The structure of the food matrix at different length scales affects the mechanisms of digestion and the nutrient bioavailability

Didier Dupont

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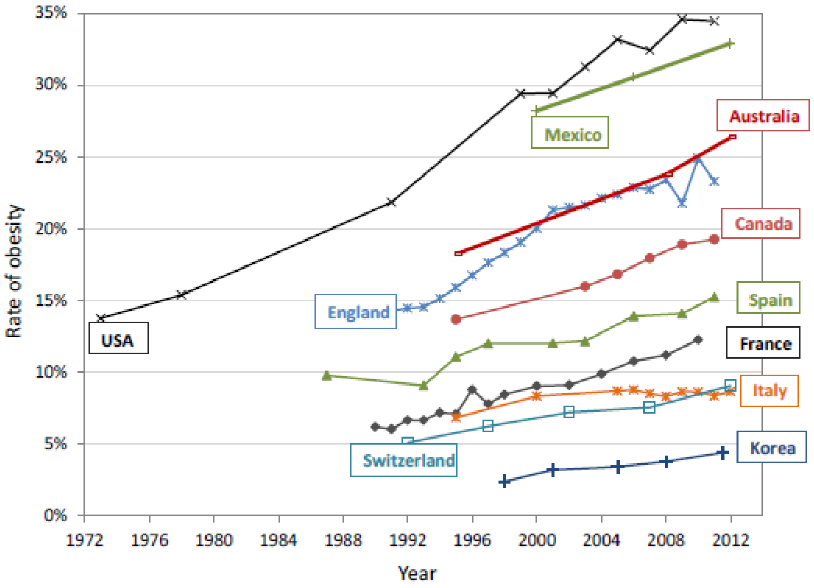
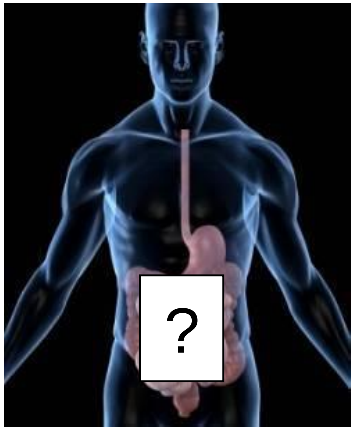
INRA
SCIENCE & IMPACT

Dr Didier DUPONT, INRAE, STLO, Rennes, France

Food and human health: the key role of digestion



Diet-related diseases ↑
Prevent these pathologies rather than cure them

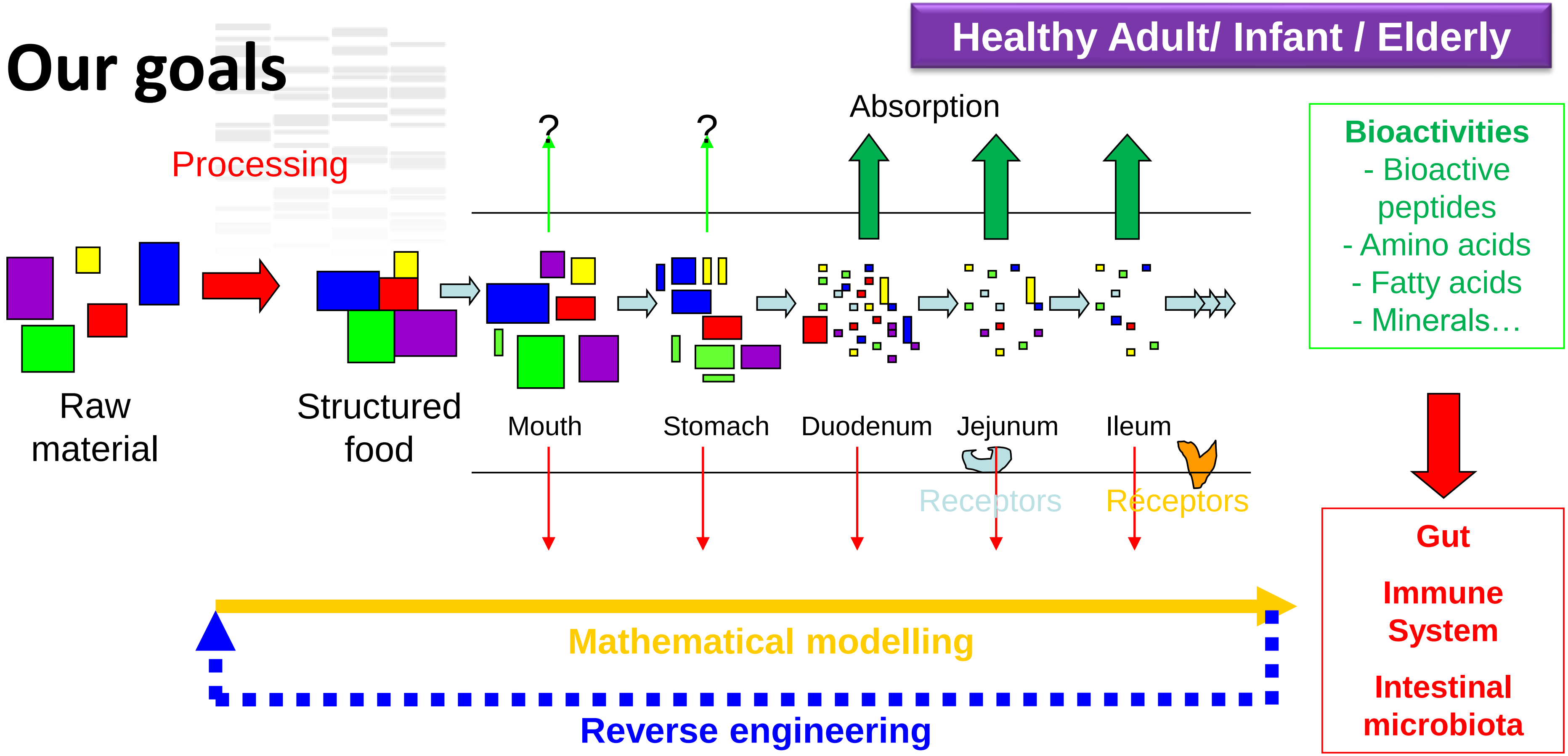


Gut = interface between food and human body
Digestion releases food components that can have a beneficial or a deleterious effect on human health

… but the mechanisms of food disintegration in the gastrointestinal tract remain unclear and the digestive process has been considered as a black box so far

By increasing our knowledge on food digestion, we will increase our knowledge on the effect of food on human health

Our goals

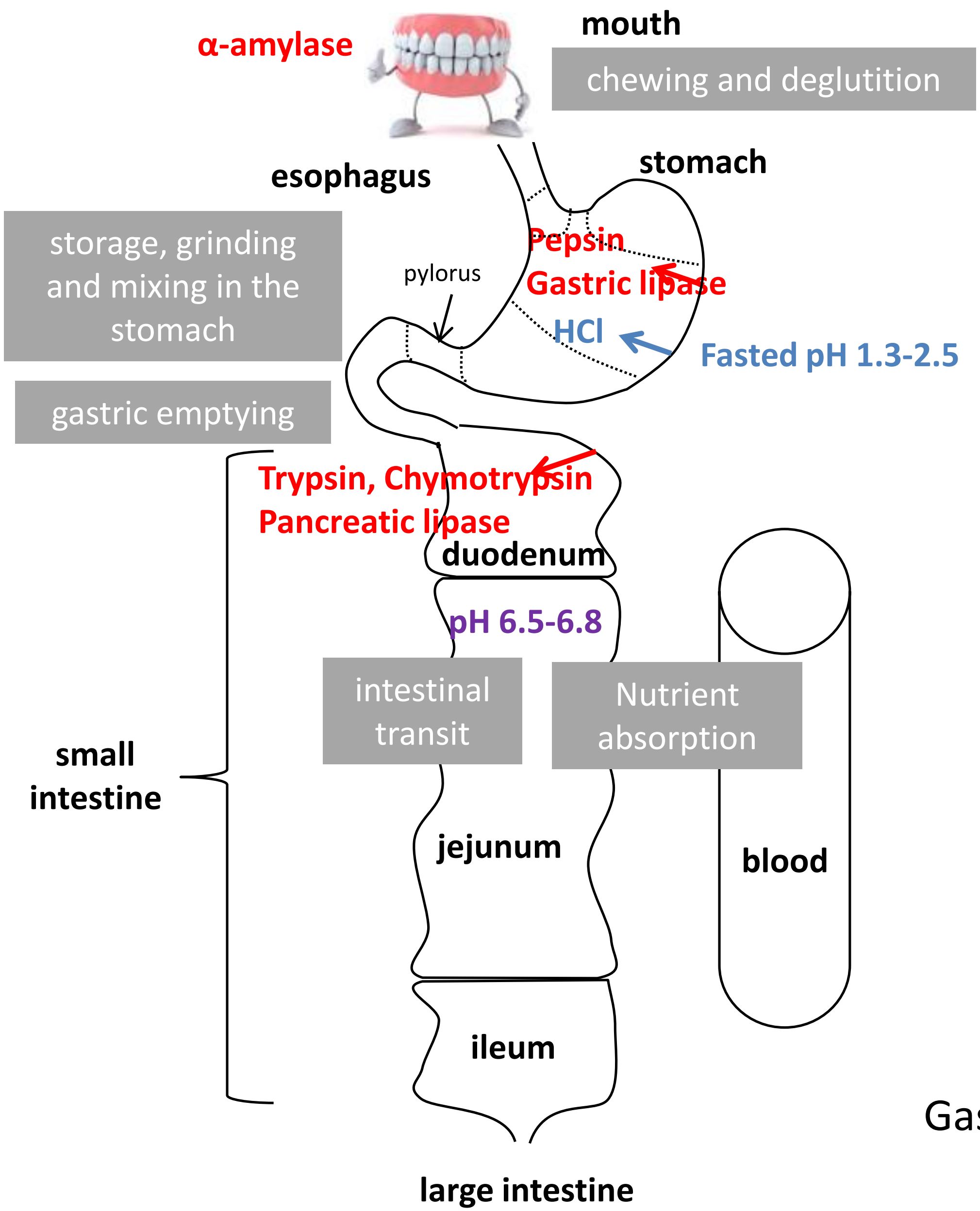


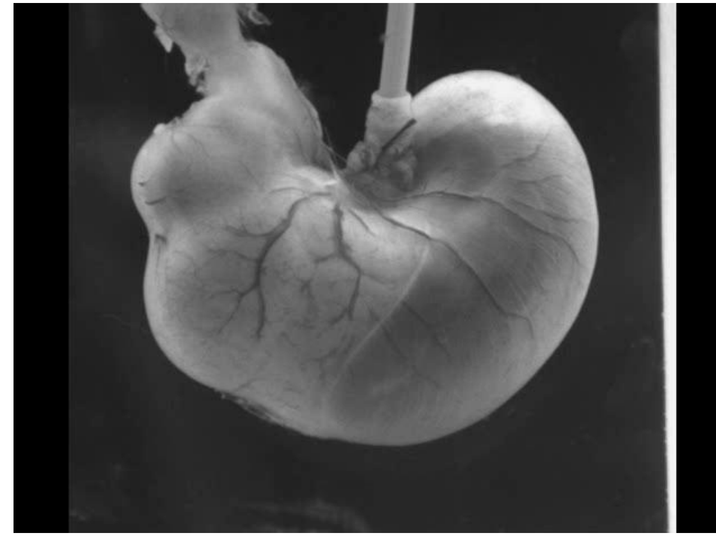
☞To understand the mechanisms of breakdown of food matrices and their constituents in the gut and identify the beneficial/deleterious food components released during digestion

☞To determine the impact of the structure of food matrices on nutrient bioavailability

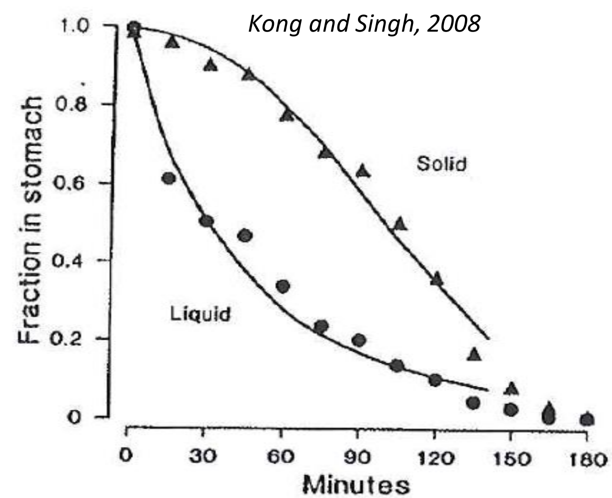
☞To model these phenomena in order to develop a reverse engineering approach

The digestive process





From Roger Lentle, Massey Univ. NZ



Gastric phase = a very complex but crucial step for the whole digestion process

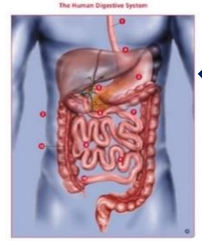
Models available at INRAE for simulating digestion

Menard et al. 2018, 2023
Wang et al. 2022

In vitro static models (infant, adult, elderly)

Peng et al. 2021
Halabi et al. 2021
Giribaldi et al. 2021
Chauvet et al. 2023
Nebbia et al. 2022, 2023

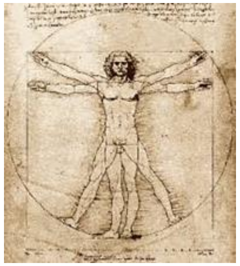
In vitro dynamic models (infant, adult, elderly)



Le Feunteun et al. 2014, 2020

In silico models

$$\Phi_{12} = k_{12whey} \times \left(V_1 - m_{caswpd1} \times \alpha\right) + k_{12aggr} \times m_{caswpd1} \times \alpha$$



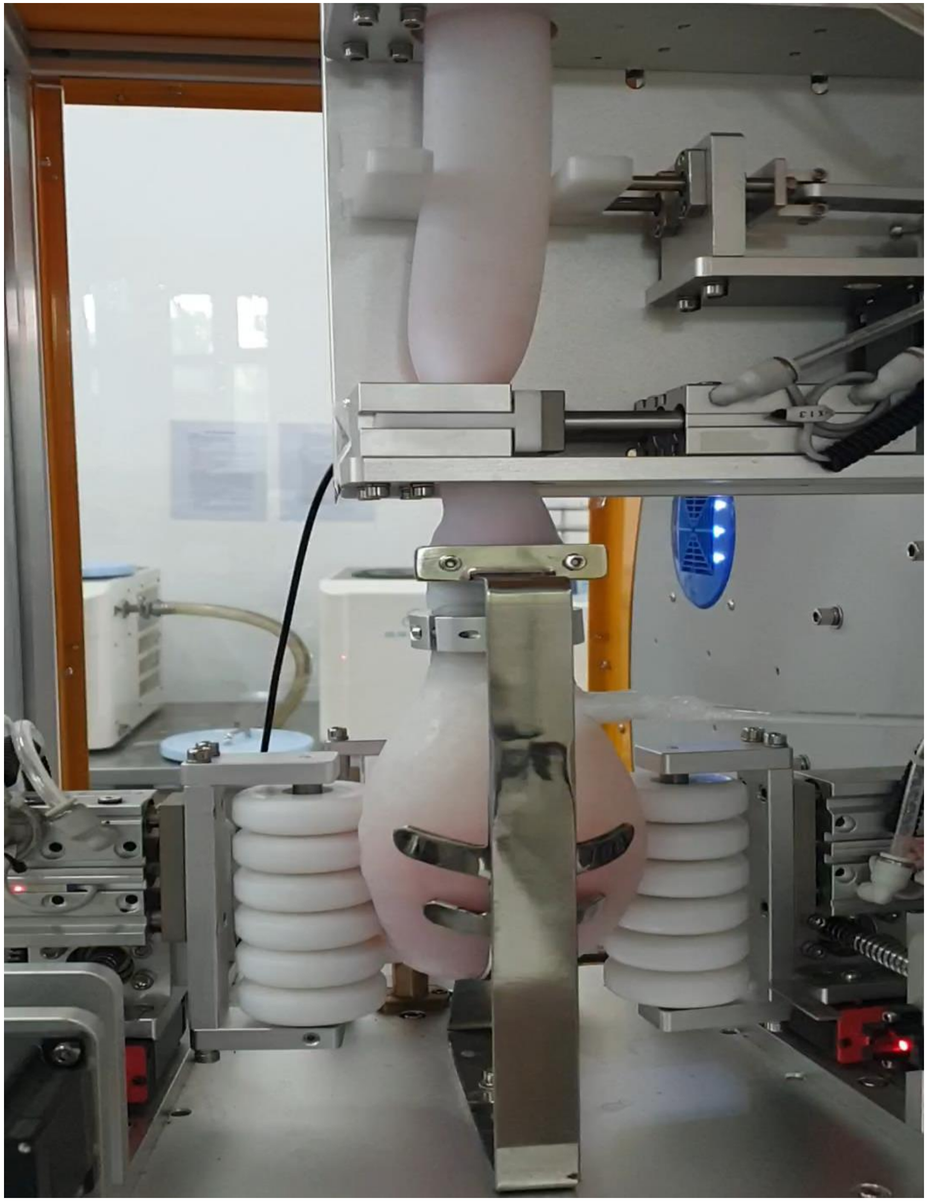
Human models

De Oliveira et al. 2016
De Oliveira et al. 2017
Buffière et al. 2020
Boulier et al. 2023

Animal models

Lemaire et al. 2021
Nau et al. 2022
Jimenez-Barrios et al. 2023
Charton et al. 2022, 2023

NERDT™ : the NEar Real Digestive Tract



STOMACH

Xiao Dong Pro-Health
Smart Digestion
Suzhou University

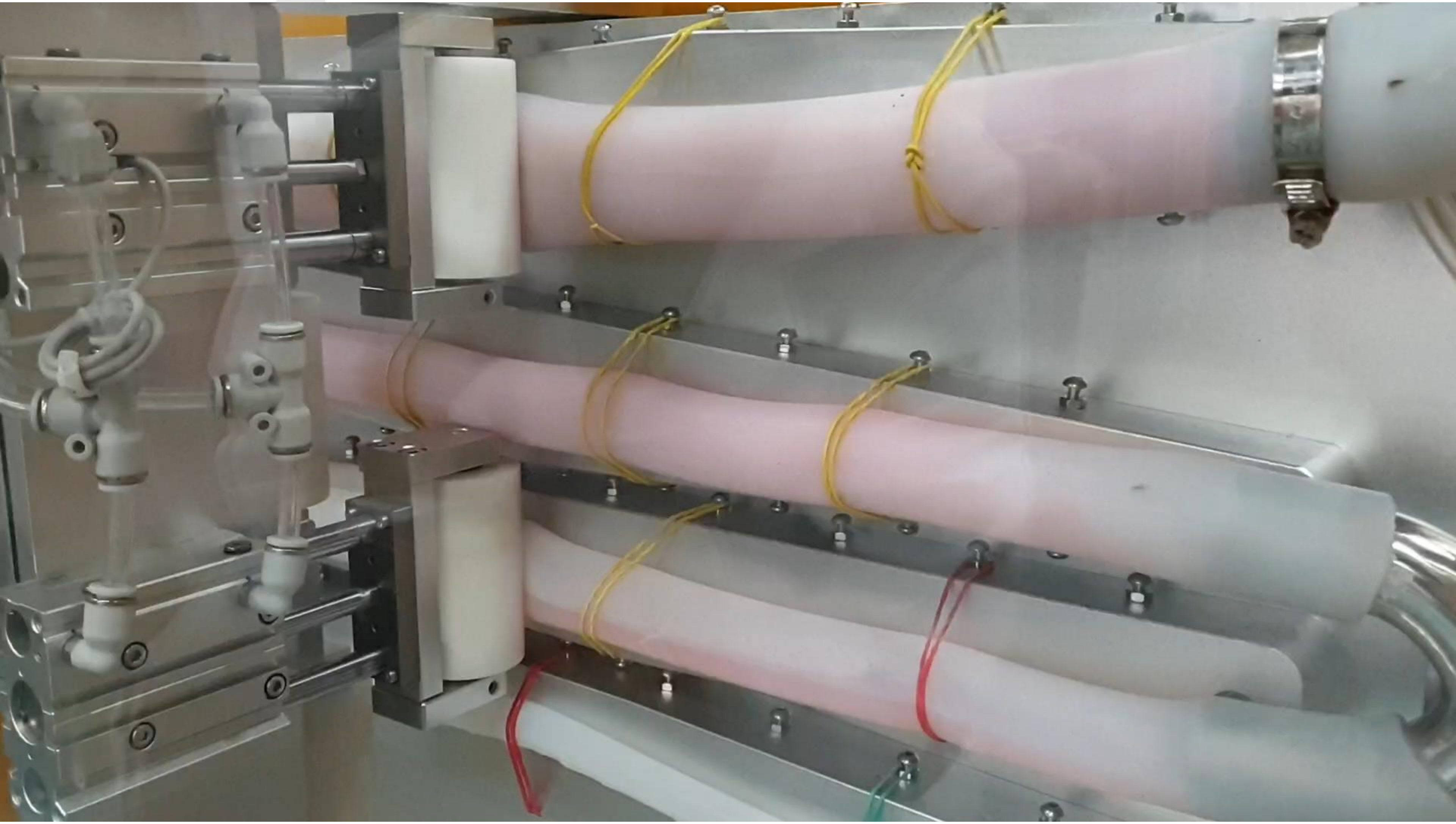
SOOCHOW UNIVERSITY
UNTO A FULL GROWN MAN

INRAE

L'INSTITUT agro Rennes Angers

INSTITUT CARNOT QUALIMENT

Simulating the small intestine

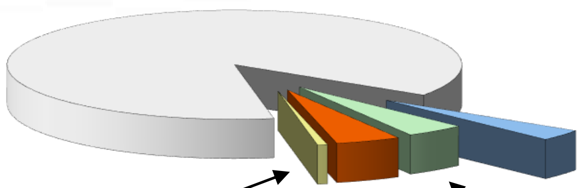


The molecular structure of food protein affects the kinetics of digestion

Boudry G,, Henry G & Dupont D.
INRAE, Rennes, France

Milk

Molecular scale

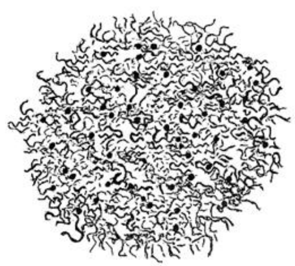


Proteins (32-35 g/L)

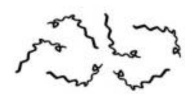
Caseins (80%)
αs_1, αs_2, β, κ

Whey Proteins (20%)
β-lg, α-la

ø~200 nm
(Holt, 1994)



Casein organized into a supramolecular structure: the **casein micelle (CM)**

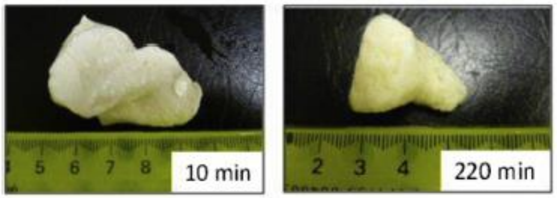


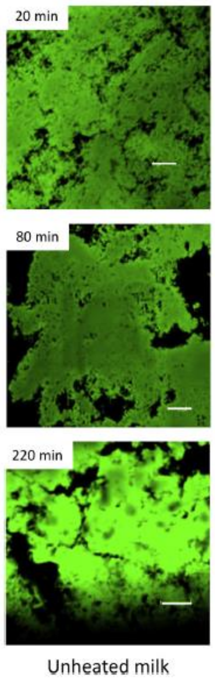
ø~11 nm
~15 casein molecules;
(Thomar *et al*. 2013)

Casein can also be extracted after acidification followed by neutralization: the **caseinate (CS)**

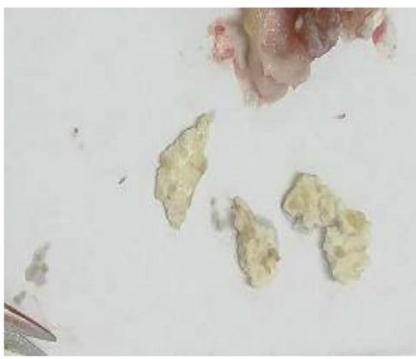
Milk coagulates in the stomach

Molecular scale

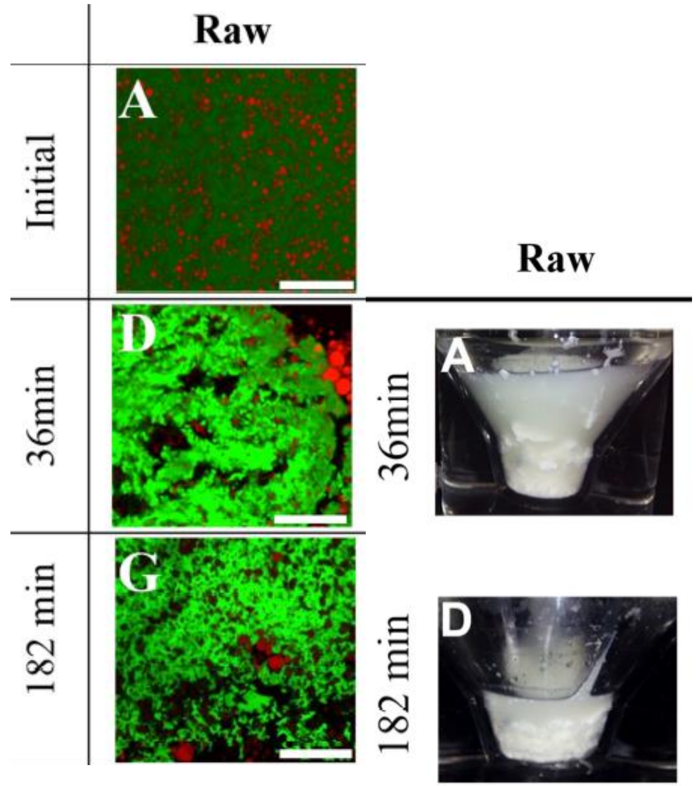




In vitro demonstration using the HGS
Ye *et al*. 2016



Ye *et al*. 2019
In vivo evidence using a rat model



Mulet-Cabero *et al*. 2019
In vitro semi-dynamic model

Casein micelles and sodium caseinate form different coagulums
Wang *et al*. 2018

Objective

Molecular scale

The objectives of the study were to:

1 Determine whether gastric emptying of an isoproteic solution of CM and CS are different or not (exp. 1)

2 Characterize the structure of the resulting chyme and determine if CM and CS are differently metabolized (exp. 2)

Experiment 1 – Determination of Gastric Emptying

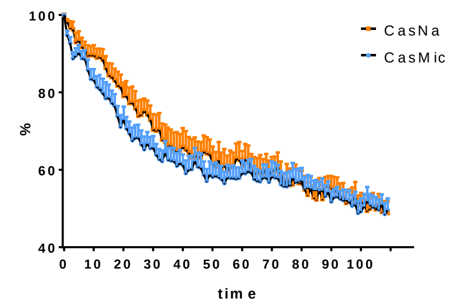
γ-scintigraphy over 120 min

96 g of CM or CS rehydrated in 800 ml of water

+12 g of glucose

+ ^{99m}Tc-colloidal (25Mbq)

9 pigs (20-25 kg)

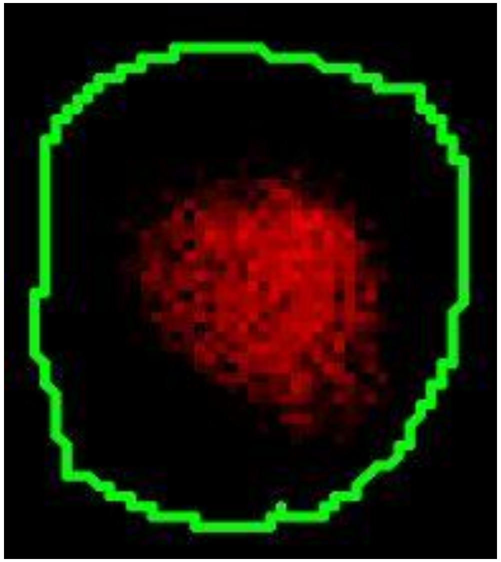


Gastric emptying half-time ($T_{1/2}$) and shape of the curve (β)

But a differential behaviour of CS and CM in the stomach

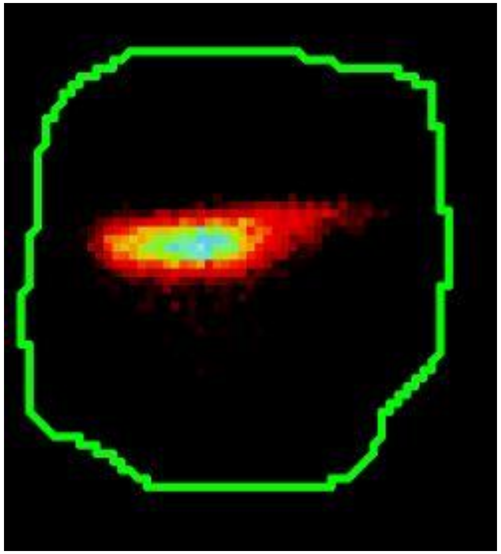
Exemple scintigraphic images at the beginning of gastric emptying (5-10 min after ingestion)

CM



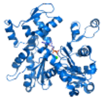
Radioactivity fully fills the stomach

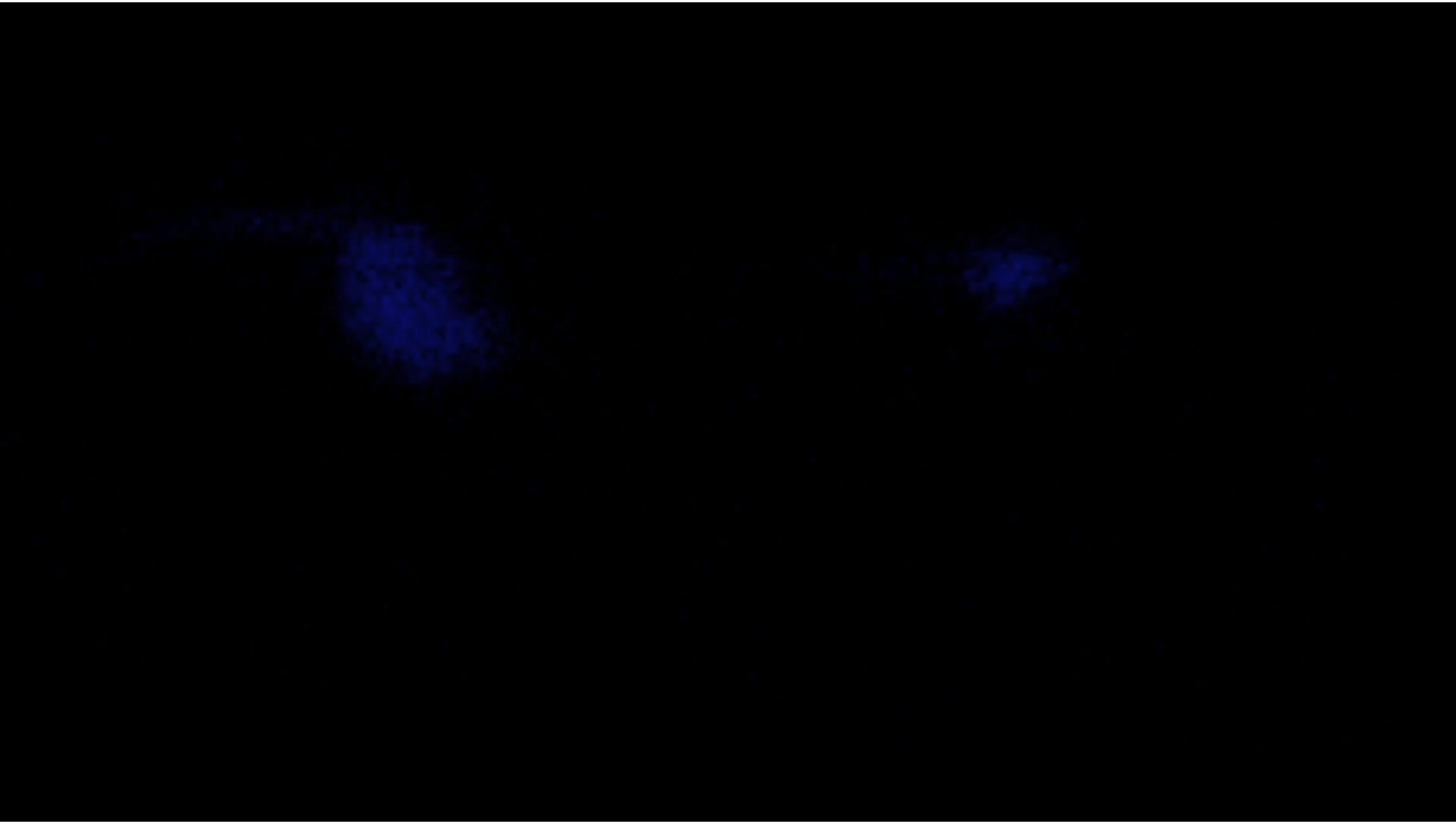
CS



Radioactivity is highly concentrated in the proximal part of the stomach

Gastric emptying

Molecular scale 



Objective

The objectives of the study were to:

1 Determine whether gastric emptying of an isoproteic solution of CM and CS are different or not (exp. 1)

2 Characterize the structure of the resulting chyme and determine if CM and CS are differently metabolized (exp. 2)

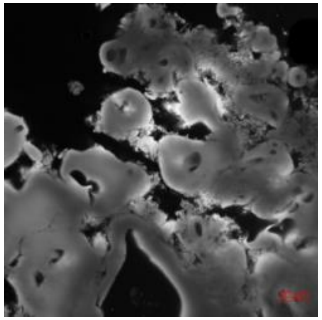
Experiment 2 – Chyme structure and protein metabolism

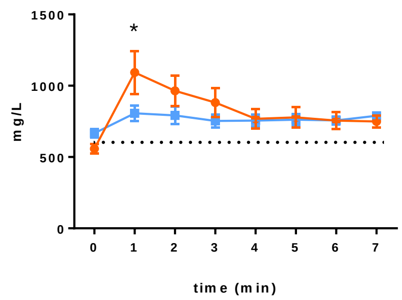
96 g of CM or CS rehydrated in 800 ml of water

+12 g of glucose

10 catheterized pigs (20-25 kg)

Characterization of the chyme structure (slaughtering after 10 min, n=4)





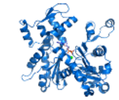
Free plasma amino acids over 7h n=6

Molecular scale

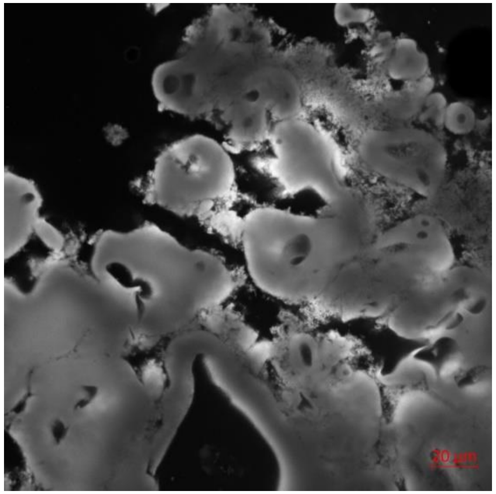
Collection of the stomach contents

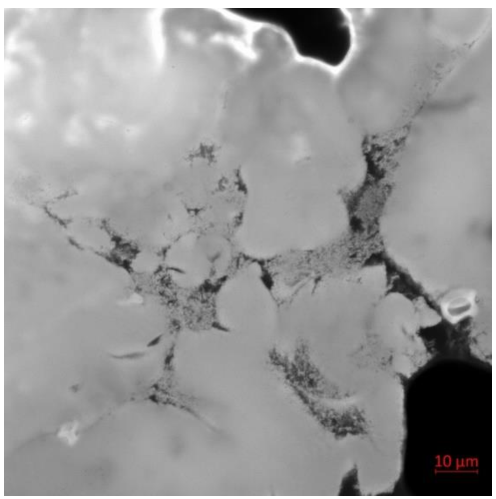
CM forms a large coagulum in the stomach whereas CS mainly remains in the liquid form

Microstructure of gastric chymes

Molecular scale 

CM





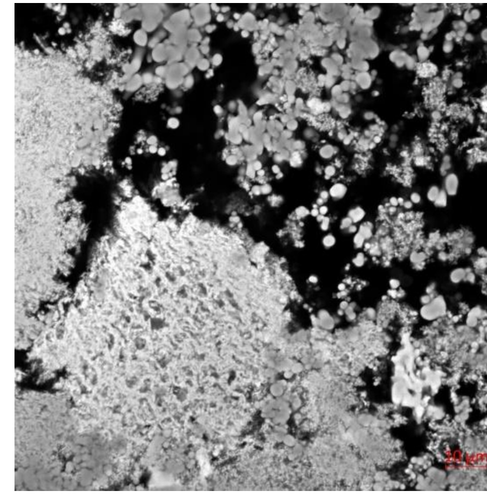
CM Gels (left) are compact and dense =

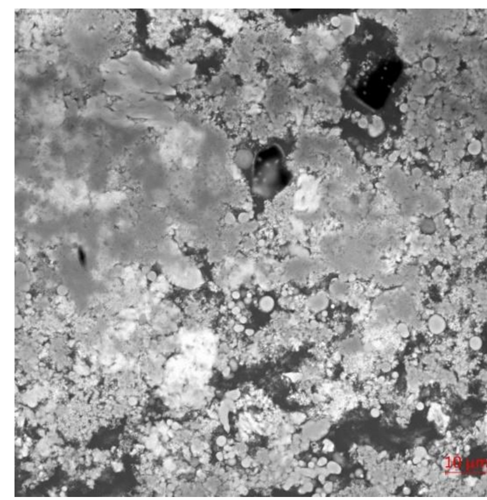
Strong coagulum

CS Gels (right) are an agglomerate of spherical particles that can easily dissociate. The gel have a very « loose » structure =

Protein precipitate

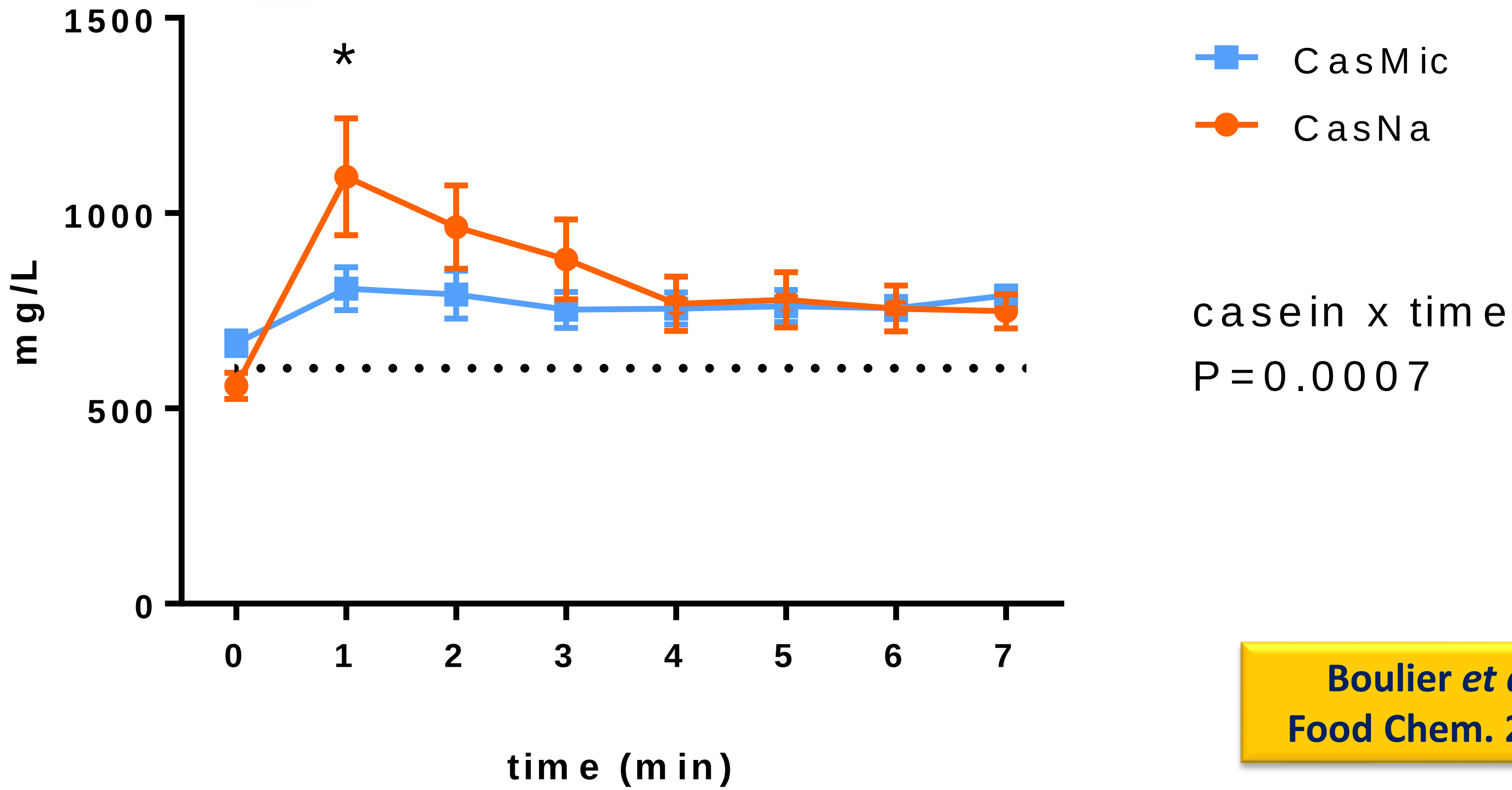
CS





Plasma amino acids

Molecular scale



Boulier *et al.*
Food Chem. 2023

AA peak after 1h for CM whereas the concentration remains stable for CS

Conclusion

* CM form a strong coagulum in the stomach leading to a slow and constant release of plasma amino acids up to 7 h

* CS form a loose precipitate in the proximal part of the stomach but most of the caseins remain solubilized in the liquid fraction

* CS are rapidly metabolized in the small intestine leading to the appearance of a peak of plasma amino acids one hour after protein ingestion

CM = slow caseins, CS = fast caseins

Perspectives

Do some *in vivo* kinetics experiments
Use ^{15}N labelled-caseins to differentiate endo/exogenous proteins

From the protein molecular structure to the the food microstructure: The case of egg white gels

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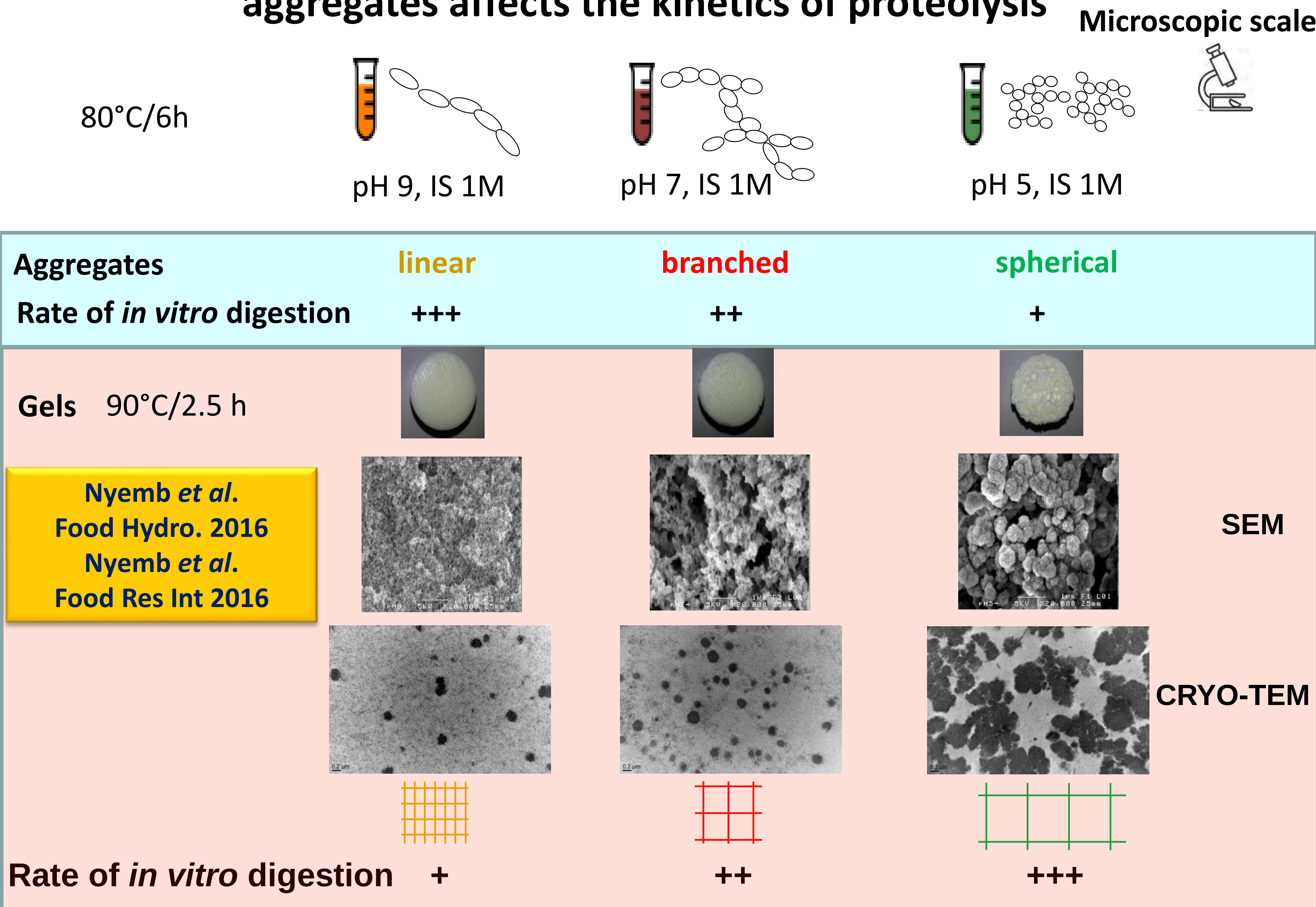
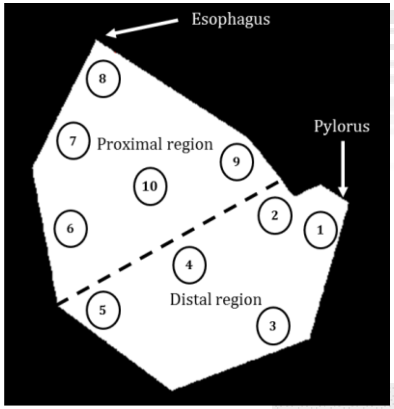
Nau F, & Dupont D.
INRAE, Rennes, France

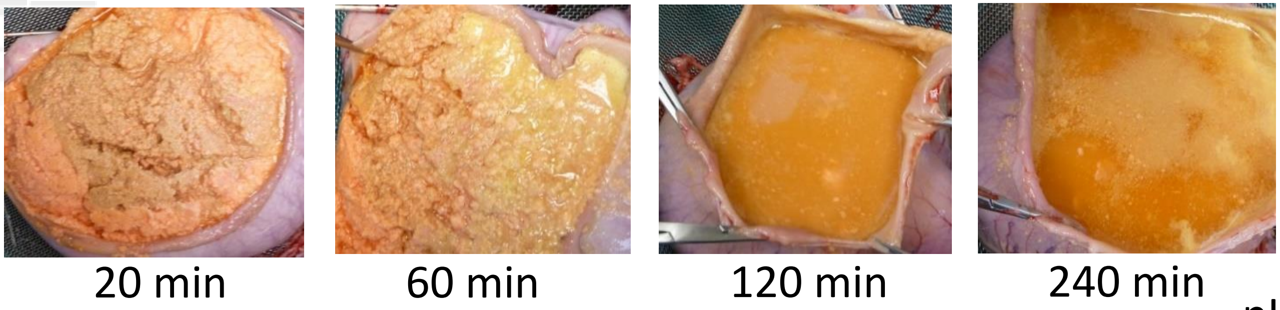
The microstructure of egg-white gels made from different types of aggregates affects the kinetics of proteolysis

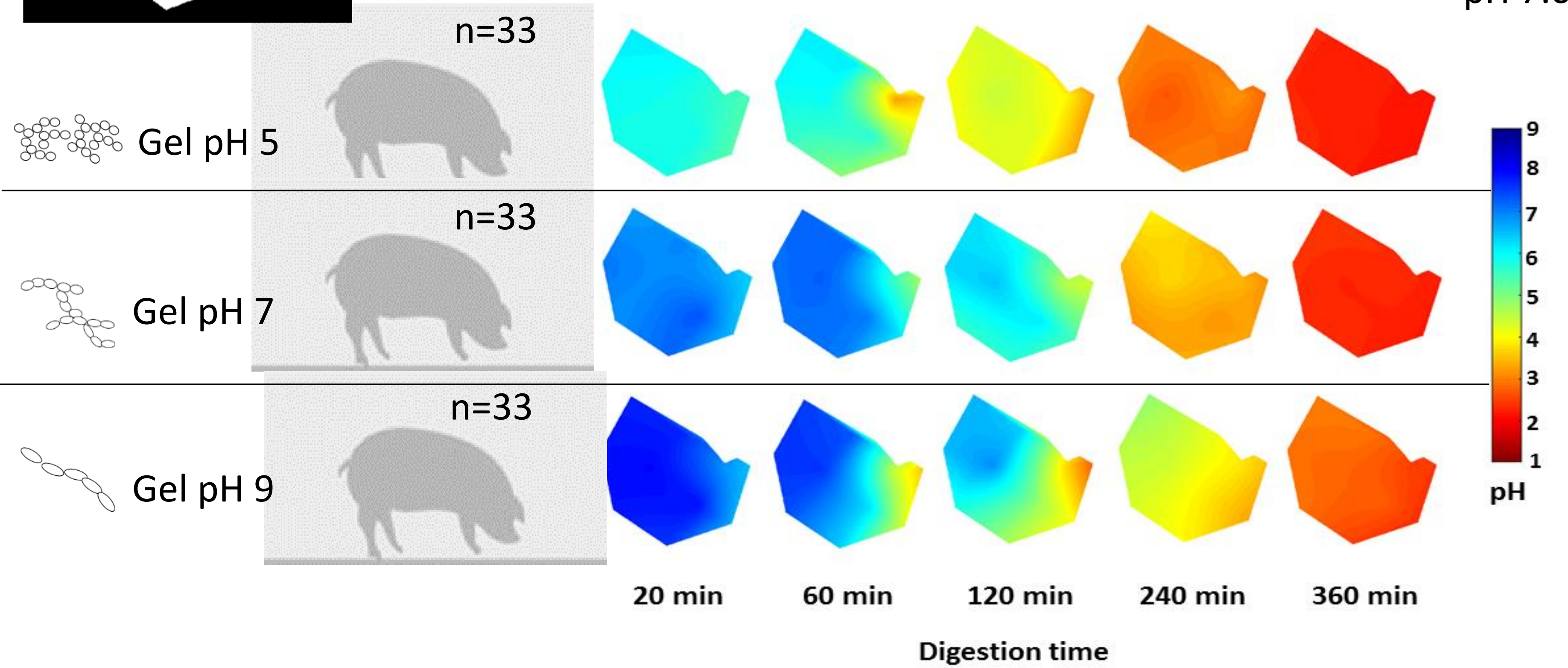


Spatial-temporal evolution of pH during an *in vivo* digestion

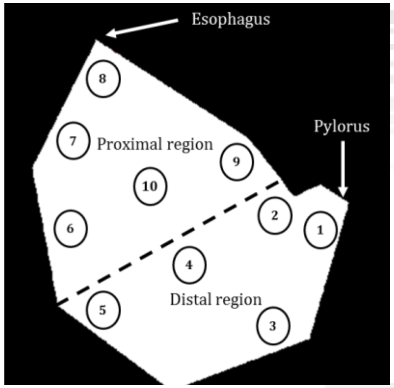
Microscopic scale

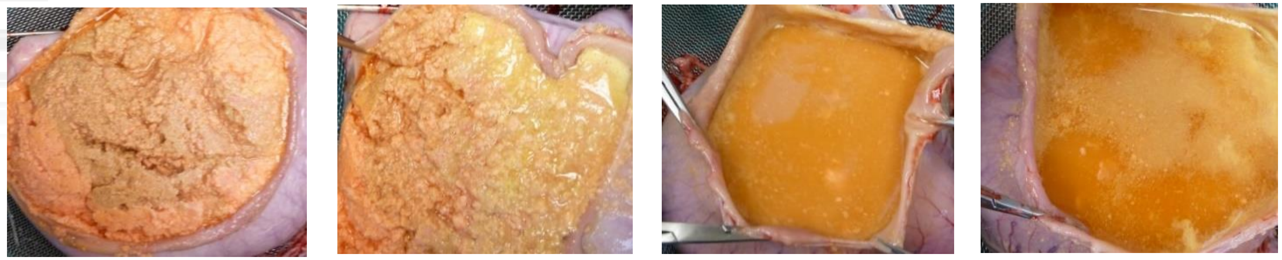






Spatial-temporal evolution of pH during an *in vivo* digestion





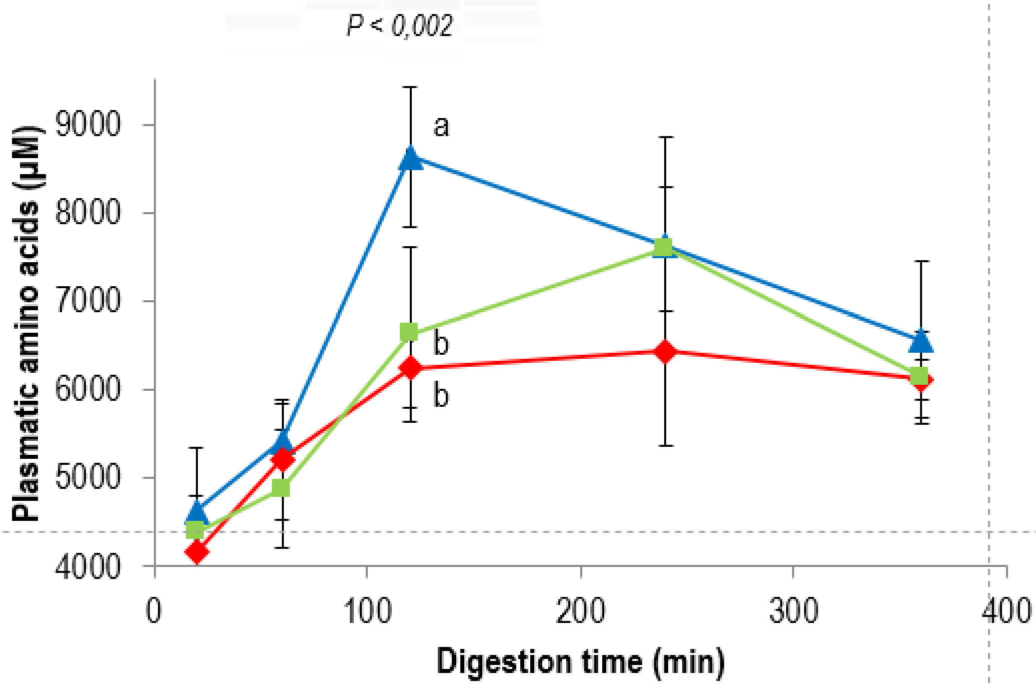
20 min

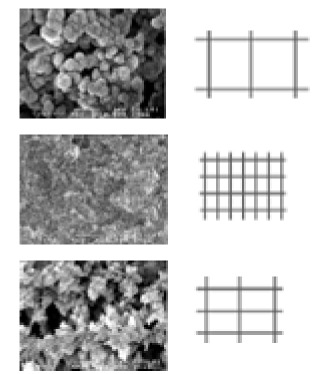
60 min

120 min

240 min

pH 7.0





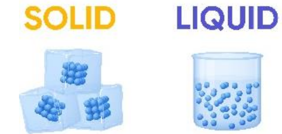
Microscopic scale

Nau *et al*.
Food Chem. 2019

Food structure as modified by processing affects the kinetics of food digestion

Le Feunteun S, Menard O, Dupont D.
INRAE, Rennes, France

Comparison of 6 dairy products of identical composition but different structure



Macroscopic scale

Ultra Low Heat powder

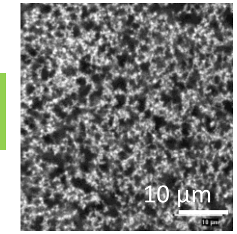
rehydration in water 14.5%

unheated milk ("raw" milk)

macrostructure

24h-20°C, rennet 0.003 % v/w

rennet gel



pH 6.6

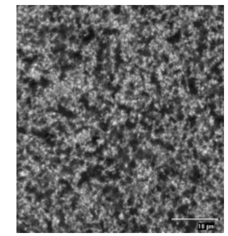
heat treatment 90°C-10 min

microstructure

heated milk

24h-20°C, rennet 0.3 % v/w

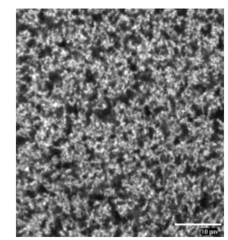
rennet gel



pH 6.6

24h-20°C, GDL 3 % w/w

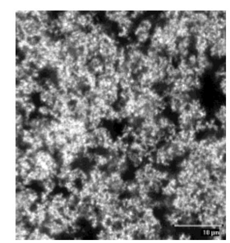
acid gel



pH 4

24h-20°C, GDL 3 % w/w + mixer 2 min

stirred acid gel



pH 4

Fat-free matrices:

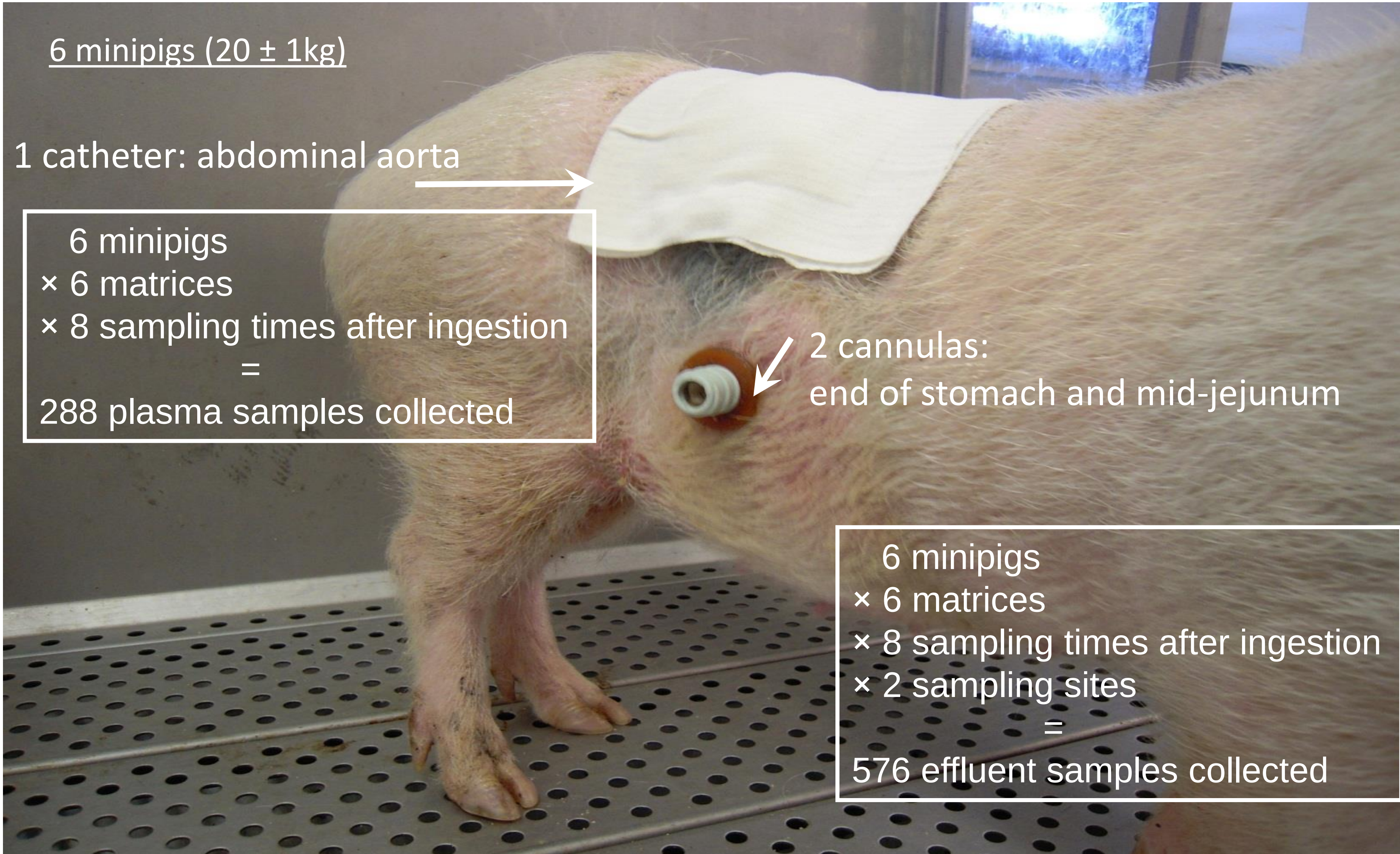
40 g/L caseins, 10 g/L whey proteins,
95 g/L lactose and minerals

+ marker of the meal transit (Cr^{2+}-EDTA) → Gastric emptying half-time

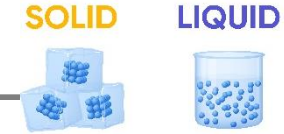
The multi-canulated mini-pigs

SOLID LIQUID

Macroscopic scale



Gastric emptying half time

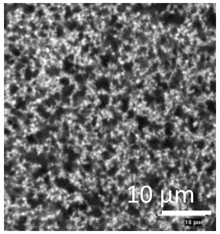


Macroscopic scale

Ultra Low Heat powder

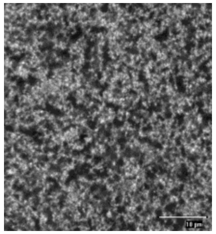
unheated milk ("raw" milk) — **96 min**

→ rennet gel — **? min** — pH 6.6

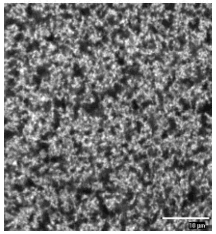


heated milk — **96 min**

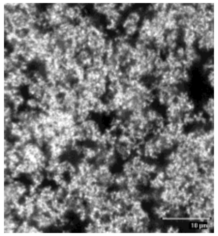
→ rennet gel — **352 min** — pH 6.6



→ acid gel — **148 min** — pH 4

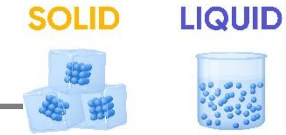


→ stirred acid gel — **124 min** — pH 4



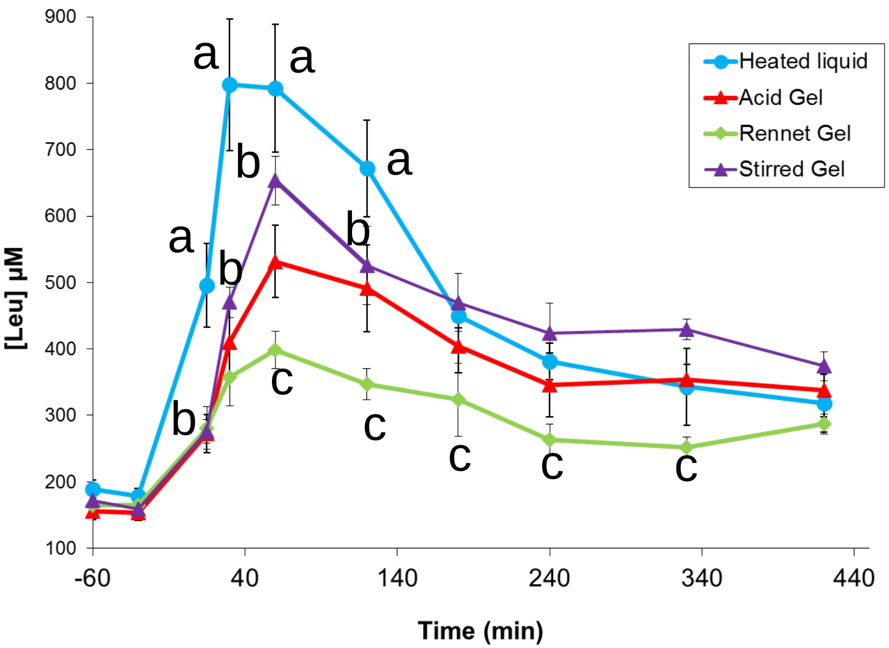
The liquid-gel transition

Barbé *et al.* Food Chem 2013



Macroscopic scale

Effect on absorption



milk gelation:

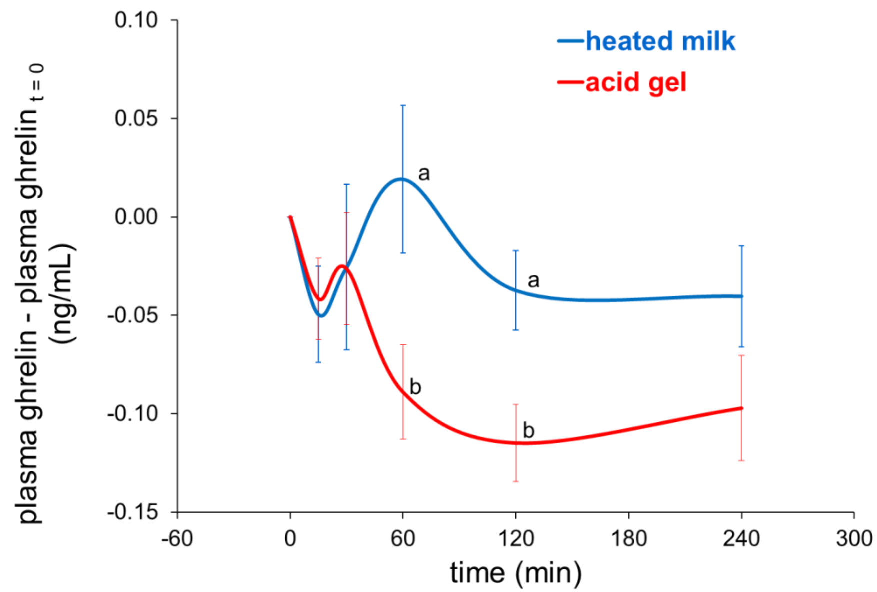
→ delayed proteins transit → delayed AA absorption

maximal AA concentration in the plasma

↘

Potential effect on satiety

ghrelin (gastrointestinal hormone → appetite stimulation)

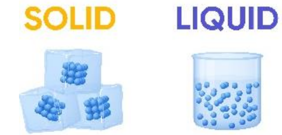


milk gelation:

↘ postprandial ghrelin concentration =

↗ satiety ?

Bioactive peptides released during digestion differ from one matrix to another



Macroscopic scale

More than 16000 peptides identified by LC-MS-MS in the jejunum

Protein	Sequence	Activity	Reference	4	20	50	105	165	225	315
αs1	1-23	EMUL	Shimizu et al. (1984)							
αs1	23-34	HYP	Maruyama & Suzuki (1982)							
αs1	30-45	MB	Meisel et al. (1991)							
αs1	40-52	MB	Adamson & Reynolds (1996)							
αs1	43-58	MB	Meisel et al. (1991)							
αs1	91-100	STRE	Miclo et al. (2001)							
αs1	99-109	MIC	McCann et al. (2006)							
αs1	167-180	MIC	Hayes et al. (2006)							
αs1	180-193	MIC	Hayes et al. (2006)							
αs2	1-24	MB	Miquel et al. (2005)							
αs2	124-146	MB	Miquel et al. (2005)							
αs2	183-206	TRAN	Kizawa et al. (1996)							
αs2	183-207	MIC	Recio & Visser (1999)							
αs2	189-197	HYP	Maeno et al. (1996)							
αs2	190-197	HYP	Maeno et al. (1996)							
β	1-24	MB	Bouhallab et al. (1999)							
β	33-52	MB	Miquel et al. (2005)							
β	60-80	OPI	Jinsmaa & Yoshikawa (1999)							
β	98-105	OXI	Rival et al. (2001)							
β	114-119	OPI	Jinsmaa & Yoshikawa (1999)							
β	132-140	HYP	Robert et al. (2004)							
β	192-209	IMM	Coste et al. (1992)							
β	193-202	IMM	Kayser & Meisel (1996)							
β	193-209	IMM	Coste et al. (1992)							
κ	18-24	HYP	Lopez-Exposito et al. (2007)							
κ	106-116	THR	Jolles et al. (1986)							
β–lg	32-40	HYP	Pihlanto-Leppala et al. (2000)							
β–lg	92-100	MIC	Pellegrini et al. (2001)							
β–lg	142-148	HYP	Mullally et al. (1997)							

Acid Gel

Protein	Sequence	Activity	Reference	4	20	50	105	165	225	315
αs1	40-52	MB	Adamson & Reynolds (1996)							
αs1	43-58	MB	Meisel et al. (1991)							
αs1	99-109	MIC	McCann et al. (2006)							
αs1	167-180	MIC	Hayes et al. (2006)							
αs1	180-193	MIC	Hayes et al. (2006)							
αs2	1-24	MB	Miquel et al. (2005)							
αs2	189-197	HYP	Maeno et al. (1996)							
β	33-52	MB	Miquel et al. (2005)							
β	166-175	HYP	Hayes et al. (2007)							
β	193-202	IMM	Kayser & Meisel (1996)							
β–lg	92-100	MIC	(8))							
β–lg	142-148	HYP	(9))							

Rennet Gel

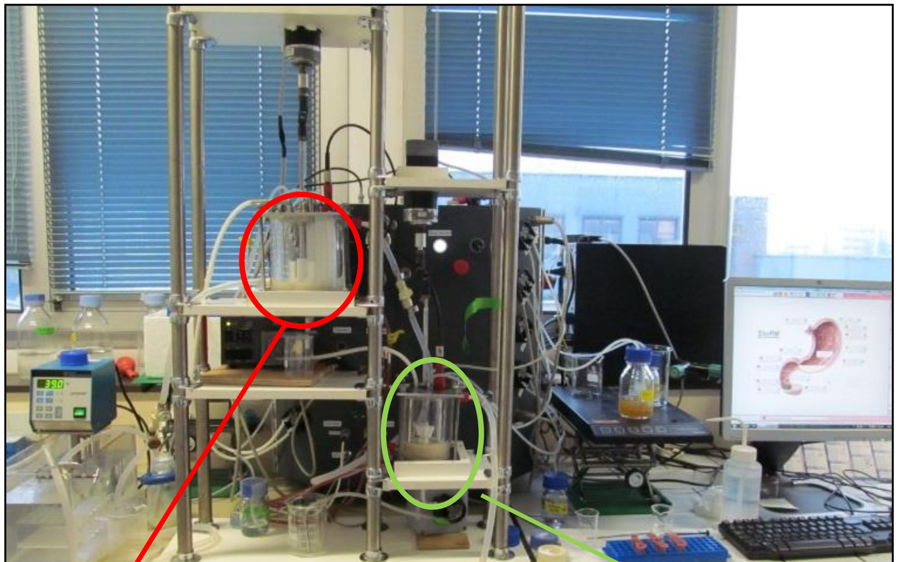
- More bioactive peptides identified during digestion of acid gel than rennet gel
- Nature of peptides is identical (clearly defined by the digestive enzyme specificity)
- Kinetics of release are different

Barbé et al. 2014
Food Res Int

Differential behaviour of acid/rennet gels in gastric conditions

- ☞ Acid/Rennet gel: identical composition, similar rheological properties and pore size
- ☞ ≠ Time of residence in the stomach (Acid 148 min /Rennet 352 min)
  - ☞ How can we explain this difference? Dynamic *in vitro* digestion of the 2 gels

Ménard *et al.*
Food Chem 2014

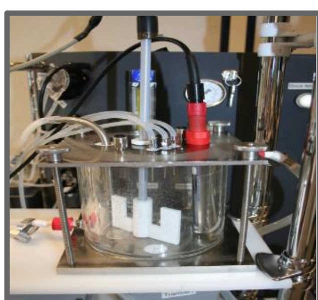


DIDGI®

StoRM® software

Stomach

- Pepsine
- Gastric lipase
- Simulated gastric fluid
- HCl



Emptying : Elashoff's model

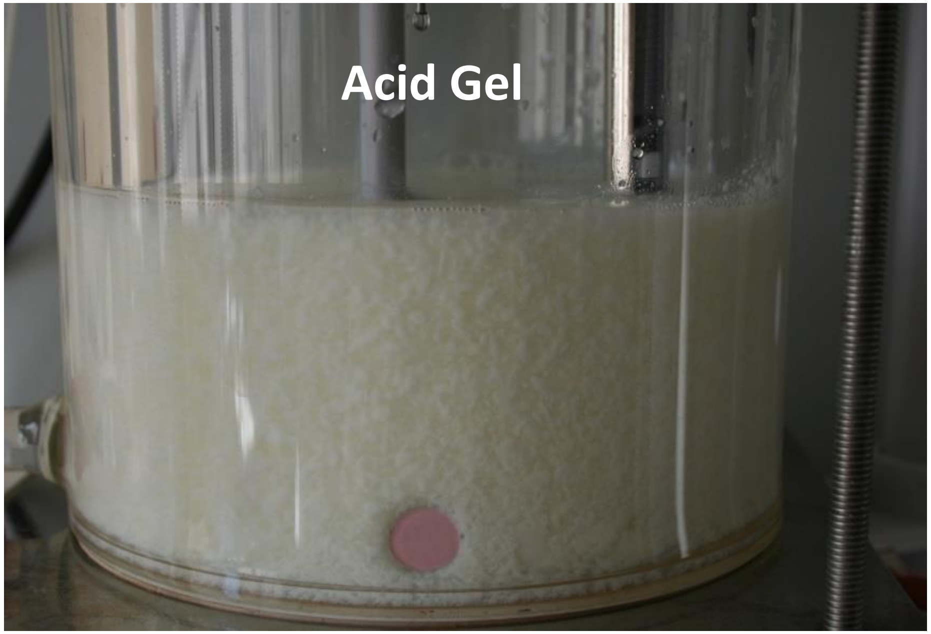
Small intestine

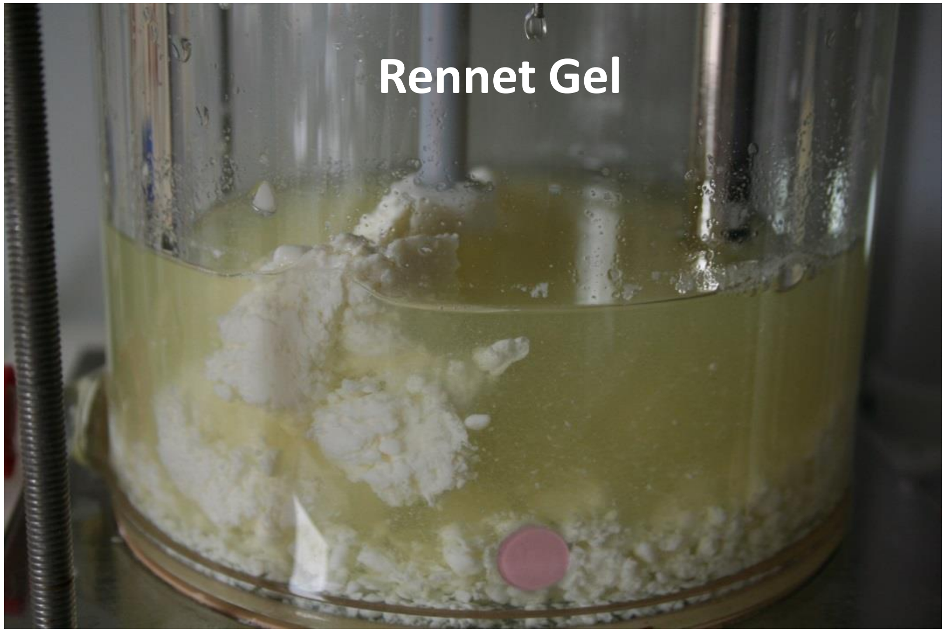
- Pancreatin
- Bile
- Simulated intestinal fluid
- $NaHCO_3$

Emptying : Elashoff's model

Behaviour of acid and rennet gels in the stomach during *in vitro* dynamic digestion

Barbé et al.
Food Chem. 2014

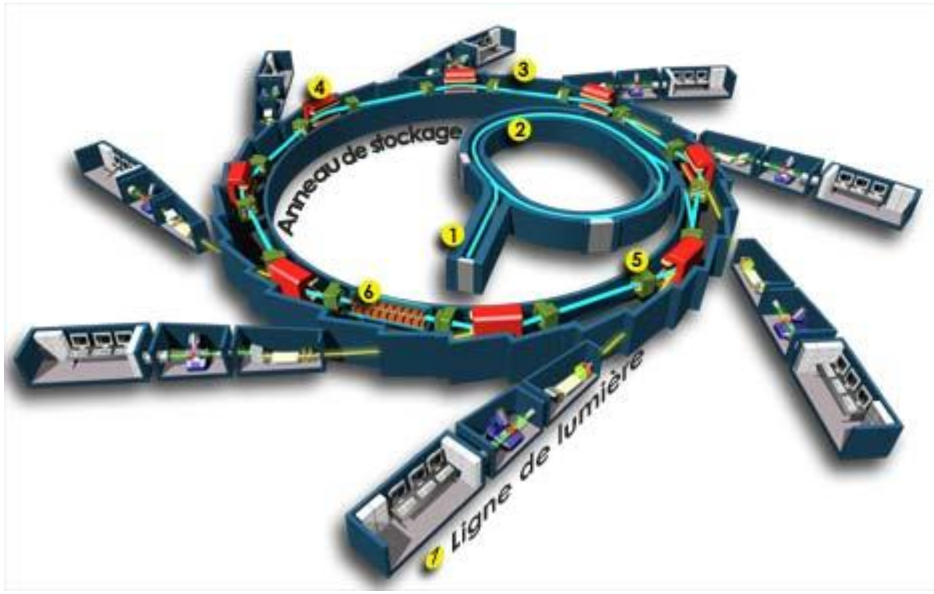




Formation of a strong coagulum with rennet gel → slow down the gastric emptying of caseins

The structure that a food adopts in the stomach is essential to understand its digestion

SOLEIL SYNCHROTRON



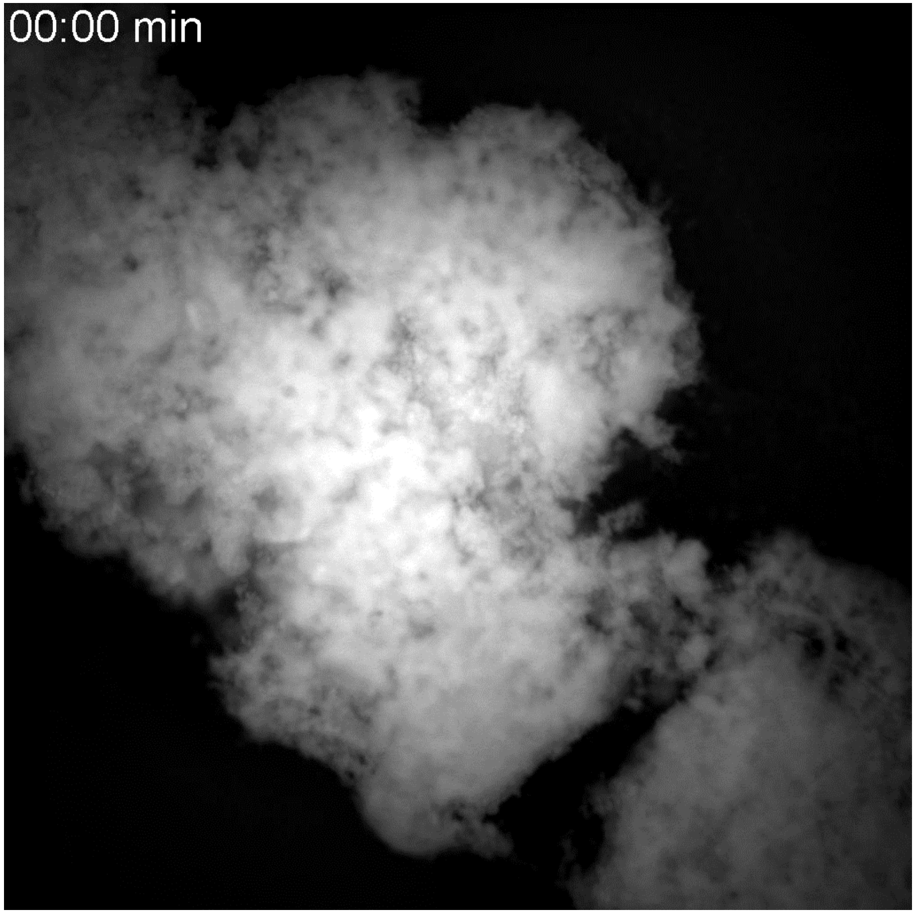
Soleil is a particle (electron) accelerator that produces the synchrotron radiation, an extremely powerful source of light that permits exploration of inert or living matter

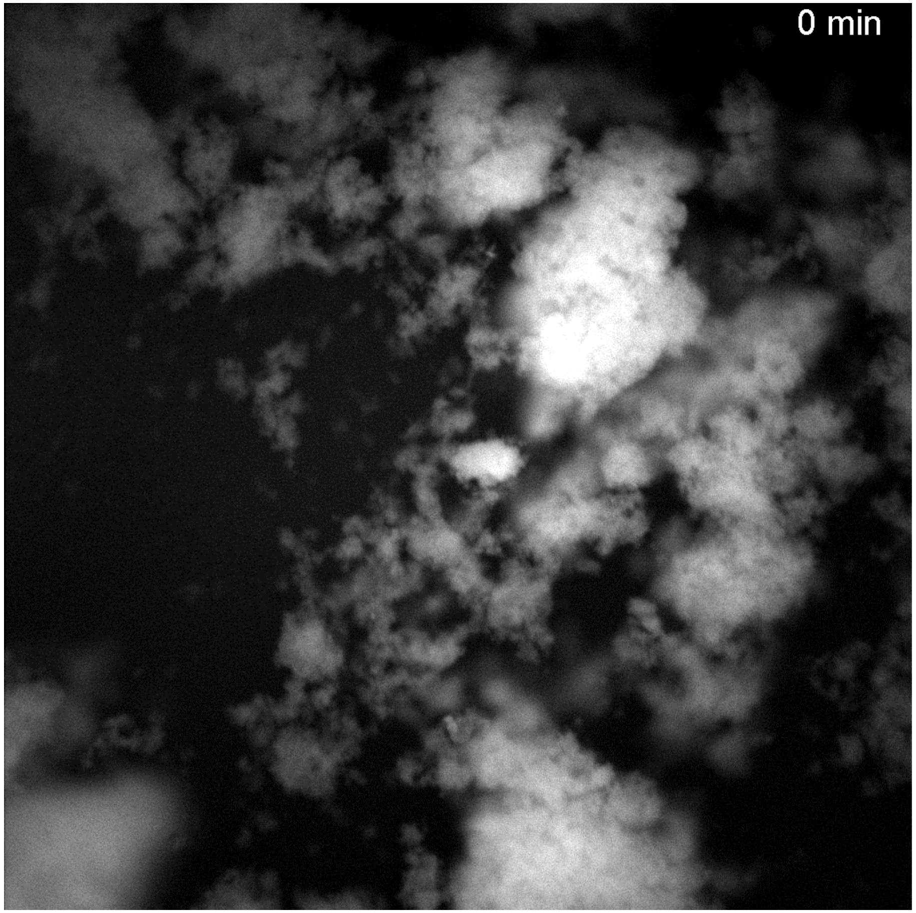
DISCO

DISCO is a VUV to visible beamline dedicated to biochemistry, chemistry and cell biology. The spectral region is optimized between 60 and 700 nm with conservation of the natural polarization of the light

☞ Allow the imaging of protein intrinsic fluorescence with a UV microscope

Kinetics of gel particles disintegration





Rennet Gel

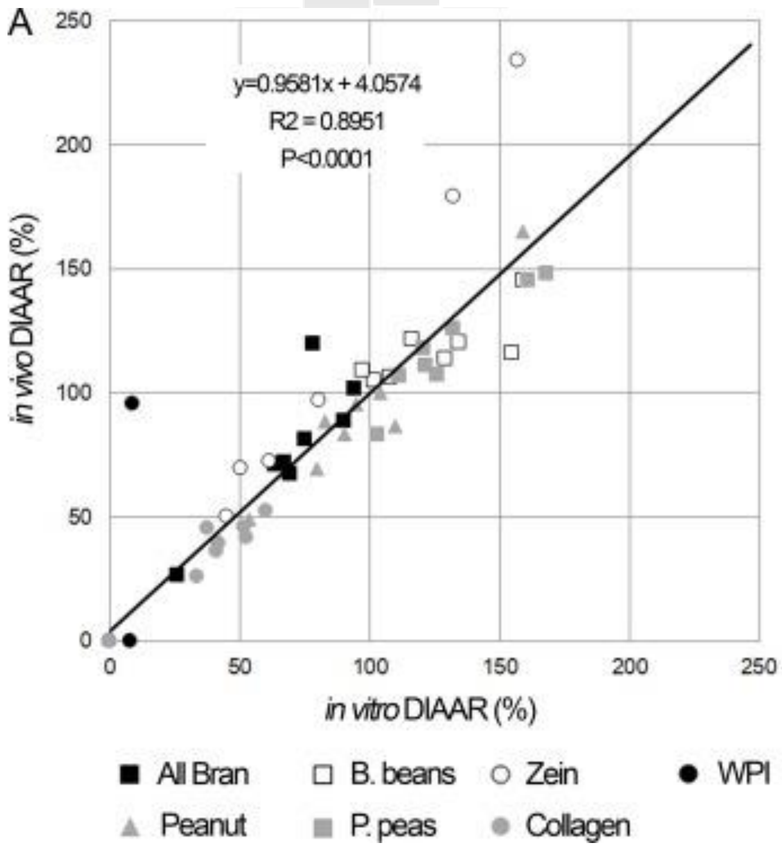
Acid Gel

Can we estimate plant protein digestibility with in vitro digestion models?

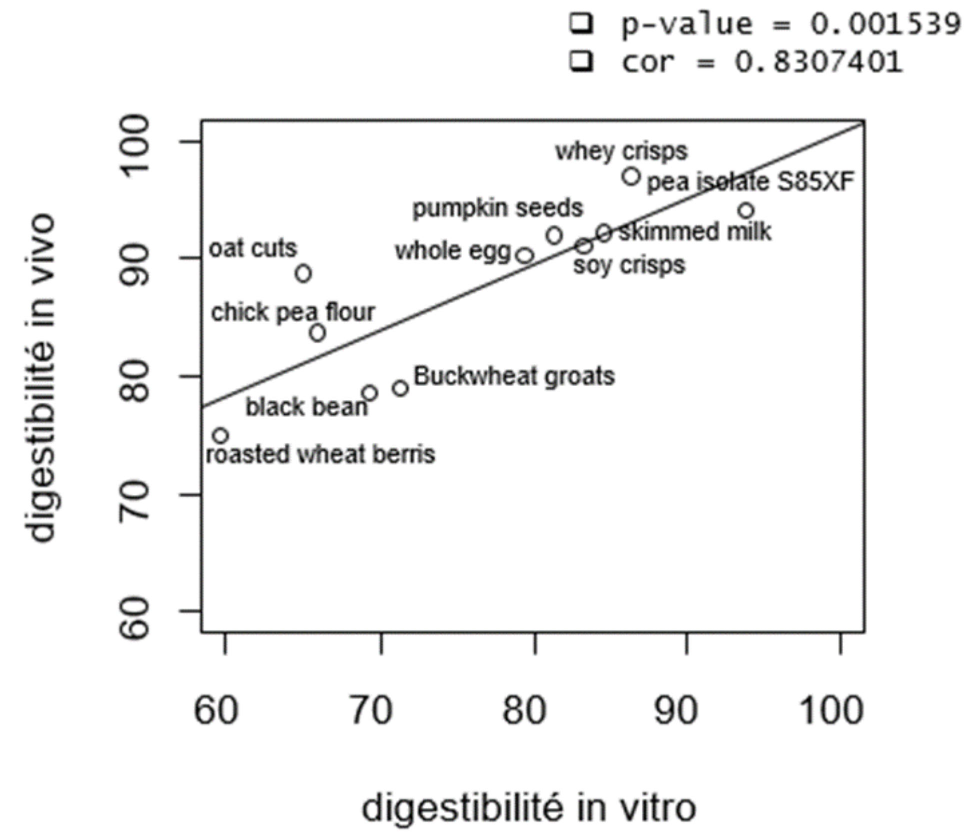
SCIENCE & IMPACT

Le Feunteun S, Menard O, Dupont D.
INRAE, Rennes, France

In vitro/ in vivo correlation for protein digestibility measurement



Sousa et al. 2023



Nau et al. unpublished

Overall, good correlation are observed but some differences between studies persist

Protein digestibility with a dynamic *in vitro* digestion model

Study of 4 plant-based foods: 2 solids / 2 liquids

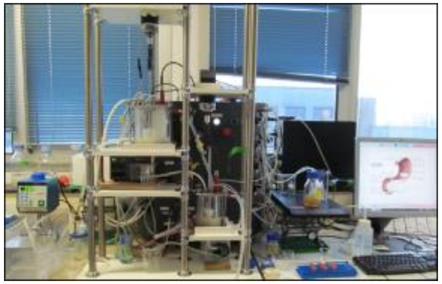
Reynaud et al. 2021
Food Chem. 341

Tofu

Soymilk

Seitan

Pea Emulsion

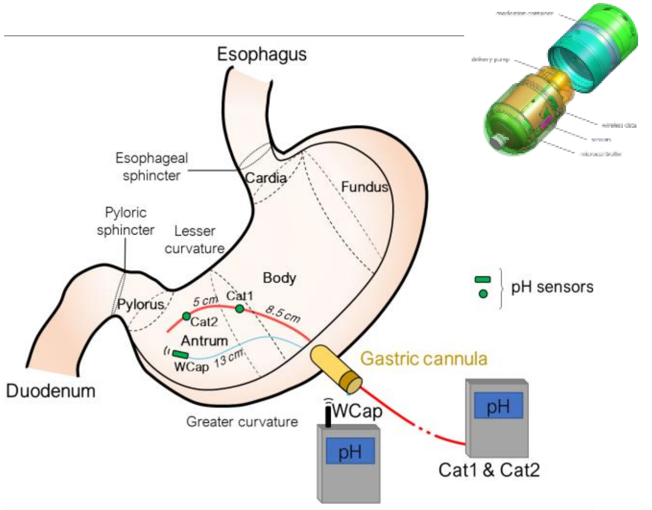


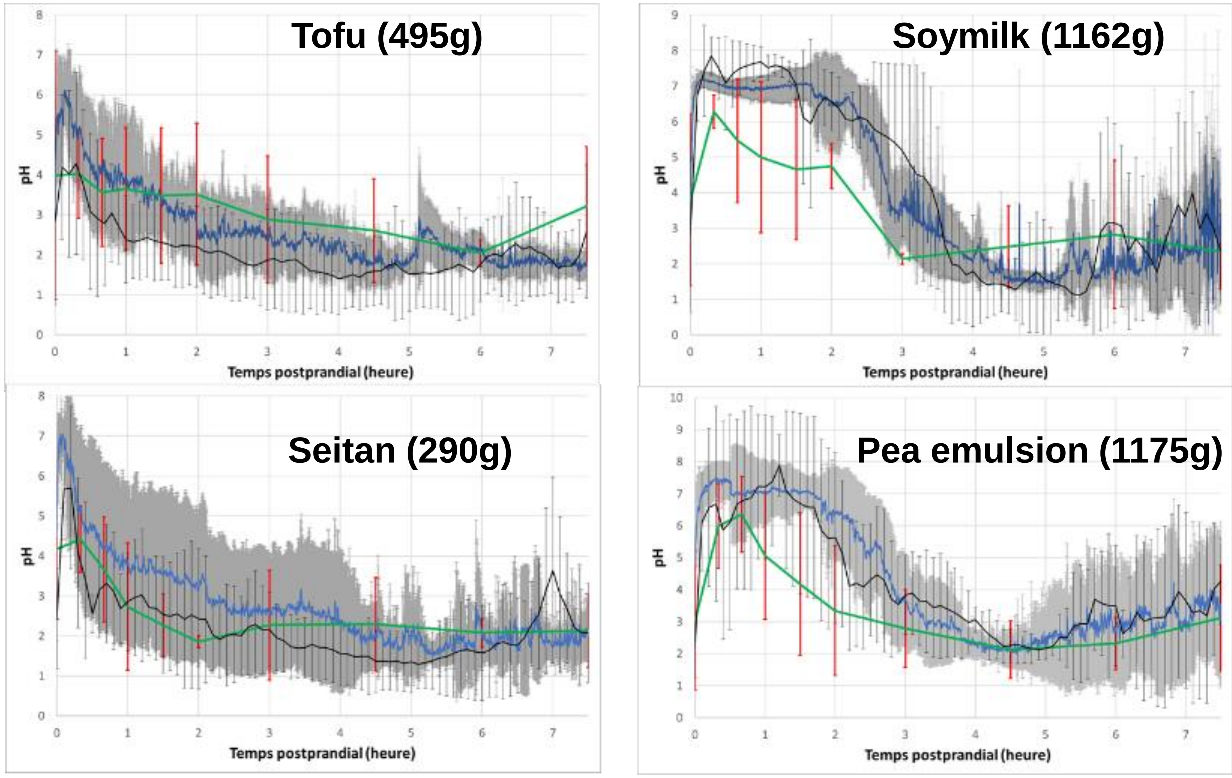
Dynamic *in vitro* digestion DiDGi®

In vitro digestibility (%)

In vivo data are needed to program the digestion simulator

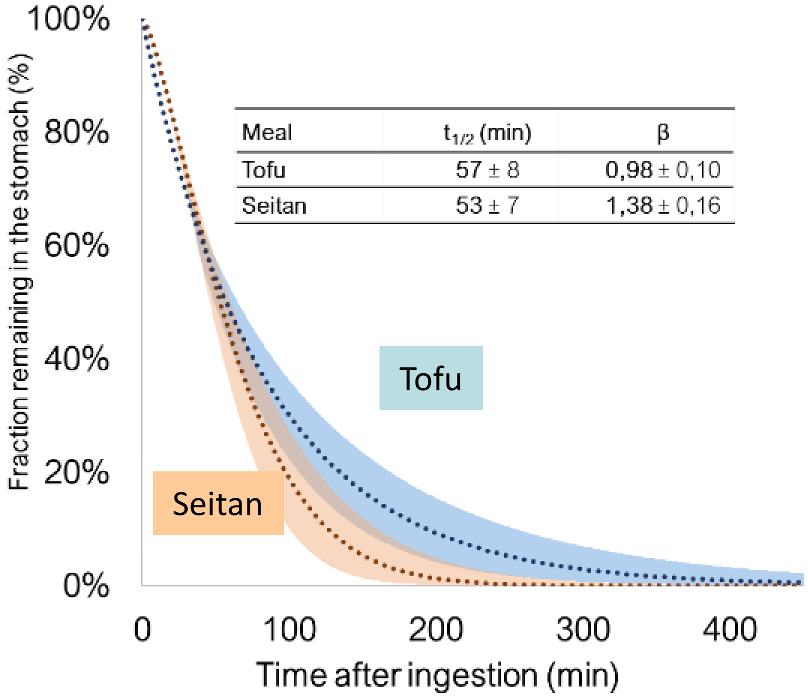
Evolution of gastric pH



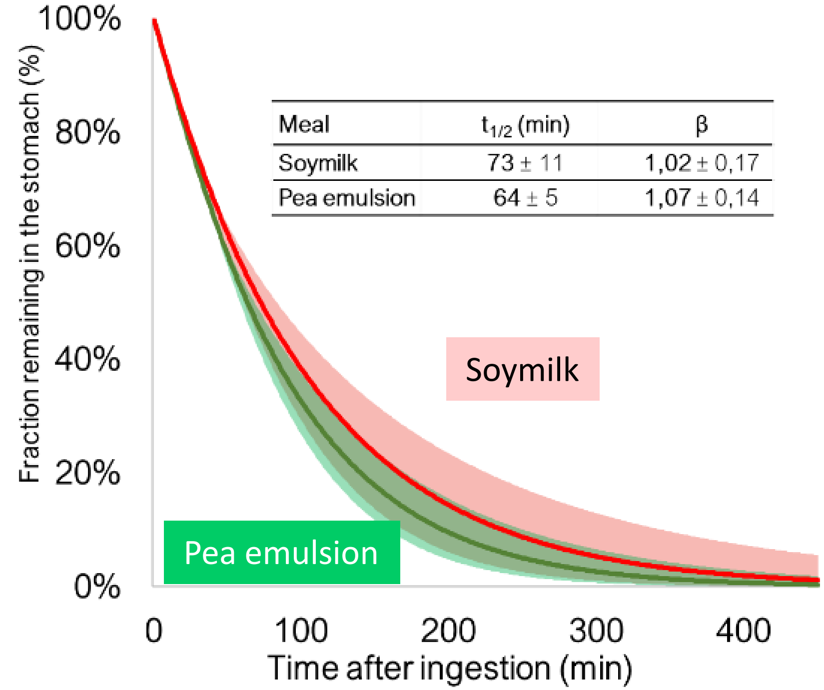


In vivo data are needed to program the digestion simulator

Gastric emptying



Meal	$t_{1/2}$ (min)	β
Tofu	57 ± 8	0,98 ± 0,10
Seitan	53 ± 7	1,38 ± 0,16



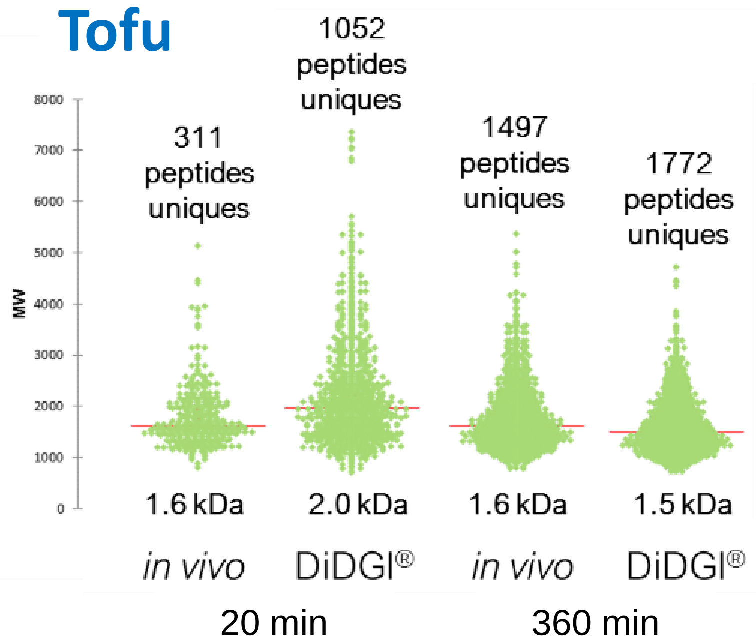
Meal	$t_{1/2}$ (min)	β
Soymilk	73 ± 11	1,02 ± 0,17
Pea emulsion	64 ± 5	1,07 ± 0,14

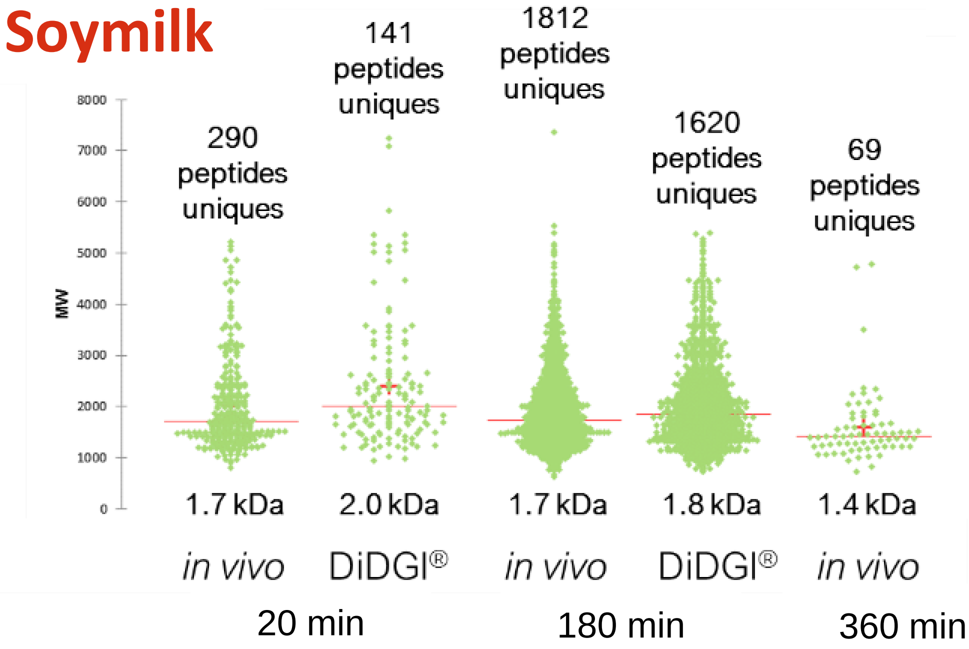
Reynaud et al. 2020
Food Res Int, 128

Comparison between pig and *in vitro* data

Model	Digestibility	Tofu	Soymilk
in vivo	True	97.1 ± 4.8%	99.4 ± 2.2%
	Apparent	**56.5 ± 7.8%[b]**	**71.3 ± 2.5%[a]**
in vitro	**Apparent simulated**	**63.7 ± 3.5%[b]**	**72.7 ± 1.4%[a]**

Comparison of the gastric peptidome



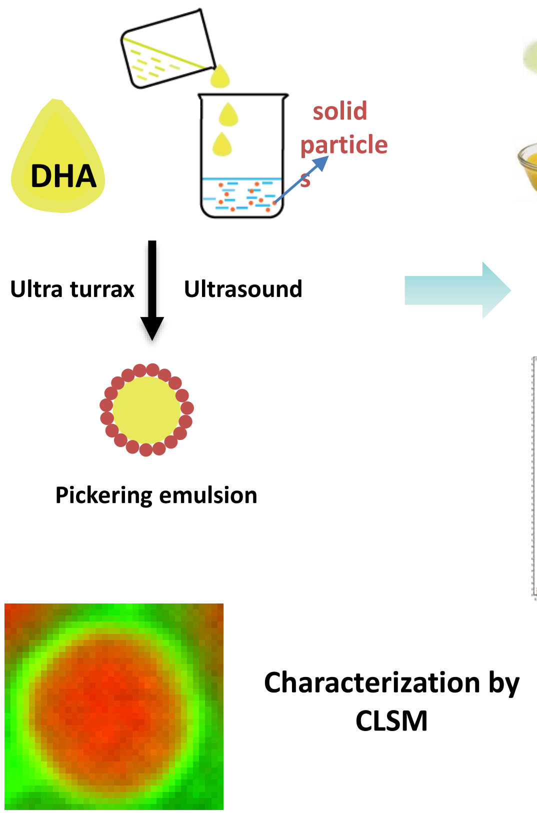


Improving DHA delivery by encapsulation and design of functional foods

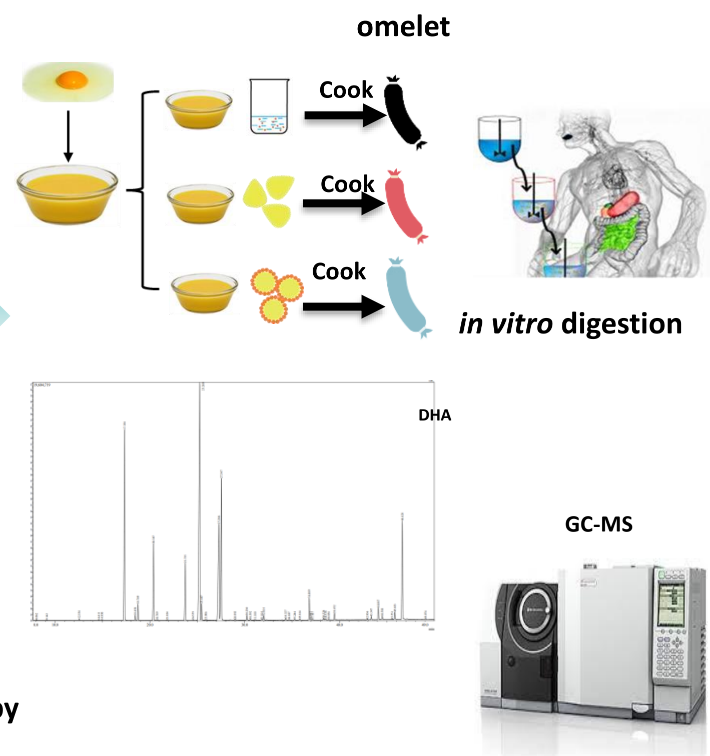
Wang J, Pedrono F, & Dupont D.
INRAE, Rennes, France

General strategy

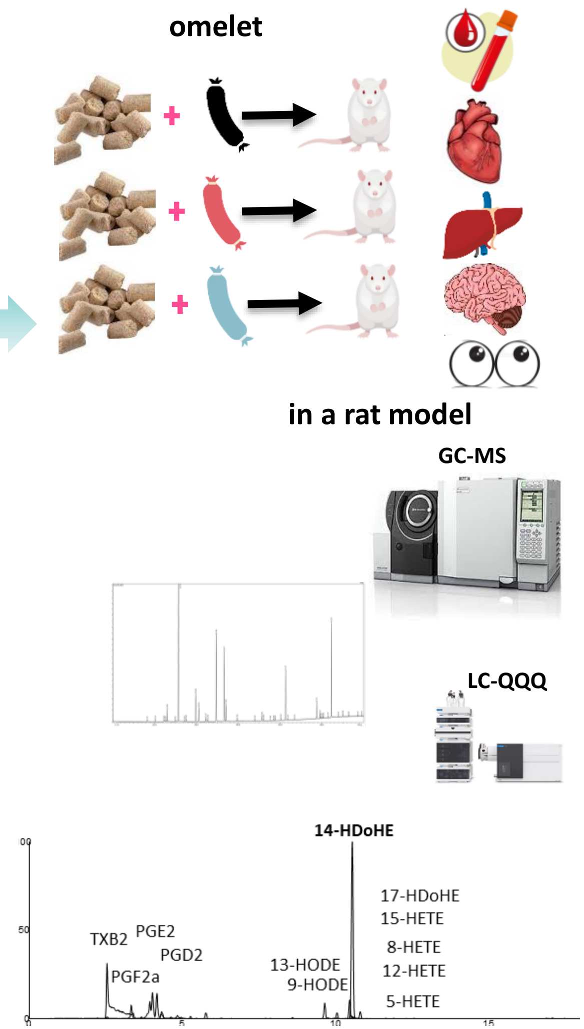
DHA oil encapsulation



DHA bioaccessibility



DHA bioavailability, accretion and metabolism



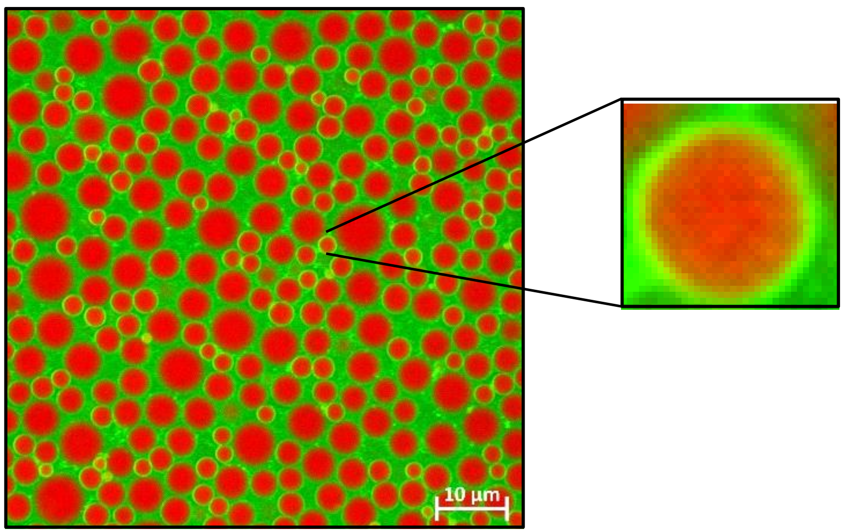
Wang *et al.* Food Res Int 2022

Wang *et al.* Frontiers in Nutr 2022

Wang *et al.* Nutrients 2023

DHA oil in emulsion and omelet

In emulsion



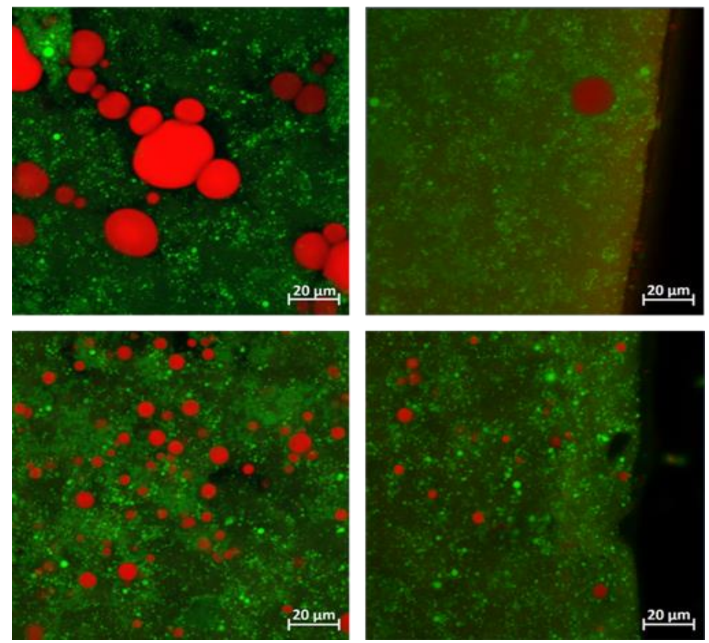
Encapsulated DHA oil with heat-denatured WPI

DHA oil stained with Nile Red and proteins stained with Fast Green.

The particle size of heat-denatured WPI on average is 42 nm.

In omelet

Center **Edge**

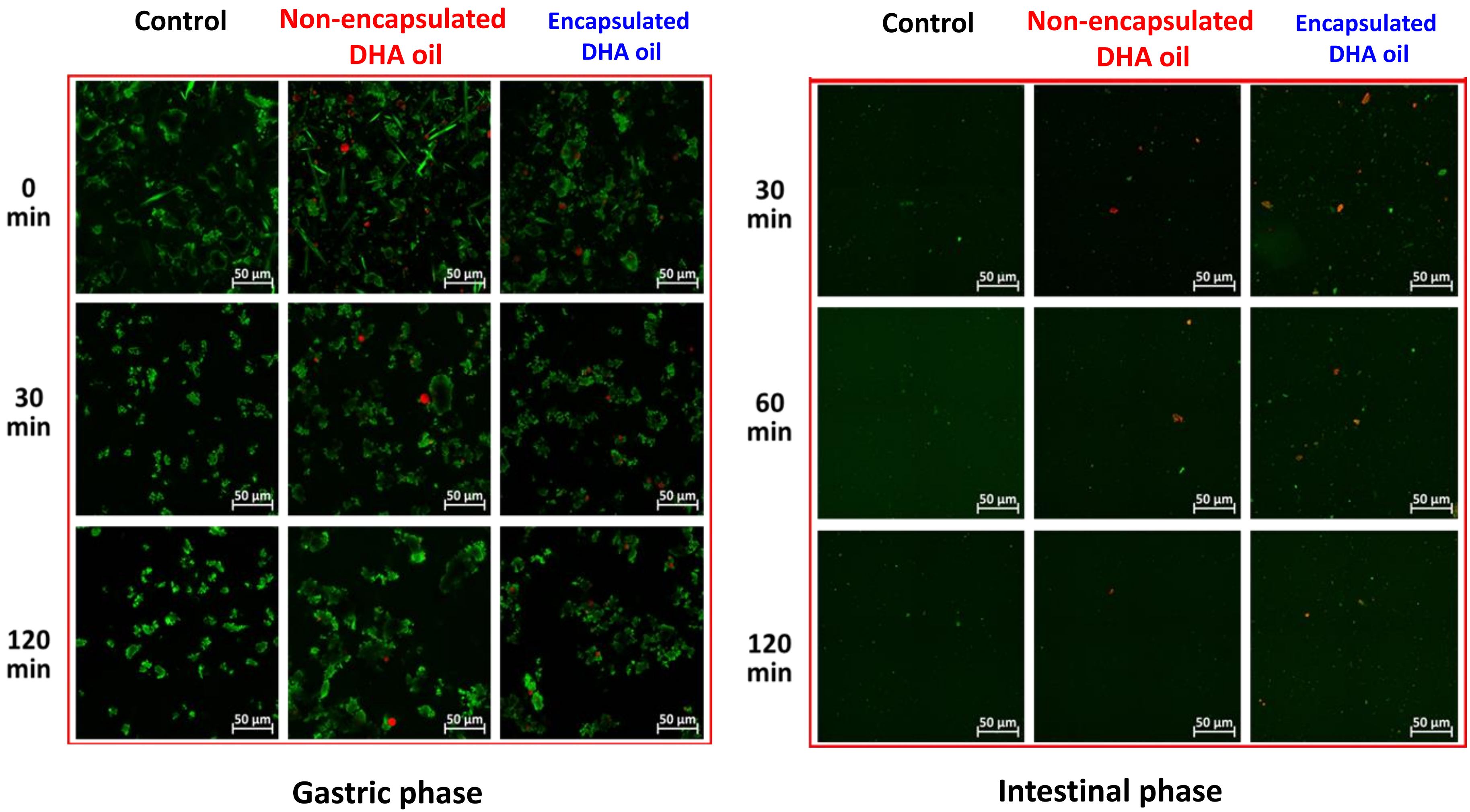


Non-encapsulated DHA oil

Encapsulated DHA oil

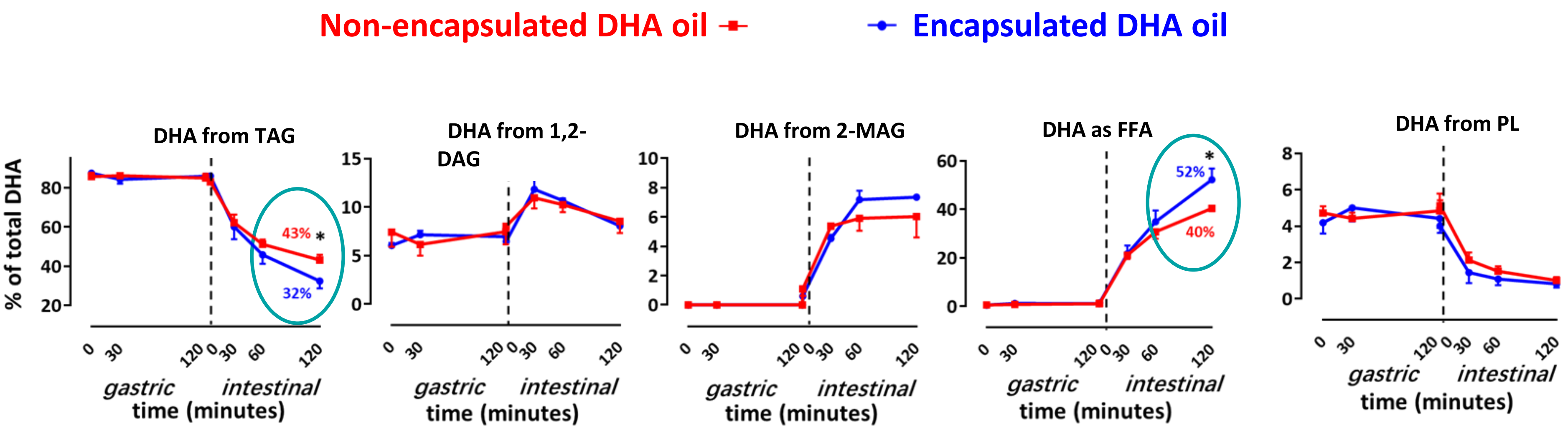
Distribution of non-encapsulated and encapsulated DHA oil in omelets.

DHA oil in omelet during digestion



DHA oil and proteins were mainly hydrolyzed in intestinal phase

The release of DHA from different lipid species during digestion



The evolution DHA from different lipid species during digestion.

In gastric phase (pepsin and RGE):

- ☐ DHA oil was not hydrolyzed in gastric phase.

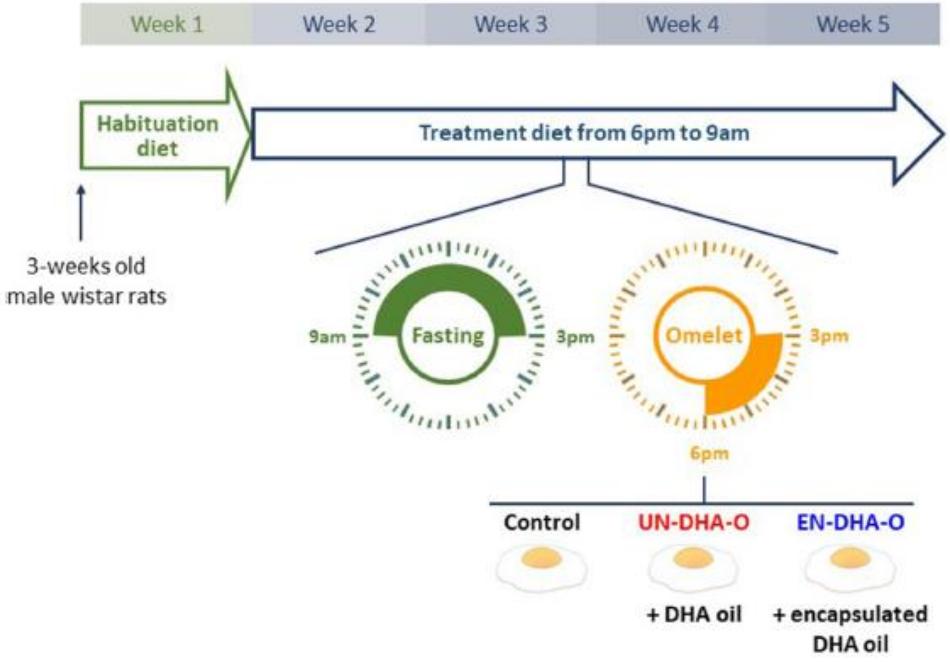
In intestinal phase (bile salt and pancreatin):

- ☐ Hydrolyzed TAG and released FFA encapsulation > unencapsulation

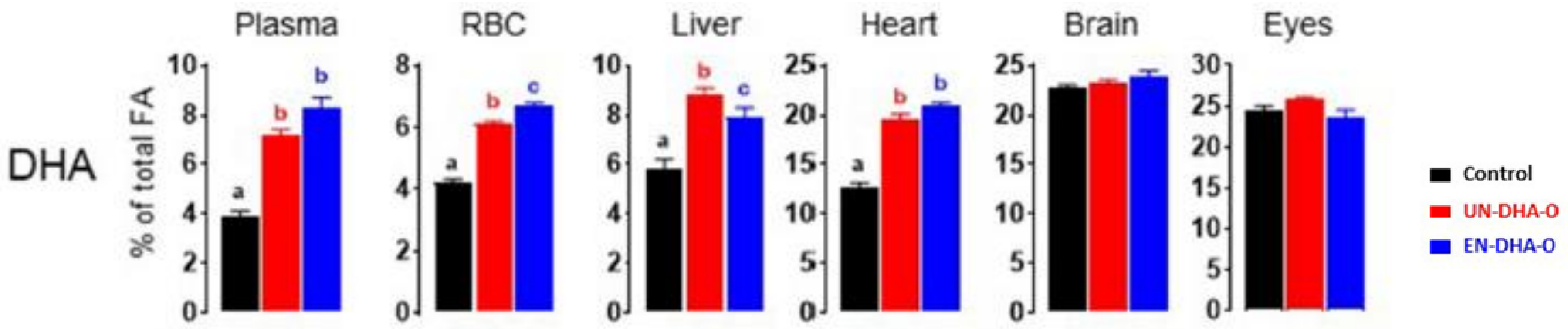
- ☐ **Larger interaction area between DHA oil and pancreatic lipase made by emulsification** *(Maljaars, 2012).*

- ☐ Around **10-25%** and 40-70% of ingested **TAG** can be hydrolyzed **in gastric** and intestinal phase, respectively *(Bauer et al; Carriere et al., 1993).*

What happens *in vivo*?



Encapsulation increased DHA concentration in plasma and red blood cells



Encapsulation increased oxylipins in heart and brain (precursors of protectins and maresins that limit inflammation and infection)

Food structure affects the delivery of hydrophilic and lipophilic micronutrients

Hiolle M., Dupont D. & Nau F.

INRAE, Rennes, France

Objective of the study:

Demonstrate the effect of the food macrostructure on the bioavailability of Vit B9, Vit B12, Vit D and lutein

Development of food matrices

Identical composition on dry matter:
- 17 % proteins
- 30 % lipids
- 52 % carbohydrates

Enriched in micronutrients

Biscuit
DM = 97 %

Sponge cake
DM = 57 %

Pudding
DM = 51 %

Custard
DM = 31 %

Hiolle *et al.*
Food Chem. 2020

Characterisation of the matrices

Extensive biochemical characterization

Macrostructure : texture analysis

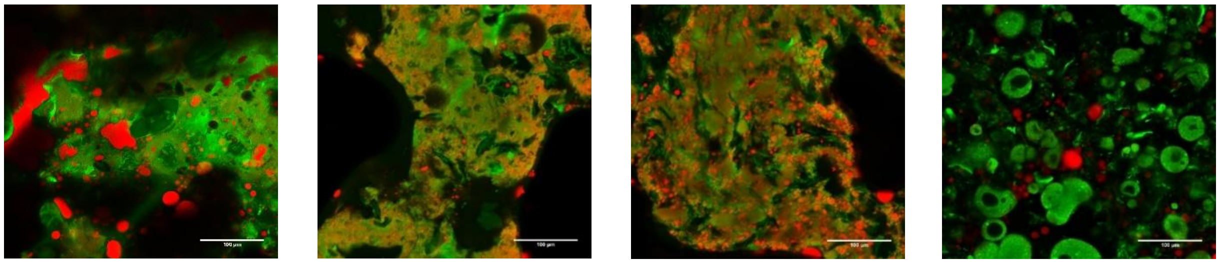
Microstructure : confocal microscopy

Clinical study

12 healthy volunteers (20-30 y)
Randomized, controlled, crossover study

Postprandial analyses over 8h

Quantification in the plasma :
- Vit B9, B12, D and lutein



Biscuit **Sponge cake** **Pudding** **Custard**

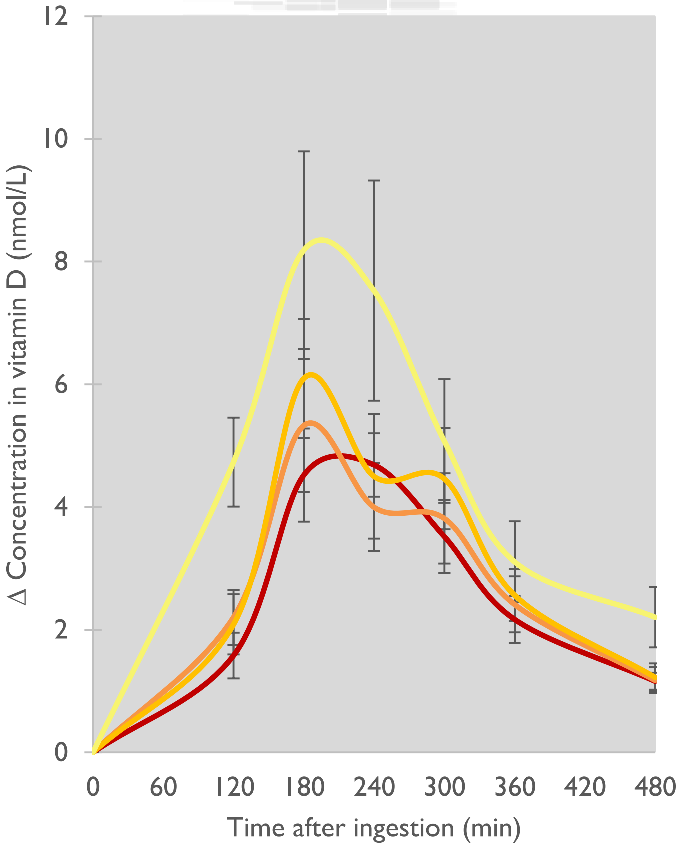
■ : lipids (Nile Red) ■ : proteins (Fast Green)

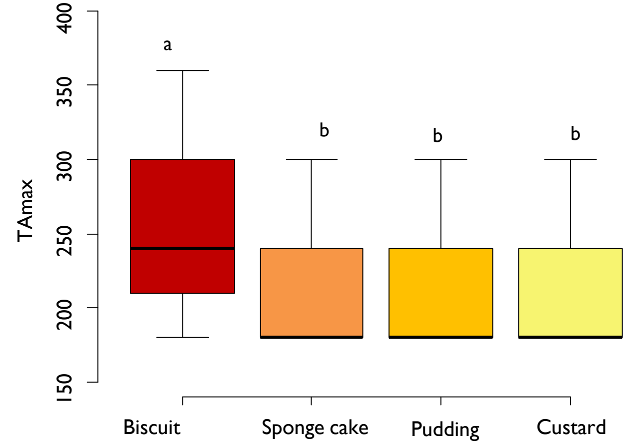
Results

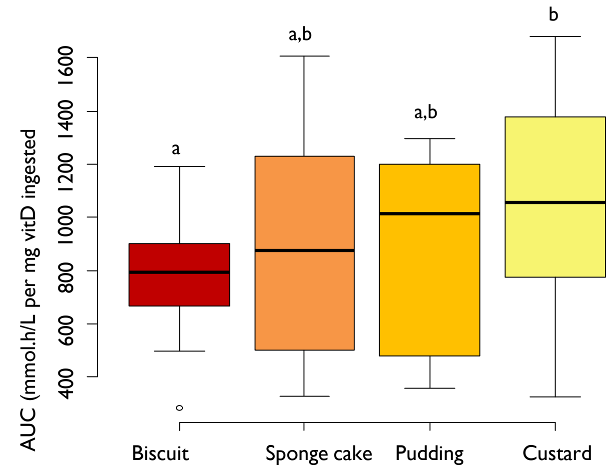
Food structure affects micronutrient kinetics of release and bioavailability

Vitamin D

Clinical study







Buffière *et al.* Food Chem. 2020

Increased AUC for vitamin D when provided via a custard

Understanding human milk digestion to design new infant formulas that will have the same behaviour in the GI tract

INRA
SCIENCE & IMPACT

Deglaire A., Menard O., De Oliveira S., Bourlieu C.
& Dupont D.

INRAE, Rennes, France

Human/ bovine milk / Infant Formula

Lipid globule structure

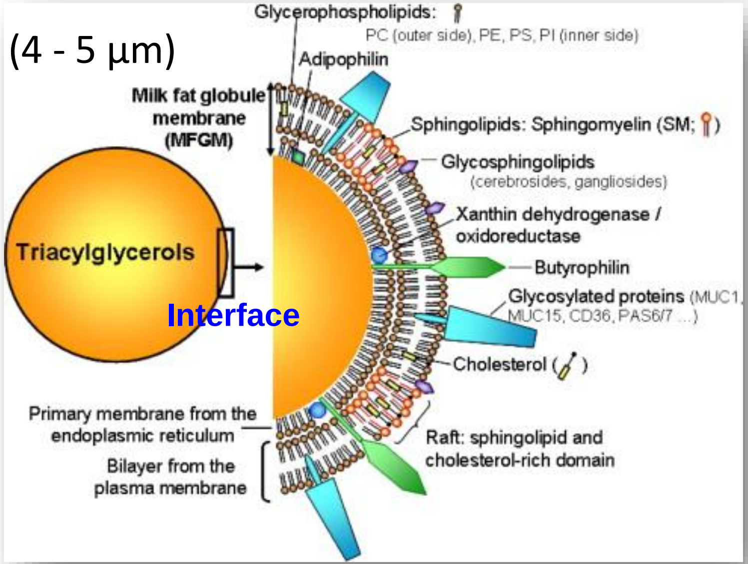
Human milk

Bovine milk

Infant Formula

Native milk fat globule

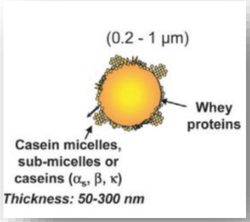
(4 - 5 µm)



(Lopez, 2010)

Lipid droplets

Triacylglycerols

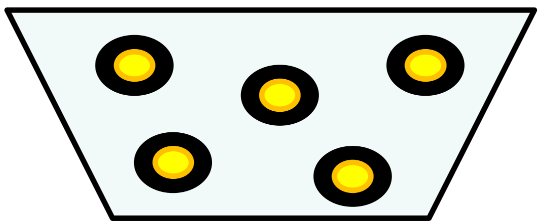


(0,2 - 1 µm)

(Lopez and Briard-Bion, 2007)

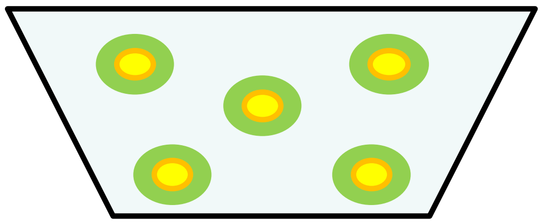
Infant formulas: can we create lipid structures biomimetic on the native fat globule?

Formula T1



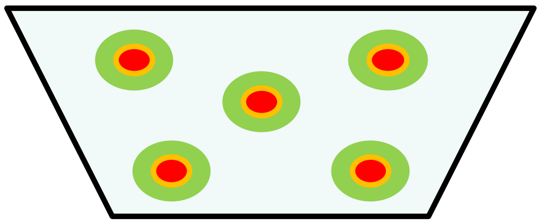
Interface 100 % Proteins
100% vegetable oil

Formula T2

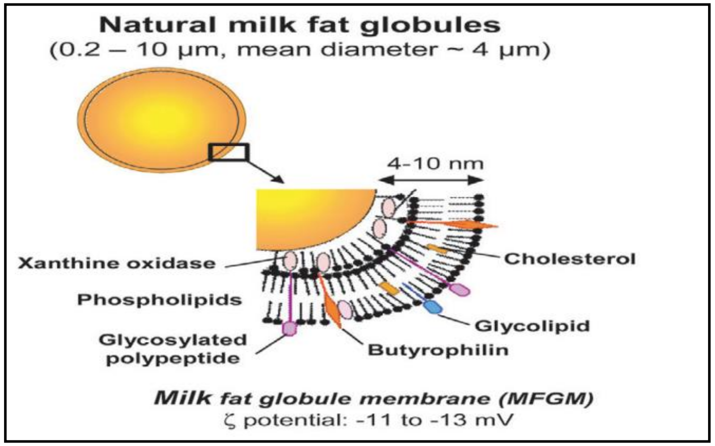


Interface 100 % phospholipids
100% vegetable oil

Formula T3

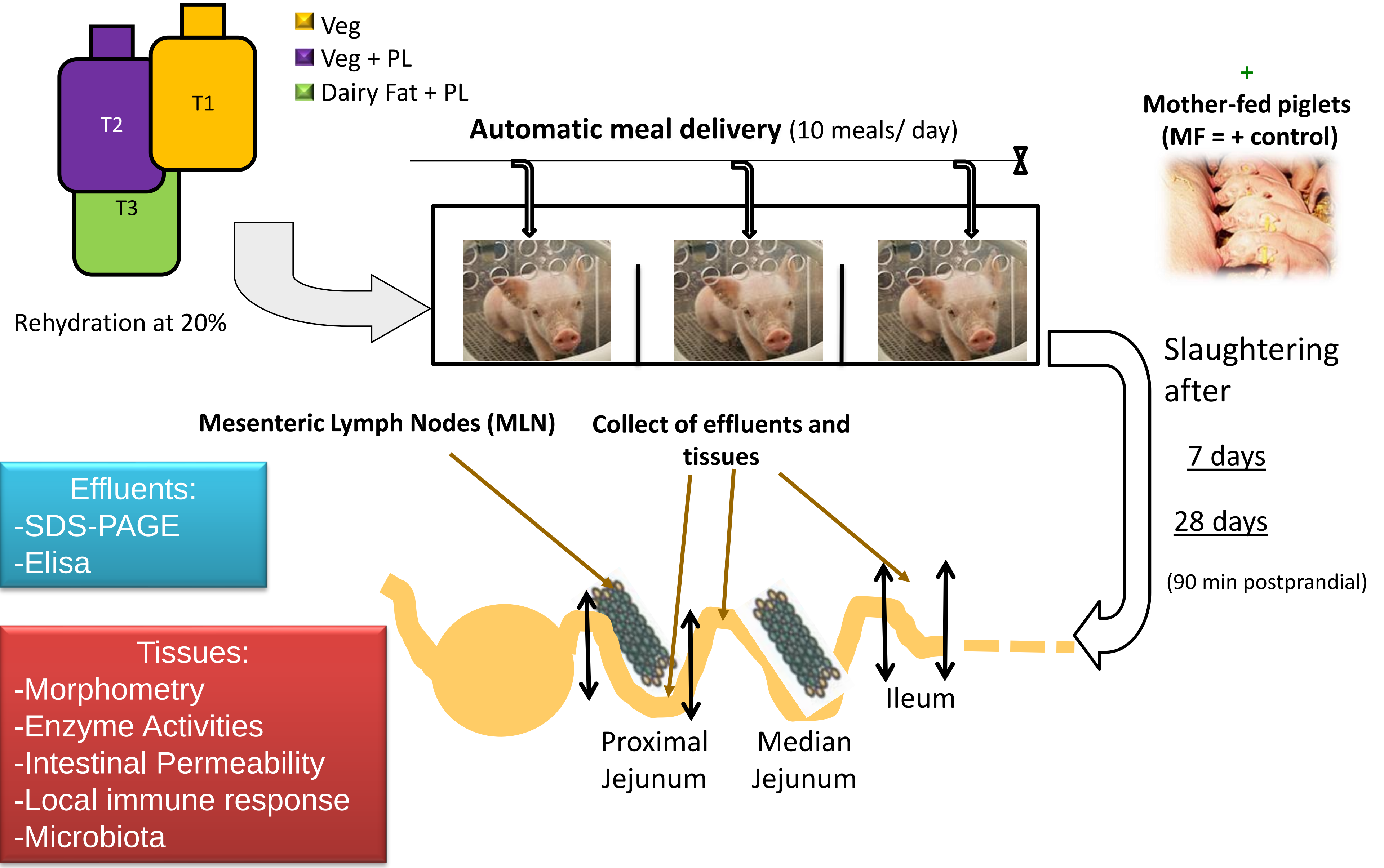


Interface 100 % phospholipides
40% vegetable oil + 60% milk fat



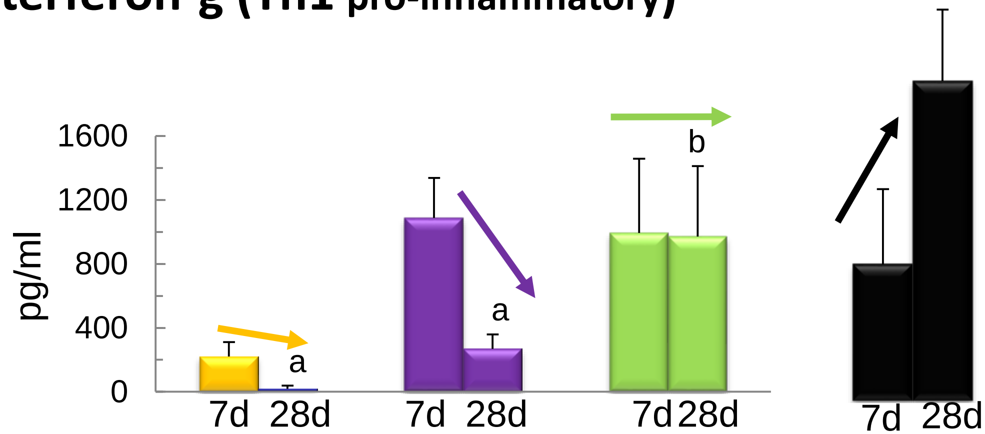
Lopez, (2007)

Can the composition of infant formula modulate the physiological response of the neonate?

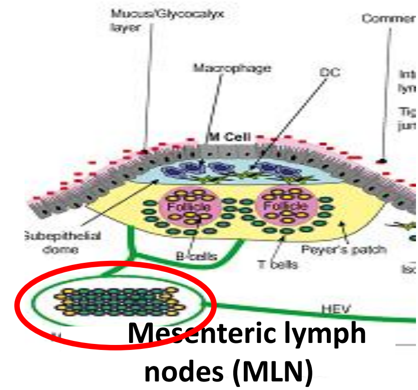


Secretory activity of MLN

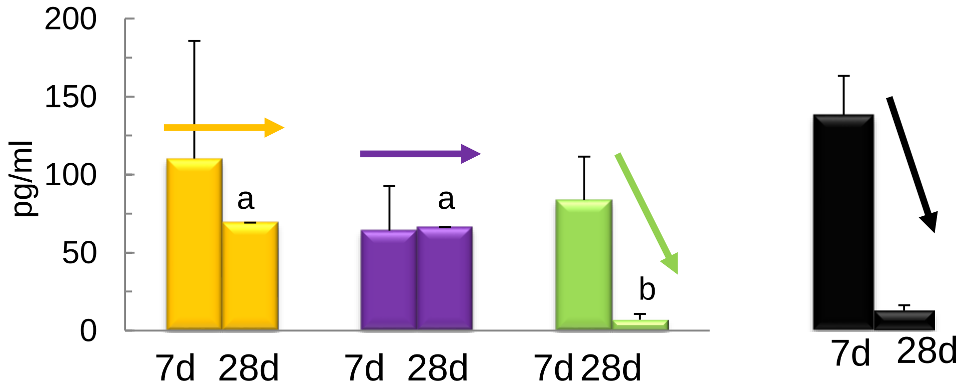
Interferon-g (Th1 pro-inflammatory)



Veg
Veg + PL
Dairy Fat + PL
Porcelets SM



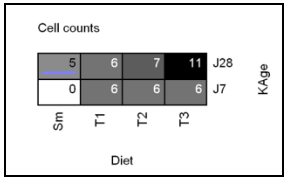
Interleukine-10 (Th2 anti-inflammatory)



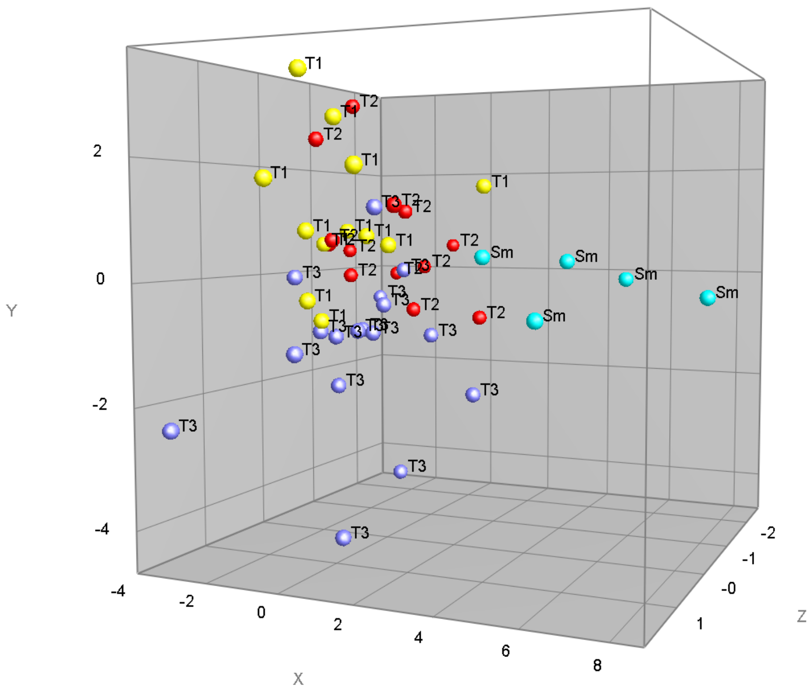
Milk lipids ➔ maturation of the piglet's immune system more similar than with sow's milk

Le Huerou et al.
Eur J Nutr 2017

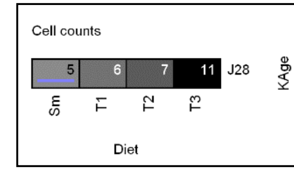
Microbiota by DHPLC

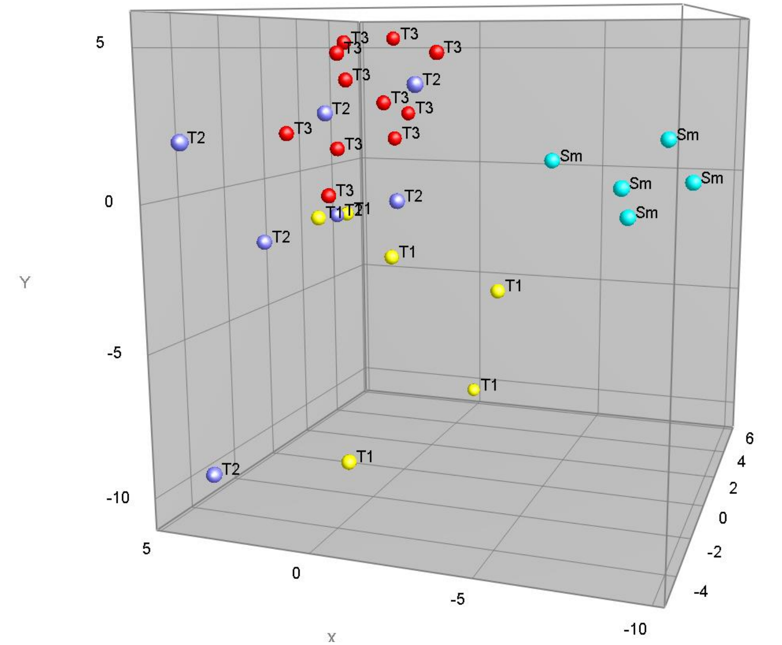


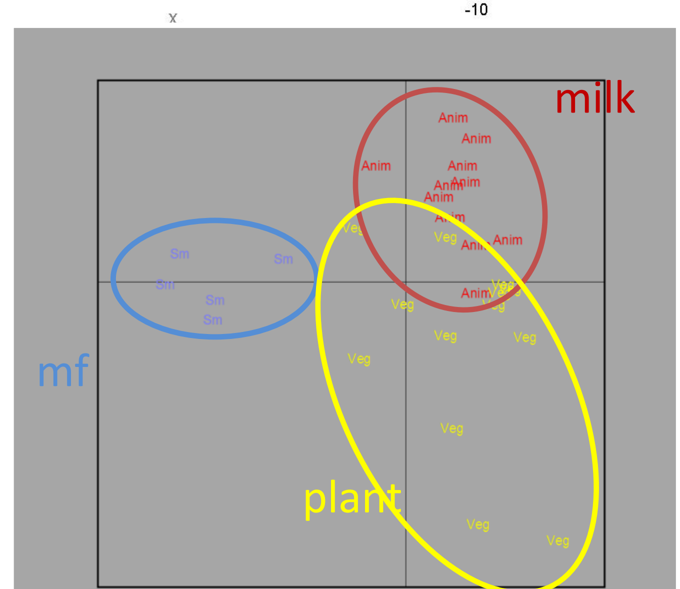
D7 & D28



D28





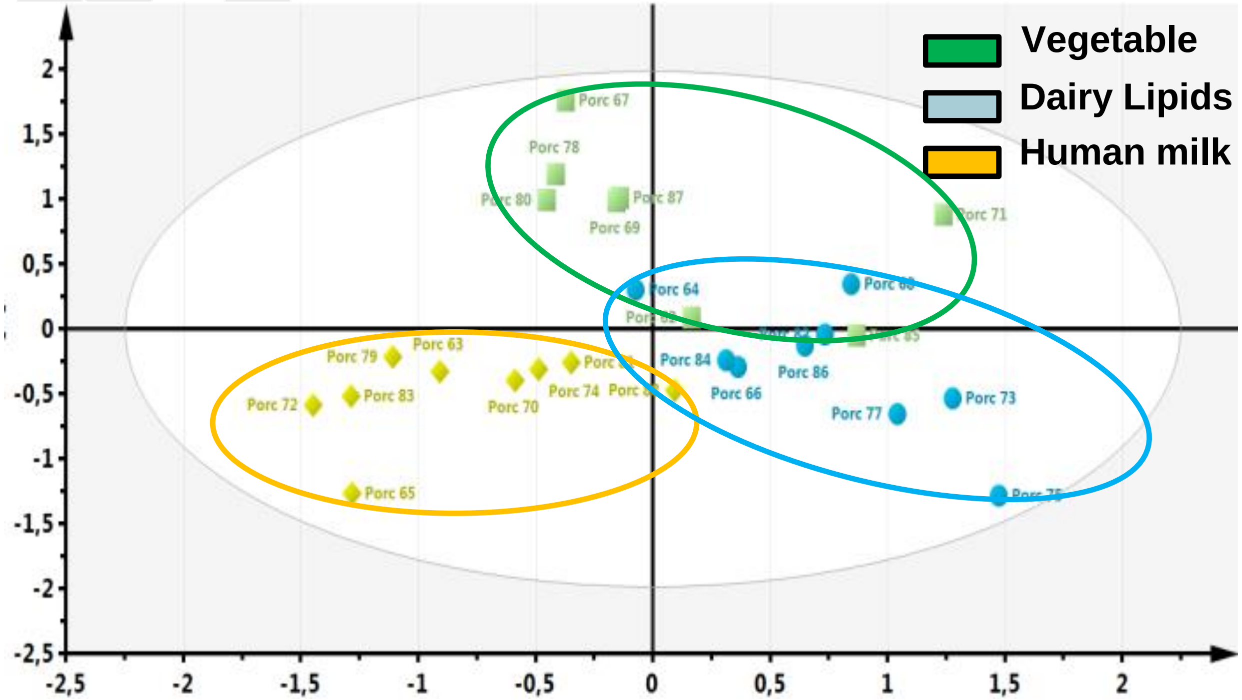


The composition/structure of the infant formula « orientates » the microbiota

More Proteobacteria with milk fat / More Firmicutes with plant oil

Bourlieu et al. Eur J Lipid Sci Technol 2016

What happens when they become older (140 d)?



If animals are submitted to a nutritional stress (high fat/sugar diet), some differences remain in:

* the microbiota composition
* the fecal metabolome with different metabolites (including propionate)
* the immune system with a reduced susceptibility to inflammation with milk lipids

Conclusion

The structure/composition of food regulate the kinetics of protein digestion and the release of amino acids in the bloodstream

Gastric emptying rate will highly depend on the structure that the product will adopt in the stomach cavity.

Understanding the mechanisms of food particle breakdown in the stomach is critical to control the structure a food will adopt in gastric conditions

Being able to design food structures for controlling the kinetics of hydrolysis of macronutrients will allow to obtain food particularly adapted to specific population

The Bioactivity & Nutrition team at INRA Rennes

Head
Didier DUPONT- Senior Scientist

Scientists
Amélie DEGLAIRE – *Lecturer*
Juliane FLOURY – *Lecturer*
Catherine GUERIN - *Lecturer*
Steven LE FEUNTEUN – *Senior Scientist*
Joëlle LEONIL – *Senior Scientist*
Martine MORZEL – *Senior Scientist*
Françoise NAU – *Professor*
Frédérique PEDRONO – *Lecturer*

Xiaoxi YU – *Post-doc*
Guilherme FURTADO – *Post-doc*

PhD students
Yohan REYNAUD *(2016-2019)*
Amira HALABI *(2017-2020)*
Jun WANG *(2018-2021)*
Lea SALLELES *(2018-2021)*
Elise CHARTON *(2019-2022)*
Lucile CHAUVET *(2019-2022)*
Ousmane SUWAREH *(2019-2022)*

Technicians
Gwenaële HENRY
Yann LE GOUAR
Nathalie MONTHEAN

Engineers
Julien JARDIN
Olivia MENARD
Jordane OSSEMOND

Masters students

Improving health properties of food by sharing our knowledge on the digestive process

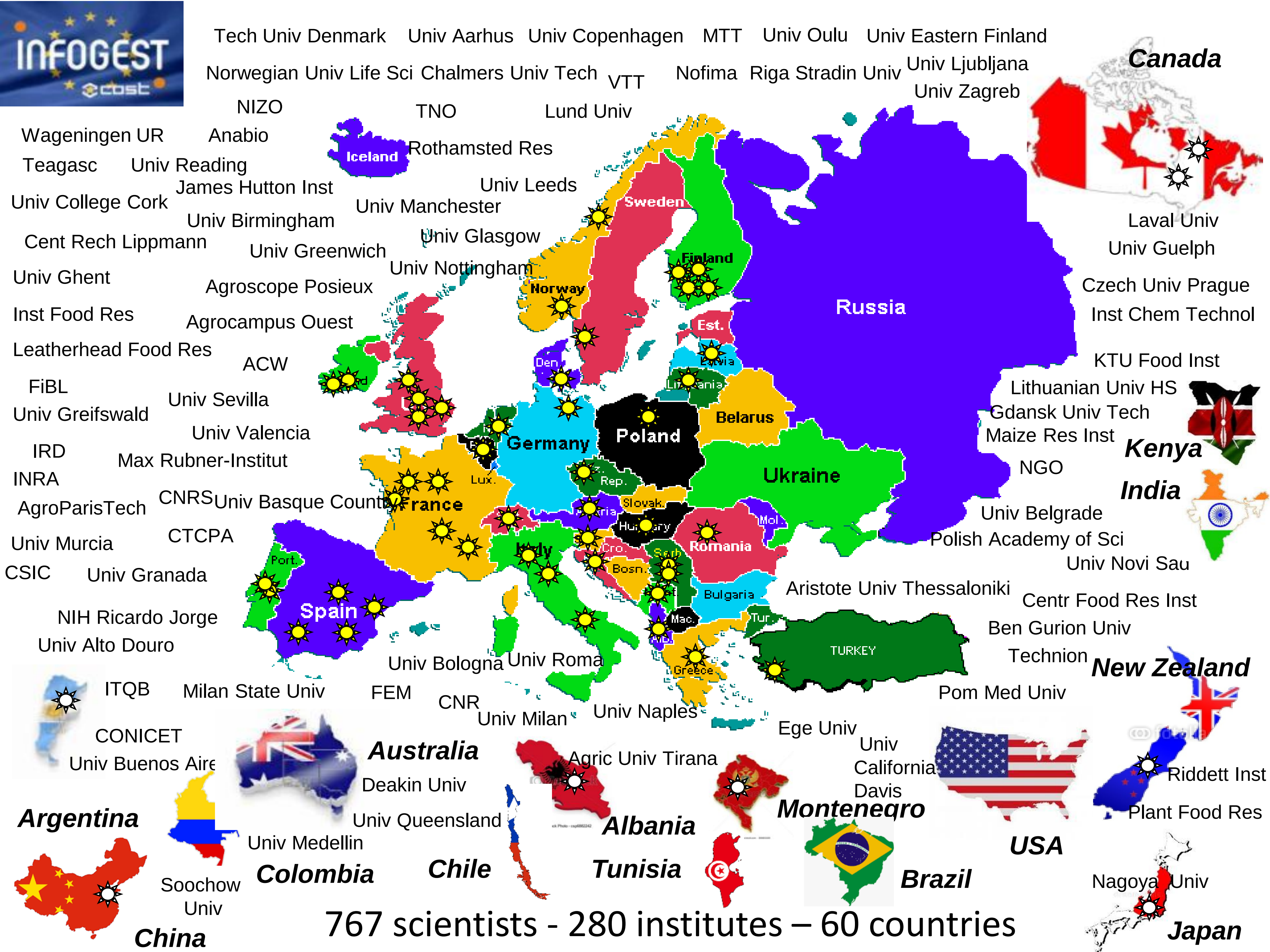
International Network

Dr. Didier DUPONT, Senior Scientist, INRAE, France

INFOGEST

Main objective: understanding the mechanisms of food digestion

- Develop new *in vitro*, *in vivo* and *in silico* digestion models including some for specific populations (infant, elderly)
- Harmonize the methodologies and propose guidelines for performing experiments
- Validate *in vitro* models towards *in vivo* data (animal and/or human)
- Identify the beneficial/deleterious components that are released in the gut during food digestion
- Determine the effect of the matrix structure on the bioavailability of food nutrients and bioactive molecules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Soochow Univ
China
767 scientists - 280 institutes – 60 countries

Industry involvement

☞ ~ 60 private companies are following INFOGEST

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Chair
Didier Dupont - France
didier.dupont@inrae.fr

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Vice-chair
Alan Mackie - UK

In vitro models of digestion WG1

Food interaction – meal digestion WG2

Absorption models WG3

Digestive lipases and lipid digestion WG4

Digestive amylases and starch digestion WG5

In silico models of digestion WG6

Isidra Recio

Pasquale Ferranti

Linda Giblin

Myriam Grundy

Daniela Freitas

Choi-Hong Lai

Andre Brodkorb

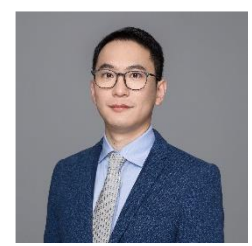
Lotti Egger

Uri Lesmes

Brigitte Graf

Frederic Carriere

Anabel Mulet-Cabero



Bin Zhang

Steven Le Feunteun

Some outputs

In vitro gastrointestinal digestion
Consensus INFOGEST protocol

Minekus et al. 2014
Food & Function, 5, 1113-1124
3125 citations

Brodkorb et al. 2019
Nature Protocol, 14, 991-1014
1325 citations

Oral phase

Mix 1:1 with Simulated Salivary Fluid (SSF)
salivary amylase (75 U/mL)
2 min, pH 7

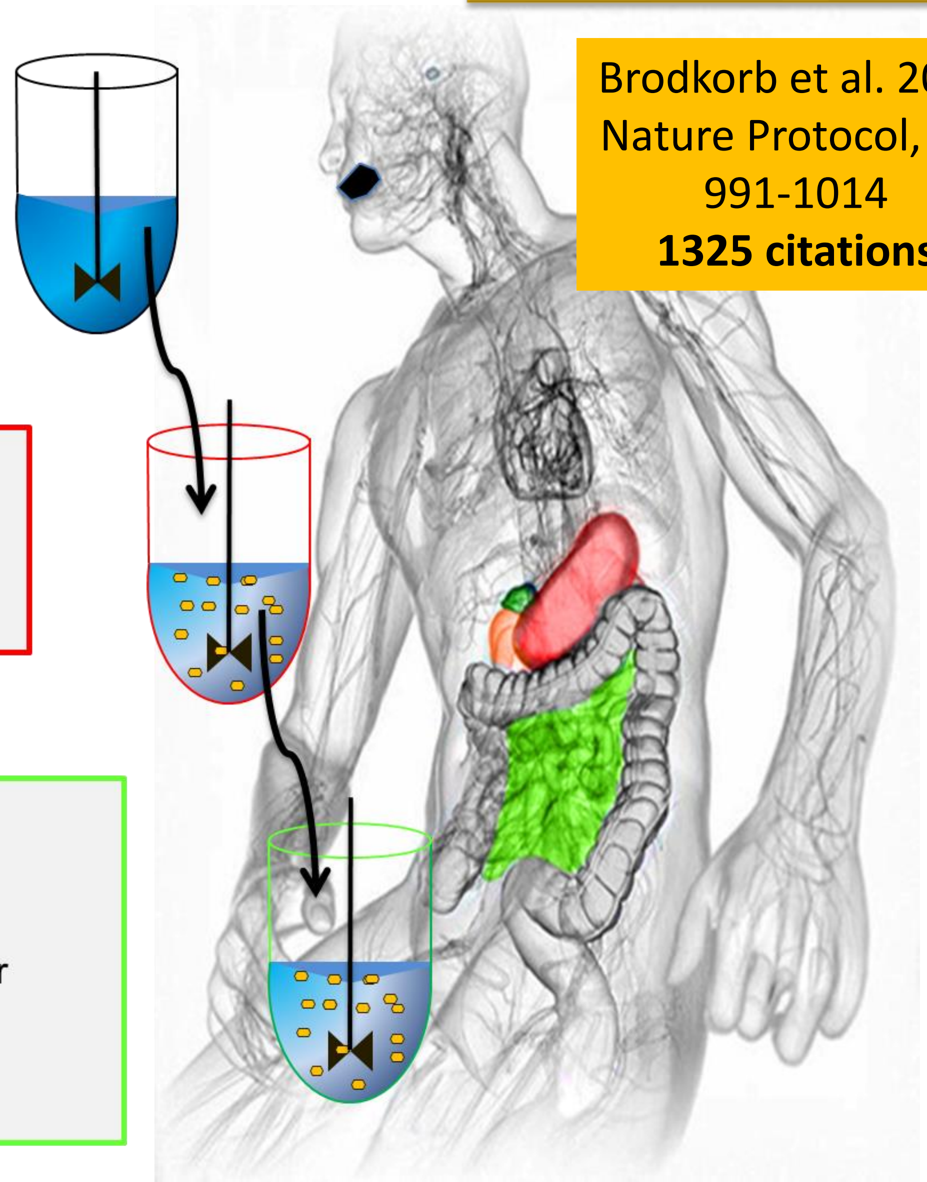
Gastric Phase

Mix 1:1 with Simulated Gastric Fluid (SGF)
Pepsin (2000 U/mL)
2h, pH 3

Intestinal Phase

Mix 1:1 with Simulated Intestinal Fluid (SIF)
Enzymes
- Pancreatin (based on trypsin 100 U/mL) or
- Pure enzymes

Bile (10mM)
2h, pH 7



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International Conference

**Porto, Portugal
2024**

We are pleased to announce the next

8th International Conference on Food Digestion

in Porto, Portugal, 9-11 April 2024