulk structuring

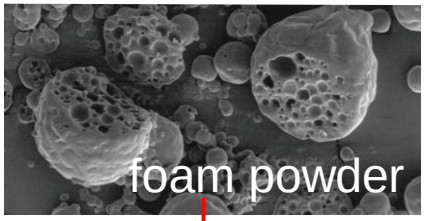
From qualitative to quantitative MRI

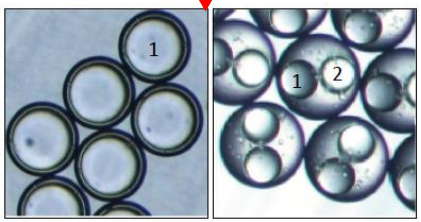


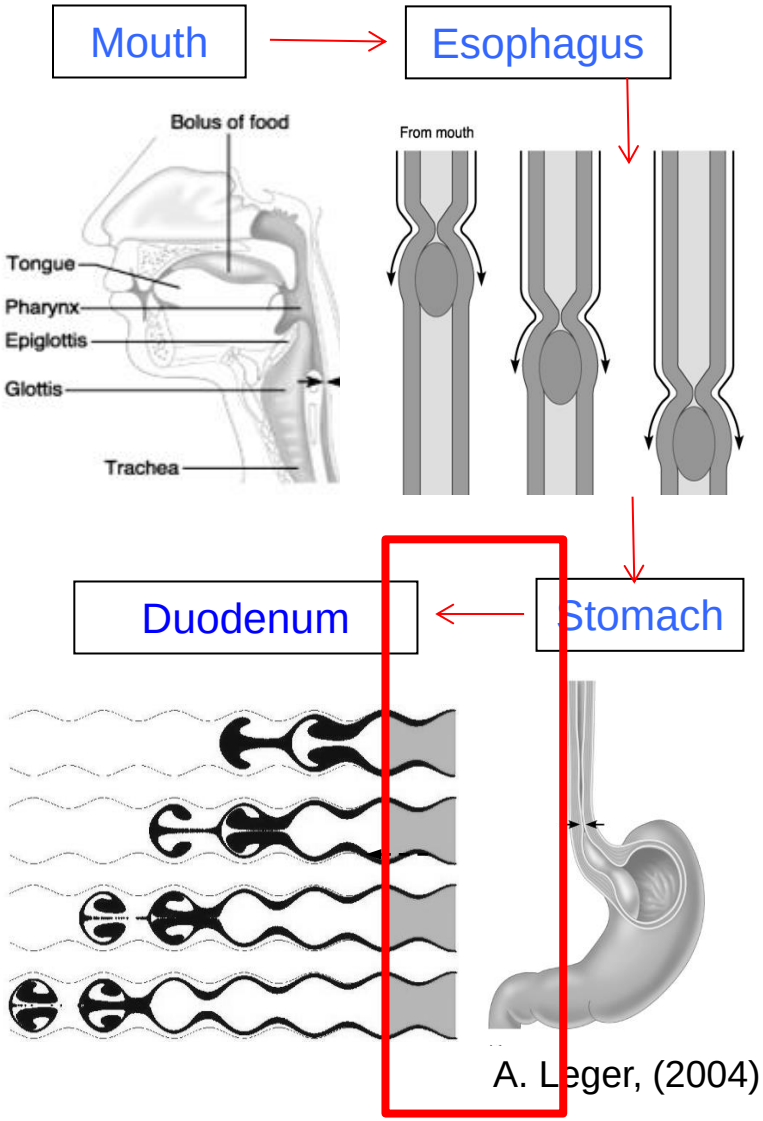
NRP69: Andreas Steingötter
(University of Zurich, Division Gastroenterology and Hepatology, 2016)

2. Oro-Gastro-Intestinal Processing

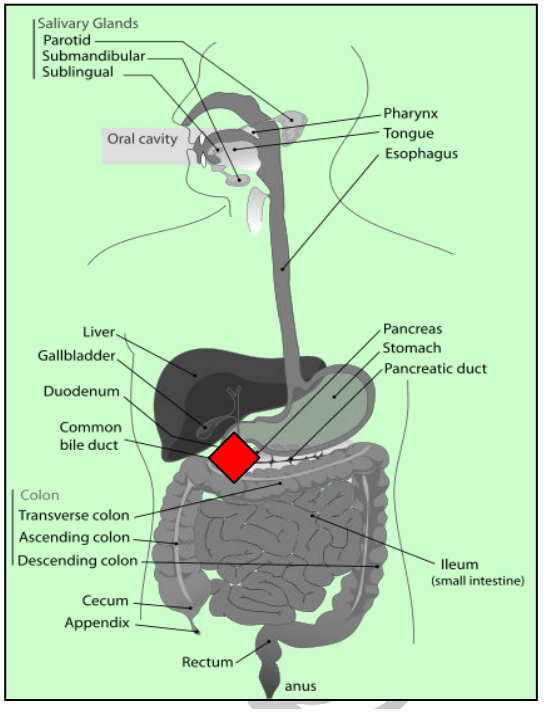
Digestion = Disintegration + Transport + Reaction







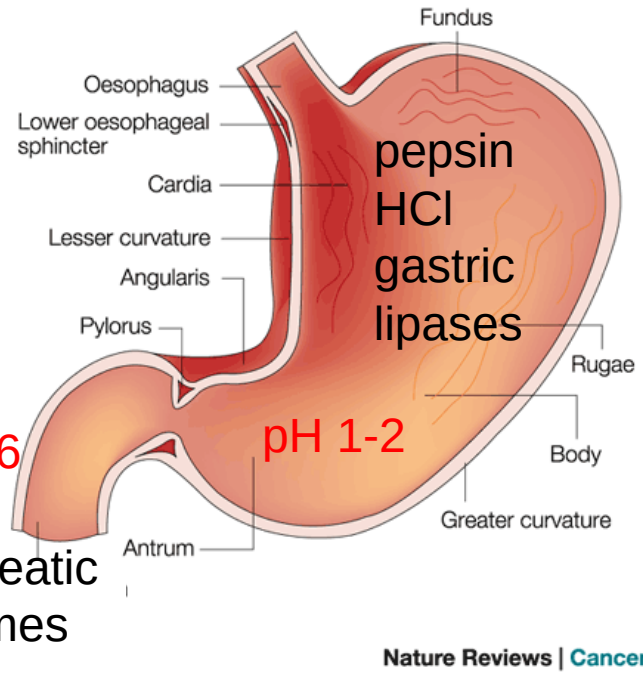
A. Léger, (2004)



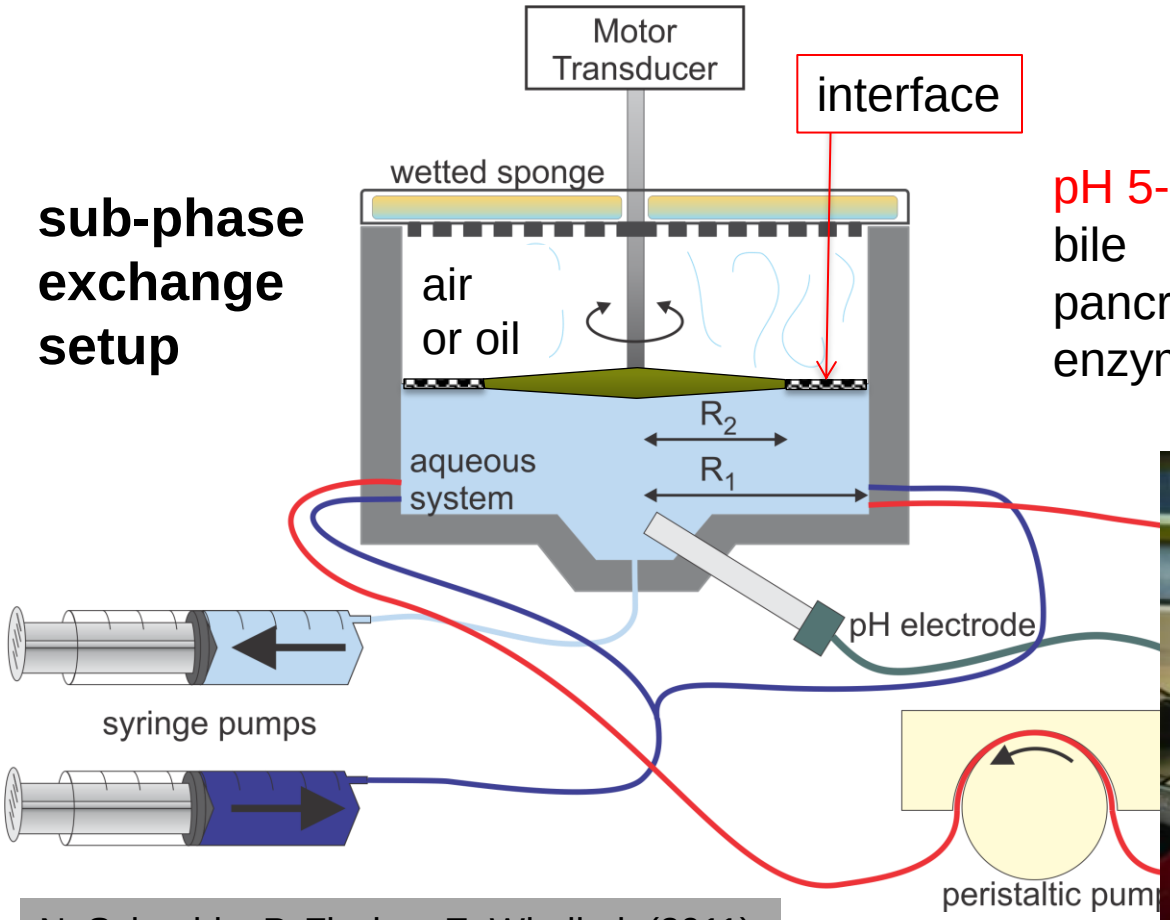
controlled release of functional molecule (◆):

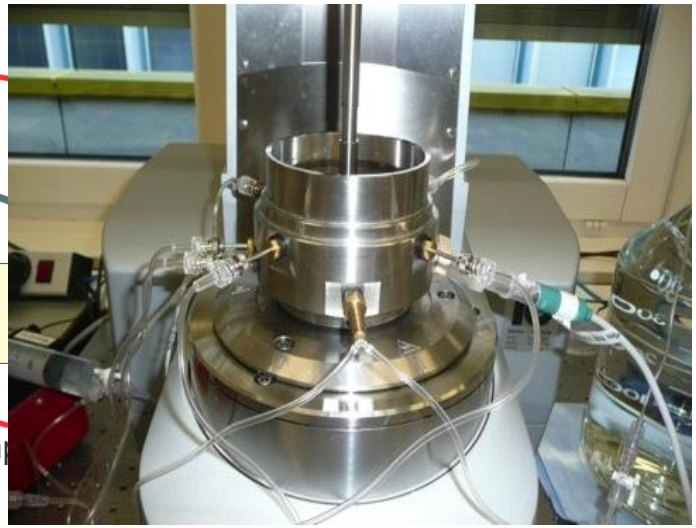
- site
- kinetics
- metabolic functionality (incl. bioavailability)

Impact of switch from gastric to duodenal conditions
on interfacial structure transformation / disintegration



sub-phase exchange setup

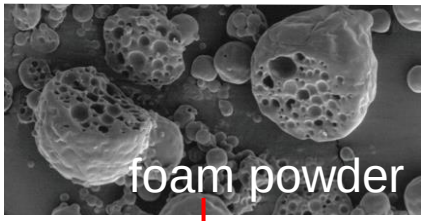


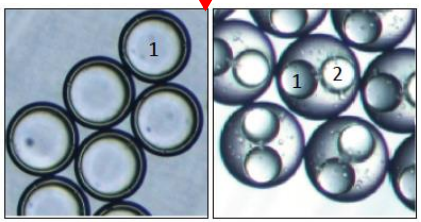


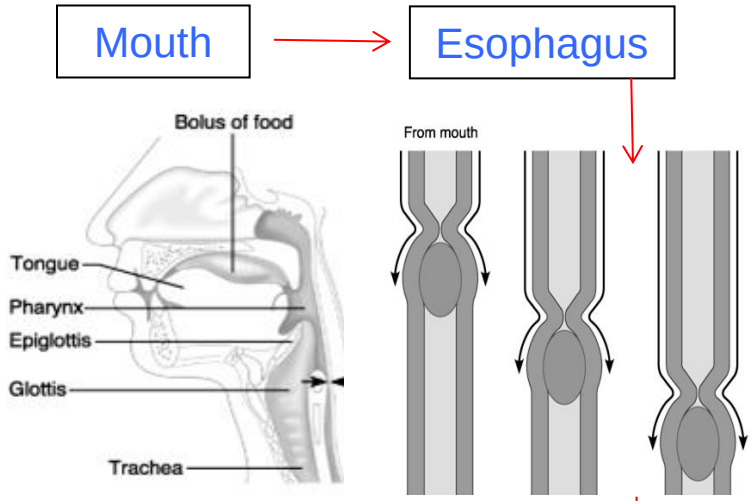
N. Scheuble, P. Fischer, E. Windhab (2011)

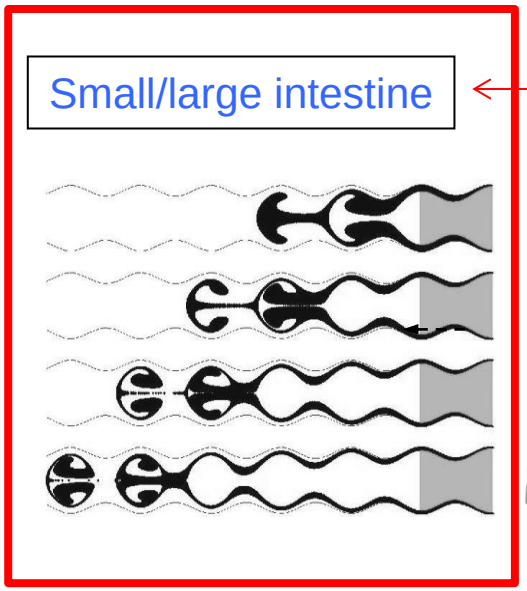
2. Oro-Gastro-Intestinal Processing

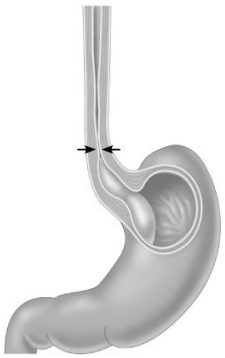
Digestion = Disintegration + Transport + Reaction



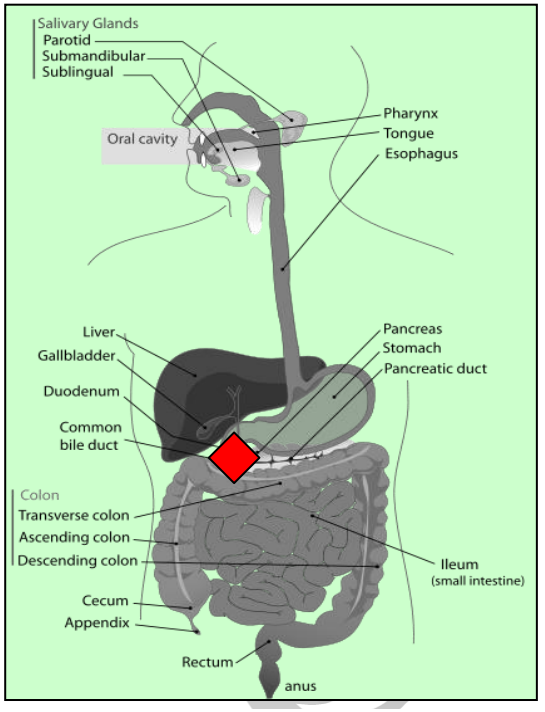








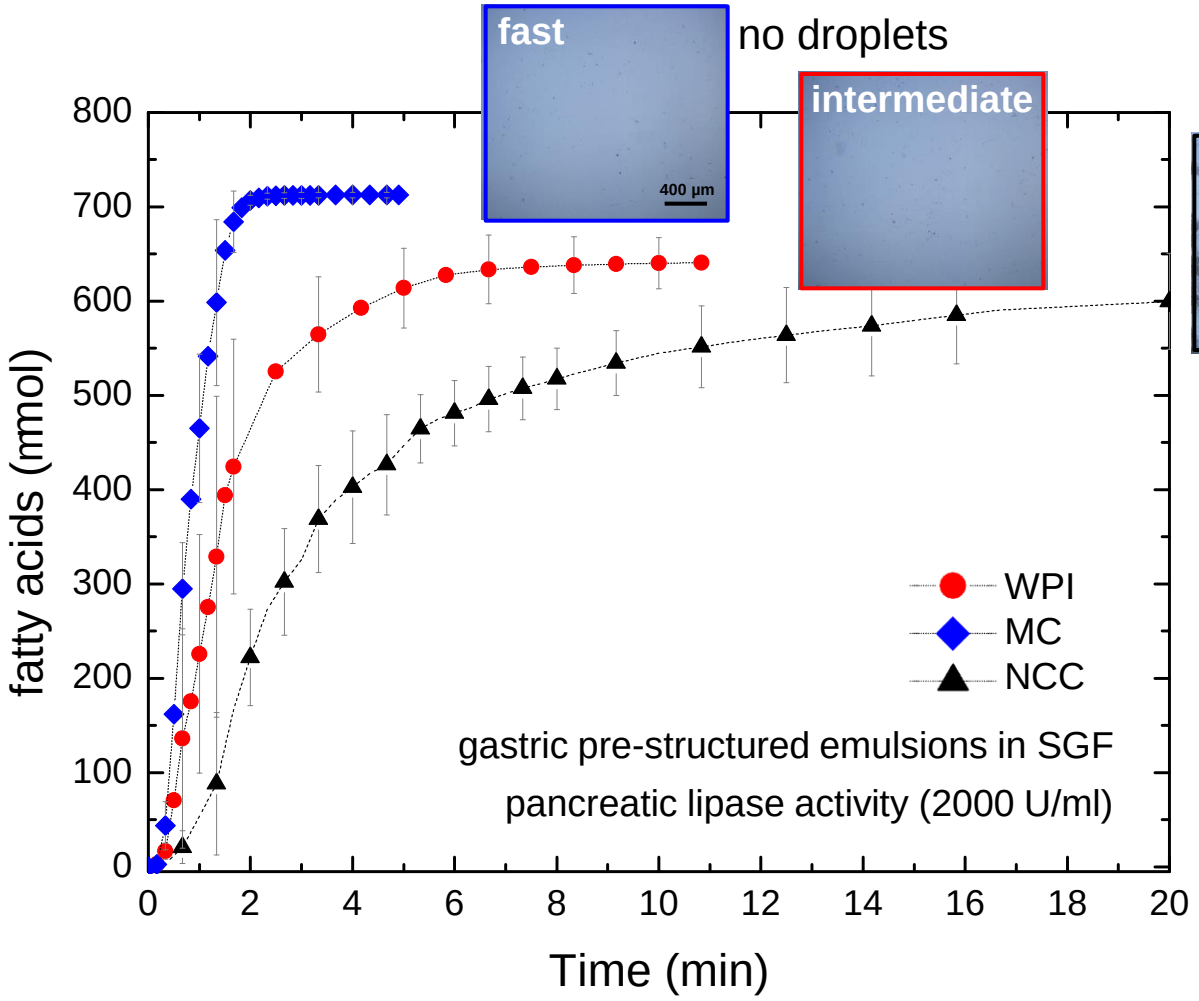
A. Leger, (2004)

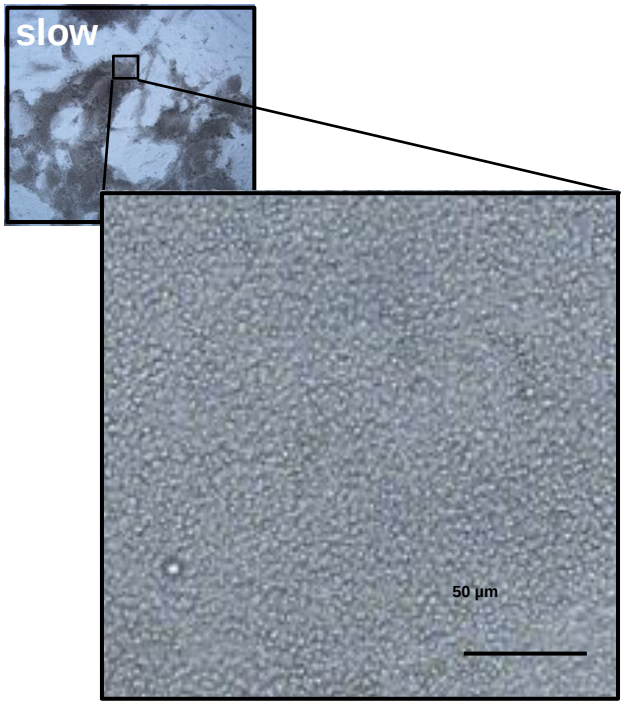


controlled release of functional molecule (◆):

- site
- kinetics
- metabolic functionality (incl. bioavailability)

Duodenum: Pancreatic lipolysis depends on gastric structures



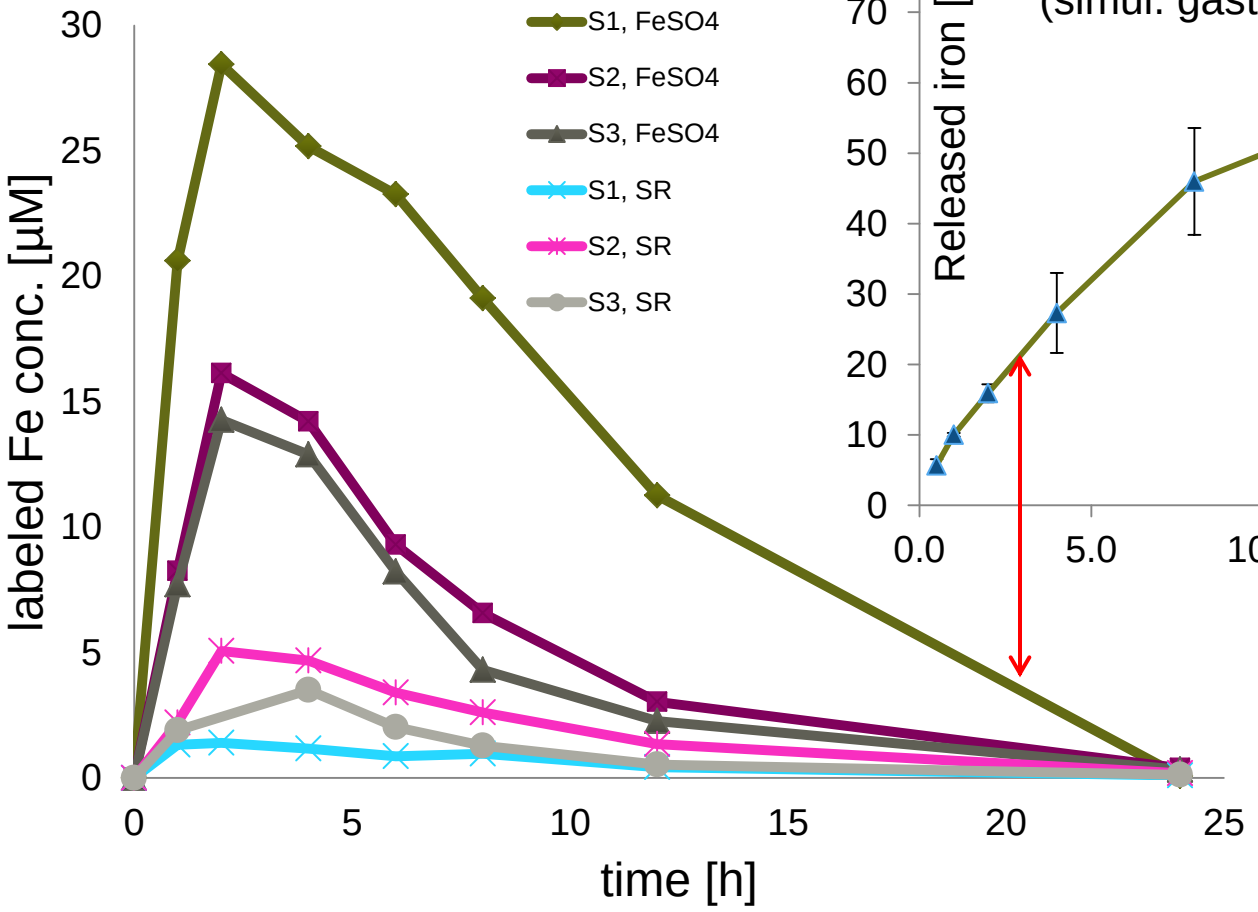


still lumps consisting of intact droplets

Iron Supplementation / Food Fortification

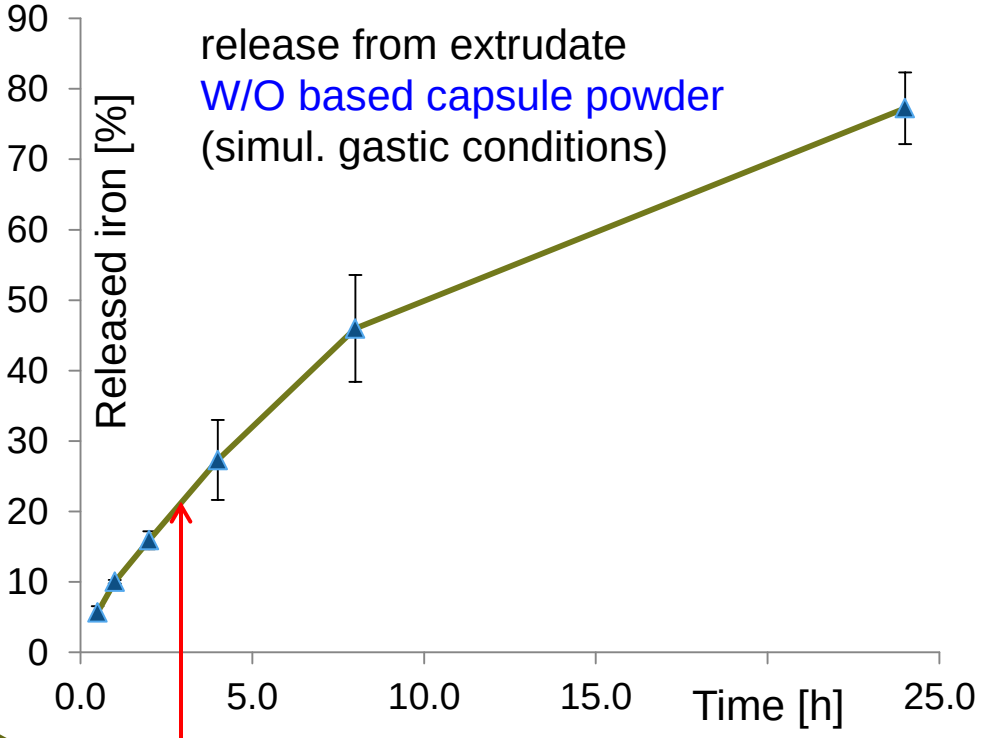
in vivo :

Human Study (pre-menopausal women): Fe serum apperance curves



in vitro :

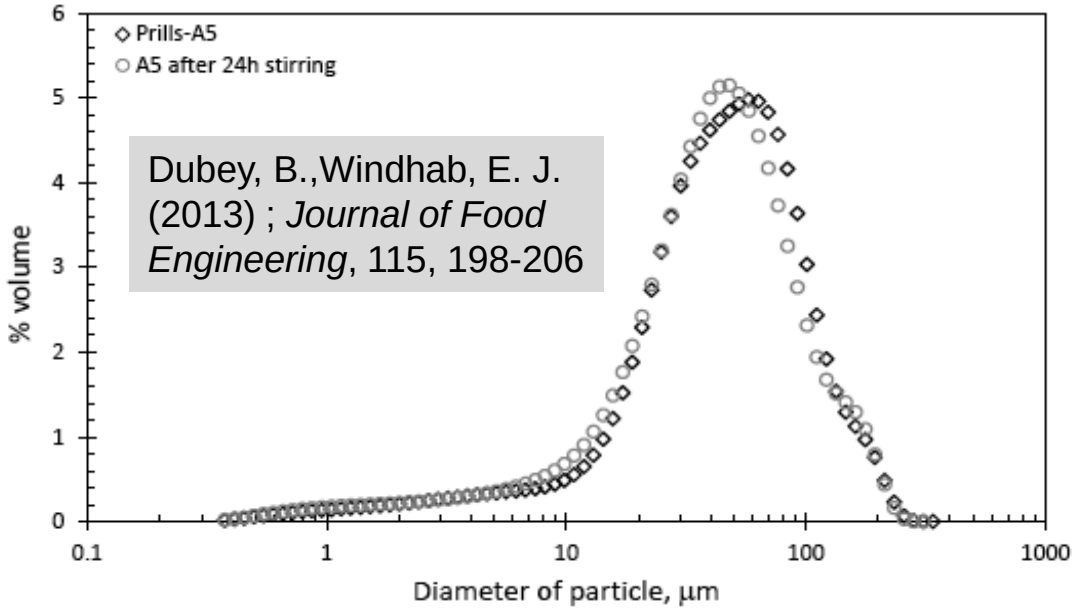
release from extrudate
W/O based capsule powder
(simul. gastic conditions)



Ch. Käppeli, E. Windhab et. al. (2013)

by Stable Isotope Technique; (I. Egli et al.; ETH HN-Lab), (2013)

2. Oro-Gastro-Intestinal Processing



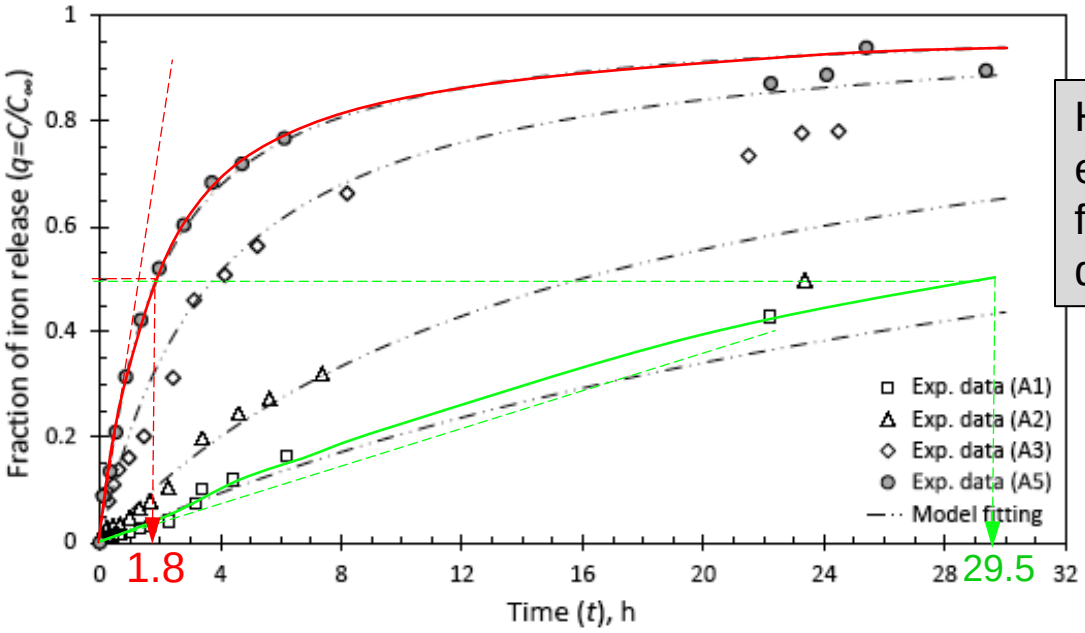
Dubey, B.,Windhab, E. J. (2013) ; *Journal of Food Engineering*, 115, 198-206

$$\frac{c(t)}{c_{¥}(t=¥)} = \frac{kt}{1+kt}$$

Iron release kinetics:

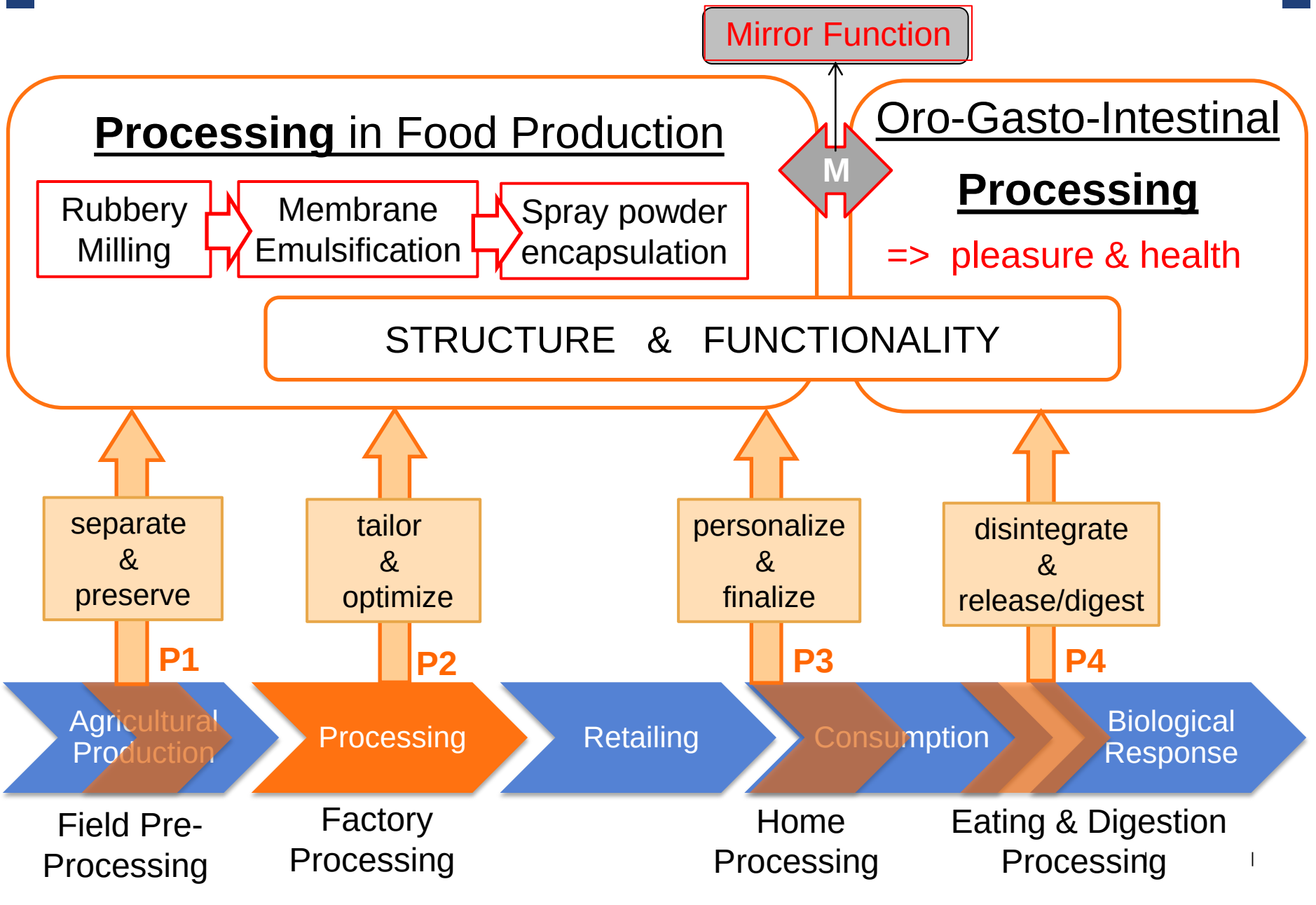
Samples	k, h^{-1} (after 1 week)
A1	0.0259
A2	0.0629
A3	0.2645
A4	0.5260
A5	0.4722
E1	2.9061
F1	0.0667
F2	0.2660
F5	2.7210

Extremes: Δ-factor ≈ 120



Here: iron (FeSO4) encapsulation/release from innermost watery (W1) double emulsion phase

Processing along the Food Value Chain



Acknowledgements

- Collaborators: A. Steingötter, W. Langhans, K. Feigl, F. Tanner (MTU)
- Sen. scienists: P. Fischer, Y. Takeda, S. Kuster, E. Rondeau, J. Shaik
- Workshops: D. Kiechl, B. Pfister, J. Corsano, P. Bigler, Dr. B. Koller
- Doctorands: L. Brütsch, S. Illmann, M. P. Erni, S. Holzapfel, J. Bahtz, P. Strähl, B. Dubey, B. Case, P. Guillet, N. Scheuble, D. Dufour, L. Pokorny, V. Lammers, S. Gstöhl, S. Nahar

&

Swiss National Research Foundation (SNF), European Union (EU, FP7), Swiss Commission of Technol. & Innovation (CTI), Deutsche Forschungsgemeinschaft (DFG) - SPPs 1273, 1423