



# Food structure affects the kinetics of food digestion and the bioavailability of nutrients.

Didier Dupont

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Submitted on 5 Jun 2020

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# Food structure affects the kinetics of food digestion and the bioavailability of nutrients



**Dr Didier DUPONT**

INRA, Rennes, France



# Portrait

## The National Institute for Agronomic Research

- Set up in 1946
- A public, scientific and technological establishment
- Under the joint authority of the Ministries of Agriculture and Research
- Second largest French public research organisation with a staff of nearly 13000 and a budget of 850 millions euros
- Largest European organisation for agricultural research



DIET  
AGRICULTURE  
ENVIRONMENT

INRA

## Three major fields

**Diet   Agriculture   Environment**

**... in six research areas:**

- > Environment and rural areas
- > Human nutrition and food safety
- > Quality of agricultural products
- > Knowledge of the living world
- > Agricultural practices and systems
- > Social sciences



# STLO ID card

Joint research unit between **INRA** and **Agrocampus Ouest**

## Keywords

Egg products, cheese technology, milk processing (spray-drying, membrane filtration, heat treatment), dairy products

Nutrition, digestion, bioactivity

Probiotics, lactic acid bacteria, propionic acid bacteria, food spoiling, mastitis.

## Facilities

Milk processing platform (PFL/800m<sup>2</sup>), spray-drying (Bionov/industrial scale),  
Strain library (CIRM-BIA), L2-level labs, cell culture labs

## Workforce

**83 permanent staff** (39 scientists and professors; 44 technicians and engineers)

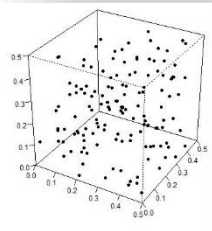
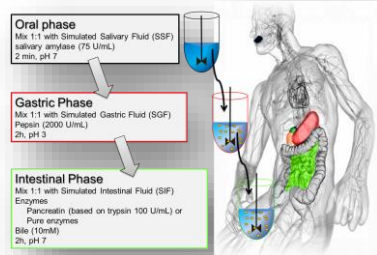
**Total workforce: 130-140 persons.**

~**25** PhD and post-docs /year

~**20** students (shorter training periods)

**16** staff from industrial R&D teams

# Organization



Vice directors

Director



Microbiology



Interaction  
Structure/  
Function



Bioactivity  
& Nutrition



Filtration  
process

Spray-drying  
process



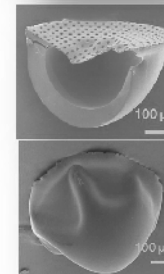
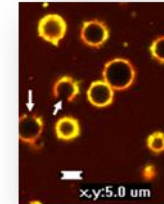
Centre de ressource biologique  
CIRM-BIA



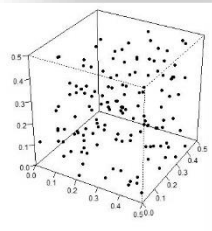
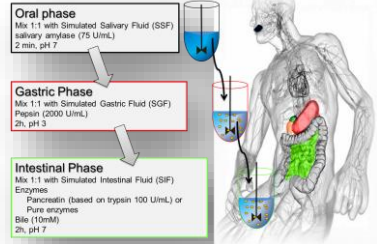
Plateforme Lait  
PFL



SAPHIRE  
Administration,  
Informatics & Infrastructure, Doc & Com



# Organization



Vice directors



Director



MICROBIO



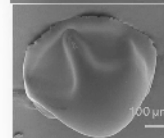
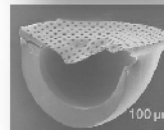
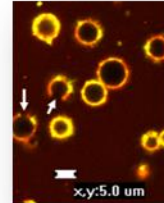
SMCF



Plateforme Lait  
PFL



SAPHIRE  
Administration,  
Informatics & Infrastructure, Doc & Com



# A 800 m<sup>2</sup> Dairy Platform





# The Bioactivity & Nutrition group at INRA in Rennes

## Head

Didier DUPONT - *Senior Scientist*

## Scientists

Rachel BOUTROU – *Junior Scientist*

Amélie DEGLAIRE – *Lecturer*

Juliane FLOURY – *Lecturer*

Catherine GUERIN - *Lecturer*

Joëlle LEONIL – *Senior Scientist*

Steven LE FEUNTEN – *Junior Scientist*

Françoise NAU – *Professor*

Frédérique PEDRONO – *Lecturer*

Guilherme FURTADO – *Post-doc*

Xaoxi YU – *Post-Doc*



## PhD students

Linda LEROUX (2016-2019)

Manon HIOLLE (2016-2019)

Yohan REYNAUD (2016-2019)

Amira HALABI (2017-2020)

Léa SALELLES (2018-2021)

Jun WANG (2018-2021)

## 2-3 Masters students

## Technicians

Gwenaële HENRY

Yann LE GOUAR

Nathalie MONTHEAN

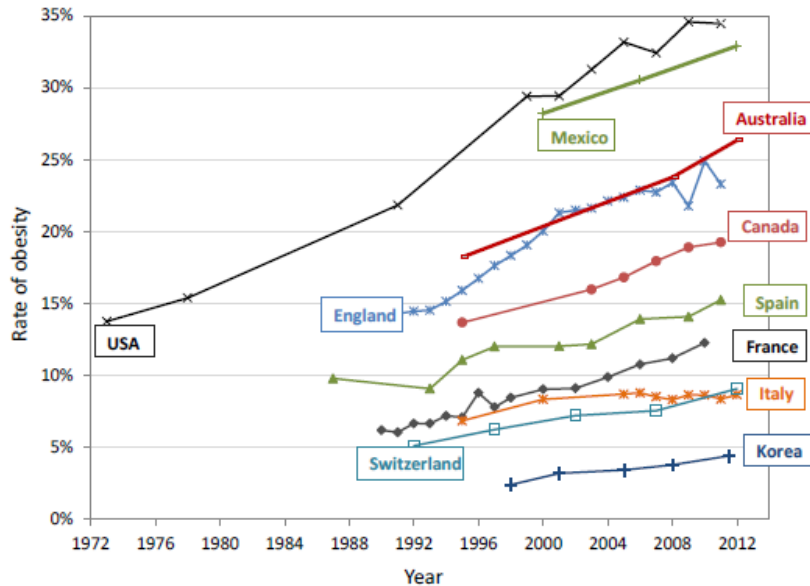
## Engineers

Julien JARDIN

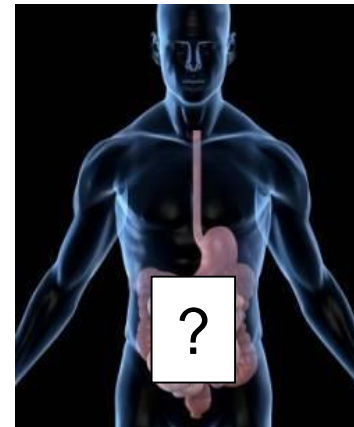
Olivia MENARD

Jordane OSSEMOND

# 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**

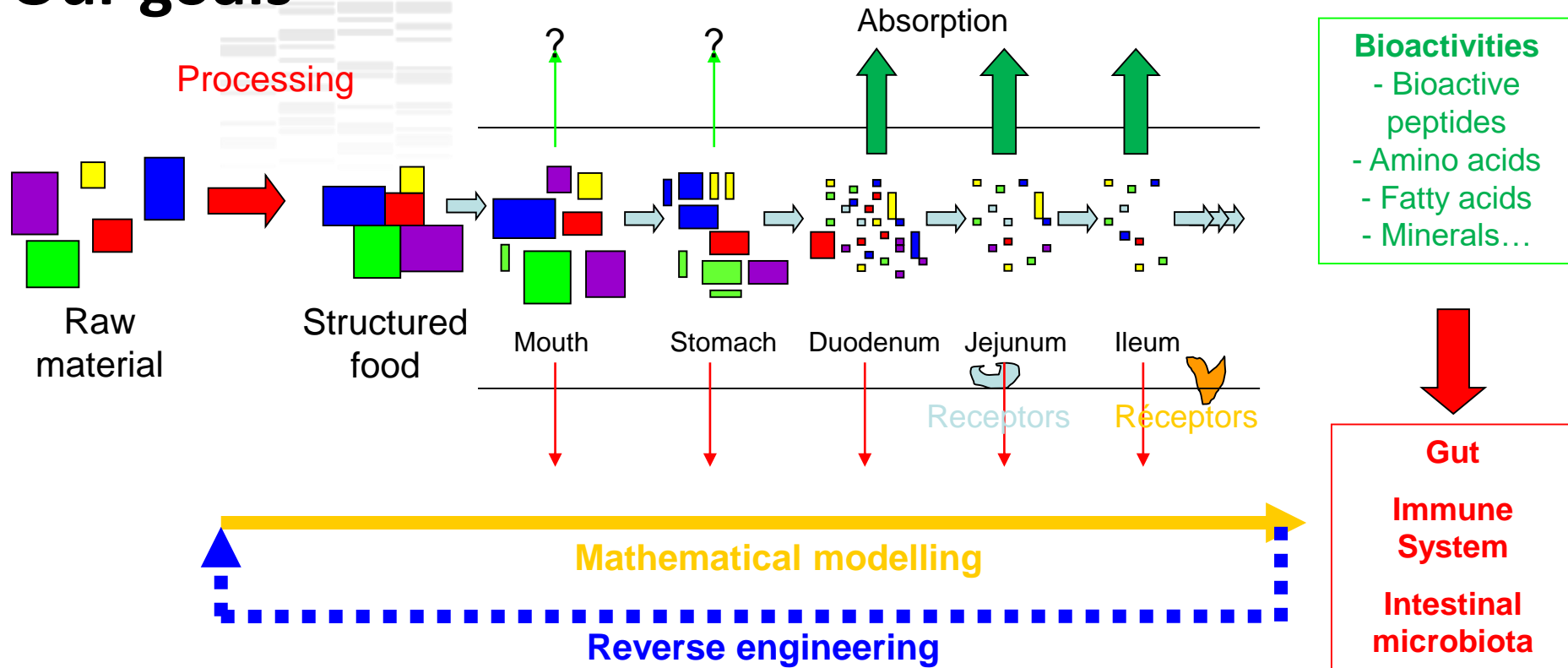
**Digestion releases food components that can have a beneficial or a deleterious effect on human health**

... 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**

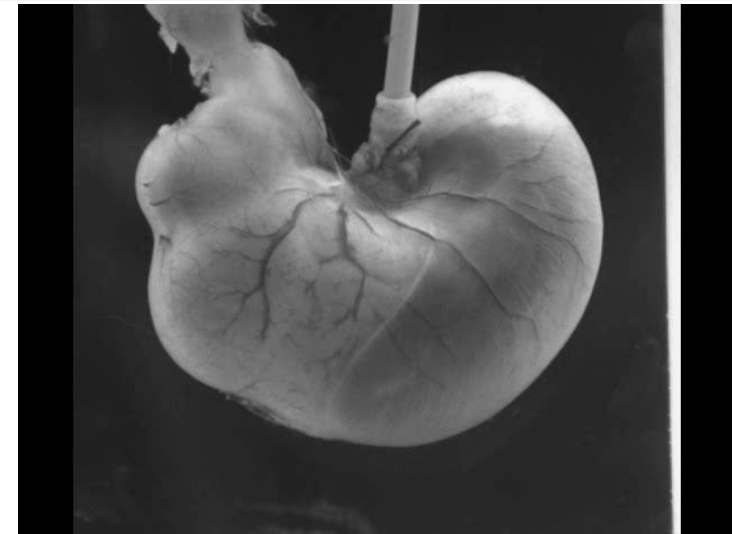
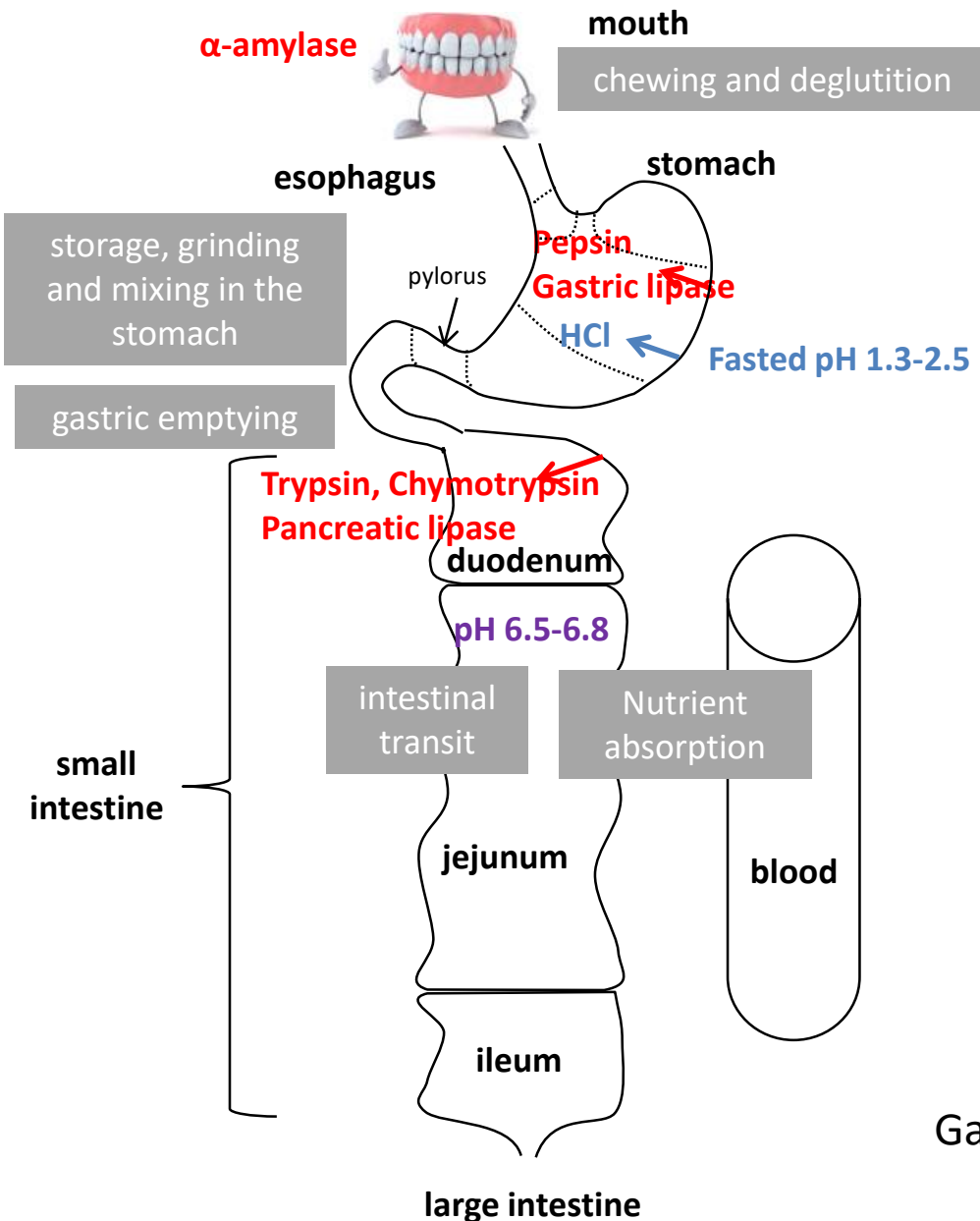
# Our goals

Healthy Adult/ Neonate/ Elderly

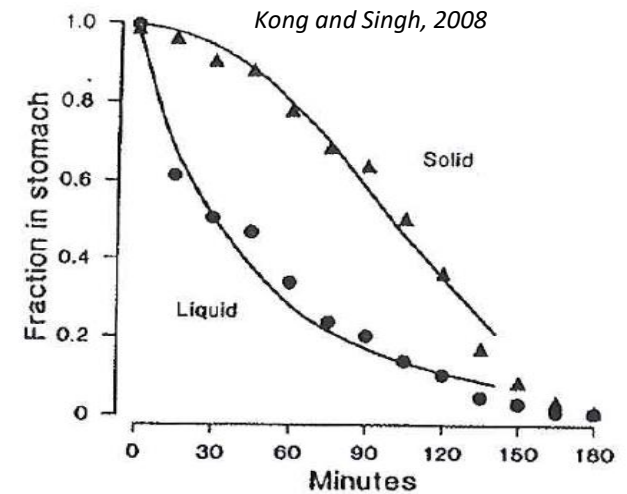


- ☞ To understand the mechanisms of breakdown of food matrices and their constituents in the gut and identify the beneficial/deleterious food components released during digestion
- ☞ To determine the impact of the structure of food matrices on nutrient bioavailability
- ☞ To model these phenomena in 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 INRA for simulating digestion

Menard et al. 2014,  
Food Chem  
Sanchez et al. 2015  
Food Res Int

Dupont et al.  
2010ab,  
Mol Nutr Food Res



*In vitro static models  
(infant, adult)*

Le Feunteun et al.  
2014  
Food Bioprocess  
Tech

*In silico  
models*

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



*In vitro dynamic models  
(infant, adult, elderly)*



*Human  
models*



*Animal models*



Barbé et al. 2013, 2014  
Food Chem  
Le Huerou-Luron et al.  
2016 Eur J Nutr

De Oliveira et al. 2016  
Am J Clin Nutr  
De Oliveira et al. 2017  
Clin Nutr

# Static *in vitro* digestion models

- ➡ Huge diversity between the models mimicking the GI tract of the adult (E/S, pH...)
- ➡ Impossible to compare results from one study to another – Need for harmonization

## Consensus *in vitro* digestion method for food

**INFOGEST**

International network  
– 410 researchers  
– 150 institutes  
– 45 countries

### Oral phase

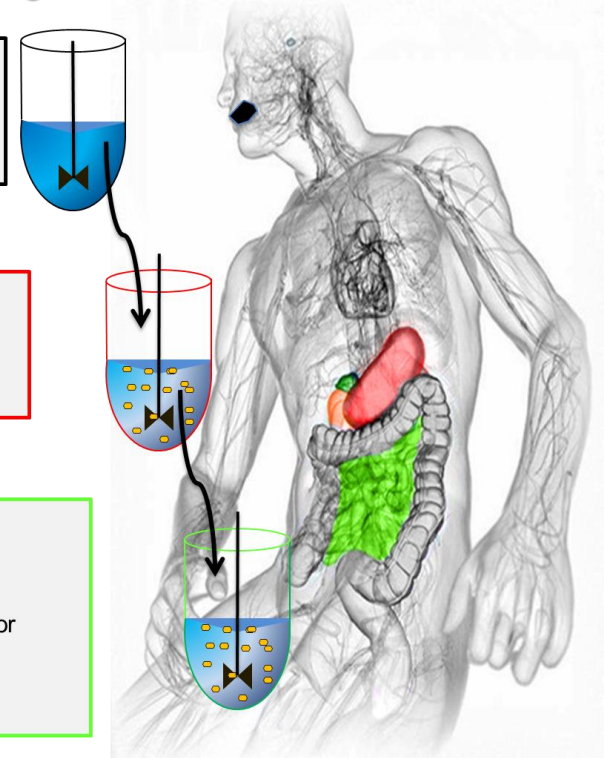
Mix 1:1 with Simulated Salivary Fluid (SSF)  
salivary amylase (75 U/mL)  
2 min, pH 7

### 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



**A standardised static *in vitro* digestion method suitable for food- an international consensus, Food & Function, Minekus et al. 2014 – Highly Cited Paper 800 citations in 4 years!**

# The INFOGEST model can be learned through videos on YouTube

Fichier Édition Affichage Historique Marque-pages Outils ?

Intranet UMR STLO - Accueil x GRR (Gestion et Réservatio... x YaZiba: 30/3 - 3/4 x In vitro food digestion - C... x +

https://www.youtube.com/channel/UCdc-NP9kTDGyH\_kZCgpQWg youtube

YouTube FR cost infogest

Mettre en ligne Connexion

Vidéos à regarder

LE MEILLEUR DE YOUTUBE

- Populaire sur YouTube
- Musique
- Sport
- Jeux vidéo et autres
- Films
- Émissions TV
- Actualité

Parcourir les chaînes

Connectez-vous maintenant pour consulter vos chaînes et les recommandations.

Se connecter

In vitro food digestion - COST action INFOGEST

Accueil Vidéos Playlists Chaînes Discussion À propos

Toutes les activités

In vitro food digestion - COST action INFOGEST a mis en ligne une vidéo. il y a 10 mois

Oral phase  
Gastric Phase  
Intestinal Phase

Alpha Amylase Activity Assay for In Vitro Food Digestion

de In vitro food digestion - COST action INFOGEST  
il y a 10 mois • 846 vues  
A step-by-step description of a static  $\alpha$ -amylase activity assay for an in vitro digestion method presented suitable for food; recently published and available online (open access...)

5:12

In vitro food digestion - COST action INFOGEST a mis en ligne une vidéo. il y a 10 mois

Oral phase  
Gastric Phase  
Intestinal Phase

Static In Vitro Digestion Method for Food

de In vitro food digestion - COST action INFOGEST  
il y a 10 mois • 723 vues  
A step-by-step description of a static in vitro digestion method presented suitable for food (international consensus); recently published and available online (open access), see ...

8:55

Chaînes populaires sur YouTube

- Seb la Frite S'abonner
- MissCreatives S'abonner
- LanguedePub / M... S'abonner
- JunkFoodTasterD... S'abonner
- Madame Patachou S'abonner
- halawiyat khadija... S'abonner

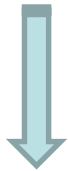
FR

10:38

# Static *In vitro* digestion models: pro's & con's



*in vivo*



*in vitro*

Bohn et al. 2017  
Crit Rev Food Sci  
Nutr

## Main Reasons:

Ethical - Technical – Financial

## Advantages:

Standardisation of the experimental conditions  
Good reproducibility and repeatability  
Easy sampling, possibility to follow kinetics

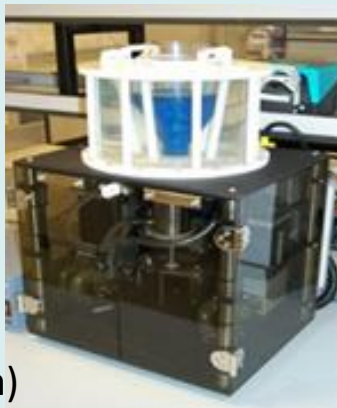
## Disadvantages:

You cannot mimic the complexity of the GI tract  
in a test tube!!!



# Dynamic *in vitro* digestion models

DGM  
(stomach)



HGS  
(stomach)

ARCOL  
(colon)



## Mono-compartmental models

DIDGI (stomach + small intestine)



Dupont et al. 2017  
Crit Rev Food Sci  
Nutr

TIM  
(TIM1 =  
duod+jej+ile  
TIM2 = colon)



## Multi-compartmental models

SIMGI (whole GI tract)



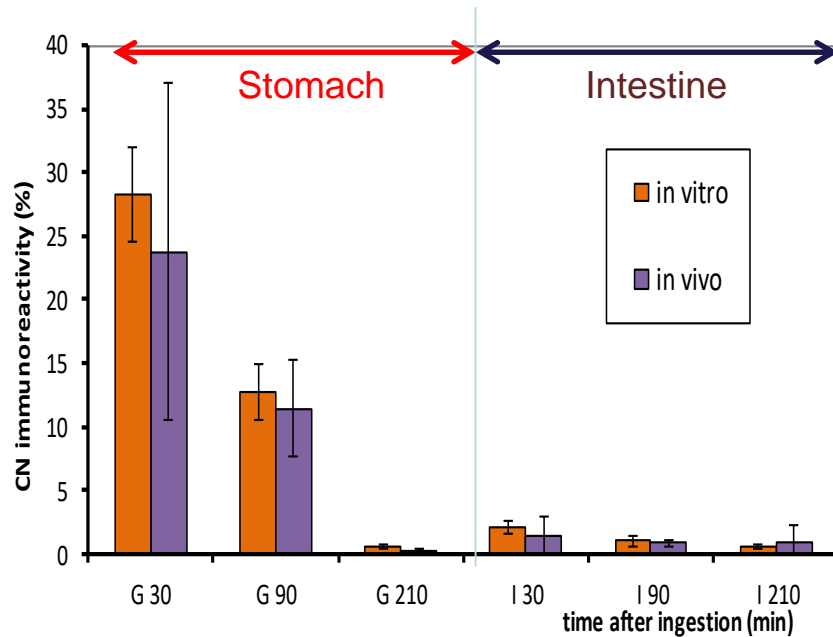
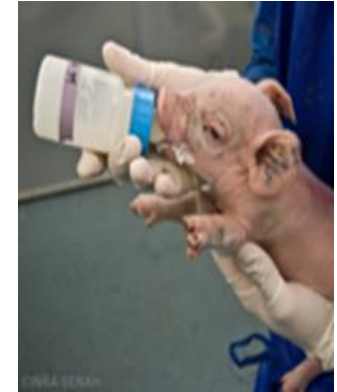
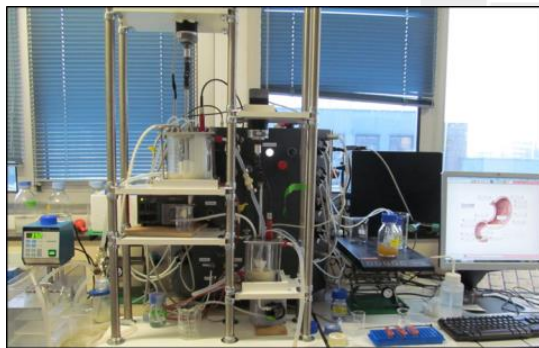
SHIME (whole GI tract)



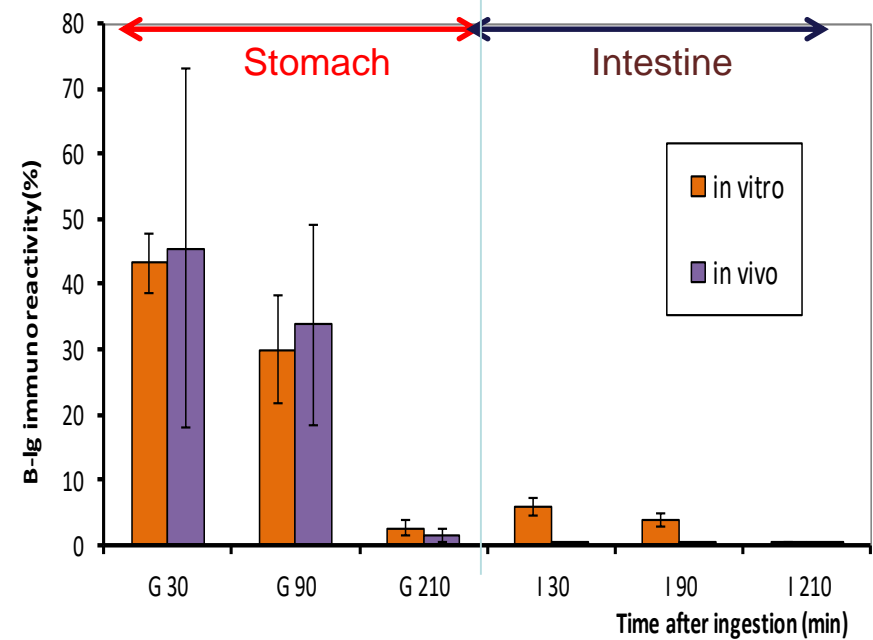
ESIN  
(stomach  
+ small  
intestine)



# Validation of the dynamic *in vitro* digestion system



Caseins



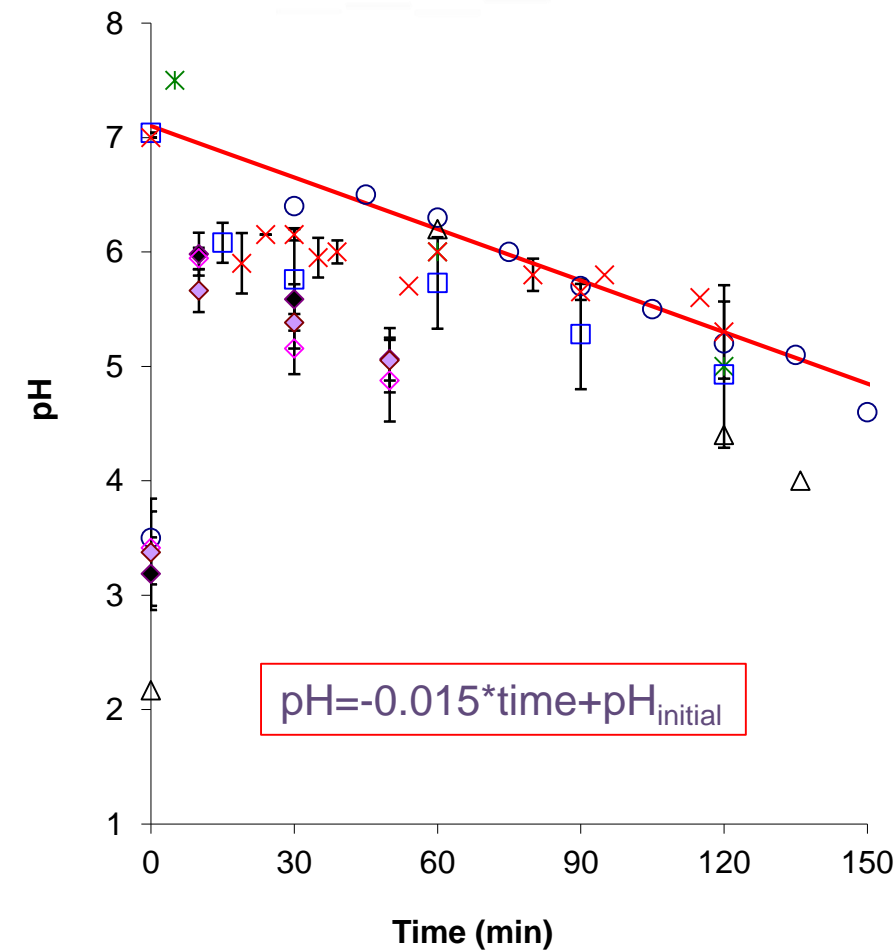
$\beta$ -lactoglobulin

Menard et al.  
2014  
Food Chem

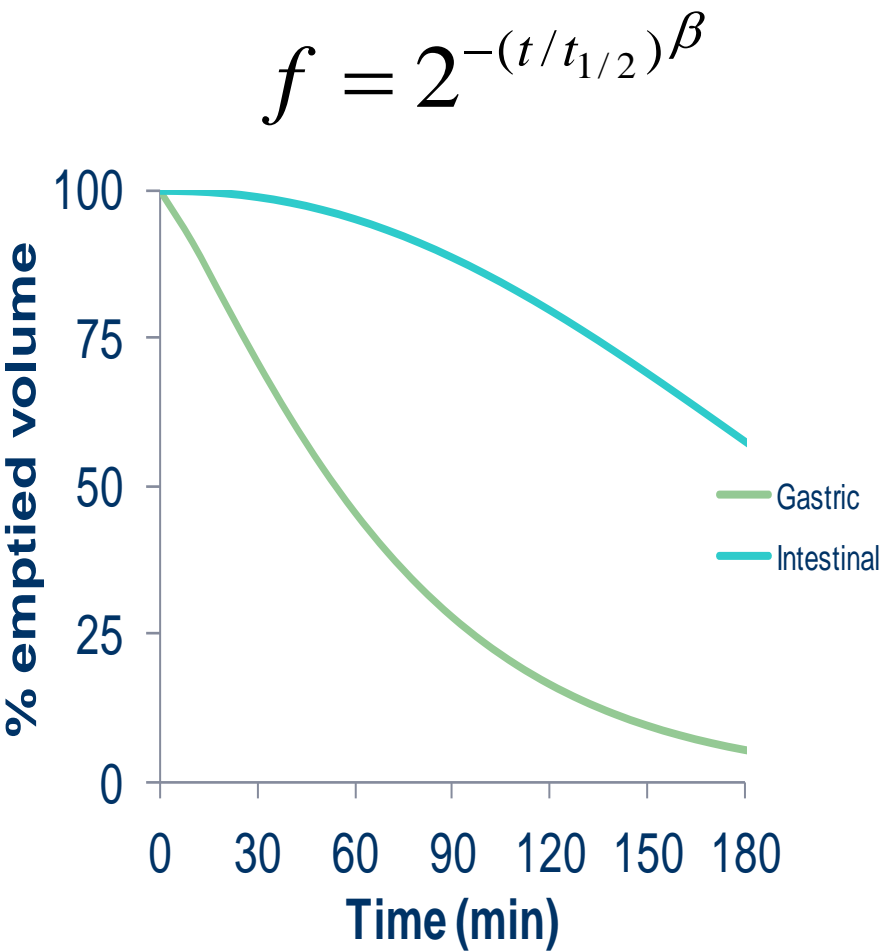
# Need parameters to set up the simulator

Parameters taken from previous *in vivo* studies

pH evolution in the stomach



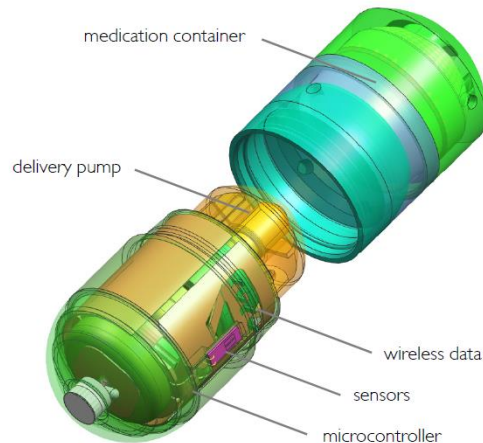
Gastric emptying rate



# When parameters are not available, you need to determine them

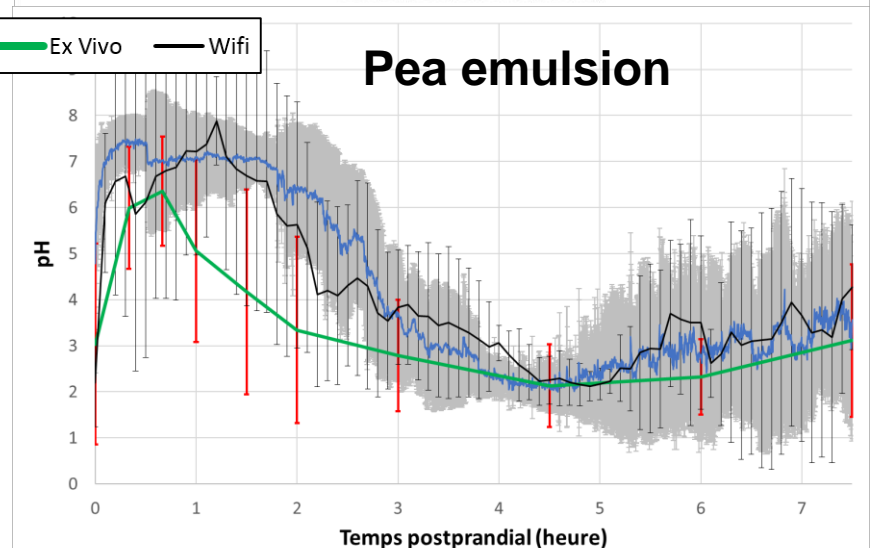
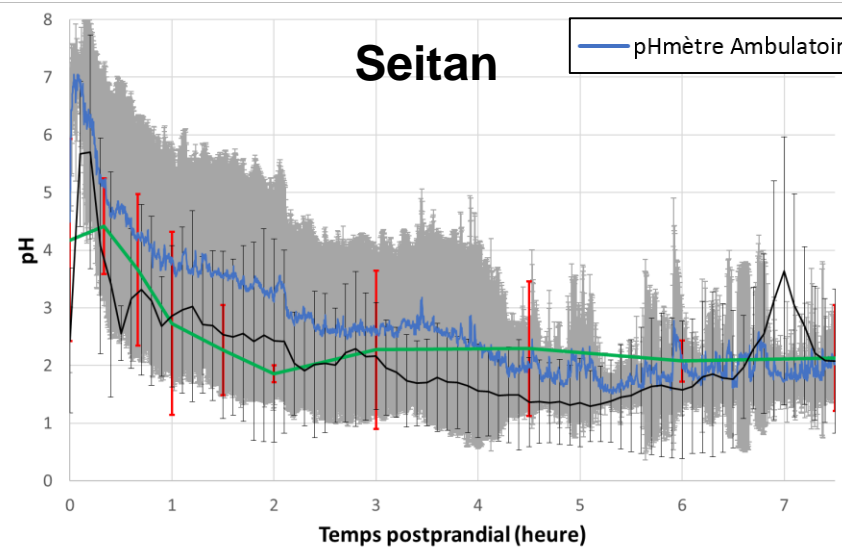
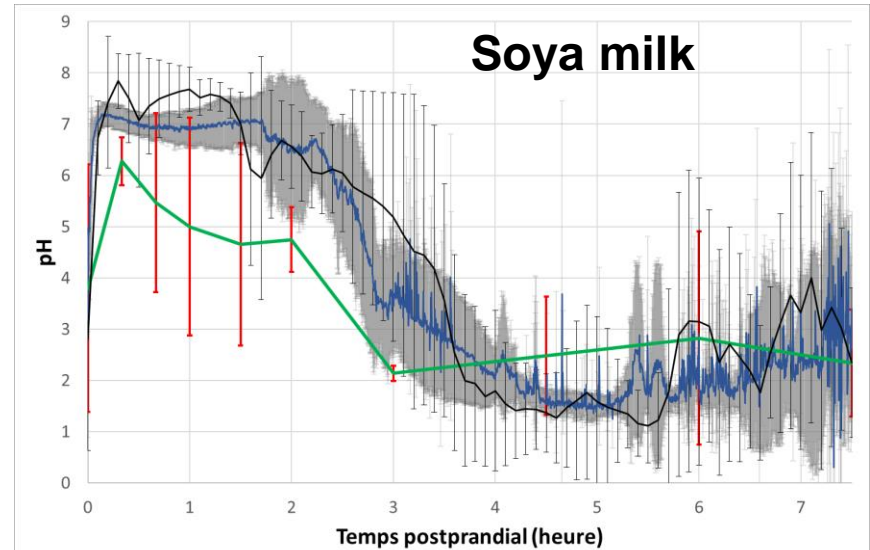
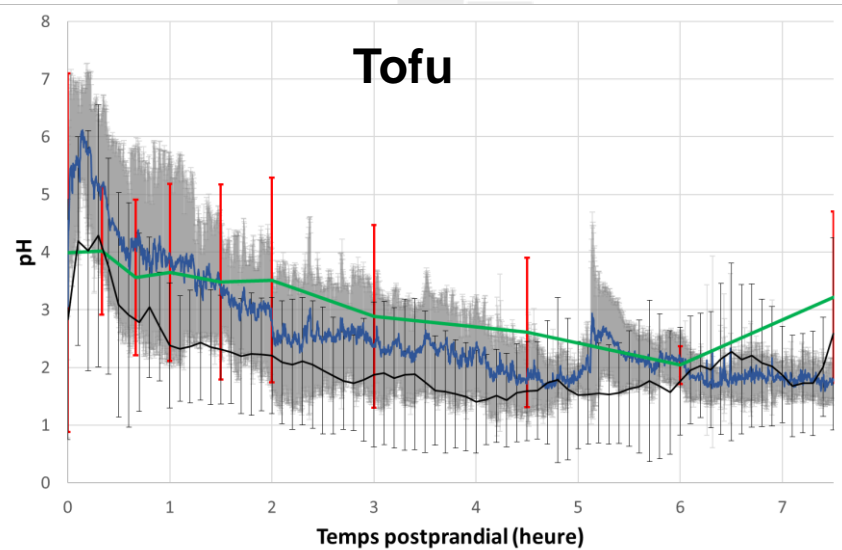
## For example, for the pH, the Intellicap<sup>®</sup> System

- Ingestible capsules
- Real-time monitoring of physiological parameters
- Controlled drug delivery unit
- Size: 11 x 26 mm
- IntelliCap<sup>®</sup> measurements:
  - pH (relative accuracy:  $\pm 0.3$  pH units)
  - Temperature (relative accuracy:  $\pm 0.1$  °C)



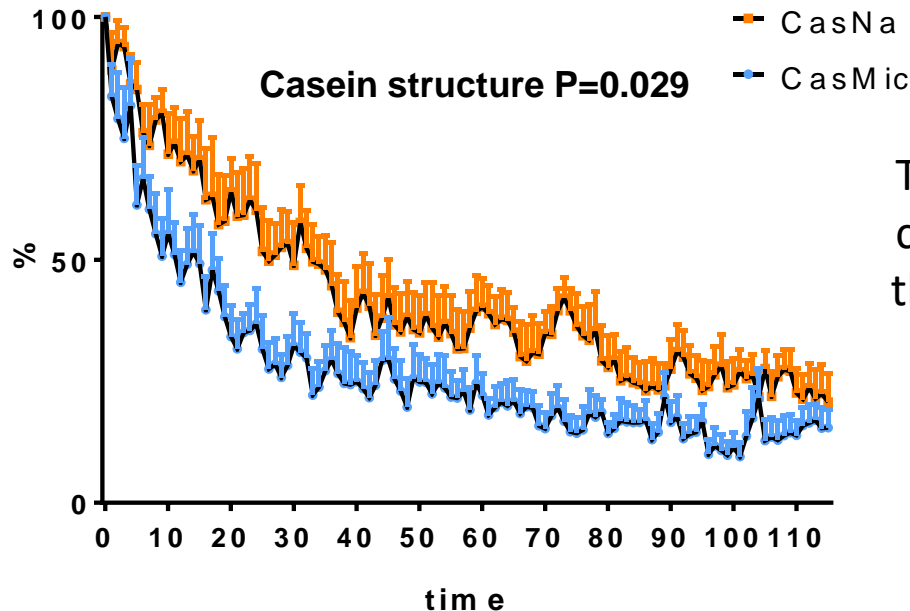
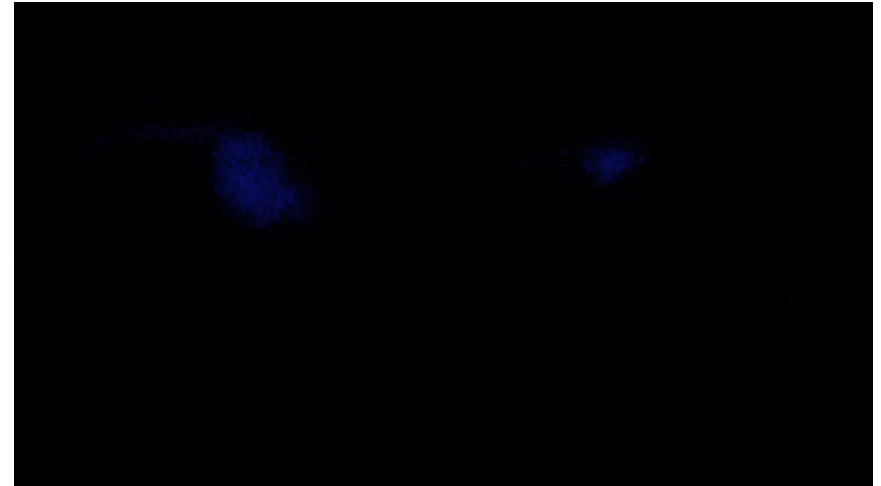
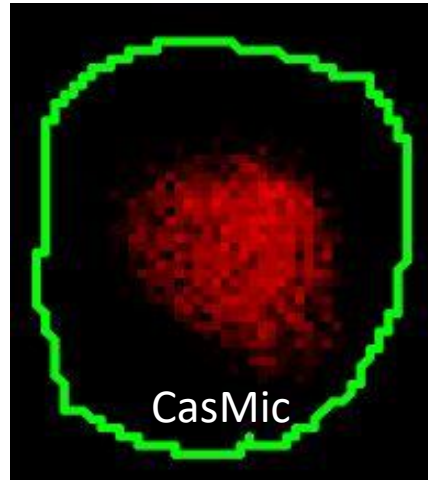
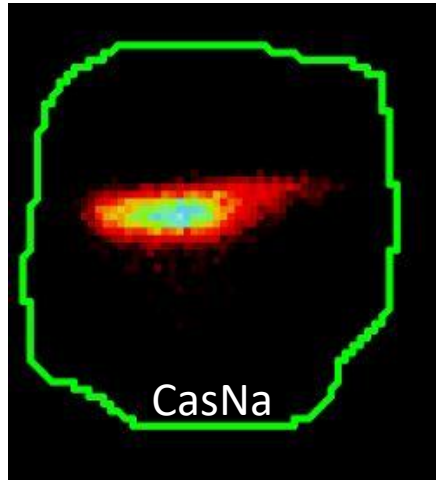


# Evolution of gastric pH in mini-pigs during digestion of plant matrices comparison of 3 measurement systems

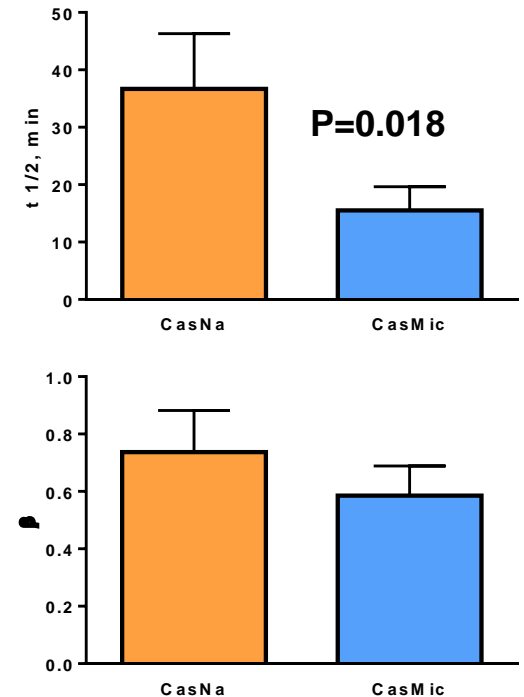


# Gastric emptying by gamma-scintigraphy on pigs

Comparison of sodium caseinate/ casein micelles



The structure of caseins regulate their behavior in the stomach



# Dynamic *in vitro* digestion models: Pro's & con's

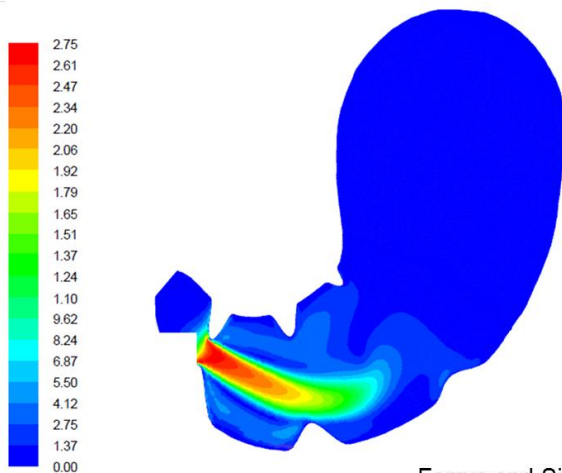


- Highly reproducible
- Physiologically relevant if parameters are available



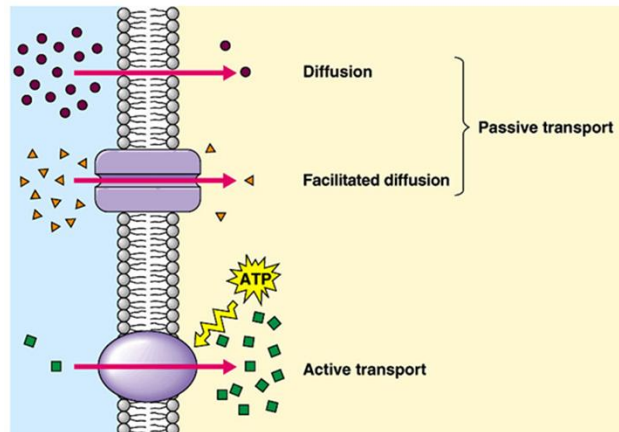
- More expensive than static models
- Too « large » to use pure enzymes (gastric lipase)
- Low throughput

## Limitations



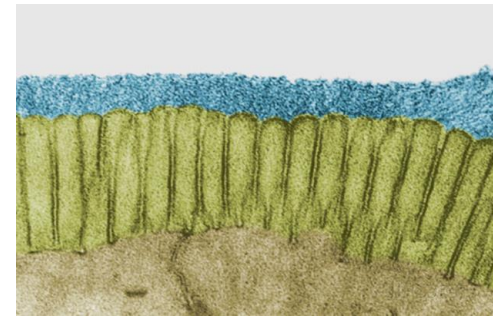
Ferrua and Singh, 2010

Shape of the stomach

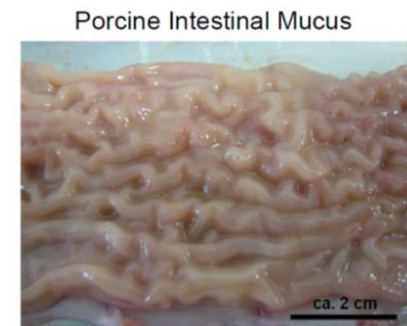


Copyright © Pearson Education, Inc., publishing as Benjamin Cummings.

Absorption is usually poorly mimicked



Role of the brush border



Role of the mucus layer

# ***In vivo* (animal) models**

## **Rodents**



Probably not the best model to mimic the upper part of the human GI tract  
Gnotobiotic animals (« humanized » mice) are of interest to study the effect of food on the microbiota

## **Pigs**



Piglets



Mini-pigs



Multi-canulated and  
catheterized pigs

Pretty good model of the upper GI tract  
Canulas and catheters allow to collect effluent and plasma throughout digestion (kinetics)



# Human Models

Patients with ileostomy



Naso-gastric or naso-jejunal probes





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

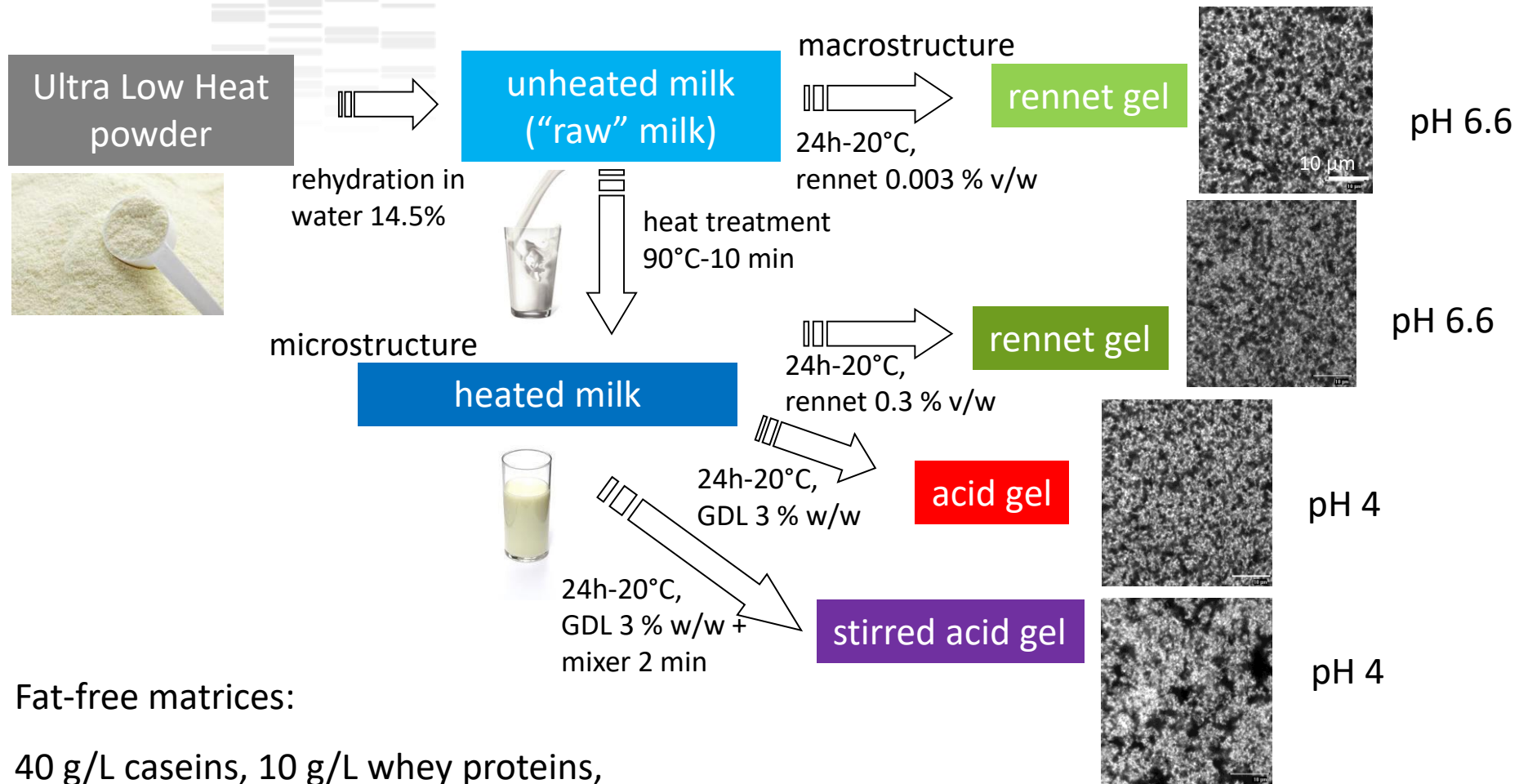


Dupont D.

INRA, Rennes, France



# Comparison of 6 dairy products of identical composition but different structure



Fat-free matrices:

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

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



# The multi-canulated mini-pigs

6 minipigs (20 ± 1kg)

1 catheter: abdominal aorta

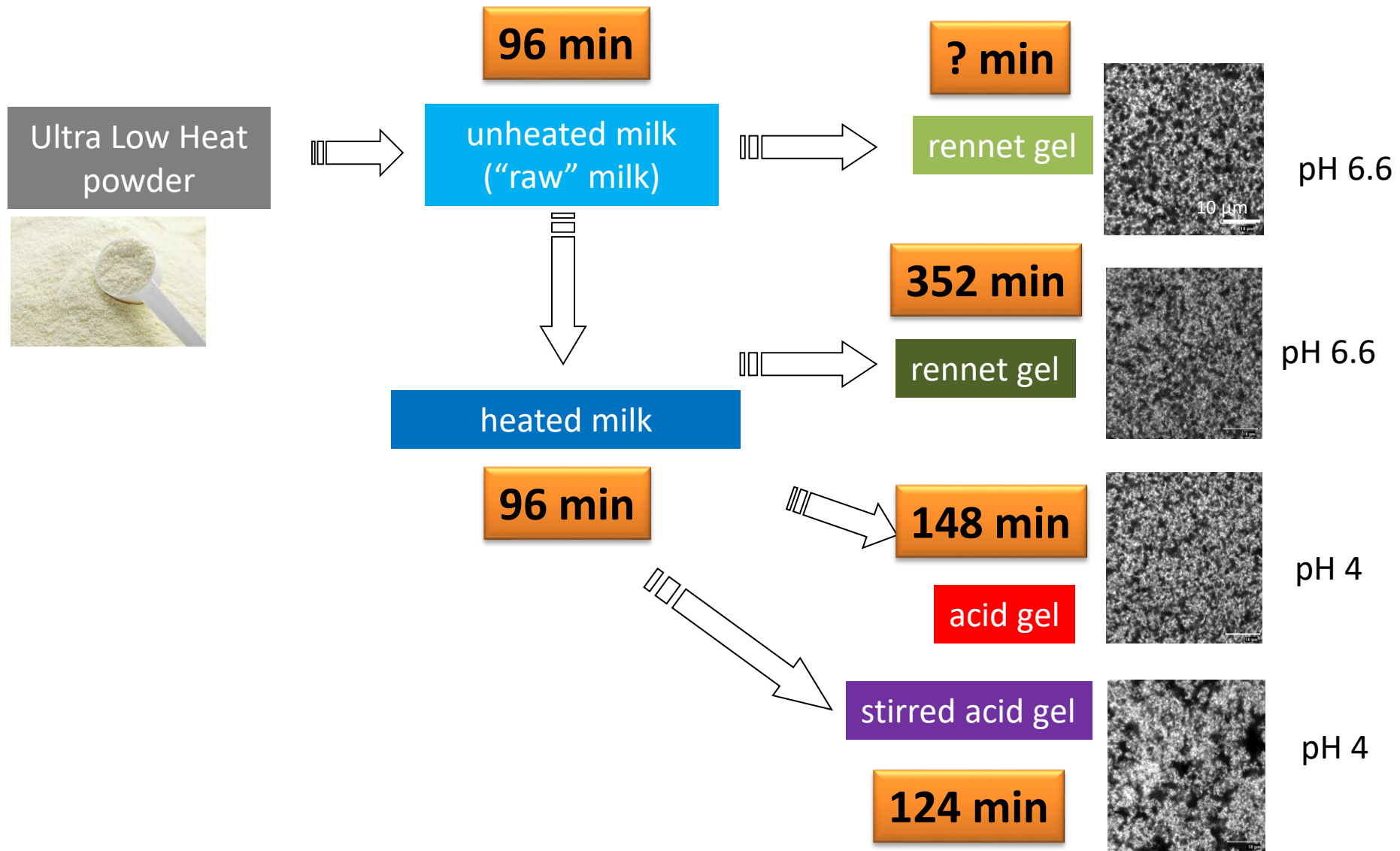
6 minipigs  
× 6 matrices  
× 8 sampling times after ingestion  
=  
288 plasma samples collected

2 cannulas:  
end of stomach and mid-jejunum

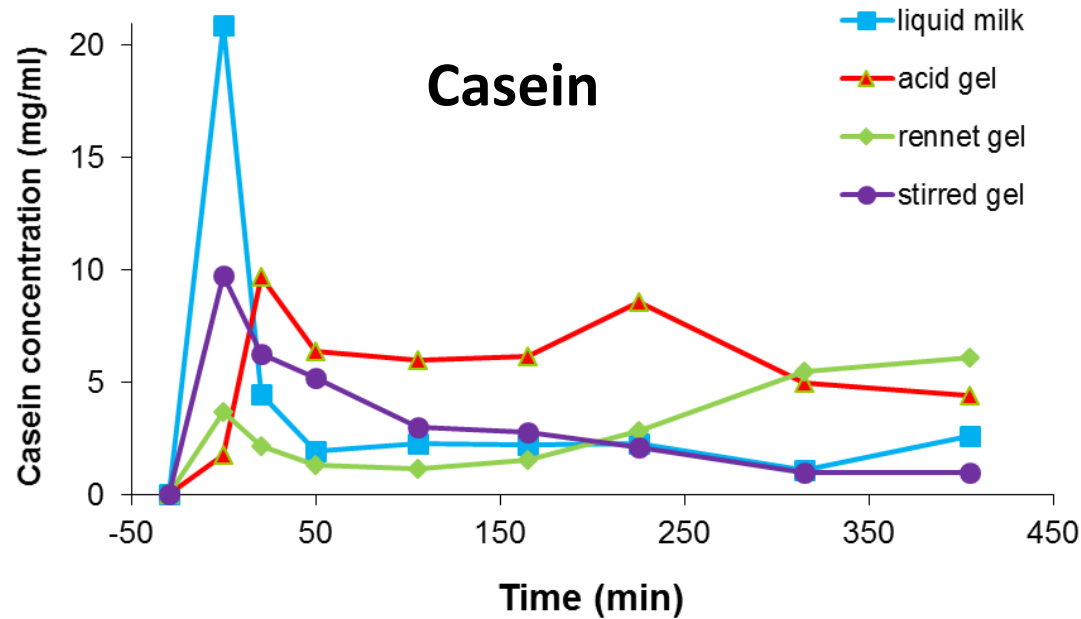
6 minipigs  
× 6 matrices  
× 8 sampling times after ingestion  
× 2 sampling sites  
=  
576 effluent samples collected



# Gastric emptying half time

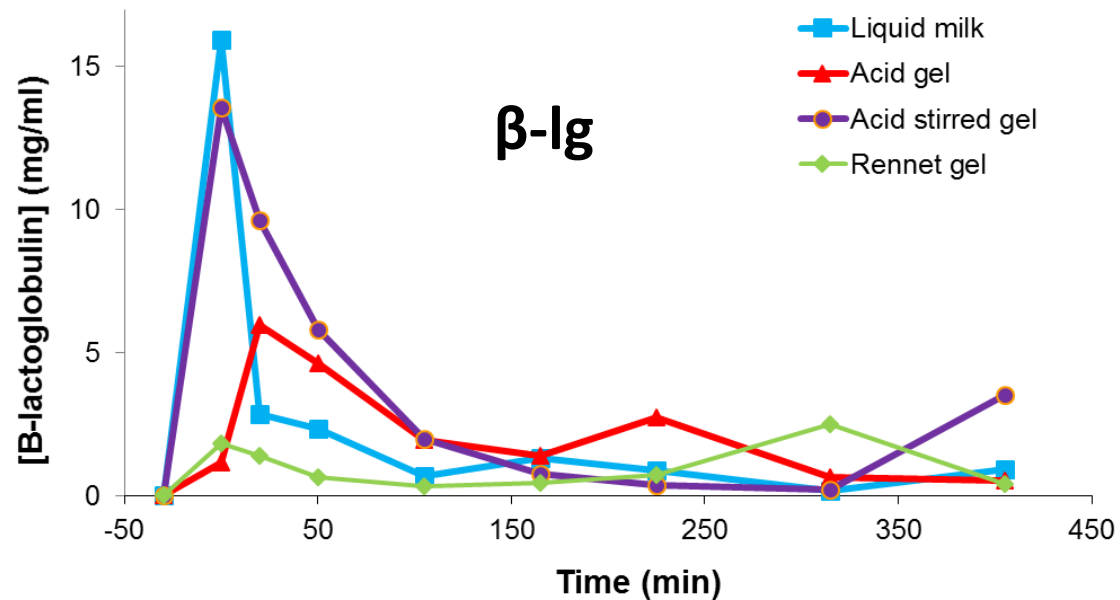


# Milk proteins in the duodenum (ELISA)



- Intense and early peak with milk
- Lower and delayed with gels
- Intermediate behaviour with stirred gel
- Low concentrations with rennet gel but casein release tends to increase over time

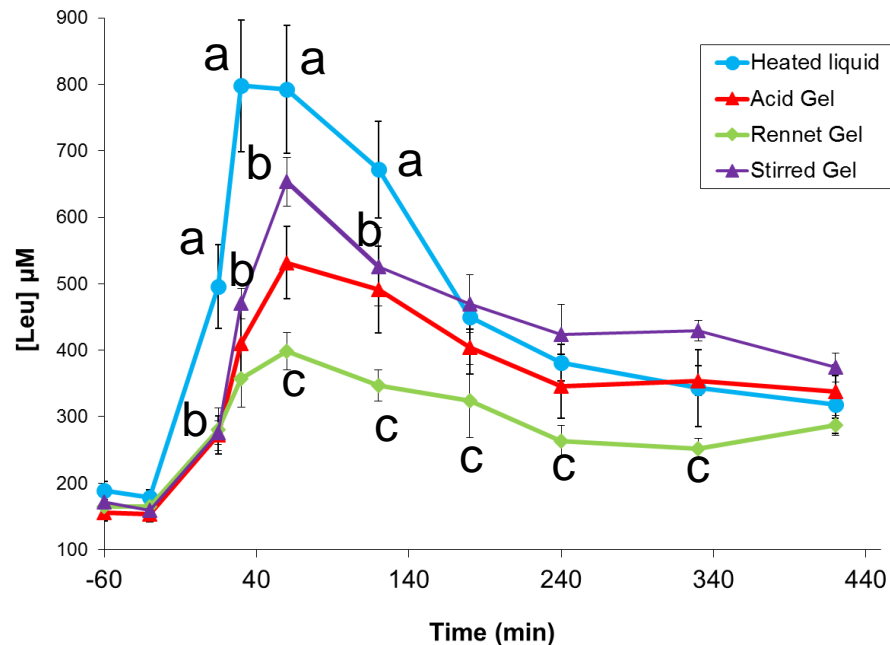
- Only traces of milk proteins found in the jejunum
- Dairy products remain highly digestible



# The liquid-gel transition

Barbé *et al.* Food Chem  
2013  
Highly cited paper

## Effect on absorption



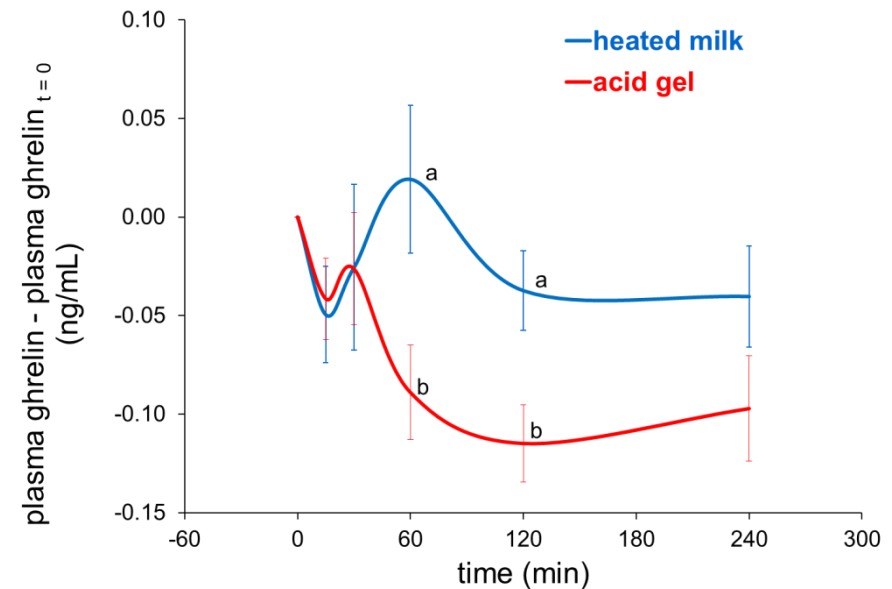
### milk gelation:

→ 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

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

Protein	Sequence	Activity	Reference	4	20	50	105	165	225	315
$\alpha$ s1	1-23	EMUL	Shimizu et al. (1984)	■						
$\alpha$ s1	23-34	HYP	Maruyama & Suzuki (1982)	■	■					
$\alpha$ s1	30-45	MB	Meisel et al. (1991)		■					
$\alpha$ s1	40-52	MB	Adamson & Reynolds (1996)				■	■	■	■
$\alpha$ s1	43-58	MB	Meisel et al. (1991)	■	■	■				
$\alpha$ s1	91-100	STRE	Miclo et al. (2001)	■						
$\alpha$ s1	99-109	MIC	McCann et al. (2006)	■			■	■	■	
$\alpha$ s1	167-180	MIC	Hayes et al. (2006)				■	■	■	
$\alpha$ s1	180-193	MIC	Hayes et al. (2006)				■	■	■	
$\alpha$ s2	1-24	MB	Miquel et al. (2005)	■	■	■	■	■	■	■
$\alpha$ s2	124-146	MB	Miquel et al. (2005)				■	■	■	■
$\alpha$ s2	183-206	TRAN	Kizawa et al. (1996)				■	■	■	■
$\alpha$ s2	183-207	MIC	Recio & Visser (1999)				■	■	■	■
$\alpha$ s2	189-197	HYP	Maeno et al. (1996)	■	■	■	■	■	■	■
$\alpha$ s2	190-197	HYP	Maeno et al. (1996)	■	■	■	■	■	■	■
$\beta$	1-24	MB	Bouhallab et al. (1999)	■	■	■	■	■	■	■
$\beta$	33-52	MB	Miquel et al. (2005)	■	■	■	■	■	■	■
$\beta$	60-80	OPI	Jinsmaa & Yoshikawa (1999)	■	■	■	■	■	■	■
$\beta$	98-105	OXI	Rival et al. (2001)	■	■	■	■	■	■	■
$\beta$	114-119	OPI	Jinsmaa & Yoshikawa (1999)	■	■	■	■	■	■	■
$\beta$	132-140	HYP	Robert et al. (2004)	■	■	■	■	■	■	■
$\beta$	192-209	IMM	Coste et al. (1992)	■	■	■	■	■	■	■
$\beta$	193-202	IMM	Kayser & Meisel (1996)	■	■	■	■	■	■	■
$\beta$	193-209	IMM	Coste et al. (1992)	■	■	■	■	■	■	■
$\kappa$	18-24	HYP	Lopez-Exposito et al. (2007)	■	■	■	■	■	■	■
$\kappa$	106-116	THR	Jolles et al. (1986)	■	■	■	■	■	■	■
$\beta$ -lg	32-40	HYP	Pihlanto-Leppala et al. (2000)		■	■	■	■	■	■
$\beta$ -lg	92-100	MIC	Pellegrini et al. (2001)		■	■	■	■	■	■
$\beta$ -lg	142-148	HYP	Mullally et al. (1997)			■	■	■	■	■

Acid Gel

Protein	Sequence	Activity	Reference	4	20	50	105	165	225	315
$\alpha$ s1	40-52	MB	Adamson & Reynolds (1996)						■	■
$\alpha$ s1	43-58	MB	Meisel et al. (1991)	■	■					■
$\alpha$ s1	99-109	MIC	McCann et al. (2006)				■	■	■	■
$\alpha$ s1	167-180	MIC	Hayes et al. (2006)				■	■	■	■
$\alpha$ s1	180-193	MIC	Hayes et al. (2006)				■	■	■	■
$\alpha$ s2	1-24	MB	Miquel et al. (2005)	■	■	■	■	■	■	■
$\alpha$ s2	189-197	HYP	Maeno et al. (1996)	■	■	■	■	■	■	■
$\beta$	33-52	MB	Miquel et al. (2005)	■	■	■	■	■	■	■
$\beta$	166-175	HYP	Hayes et al. (2007)				■	■	■	■
$\beta$	193-202	IMM	Kayser & Meisel (1996)	■	■	■	■	■	■	■
$\beta$ -lg	92-100	MIC	(8))	■	■	■	■	■	■	■
$\beta$ -lg	142-148	HYP	(9))						■	■

Rennet Gel

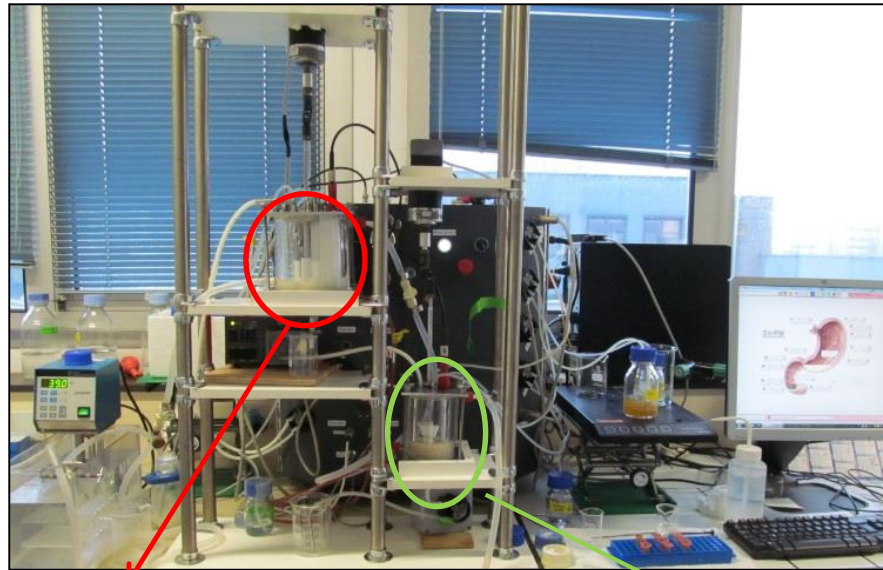
- More bioactive peptides identified during digestion of acid gel than rennet gel
- Nature of peptides is identical (clearly defined by the digestive enzyme specificity)
- Kinetics of release are different

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
- ☞  $\neq$  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

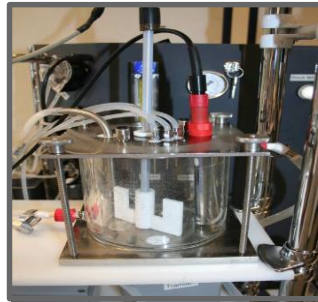


DIDGI®

StoRM® software

**Stomach**

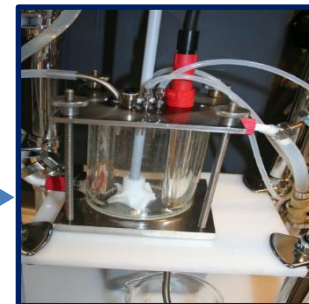
- Pepsine
- Gastric lipase
- Simulated gastric fluid
- HCl



Emptying :  
Elashoff's model

**Small intestine**

- Pancreatin
- Bile
- Simulated intestinal fluid
- NaHCO<sub>3</sub>



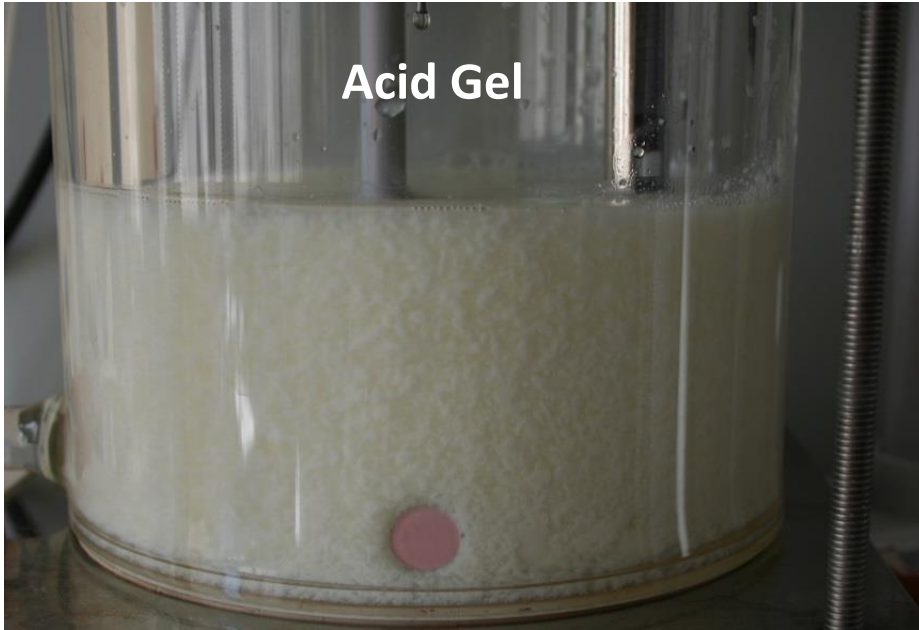
Emptying :  
Elashoff's model



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

Barbé et al.  
Food Chem. 2014

Acid Gel



Rennet Gel



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**

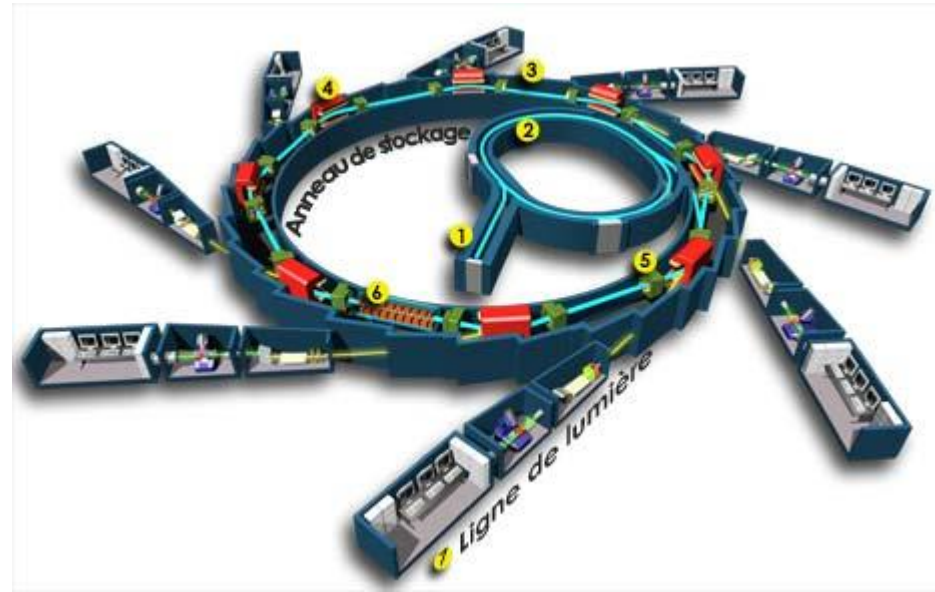


Soleil is a particle (electron) accelerator that produces the synchrotron radiation, an extremely powerful source of light that permits exploration of inert or living matter



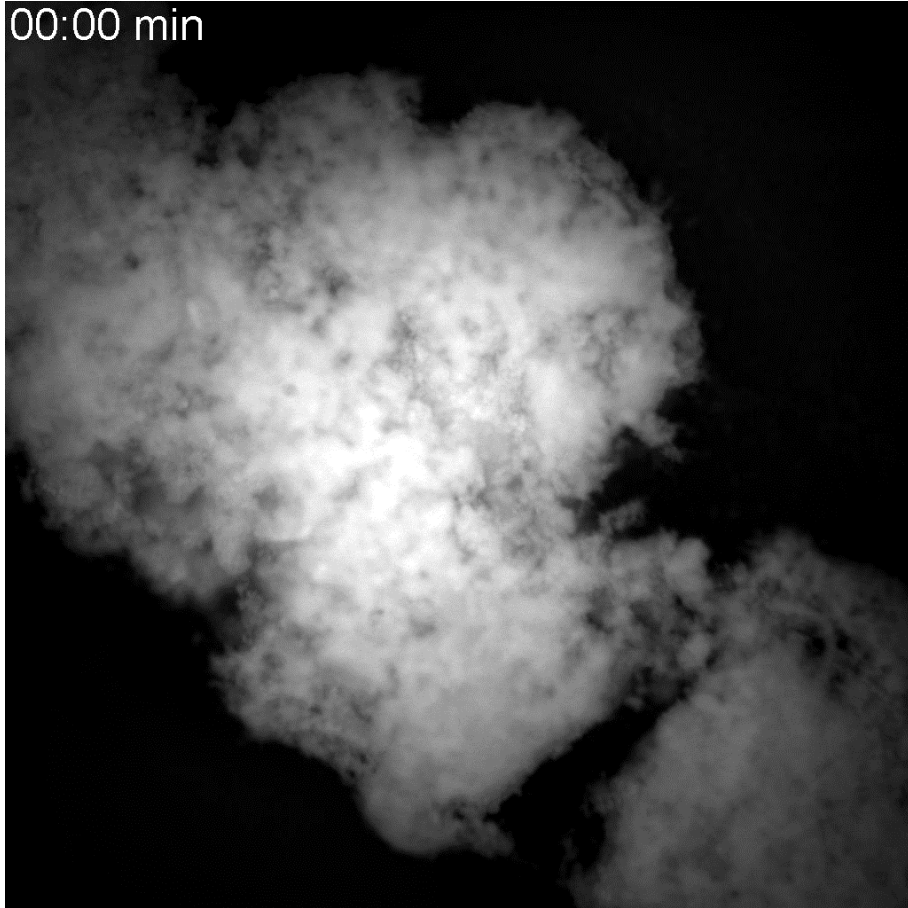
DISCO is a VUV to visible beamline dedicated to biochemistry, chemistry and cell biology. The spectral region is optimized between 60 and 700 nm with conservation of the natural polarization of the light

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



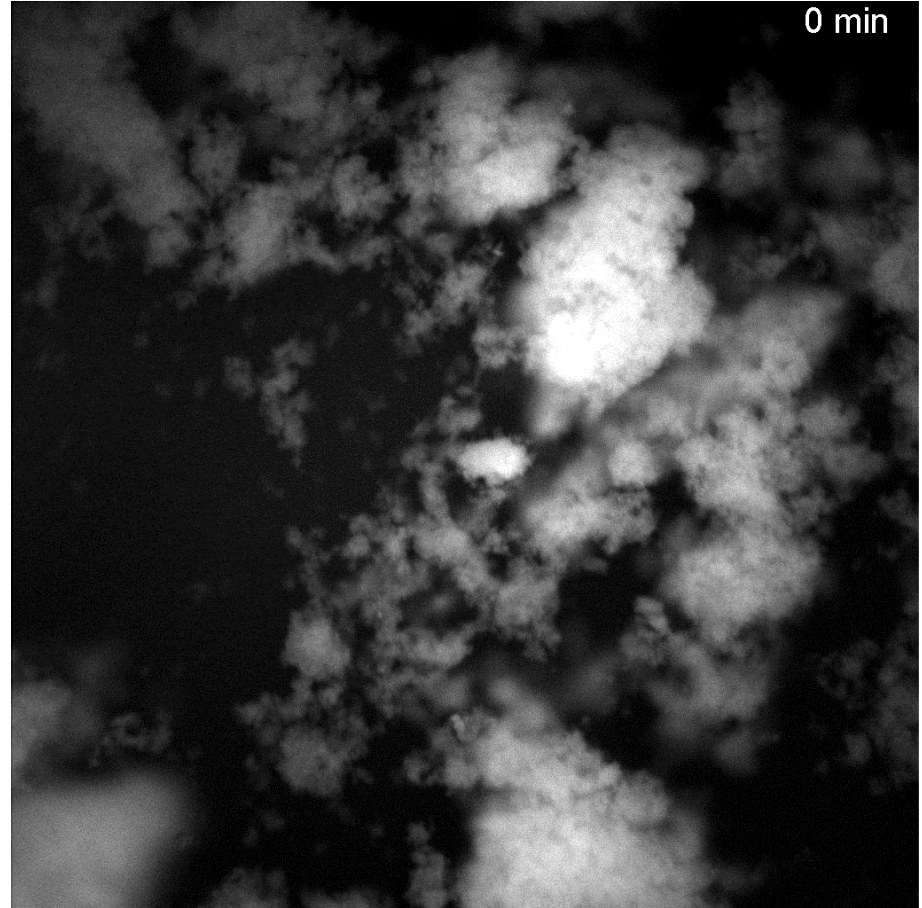
# Kinetics of gel particles disintegration

00:00 min



**Rennet Gel**

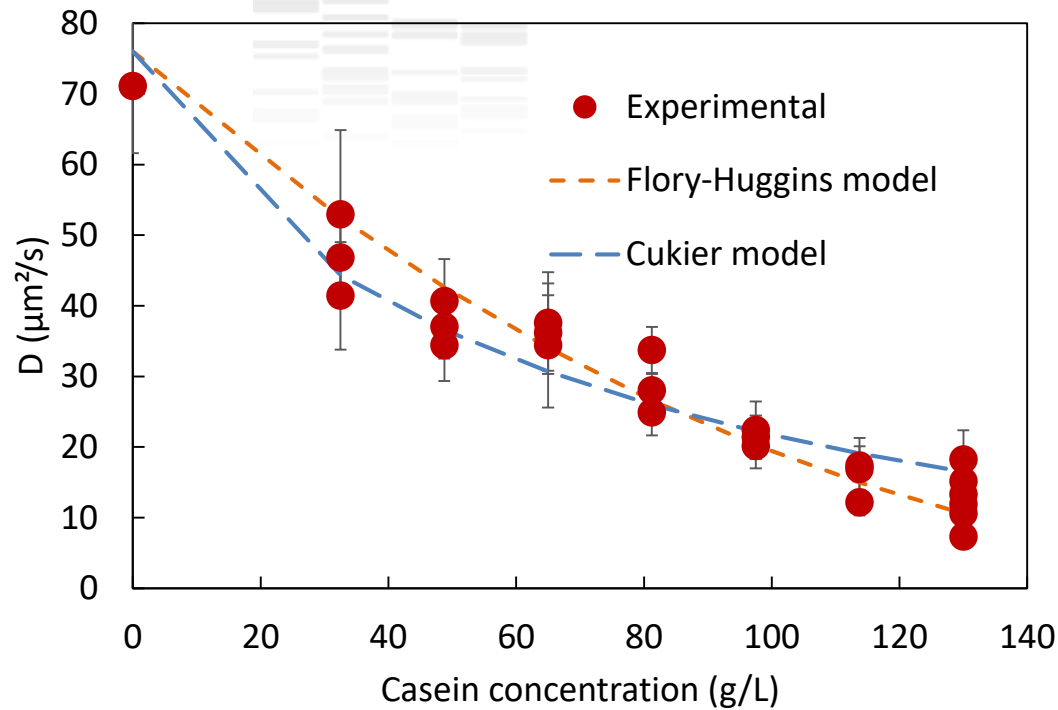
0 min



**Acid Gel**



## Diffusion of FITC-pepsin in Rennet gel of increasing casein concentration (37°C)

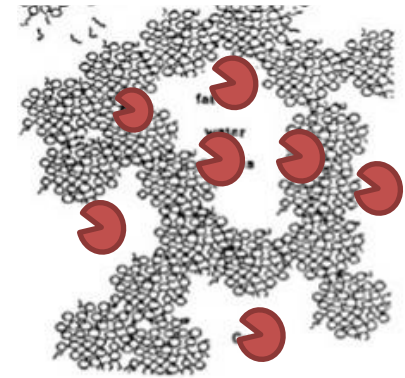


Thevenot et al. Food Chem 2017

Pepsin diffusion of enzyme through the protein network is possible



Food proteins can effectively be hydrolyzed by pepsin from the interior of the gel pores.



Gastric  
acidic  
environment



Syneresis  
and gel  
contraction



protein  
concentration



sieving  
effect of  
the  
polymer  
network



pepsin  
diffusion



digestion  
rate



# What happens when food have the same macrostructure but different microstructures? The case of egg white gels



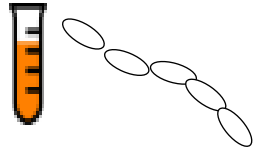
Dupont D.

INRA, Rennes, France

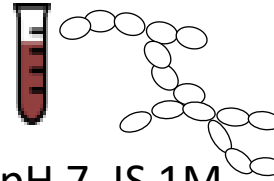


# The microstructure of egg-white gels made from different types of aggregates affects the kinetics of proteolysis

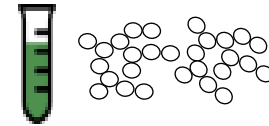
80°C/6h



pH 9, IS 1M




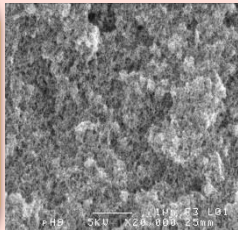
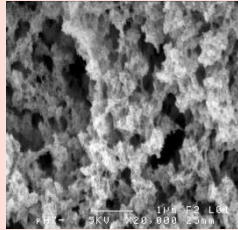
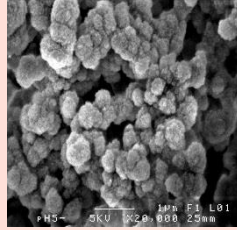
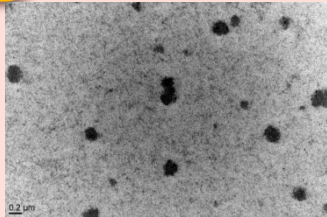
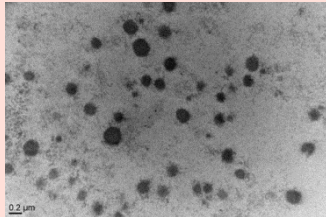
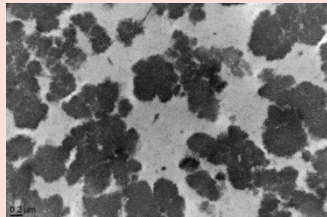

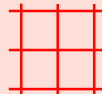
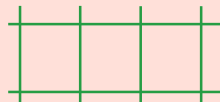



pH 7, IS 1M




pH 5, IS 1M

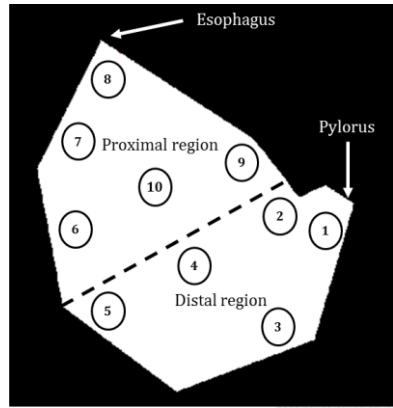
Aggregates	linear	branched	spherical
Rate of <i>in vitro</i> digestion	+++	++	+

Gels	90°C/2.5 h			
				
				SEM
				CRYO-TEM
				
Rate of <i>in vitro</i> digestion	+	++	+++	

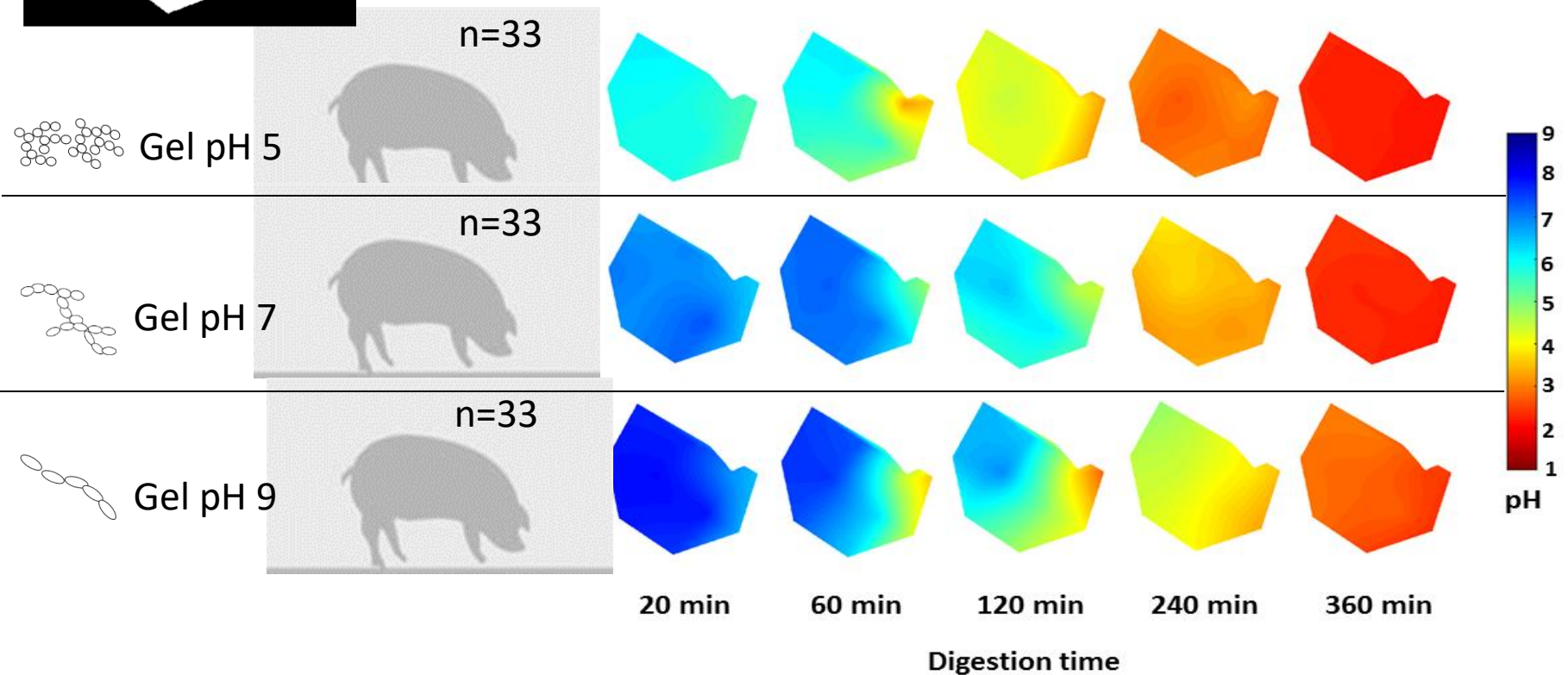
 Nyemb et al., 2016.  
Food Hydrocolloid, 54,  
315-27

 Nyemb et al., 2016.  
Food Res. Int., 88, 302-9

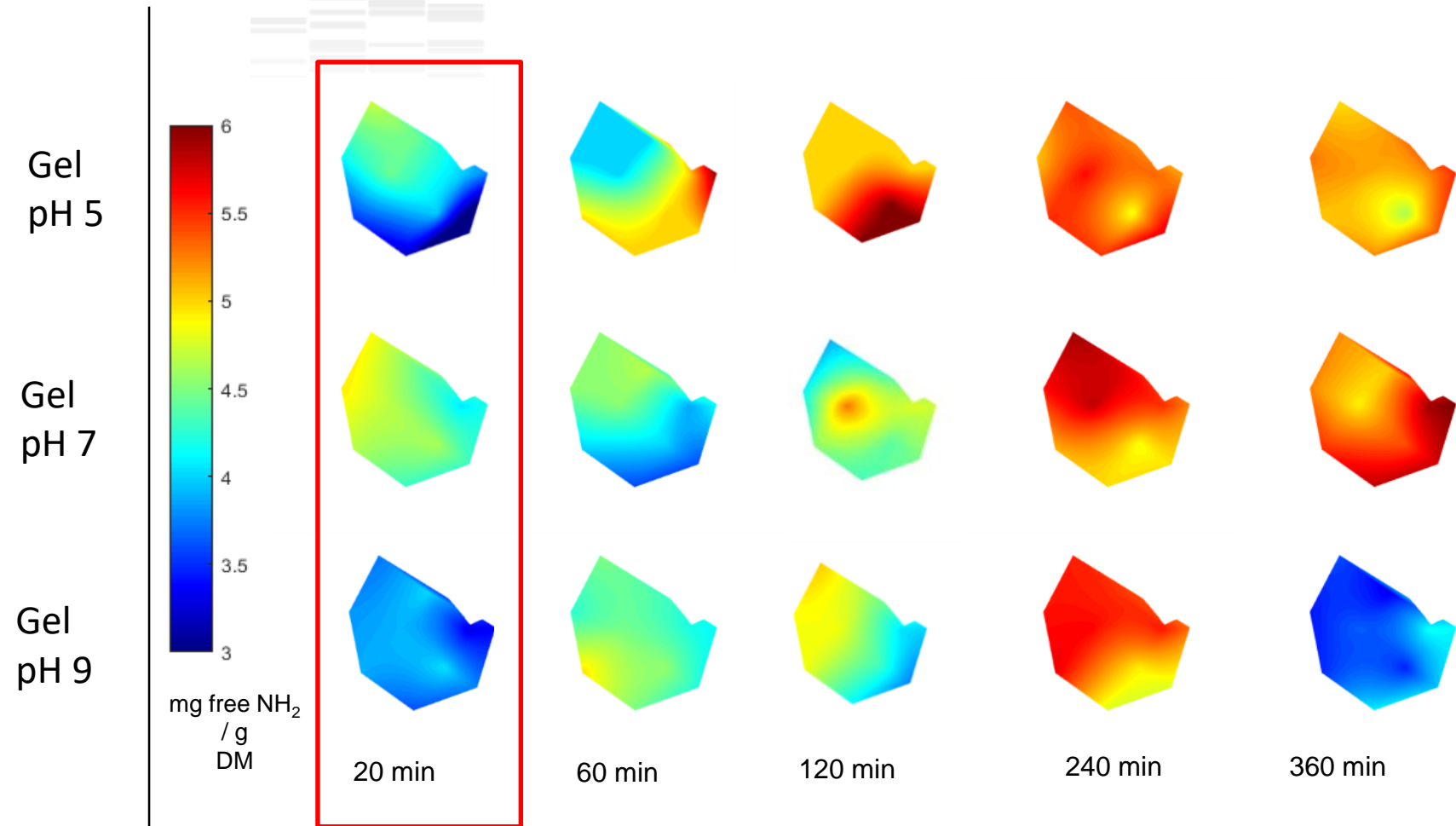
# Spatio-temporal evolution of pH during an *in vivo* digestion



pH 7.0



# Kinetics of proteolysis



Proteolytic activity even at pH 7 and 9: probably driven by local pH



# Digestion and oral comfort of cheese developed to meet the sensory and nutritional needs of the elderly



L Lorieau, J Flourey & D Dupont

STLO, UMR 1253, INRA, Agrocampus Ouest, 35000 Rennes, France

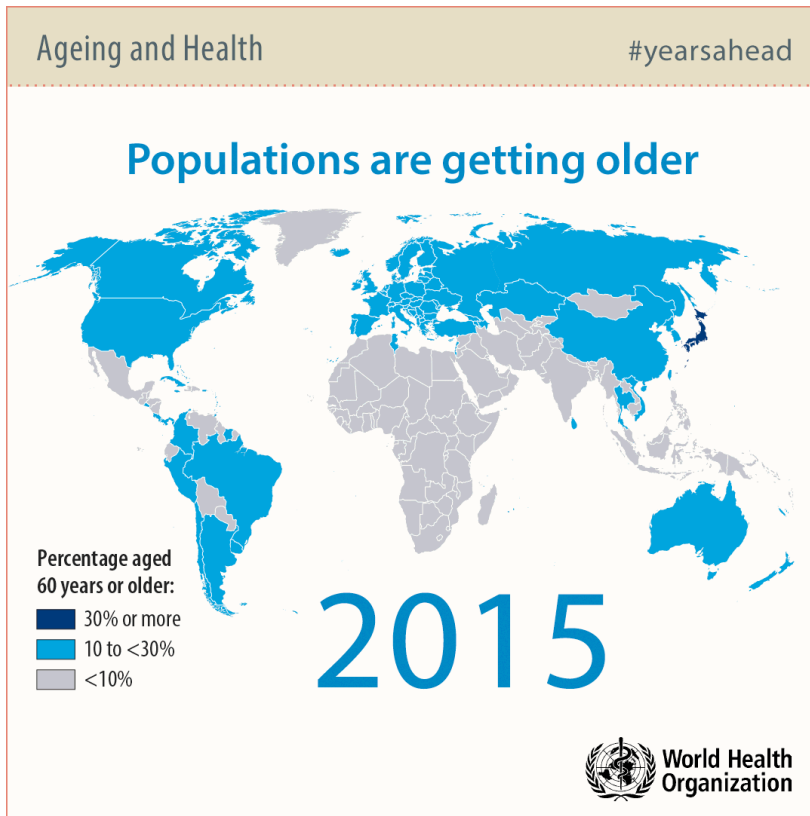


# AGEING = a world problem...

The EU population over 65

2015 : **1/5** of the population

2050 : **1/3** of the population



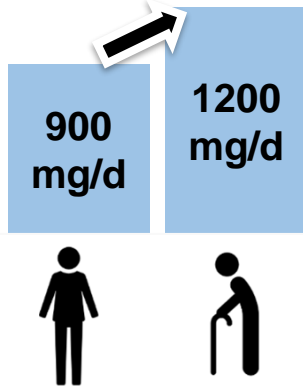
## Challenge : healthy ageing

=

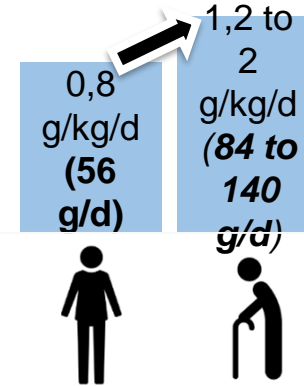
- Keeping people autonomy
- Offering them physical and social activities
- Preventing the development of pathologies
- **Offering them an adequate diet**

# The nutritional needs of elderly people

## Calcium

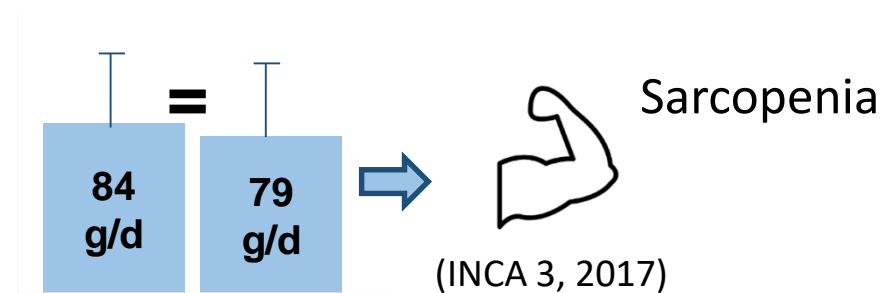
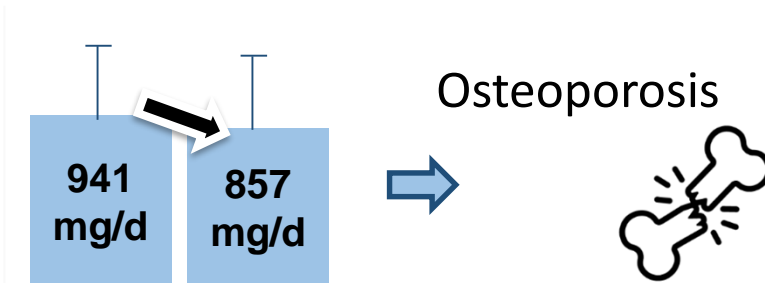


## Proteins



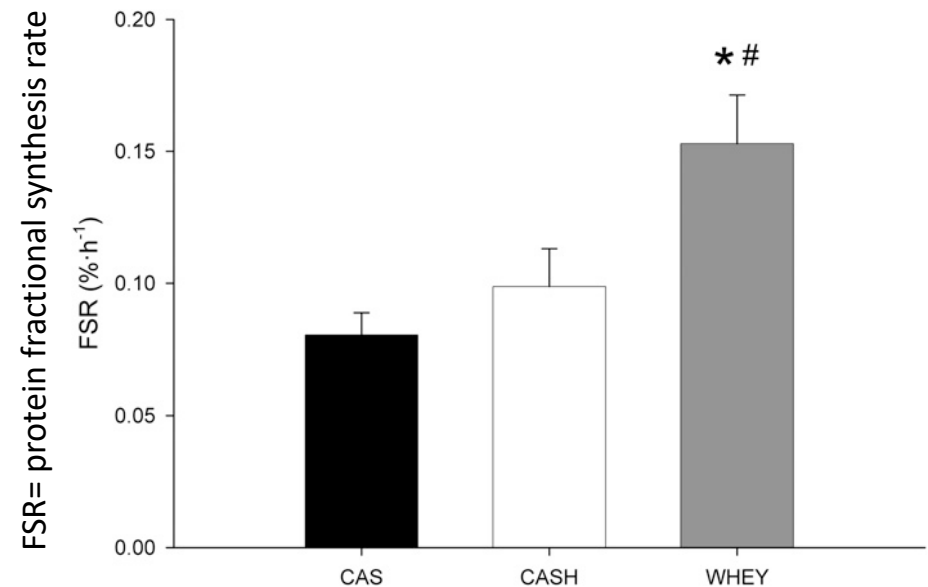
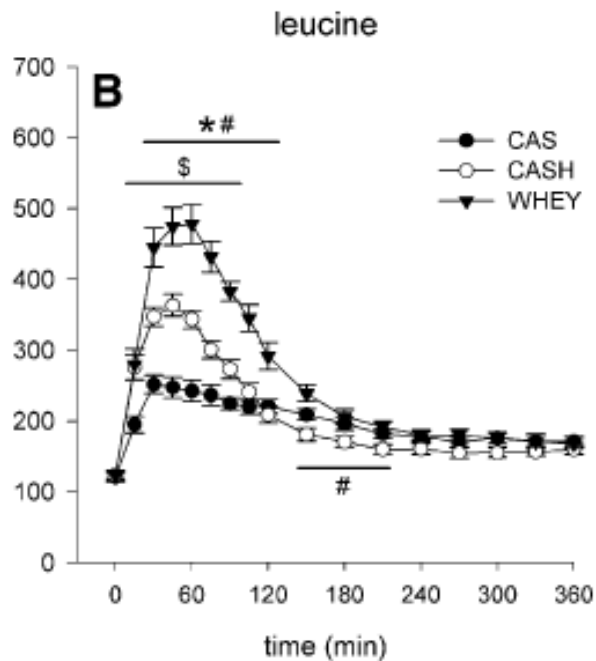
(Baum et al. 2017)

## Mean daily intake



(INCA 3, 2017)

# Muscle protein synthesis can be restored when providing high amounts of Leucine through whey proteins (10 g) but not caseins



Pennings et al. 2013

# Objectives of the project

To **design a range of cheeses** with identical composition (n=4):

- ☞ exclusively made of whey proteins to provide 10 g of protein/portion and high intake of Leucine

- ☞ enriched in calcium to provide 280 mg of calcium (25% of the daily intake)

To **assess the sensory perception of these cheeses** by elderly people with impaired or intact dental health (n=76)









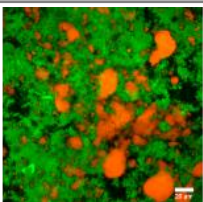
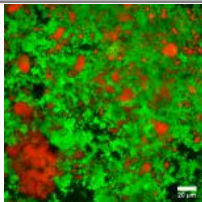
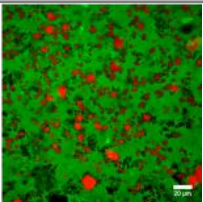
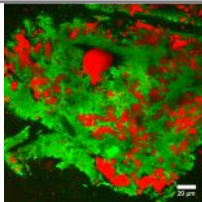
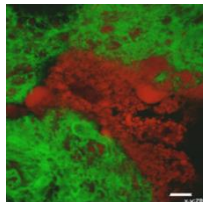
To **assess the calcium and amino acid bioavailability** in conventional pigs





# Design of the cheeses



	Liquid (24%) 	Soft 	Processed 	Hard 	Whipped 	Mozzarella 
Texture perception		Soft and melting	Sticky and pasty	Firm and slightly dry	Dry and granular	Elastic
pH	<b>6.4</b> $\pm 0.05$	<b>6.4</b> $\pm 0.05$	<b>6.0</b> $\pm 0.05$	<b>6.4</b> $\pm 0.05$	<b>5.6</b> $\pm 0.05$	<b>5.3</b> $\pm 0.05$
Hardness		<b>16</b> $\pm 8$	<b>9</b> $\pm 4$	<b>108</b> $\pm 20$	<b>6</b> $\pm 1$	<b>95</b> $\pm 1$
Type of protein	Whey proteins					Caseins
[Leucine] g/kg	<b>4.70</b> $\pm 0.41$					<b>3.61</b> $\pm 0.01$
Microstructure confocale x60 scale: 20 $\mu$ m  Proteins  Lipids						

# Which textures of cheeses are comfortable for older people with or without oral health impairment?



76 volunteers + 65 y.o  
(Dentition and Flow saliva)  
x  
4 cheese models



## Perception

Food comfortability  
*Questionnaire*  
(Vandenberghé *et al*, 2017)

- Q1. Comfort
- Q2. Bolus formation
- Q3. Pain
- Q4. Product texture
- Q5. Flavor



## Bolus formation

- **Chewing behavior :**

*Video*

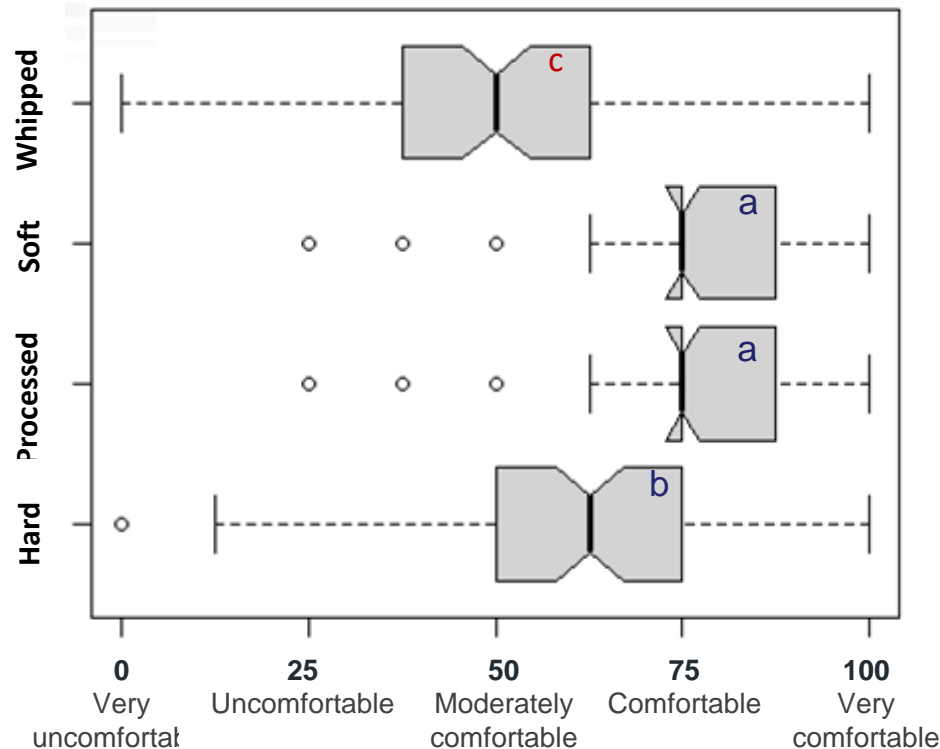
Cycle number  
Chewing time

- **Food bolus**

Rheology - *Compression*  
Quantity of saliva– *Dry extract*  
(Drago *et al*, 2011)



# The food comfortability is mainly impacted by the type of product consumed

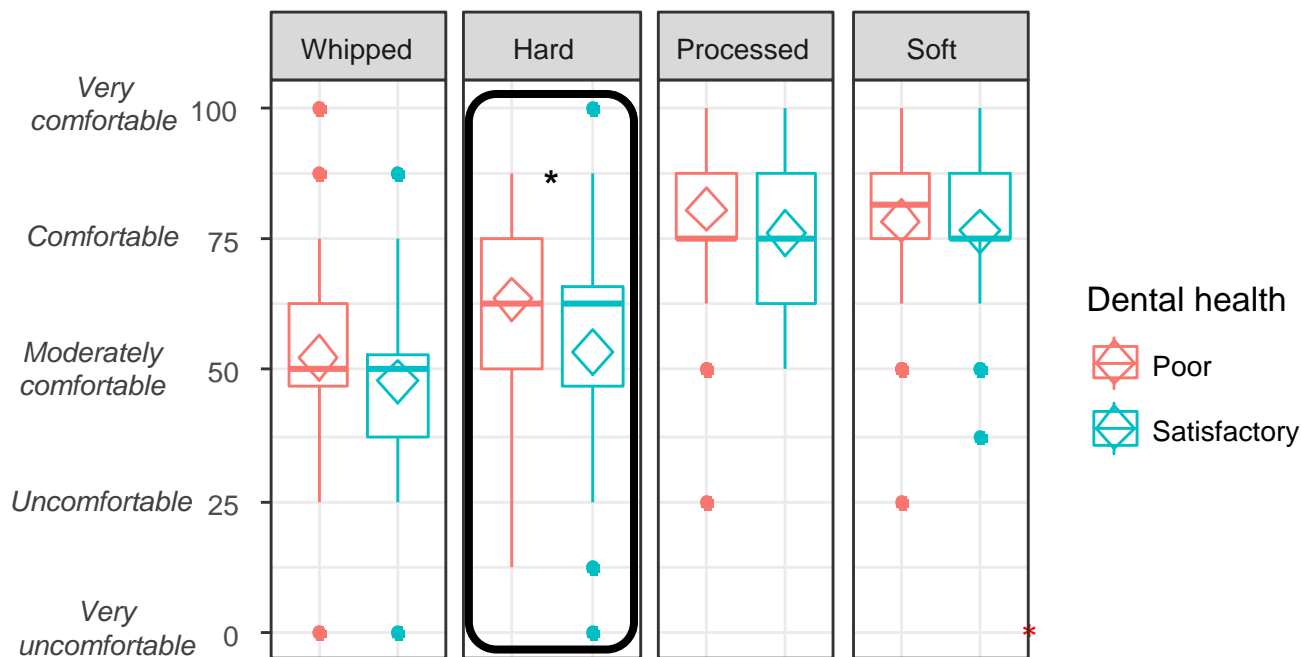


ANCOVA : Variable~ Product + Error(Subject)



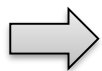
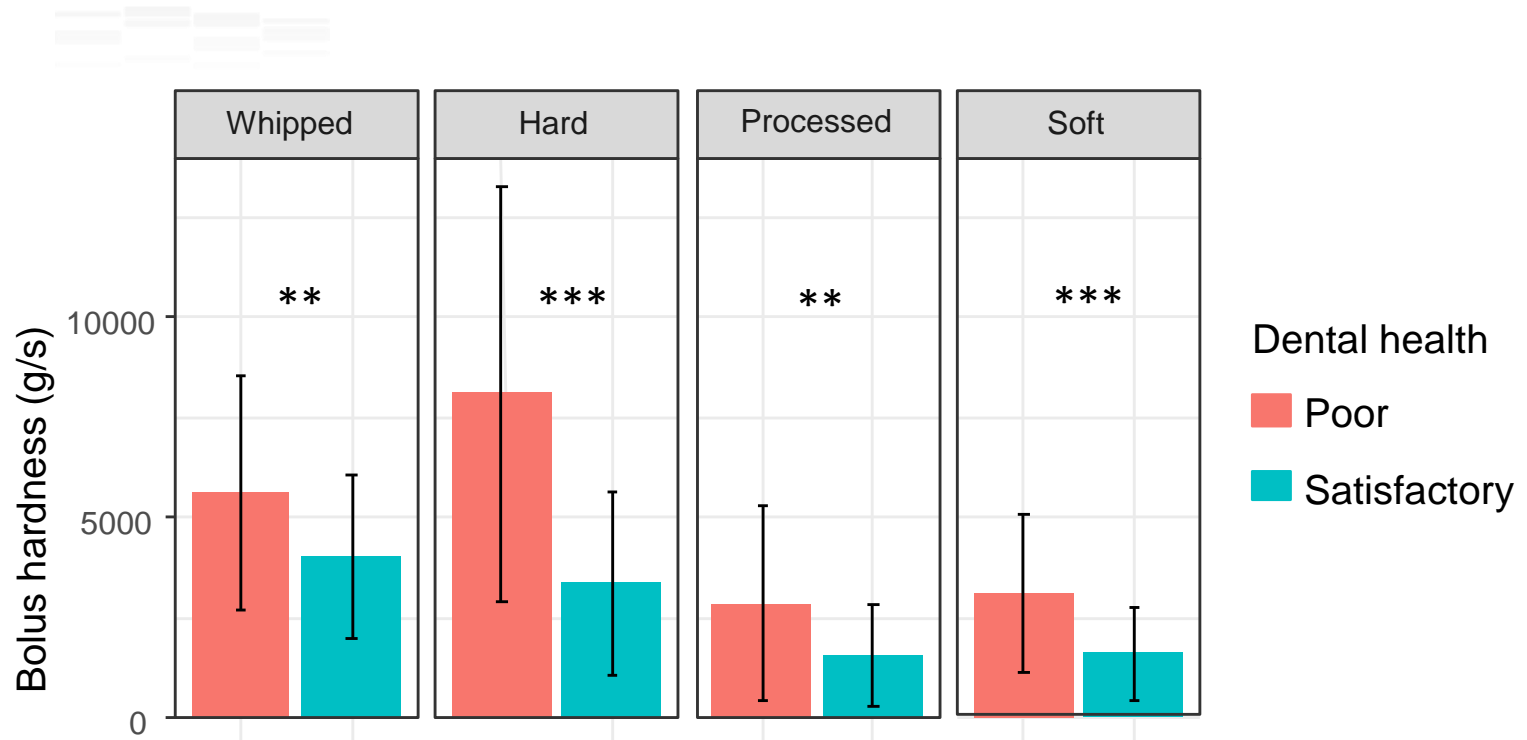
**The most comfortable products are the Soft and Processed products**

# The food comfortability is not negatively impacted by the dental health



Elderly people with a poor dental health considered the Hard product more comfortable than elderly people with a satisfactory dentition

# Elderly persons with a poor dental health made harder bolus than elderly persons with a satisfactory one

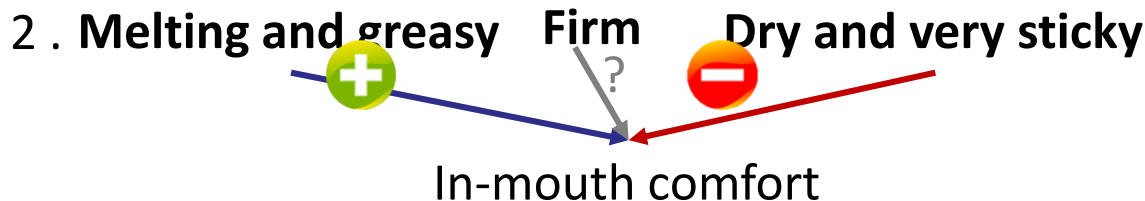


Decrease in food bolus disintegration by denture wearers observed by Mishellany-Dutour *et al.* (2008), Woda *et al.* (2006), Yven *et al.* (2006)



# Which textures of cheeses are comfortable for older people with or without oral health impairment?

1 . A product is comfortable when the bolus is easy to form



3 . Oral health alterations do not negatively impact the in-mouth comfort

Vandenbergh-Descamps et al (2017), Assad-Bustillos et al. (2017), Laguna (2016)

**But the bolus formed are different (hardness and humidity)**

# In vivo digestion

Whey-based  
Soft cheese  
 $\text{CaCO}_3$



Whey-based  
Soft cheese  
CaP



Mozzarella



Milk Calcium

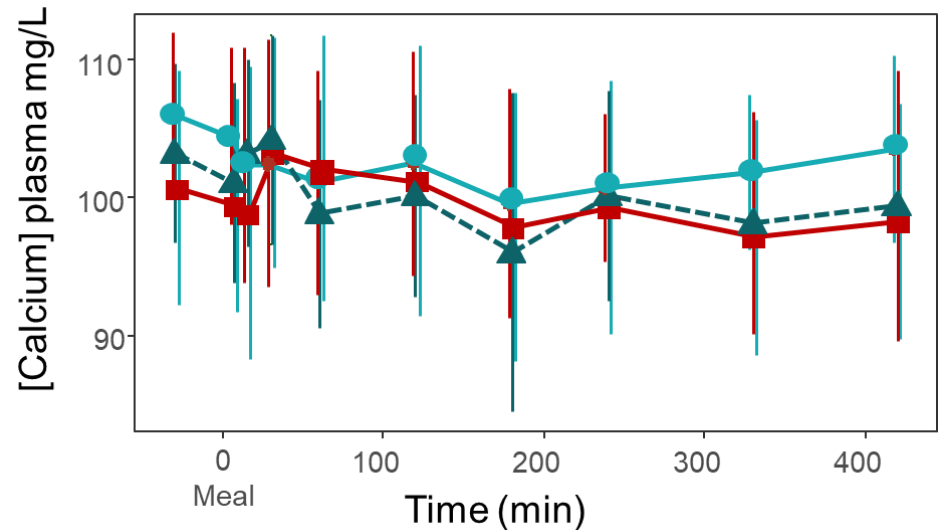
Iso-calcium : 0,7%  
Isocaloric  $\approx$   
280 kcal /100g

Test meals



Blood samples

from 30 min before to 7h after meal ingestion



6 cannulated and  
catheterized  
pigs

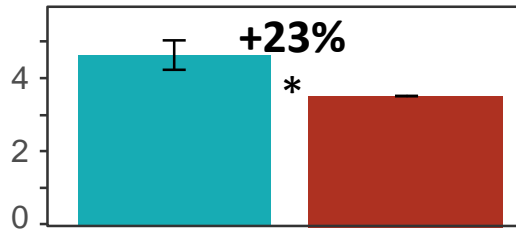
**[Calcium] in plasma is highly stable**

**Both calcium sources allow to provide bioavailable calcium**

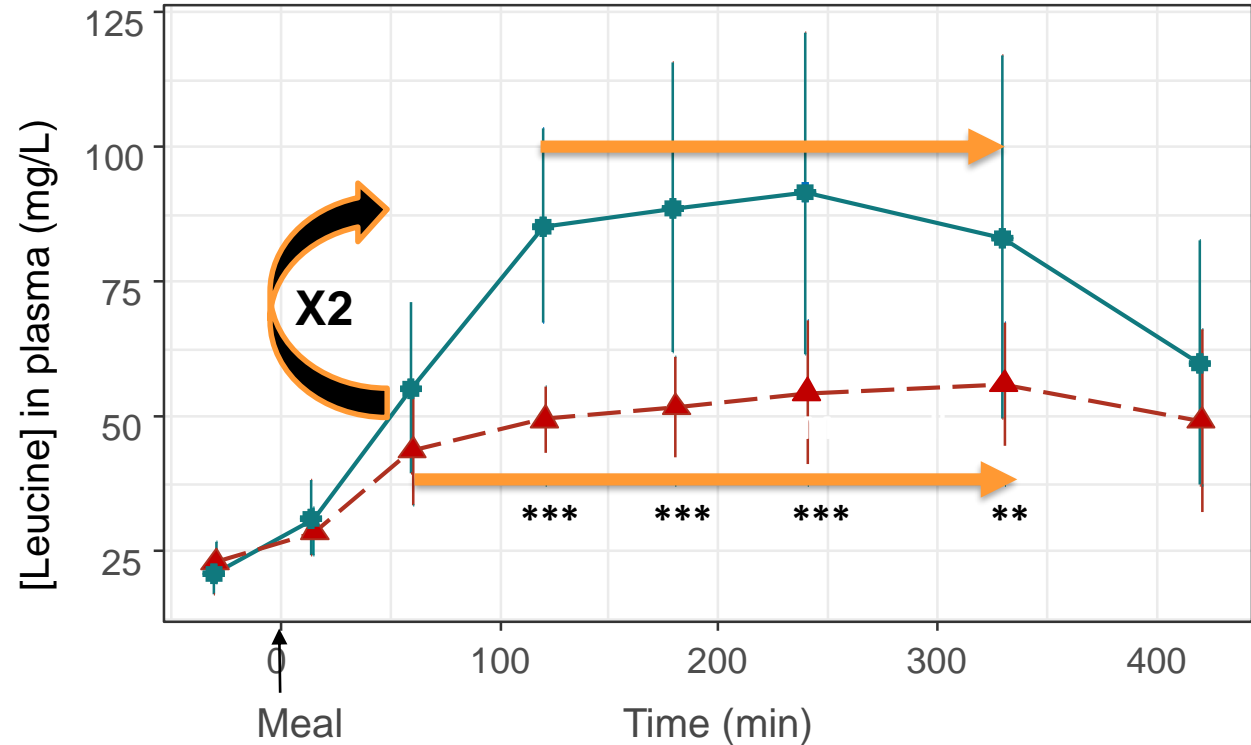
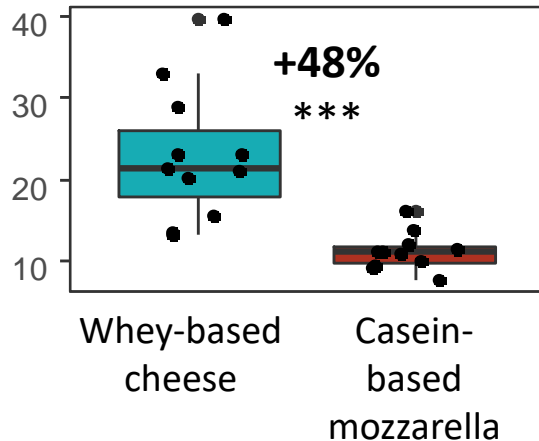
Needs long-term studies for possible consequences on bone health

# Leucine « bioavailability »

Cheese leucine content (g/kg)

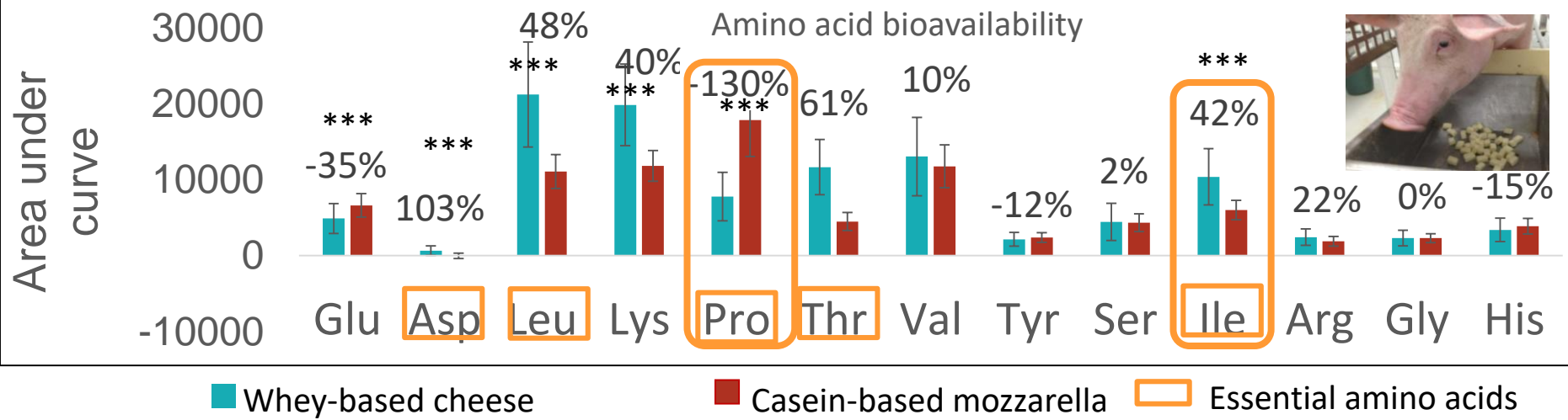
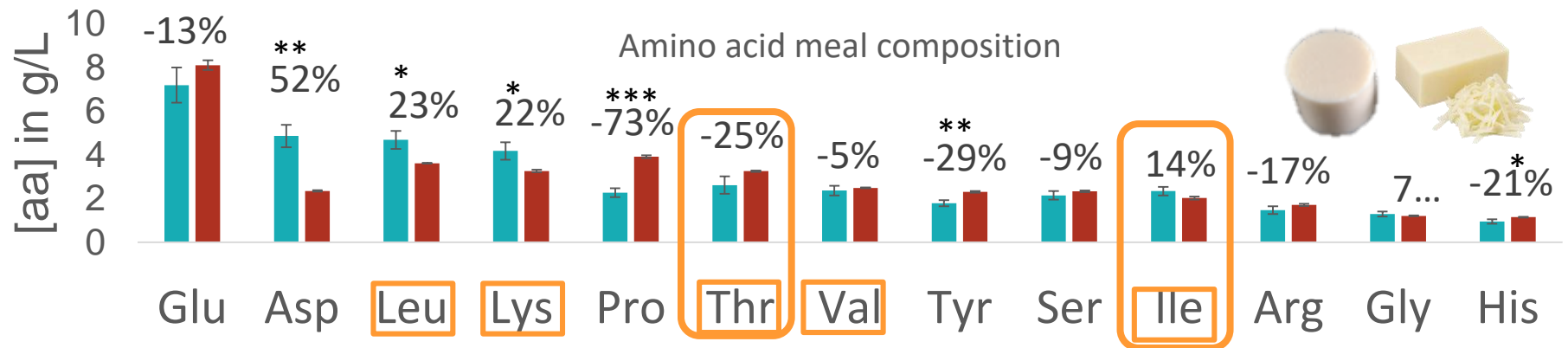


Area under the curve (g/L/min)

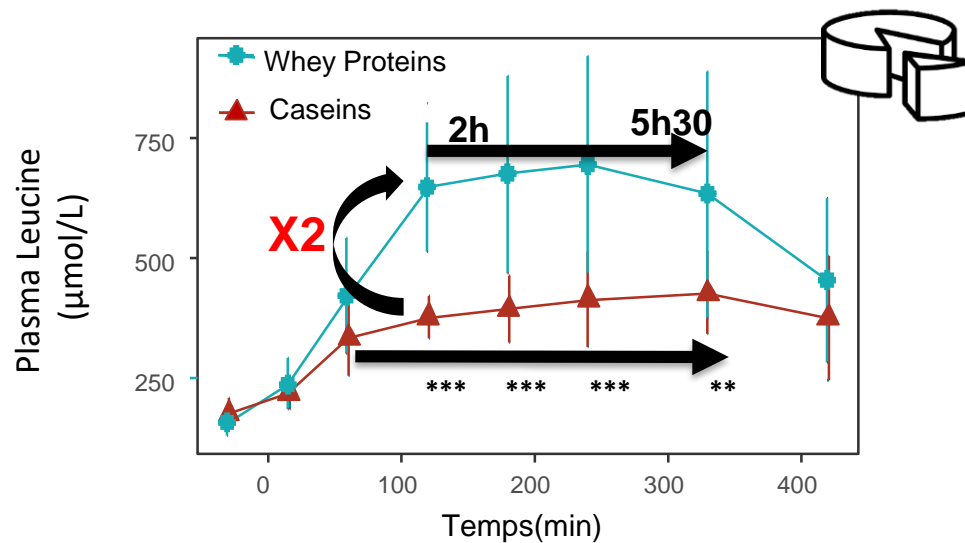


**Leucine « Bioavailability »**  
**Whey-based cheese > Casein-based Mozzarella**

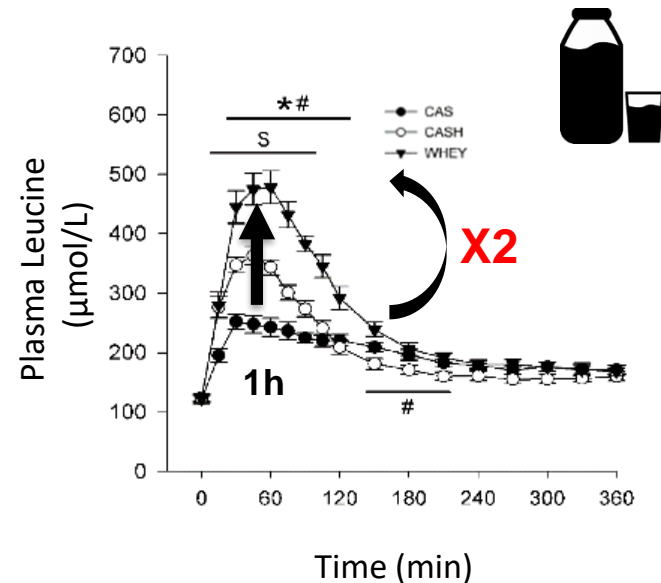
# What about the other amino acids?



# Amino acid bioavailability for solid foods



Lorieau et al. 2018



In elderly people (~74 y)

Pennings et al, 2011

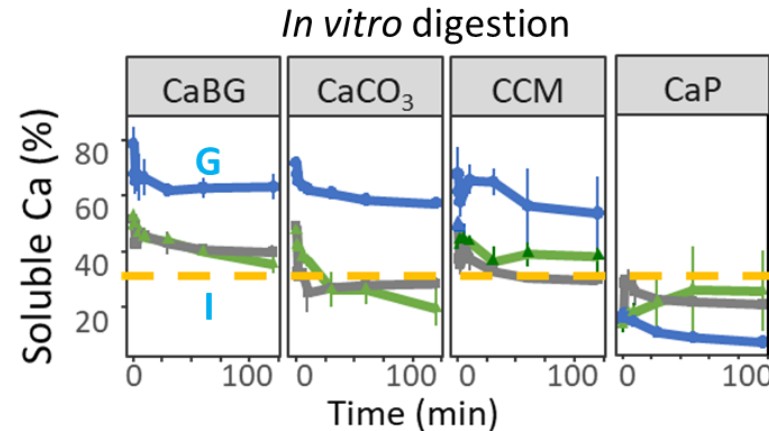
👉 Our data confirm those previously obtained on elderly for liquid samples



# Conclusion & perspectives

No differences in Ca bioavailability were seen during the *in vivo* study on pigs

Whey-based cheeses allowed to increase Leu bioavailability



The differences between casein and whey-based cheeses could be due difference in kinetics of digestion. This could result in the selective sequestration of some AA by the splanchnic area ? Or be due to oxidation of some AA before and after absorption???


**In the future, we would like to determine:**

if other sources of calcium can increase its bioavailability

how the hardness and humidity of the bolus will affect digestion in elderly

if the whey-based cheeses really allow to restore muscle synthesis in elderly





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



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

INRA, Rennes, France



# Human/ bovine milk / Infant Formula

## Protein structures

Human milk



Bovine milk



Infant Formula

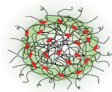


(Turck *et al*, 2010)

$\varnothing = 64 \text{ nm}$

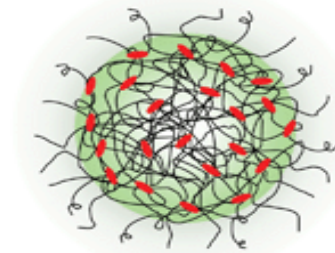
( $\beta$ ,  $\kappa$ -casein)

Casein  
micelle

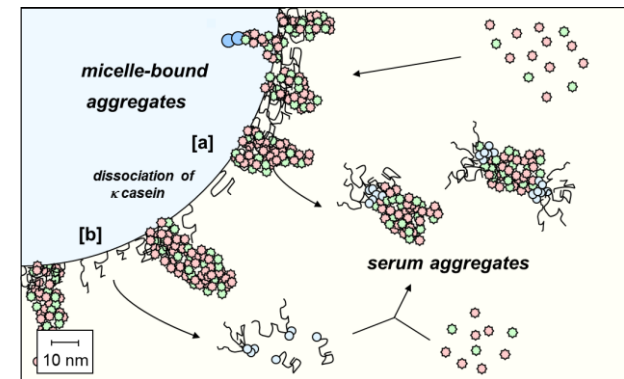
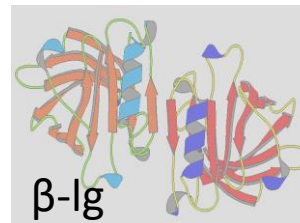
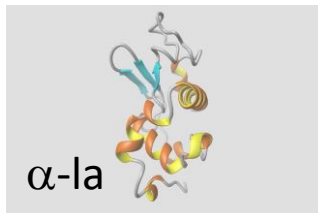


$\varnothing = 182 \text{ nm}$

( $\alpha$ s1,  $\beta$ -casein)



Whey  
Proteins



# Human/ bovine milk / Infant Formula

## Lipid globule structure

Human milk



Bovine milk



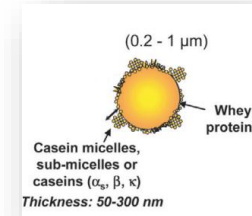
Infant Formula



Native milk fat globule

Lipid droplets

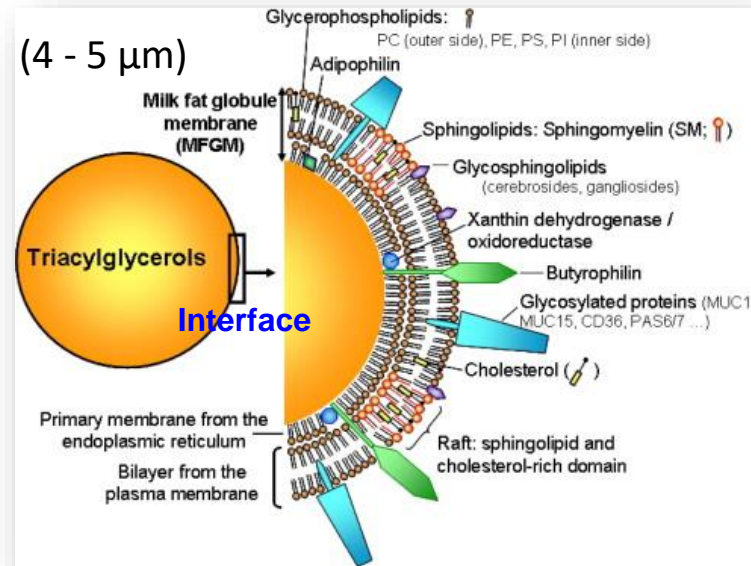
Triacylglycerols



(0,2 - 1 μm)

(Lopez and Briard-Bion, 2007)

(Lopez, 2010)



Preterm hospitalized infants  
Feeding nasogastric tube  
Fed every 3 hours

Aim: to compare meals with  
similar composition but different  
structure

Human milk from their **own mother**

Human milk from **anonymous donor**

GROUP A

GROUP B

Raw human  
milk

Pasteurized  
human milk

Pasteurized  
human milk

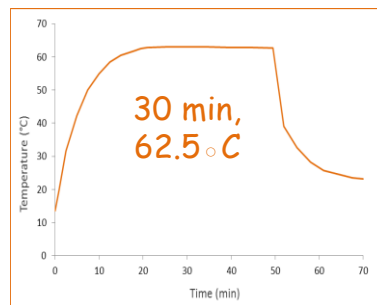
Pasteurized-  
homogenized  
human milk

24h before feeding (4°C)

Stored at -20°C  
(bank milk)

Stored at -20°C (bank milk)

Bank milk



Homogenization  
by sonication

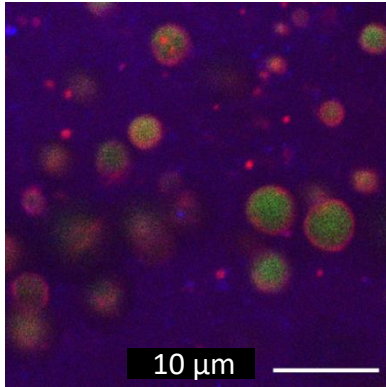


# Pasteurization affected the initial structure and the emulsion disintegration of HM

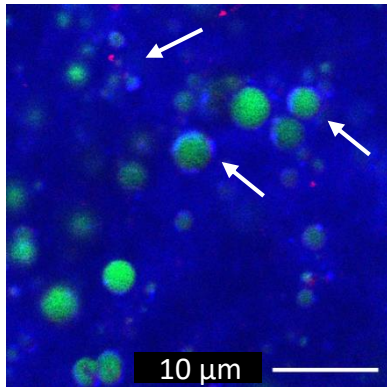
(n = 6 infants)

## Initial structure

Raw HM



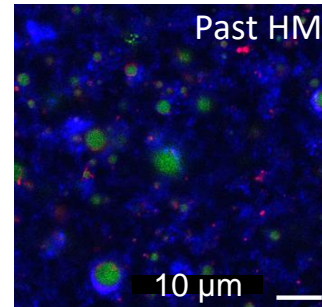
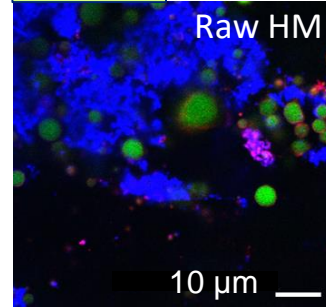
Past HM



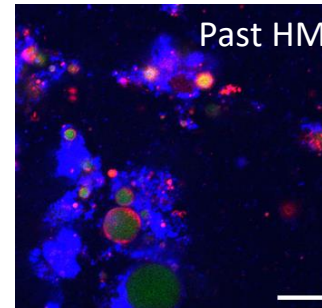
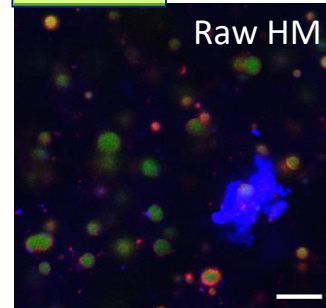
→ Protein heat-induced aggregation

## Gastric disintegration

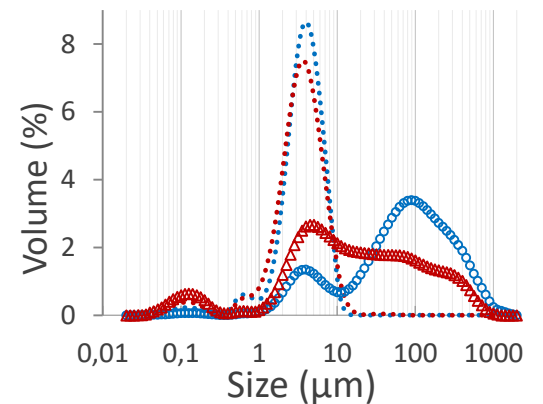
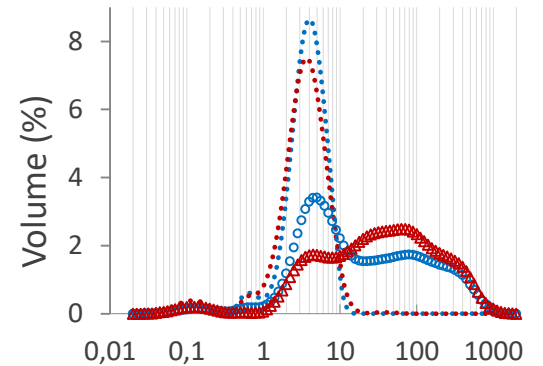
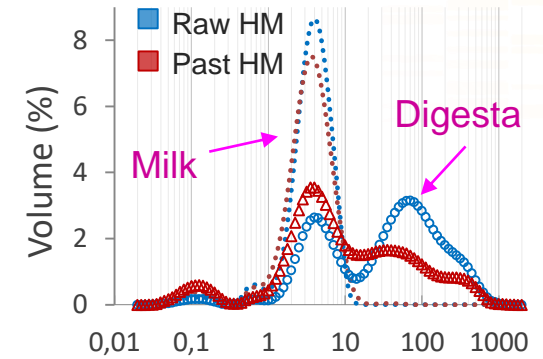
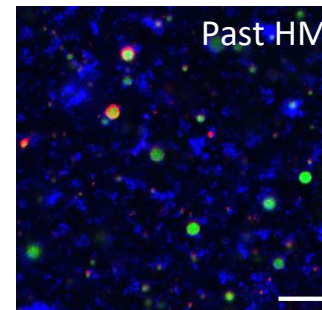
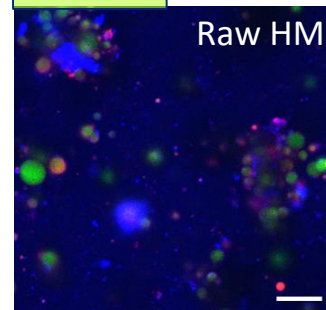
35 min



60 min



90 min

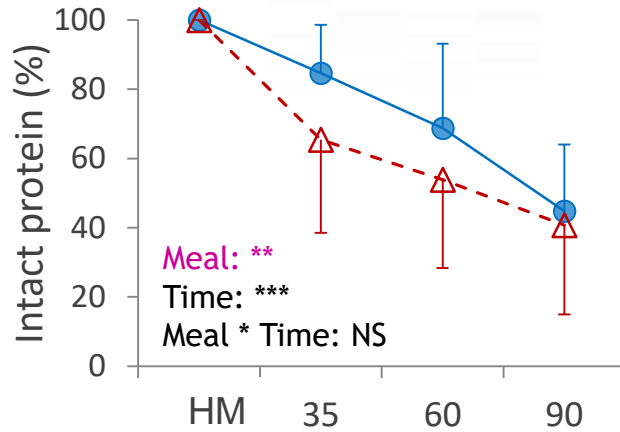


Apolar lipids Amphiphiles Proteins

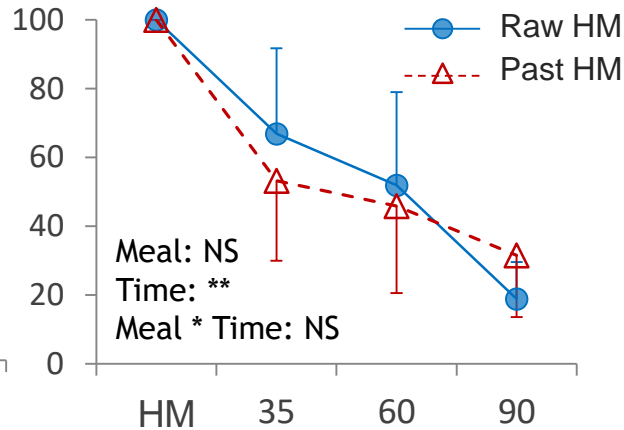
# Pasteurization selectively impacted gastric proteolysis



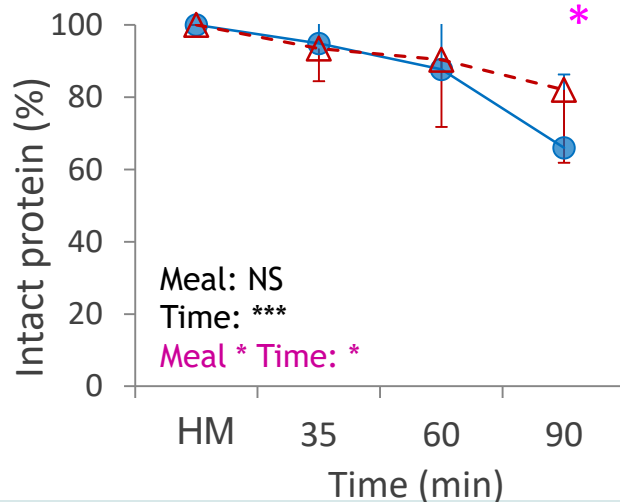
## Lactoferrin



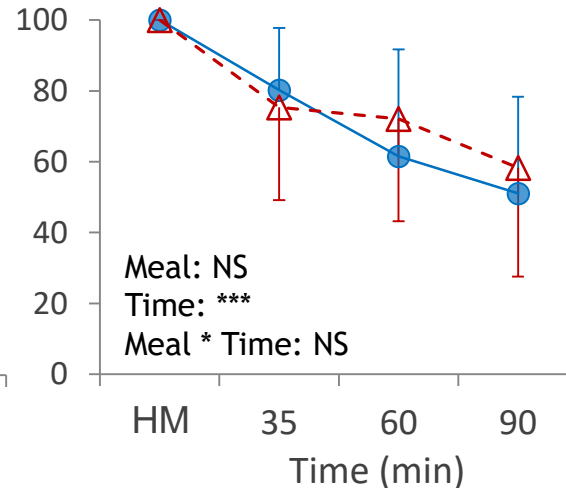
## Serum albumin



## $\alpha$ -lactalbumin



## $\beta$ -casein



- Faster decrease of lactoferrin in Past HM
- Slower decrease of  $\alpha$ -lactalbumin in Past HM (only at 90 min)
- $\alpha$ -lactalbumin was the most resistant to gastric digestion

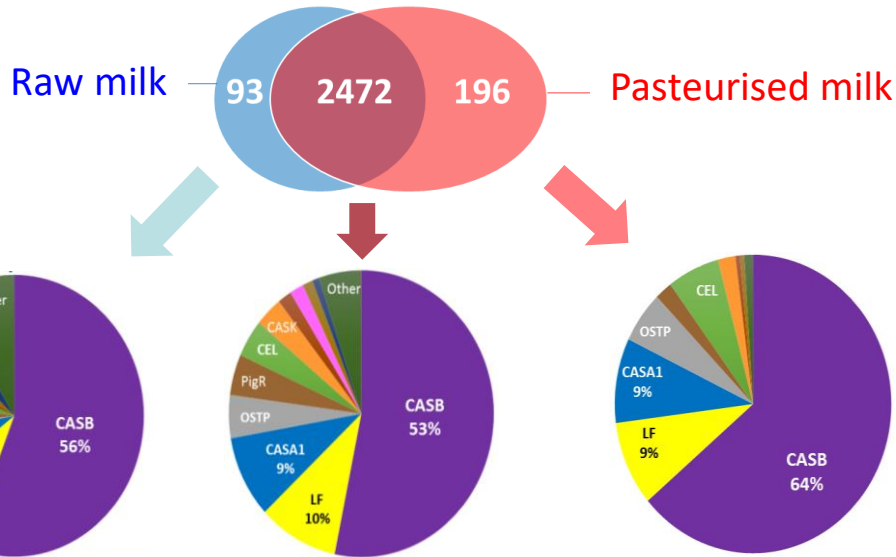
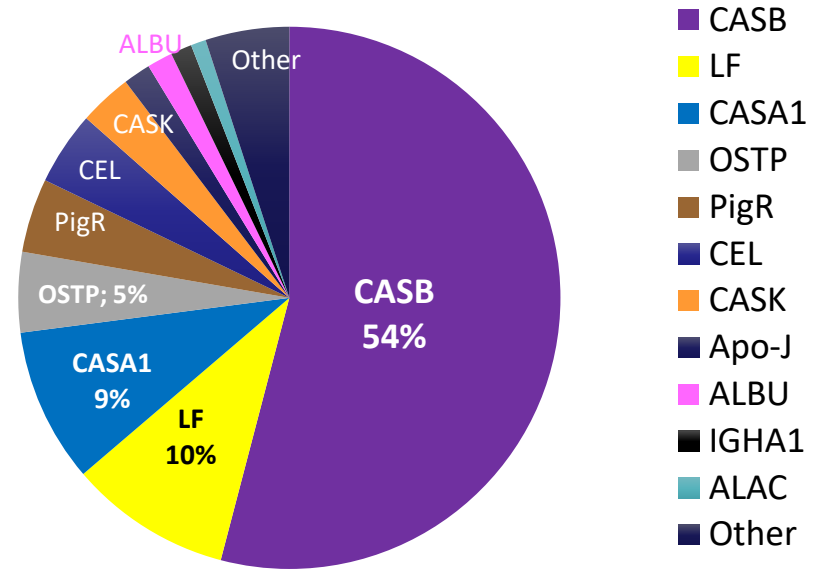
Impact on protective qualities of the native lactoferrin?

De Oliveira et al.,  
Am J Clin Nutr 2017

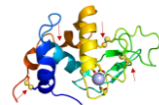
# Effect of pasteurisation on gastric peptidome

→ 2761 peptides in milk and digestas

*Originating from 18 proteins  
with 7 proteins contributing  
to less than 1% of the peptides*

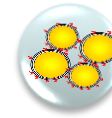
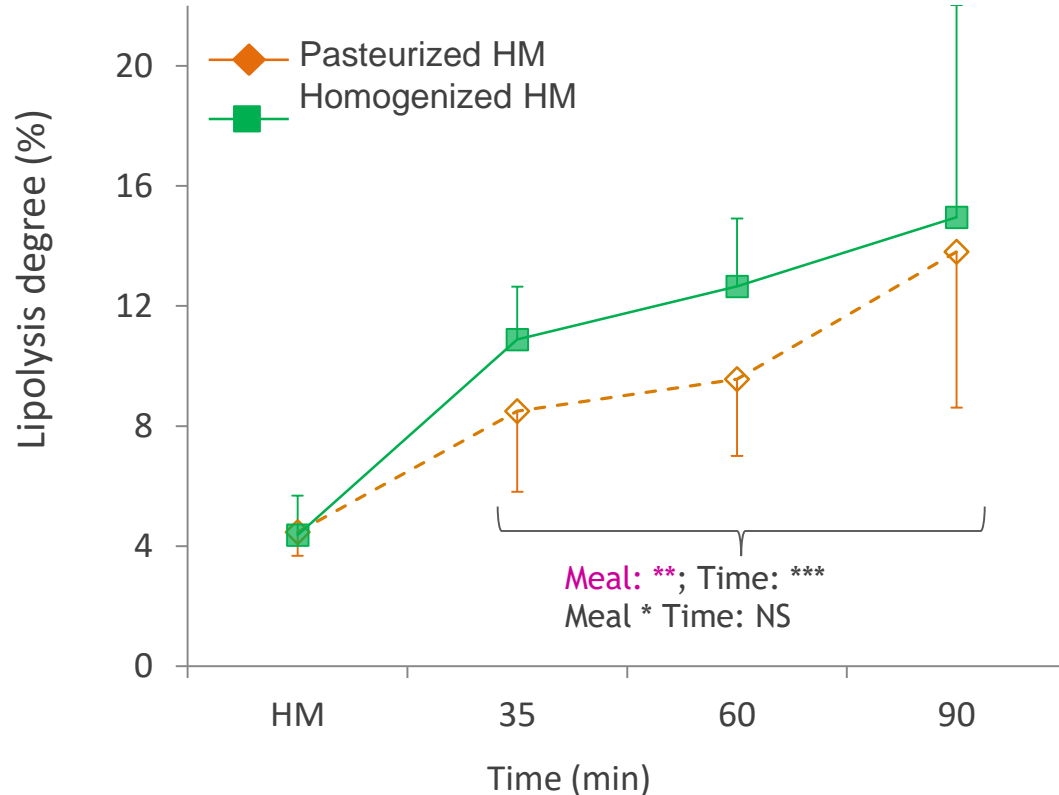


- Peptides essentially come from  $\beta$ -casein
- L' $\alpha$ -lactalbumin (ALAC) : 1% of peptides
  - → Resistant to gastric digestion
  - → 4 disulphide bridges
- More peptides specific of pasteurised milk

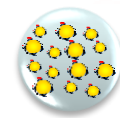


# Homogenization accelerates gastric lipolysis

## Instantaneous lipolysis level



Past HM



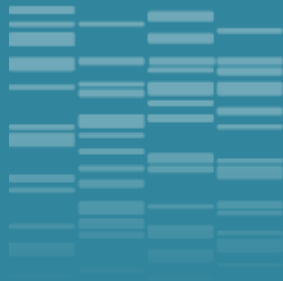
P+Homog HM

❖ Same milk composition, initial pre-lipolysis degree and inactivation of BSSL

❖ **Different structure**

➔ Increase of specific surface of droplets facilitating HGL adsorption

De Oliveira et al.,  
Clin Nutr 2017



# Effect of heat treatment on casein *in vitro* digestion in model infant formula





# Objective

☞ Does processing affect protein hydrolysis during milk powder digestion?



**Step 1 : Dissolution in milliQ water**

Skimmed ultra-low-heat powder

25% DM

35% DM

ULH Milk

ULH Milk

80°C/20 s

105°C/60 s

80°C/20 s

105°C/60 s

85°C / 3 min

85°C / 3 min

LA

LB

LC

LE

LF

LG

A

B

C

E

F

G

T

**Step 2 : Heat treatment**

**Step 3 : Spray drying**

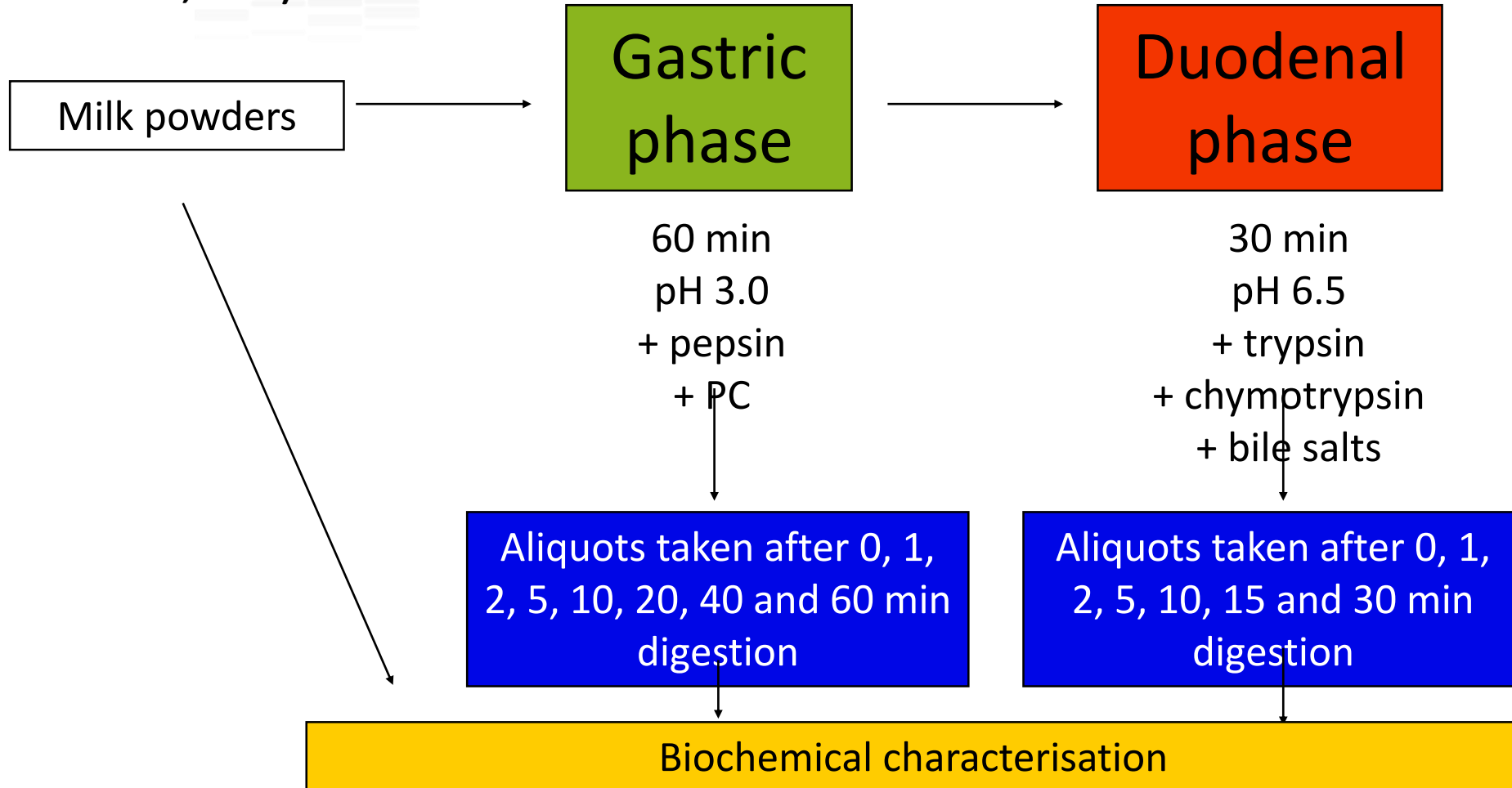
*In vitro* digestion



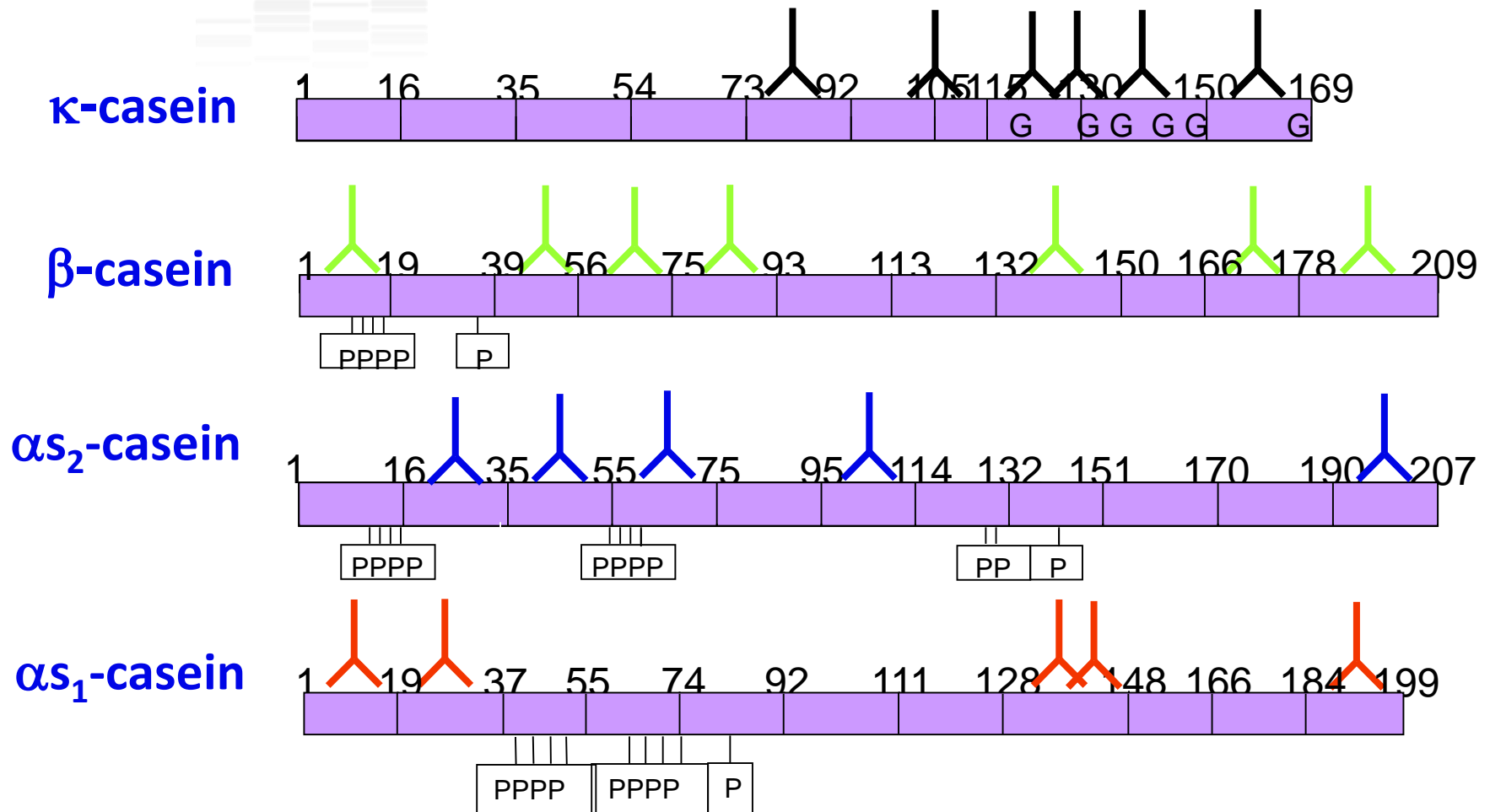
# Infant Gut Model



Cooperation with the Institute of Food Research in Norwich UK (Dupont *et al.* Mol. Nutr. Food Res., 2010)



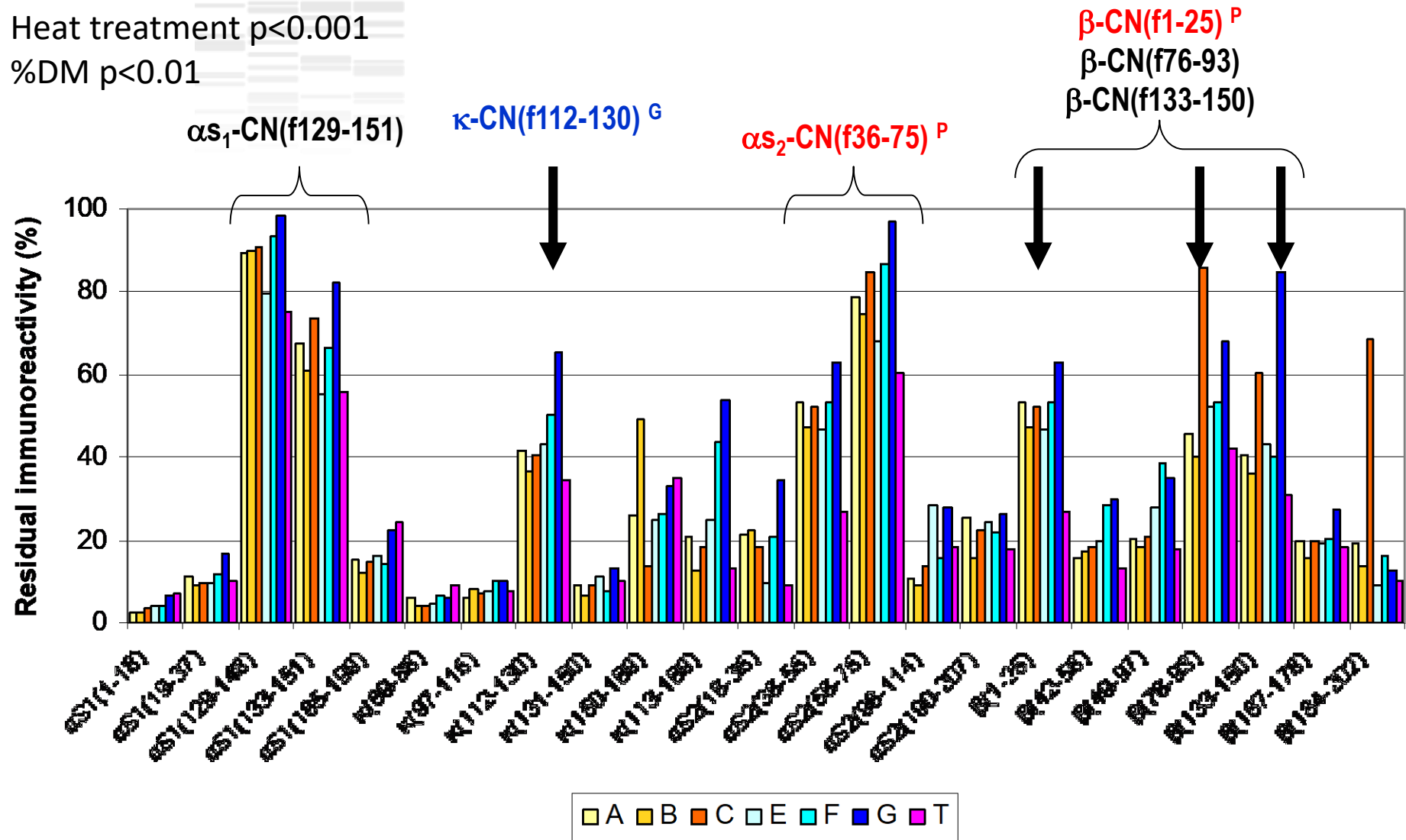
# Identification of epitopes resistant to digestion by ELISA using specific Mabs



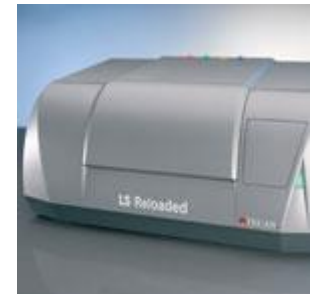
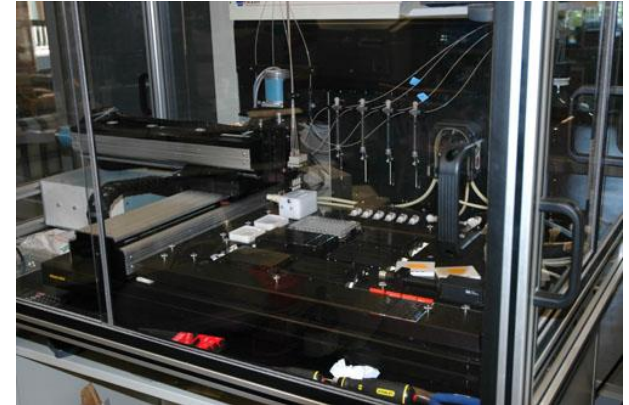
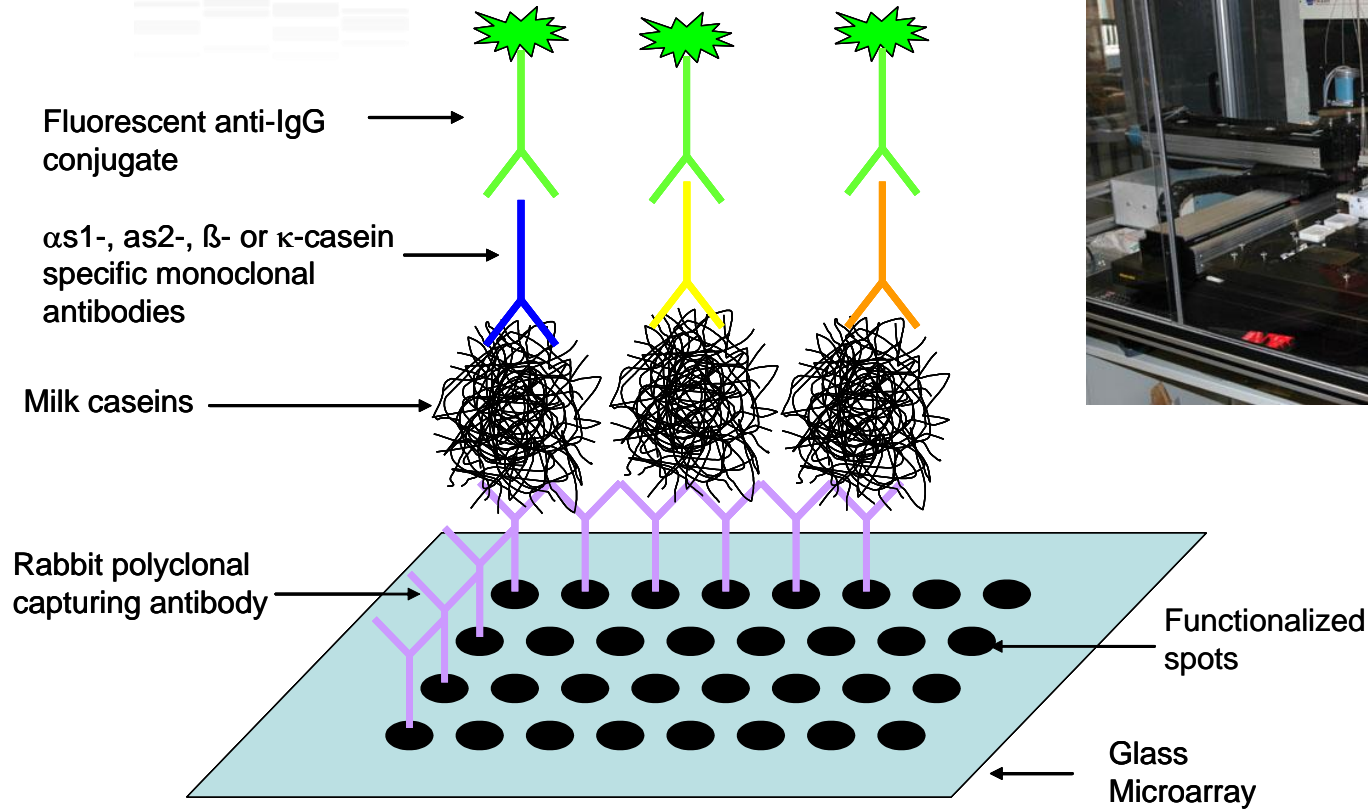
# Residual immunoreactivity of casein fragments

Heat treatment  $p < 0.001$

%DM  $p < 0.01$



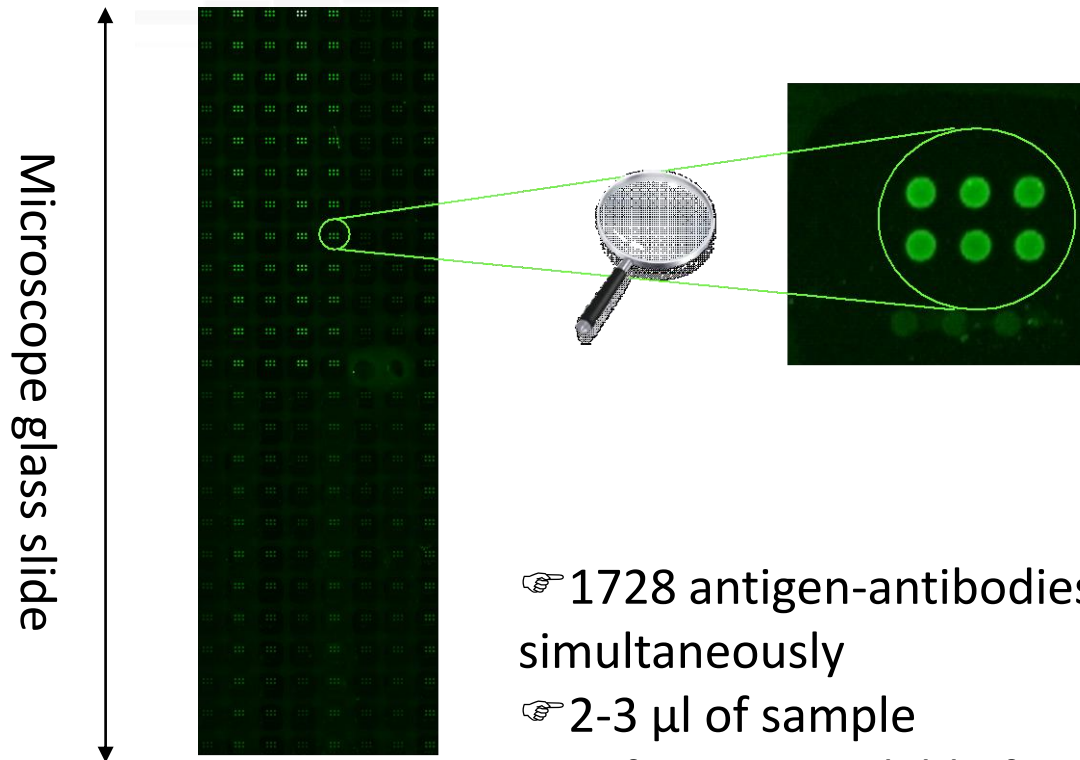
# Development of antibody array technologies



Cooperation with the Van Andel Research Institute



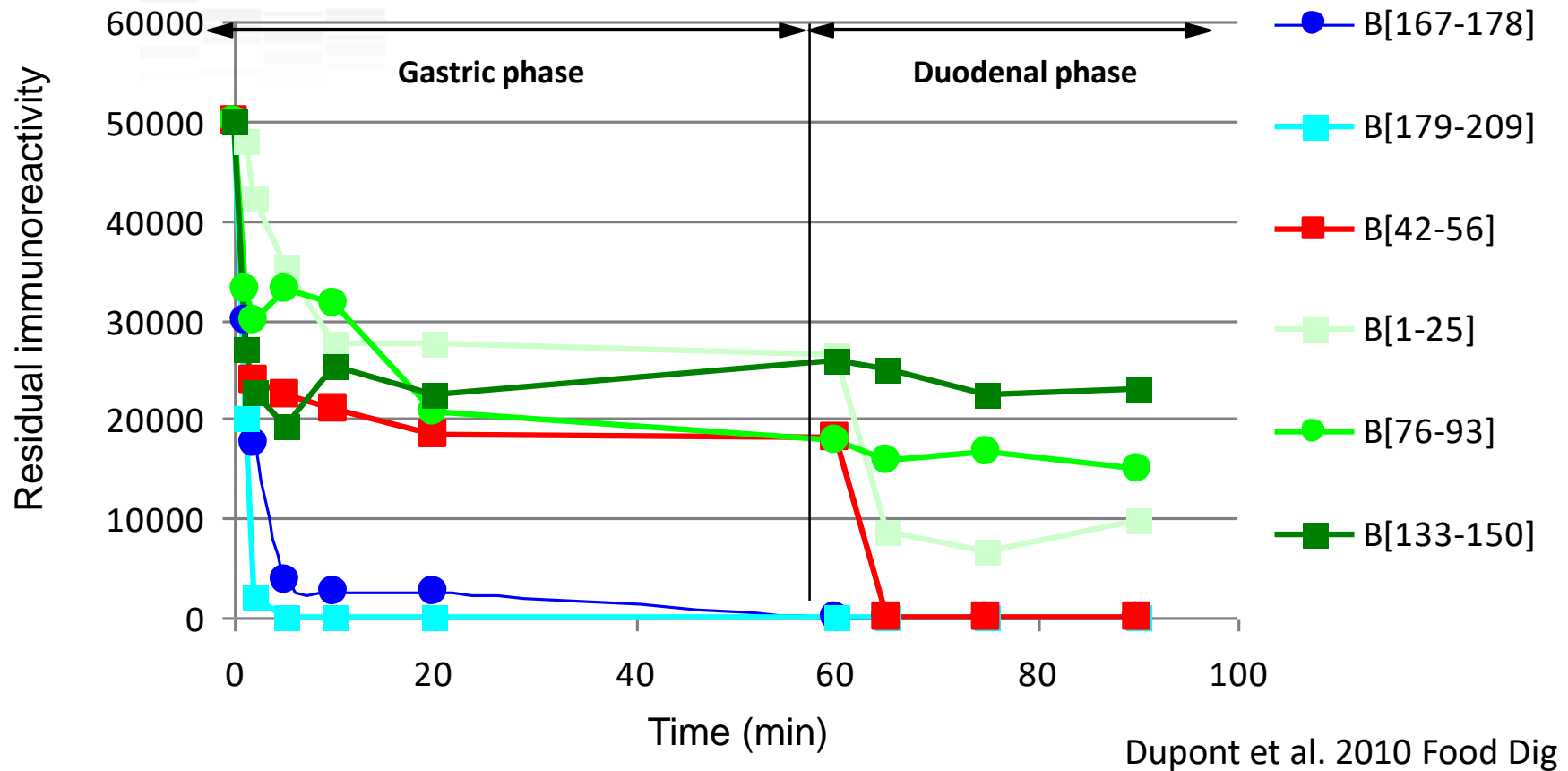
# Antibody arrays – an example of results



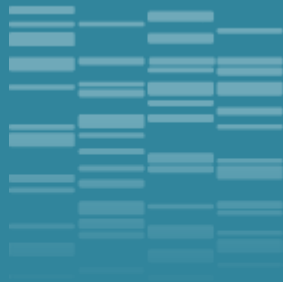
- 👉 1728 antigen-antibodies interactions studied simultaneously
- 👉 2-3  $\mu\text{l}$  of sample
- 👉 Softwares available for data integration



# Kinetics of $\beta$ -casein digestion



👉 Kinetics of  $\beta$ -casein digestion differ according to the area studied

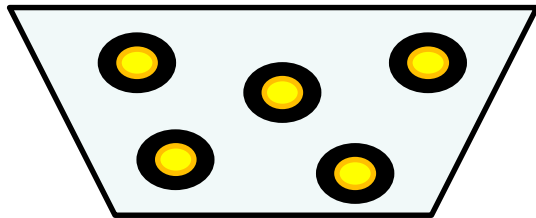


Can we design new generation of infant formula that would be biomimetic of human milk?



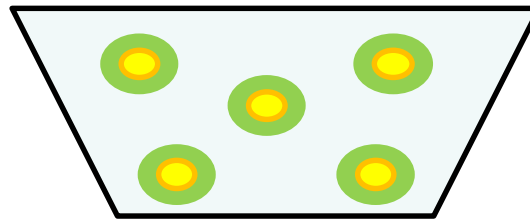
# Infant formulas: can we create lipid structures biomimetic on the native fat globule?

Formula  
T1



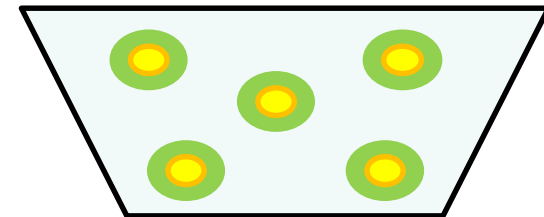
Interface 100 % Proteins  
100% vegetable oil

Formula  
T2

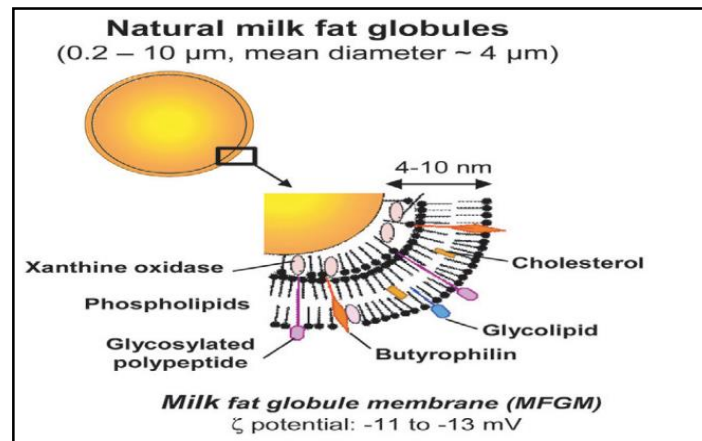


Interface 100 % phospholipids  
100% vegetable oil

Formula  
T3

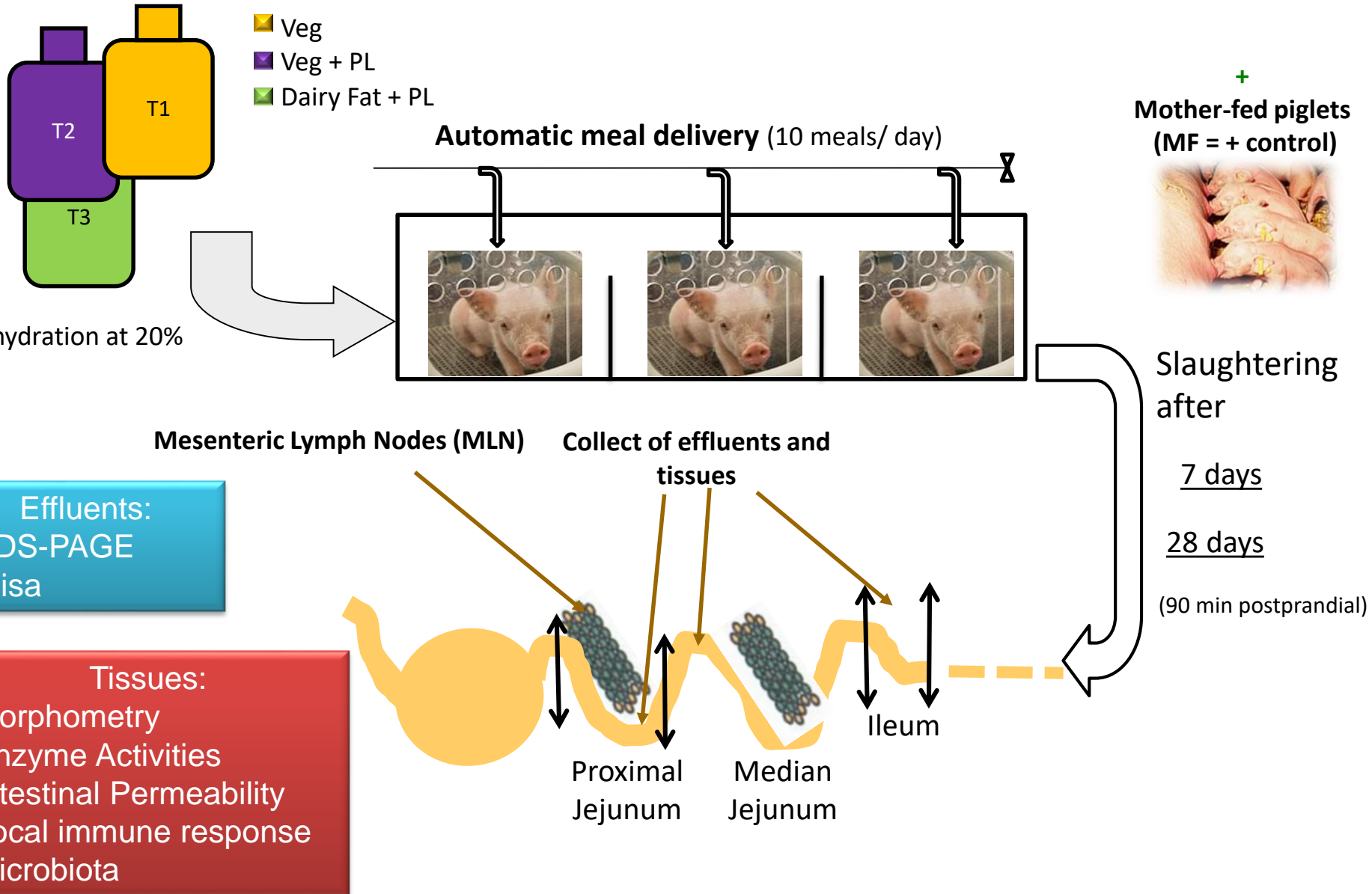


Interface 100 % phospholipids  
40% vegetable oil + 60% milk fat



Lopez, (2007)

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

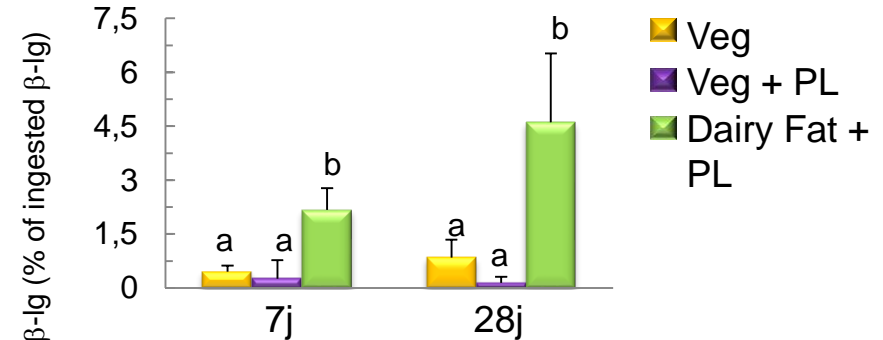
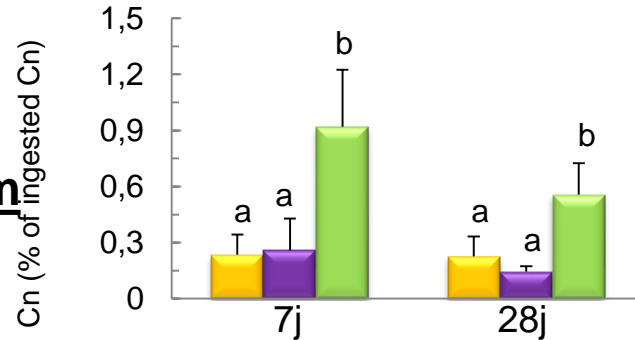


# Protein Digestion

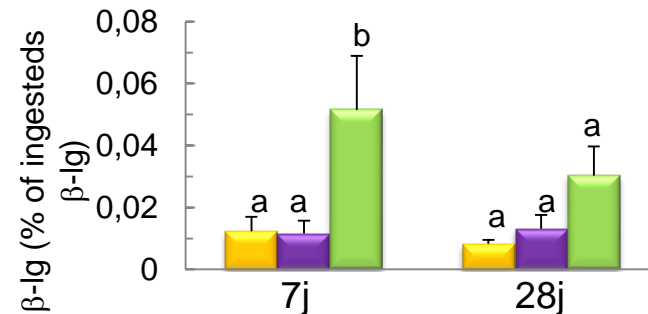
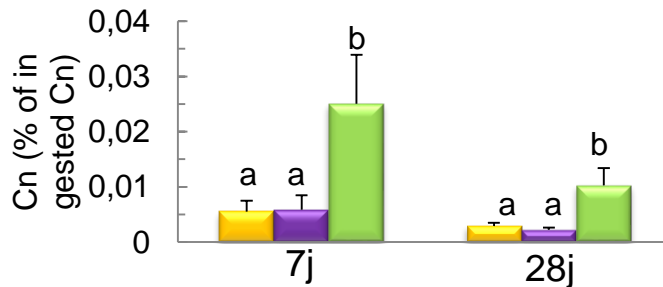
## Casein

## $\beta$ -lactoglobulin

### Jejunum



### Ileum



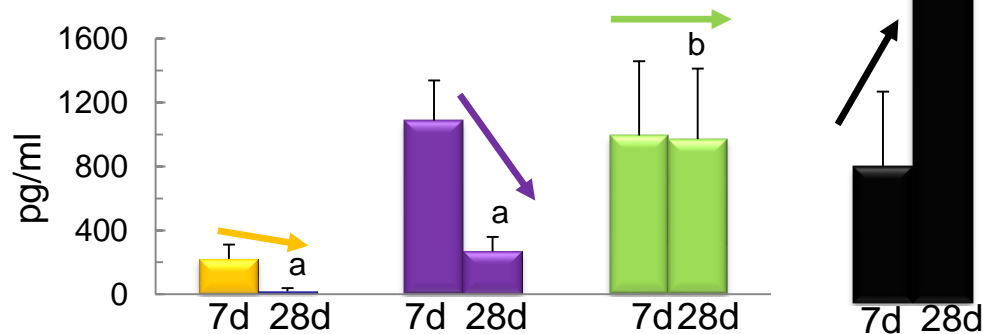
Milk Proteins better resist to intestinal digestion in the presence of dairy fat

➔ Modification of the interface

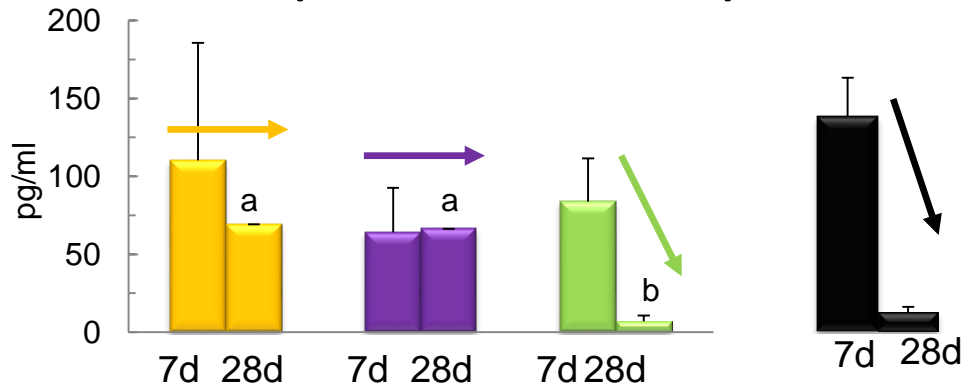
(Granger *et al* 2005; Davies *et al*, 2001)

# Secretory activity of MLN

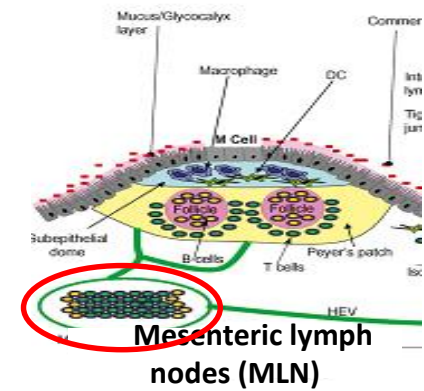
## Interferon-g (Th1 pro-inflammatory)



## Interleukine-10 (Th2 anti-inflammatory)



- Veg
- Veg + PL
- Dairy Fat + PL
- Porcelets SM

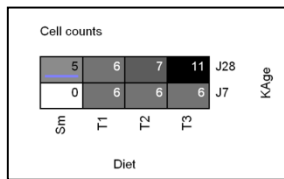


Milk lipids → maturation of the piglet's immune system more similar than with sow's milk

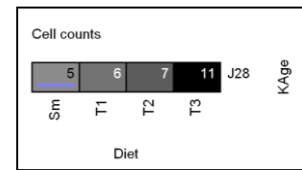
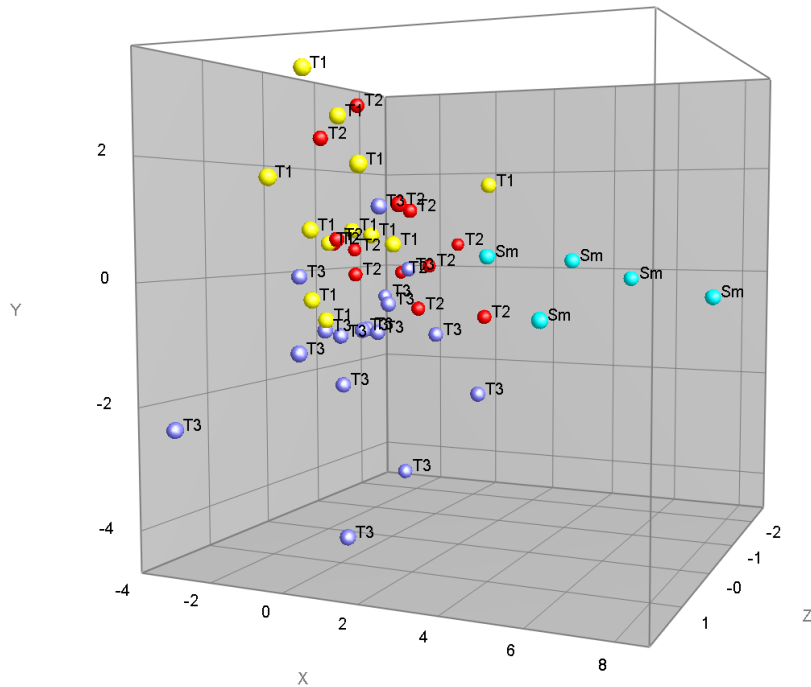
Le Huerou et al.  
Eur J Nutr 2017



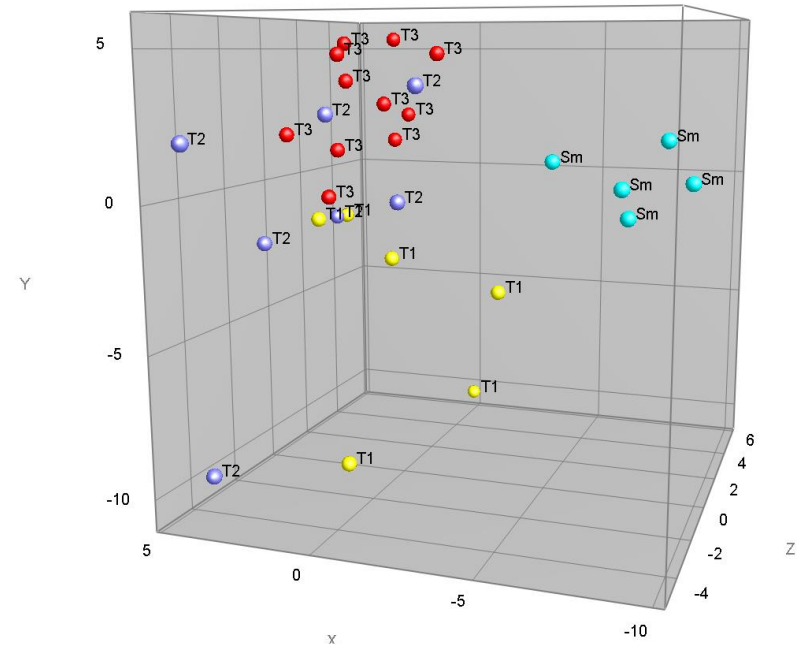
# Microbiota by DHPLC



D7 & D28



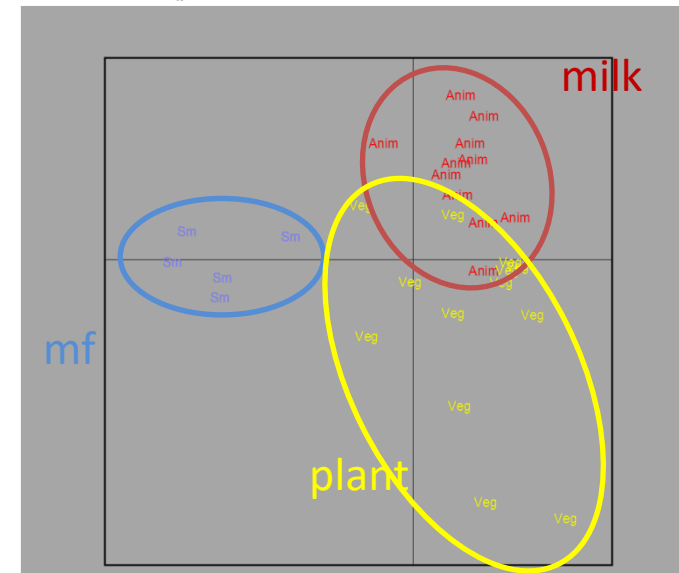
D28



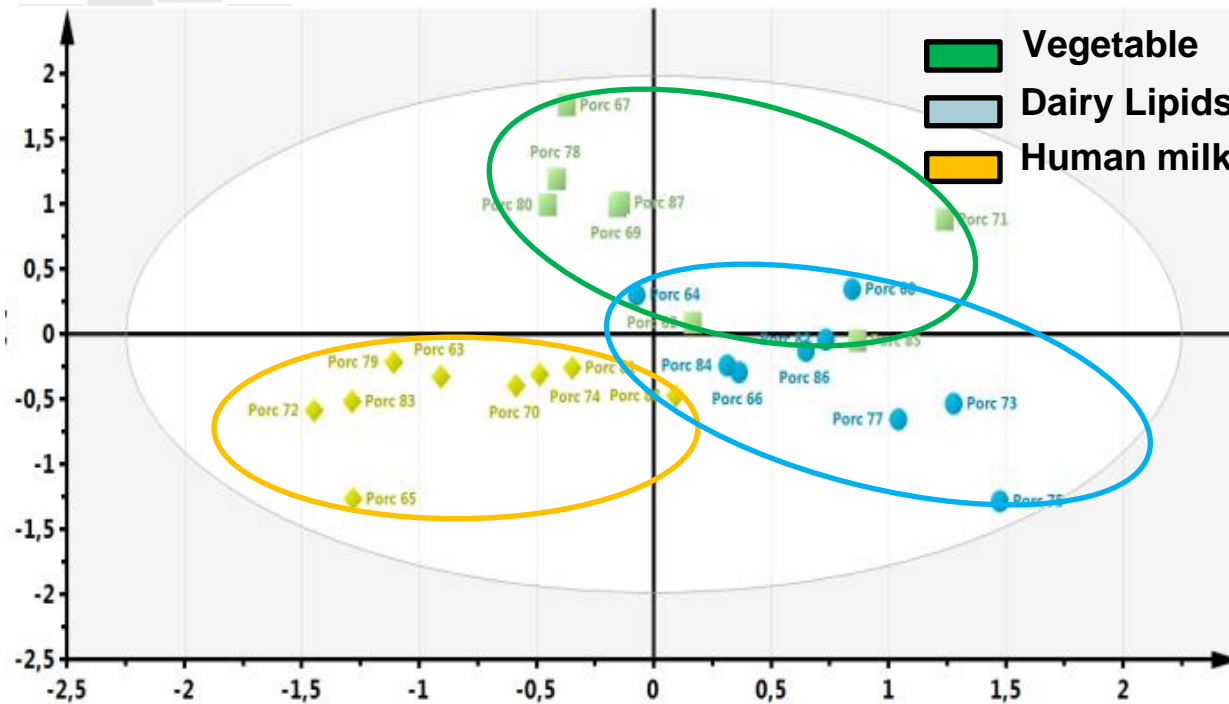
The composition/structure of the infant formula « orientates » the microbiota

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)?



Some differences remain in:

- \* the microbiota composition
- \* the metabolome with 5 discriminating metabolites (including propionate)
- \* the immune system with a reduced susceptibility to inflammation with milk lipids (lower TNF $\alpha$  and IL8 with dairy lipids)



## Design of a «native » infant formula using filtration technologies : nutritional, physiological and sensory impacts

**Coordinator :** Amélie Deglaire



**Involved partners :** PNCA (AM Davila), CSGA (S Nicklaus)

Laboratoire de Physiologie de la Nutrition et du Comportement Alimentaire



**Duration of the project :** 36 months (January 2018-December 2020)



### Main objective :

To assess the nutritional, physiological and sensory potential of infant formula as native as possible but microbiologically safe using a cascade of filtration technologies compares to one submitted to several heat treatments



# NativIF - phase 1 : results



Formula produced	T- : No heat treatment	T+ : One final heat treatment (75°C, 2 min)	T+++ : Multiple heat treatments (Max: 85°C, 2 min)
<b>Microbiological safety/ Nutritional Composition</b>	<b>validated</b>	<b>validated</b>	<b>validated</b>
% of protein denaturation	<b>4,1 ± 0,7 %</b>	<b>7,2 ± 1,1 %</b>	<b>57,6 ± 0,2%</b>
Furosine (mg / 100 g Total Nitrogen) Carboxymethyl-lysine (mg / 100 g NT)	576 ± 14 8,2 ± 0,3	516 ± 48 8,2 ± 0,3	544 ± 29 10,3 ± 2,1
Amount conditioned in boxes	35 kg	35 kg	35 kg

## Bacteriological analysis of the formulas

	T-	T+	T+++
	ufc / g poudre		
Flore totale à 30°C	500	340	100
Bacillus cereus	<10	<10	<10
Coliformes totaux	<10	<10	<10
Cronobacter spp	non détecté	non détecté	non détecté
Entérobactéries	non détecté	non détecté	non détecté
Listeria monocytogenes	absence	absence	absence
Salmonella	absence	absence	absence
Staphylocoque à coagulase positive	absence	absence	absence
Levures	<10	<10	<10
Moisissures	<10	<10	<10

→ In agreement with the legislation

## Nutritional composition

		T-	T+	T+++
	Unité	/ 100 g poudre		
Extrait Sec Total	g	97.9	97.8	97.7
Energie	kcal	526	532	531
Proteines	g	10.6	11.2	10.2
ratio massique CN : PS		55:45	55:45	57:43
Lipides	g	29	30	30
Lactose	g	56	54	55
Cendres	g	2.7	2.5	2.7

**Minerals and vitamins added**

→ Composition in agreement with the legislation



## Phase 2

### Task 1 : Impact of the infant formulas T- and T+++ on the homeostasis of the intestinal microbiota on a rat model (12 months)

Laboratoire de Physiologie de la Nutrition et du  
Comportement Alimentaire

#### T1.1 : Kinetics of digestion and protein and amino acid digestibility

Nitrogen and amino acid quantification in intestinal effluents and in the bloodstream

- After weaning, adaptation to the formulas during 2 weeks
- At 1h, 2h, 3h and 6h after the meal (n = 6)



#### T1.2 : Impact on the differentiation and the energy metabolism of the intestinal epithelium

Rats adapted to the formulas between 14 and 21d, then fed the formulas during 2 weeks (n = 8)

- Assessment of the growth, food intake and bone density
- Euthanasia at 35d : intestinal epithelium (**differentiation, permeability**), colon cryptes (**energy metabolism**)

#### T1.3 : Impact on the structuration of the intestinal microbiota

Microbiota characterization and quantification of amino acid-derived bacterial metabolites

### Task 3: Data analysis (6 months)

### Task 2 : Sensory properties of infant formulas and acceptability by the neonate (12 months)

#### T2.1 : Sensory characterization

Global Difference between T-, T+, T+++ and a control commercial infant formula → triangular test, adult panel

#### T2.2 : Analytical characterization

Aroma characterization of T-, T+, T+++ by GC-MS

Olfactometry coupled to gas chromatography if important differences

#### T2.3 : Acceptability by the neonate (T- vs T+++)

Consumer behavior by comparing formula T- vs. T+++

- 25 infants between 4 and 6 months
- oro-facial behavior, liking, amount consumed, digestive confort
- 3 sequences in laboratory + 1 day trial at home



**ChemoSens**



# Amino acid bioavailability, particularly tryptophane, in human milk and infant formula

**Supervisor of the thesis : Didier Dupont (INRA, STLO)**

**Co-supervisors :**

- **Amélie Deglaire** (Agrocampus Ouest, STLO)
- **Isabelle Le Huërou-Luron** (INRA Saint Gilles, Numecan - NGB)
- **Paul Moughan** (Riddet Institute, Nouvelle-Zélande)

**Funding**

**Student salary:**

½ AO + ½ Brittany Council

**Consumables :**

22 k€/year (Riddet Institute) for part 1



## Research Questions :

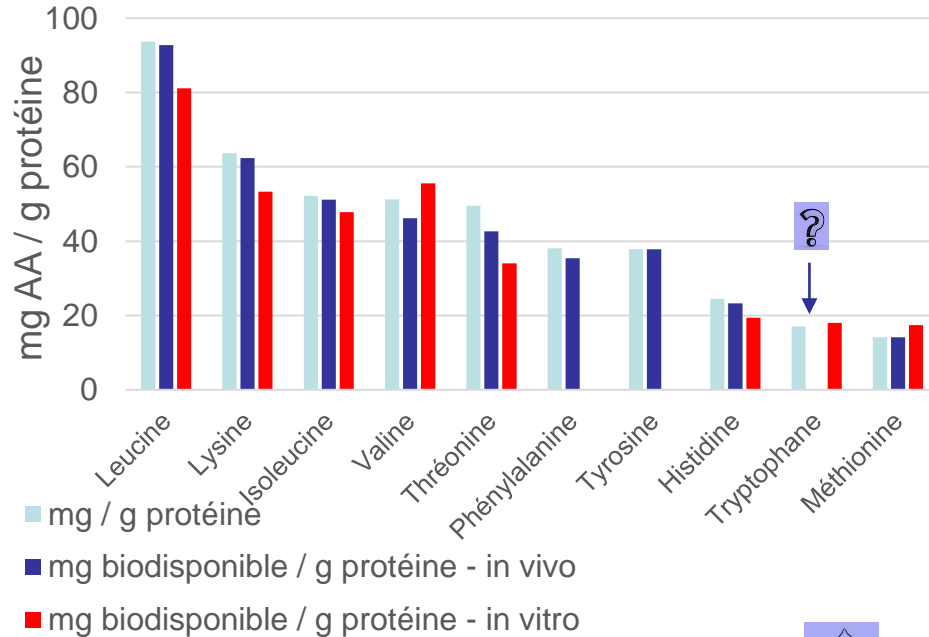
- What is the amino acid bioavailability, especially that of tryptophane, in human milk and infant formula?
- What is the effect of the protein type and amount of the infant formula on :
  - the tryptophane bioavailability?
  - the production of tryptophane metabolites (e.g. sérotonine, mélatonine, indole) ?
  - The intestinal maturation and the brain development ?





# Scientific context

## Essential amino acid bioavailability in human milk



(Darragh & Moughan, 1998)

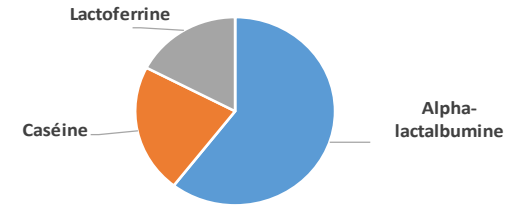
(Maathuis et al., 2017)

More research needed especially for Trp (FAO, 2013)



## Tryptophane: an essential amino acid

### Origin in human milk



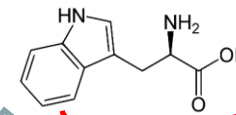
### Digestion

Bacterial metabolism

Indol

inflammation  
Intégrité barrière intestinale  
(Bansal et al., 2010; Shimada et al., 2013)

Forte dose : Cpt anxieux et dépressif (Jaglin et al. 2018)



Niacin (Vit B3)

### Absorption

Intestine  
Brain

Serotonin

Neuro-transmitter

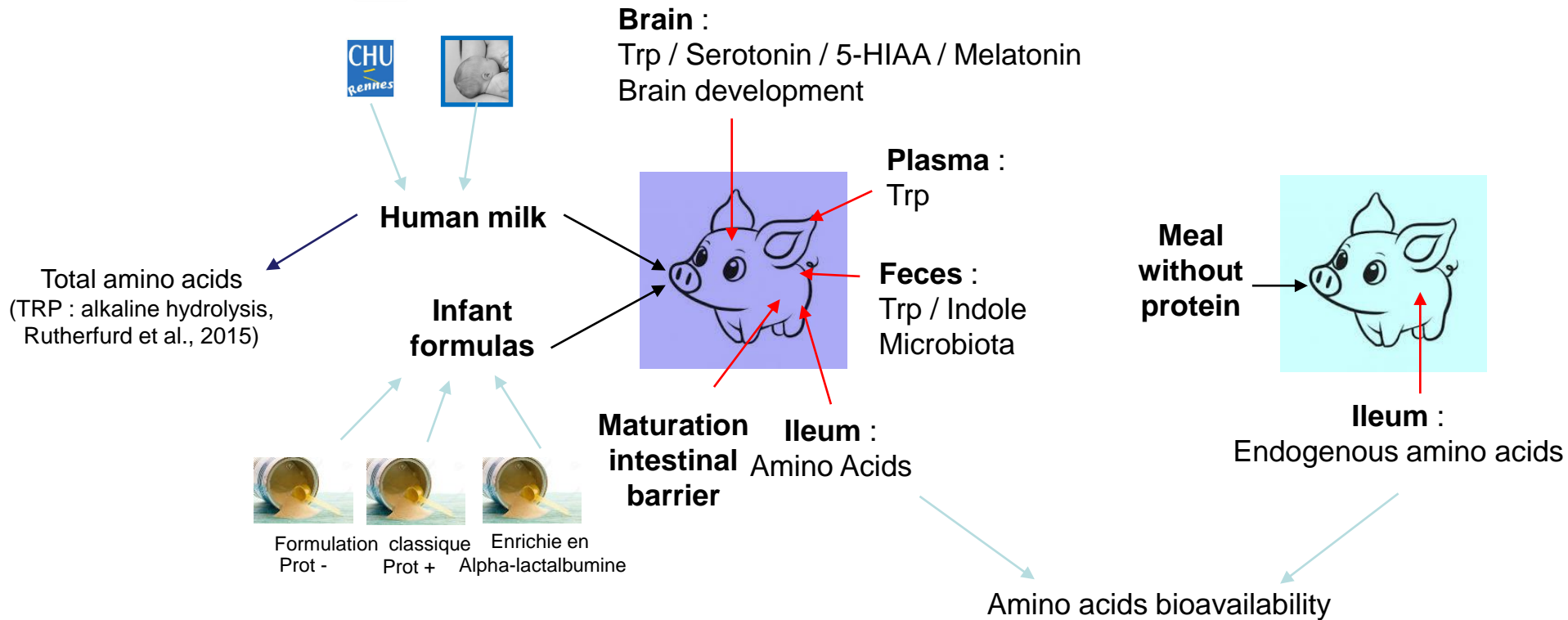
Melatonin

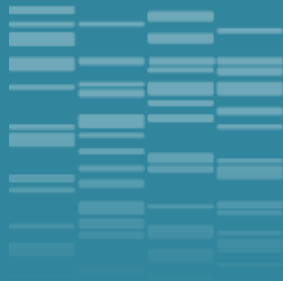
Hormone of the chronobiological regulation

Protein synthesis



# Experimental Plan



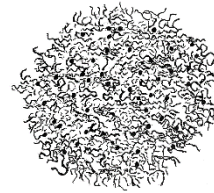


May bioactive peptides released  
during digestion have an effect *in*  
*vivo*?

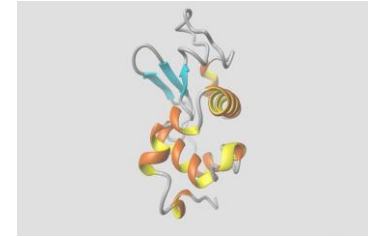


# *In vivo* digestion of milk proteins

- 16 subjects were fed with 30g of either:
  - Caseins
  - Whey proteins



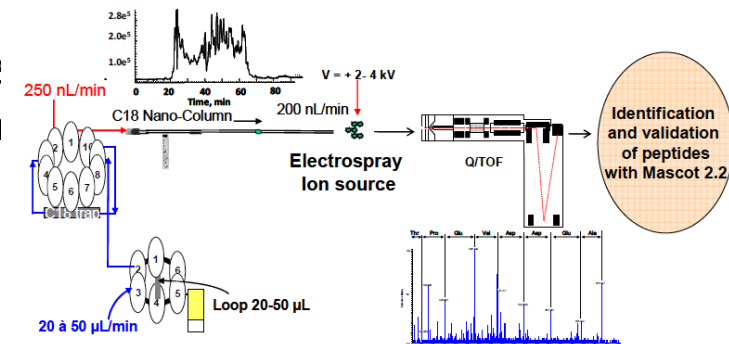
/



- Intestinal contents were collected through a double lumen nasogastric tube placed in their jejunum during 6 h after ingestion (location of the sampling site was controlled by radiography)



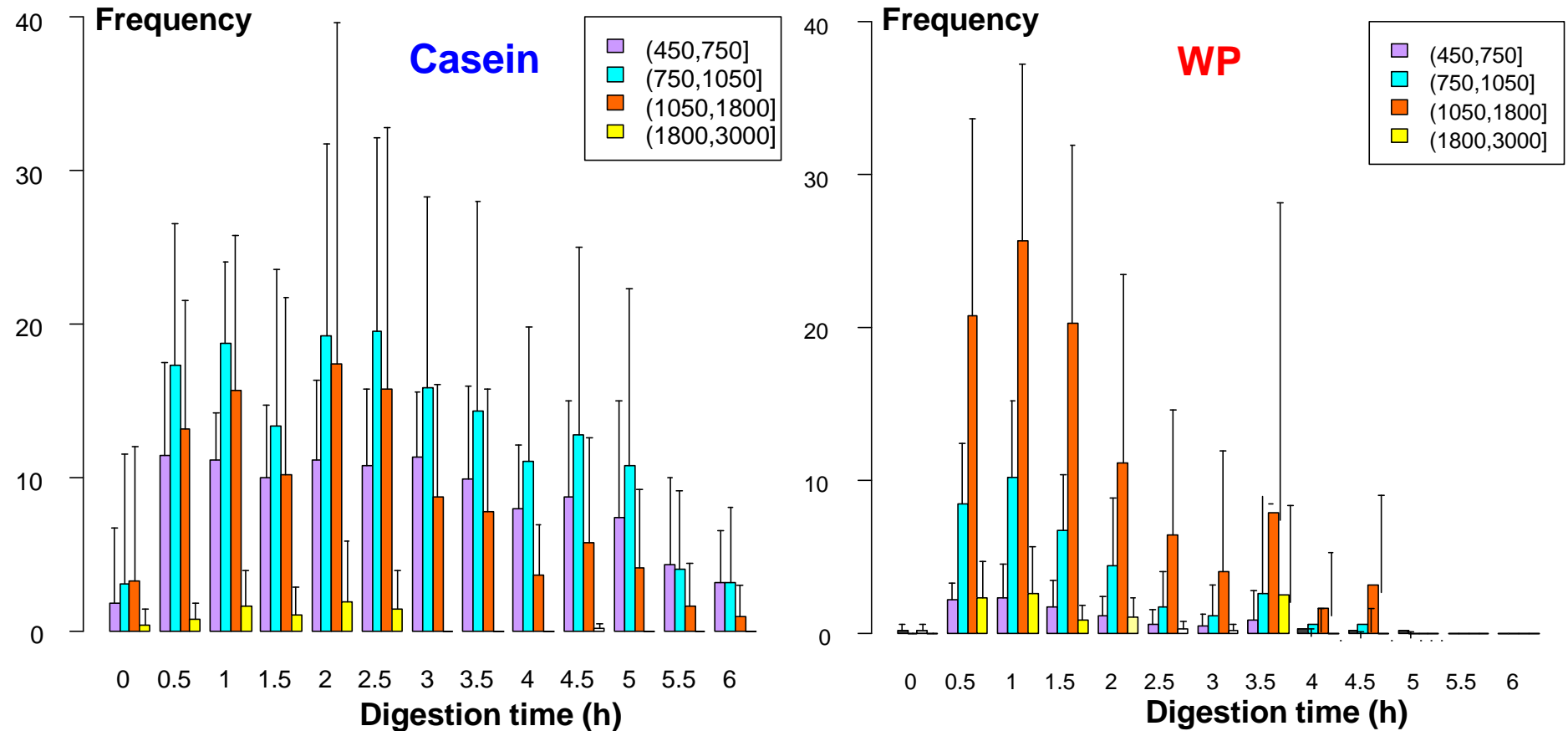
- Effluents were then freeze-dried until further use. Before analysis, effluents were rehydrated in 50 mM Tris HCl buffer pH 8.0 and 2M urea, centrifuged for 10 min at 2000 g



- Samples were characterized by ESI-MS-MS. Only peptides larger than 5 amino acids are considered

# Kinetics of peptides release

↪ 4704 dietary peptides unambiguously identified



☞ Release of casein peptides throughout digestion

☞ Peptides generated from whey proteins digestion are larger

↪ Generation of a unique database of dietary peptides bioaccessible

# A great variability in patterns but some peptides present in all subjects

31 peptides present throughout digestion

14 peptides found in all the subjects

1-6	RELEEL	
57-66	SLVYFPFGPI	57-66 SLVYFPFGPI
58-66	LVYFPFGPI	
58-68	LVYFPFGPIPN	
59-66	VYFPFGPI	59-66 VYFPFGPI
59-67	VYFPFGPIP	
59-68	VYFPFGPIPN	59-68 VYFPFGPIPN
60-66	YFPFGPI	60-66 YFPFGPI
61-66	PFPFGPI	60-67 YFPFGPIP
73-79	NIPPLTQ	
73-80	NIPPLTQT	
73-82	NIPPLTQTPV	
80-91	TPVVVPFLQPE	
81-87	PVVVPPF	
81-91	PVVVPPFLQPE	81-91 PVVVVPFLQPE
81-92	PVVVPPFLQPEV	81-92 PVVVPPFLQPEV
83-91	VPPFLQPE	
84-91	VPPFLQPE	
85-091	PPFLQPE	
107-113	KEMPFPK	
108-113	EMPFPK	108-113 EMPFPK
114-119	YPVEPF	114-119 YPVEPF
134-139	HLPLPL	
135-139	LPLPL	
156-160	MFPPQ	
168-173	VAPFPQ	168-173 VAPFPQ
170-175	VLPVPQ	170-175 VLPVPQ
171-175	LPVPQ	
194-201	QEPVLGPV	177-182 AVYPYQ
195-201	EPVLGPV	194-201 QEPVLGPV
196-201	PVLGPV	195-201 EPVLGPV

$\beta$ -CN

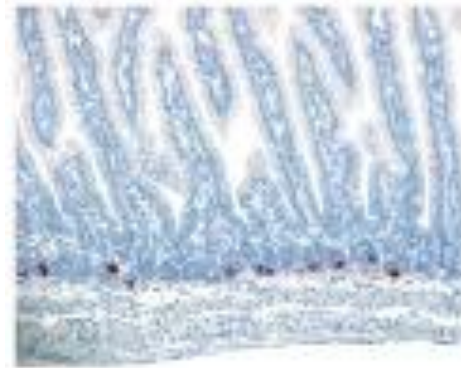
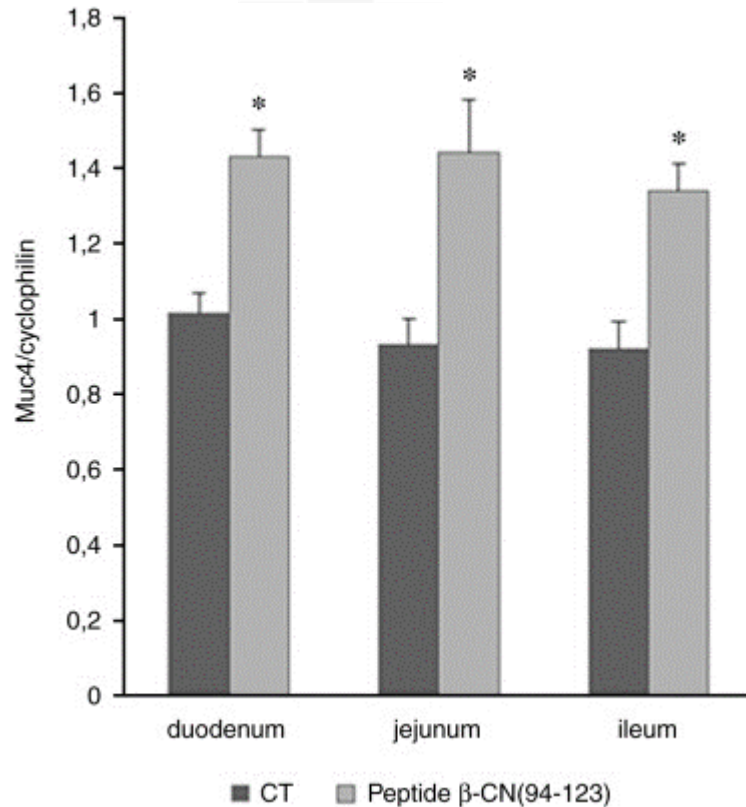
Among those 5 bioactive peptides

59-66	VYFPFGPI	} Anti-hypertensive Opioid
59-68	VYFPFGPIPN	
60-66	YFPFGPI	
108-113	EMPFPK	
114-119	YPVEPF	

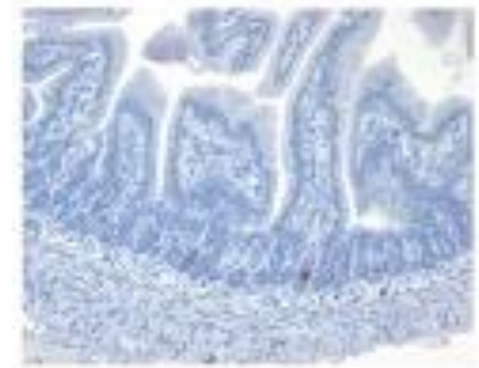
Boutrou et al. 2013  
Am J Clin Nutr



# Bioactive peptides released during digestion can reinforce the defense of the intestinal epithelium



Before



After

Sections of duodenum after 10 d of administration of peptide  $\beta$ -CN (94-123)

$\beta$ -CN(94-123) stimulates the mucus production *in vitro* (HT-29 MTX) and *in vivo* (rat)

Plaisancie et al. 2013, J Nutr Biochem  
Plaisancie et al. 2015, J Dairy Res

# 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 group at INRA in Rennes

## Head

Didier DUPONT - *Senior Scientist*

## Scientists

Rachel BOUTROU – *Junior Scientist*

Amélie DEGLAIRE – *Lecturer*

Juliane FLOURY – *Lecturer*

Catherine GUERIN - *Lecturer*

Joëlle LEONIL – *Senior Scientist*

Steven LE FEUNTEN – *Junior Scientist*

Françoise NAU – *Professor*

Frédérique PEDRONO – *Lecturer*

Guilherme FURTADO – *Post-doc*

Xaoxi YU – *Post-Doc*



## PhD students

Linda LEROUX (2016-2019)

Manon HIOLLE (2016-2019)

Yohan REYNAUD (2016-2019)

Amira HALABI (2017-2020)

Léa SALELLES (2018-2021)

Jun WANG (2018-2021)

## 2-3 Masters students

## Technicians

Gwenaële HENRY

Yann LE GOUAR

Nathalie MONTHEAN

## Engineers

Julien JARDIN

Olivia MENARD

Jordane OSSEMOND

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

## International Network

Dr. Didier DUPONT, Senior Scientist, INRA, France

INFOGEST







# Industry involvement

☞ ~ 50 private companies are following INFOGEST







# INFOGEST



Chair

Didier Dupont - France

didier.dupont@inra.fr



Vice-chair

Alan Mackie - UK

[www.cost-infogest.eu](http://www.cost-infogest.eu)

**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**



Didier Dupont

Pasquale Ferranti

Linda Giblin

Myriam Grundy

Nadja Siegert

Choi-Hong Lai



Milena  
Corredig



Alan Mackie

Uri Lesmes

Brigitte Graf

Frederic Carriere

Caroline Orfila

Steven Le Feunteun

# Some outputs

## *In vitro* gastrointestinal digestion Consensus INFOGEST protocol

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

### Oral phase

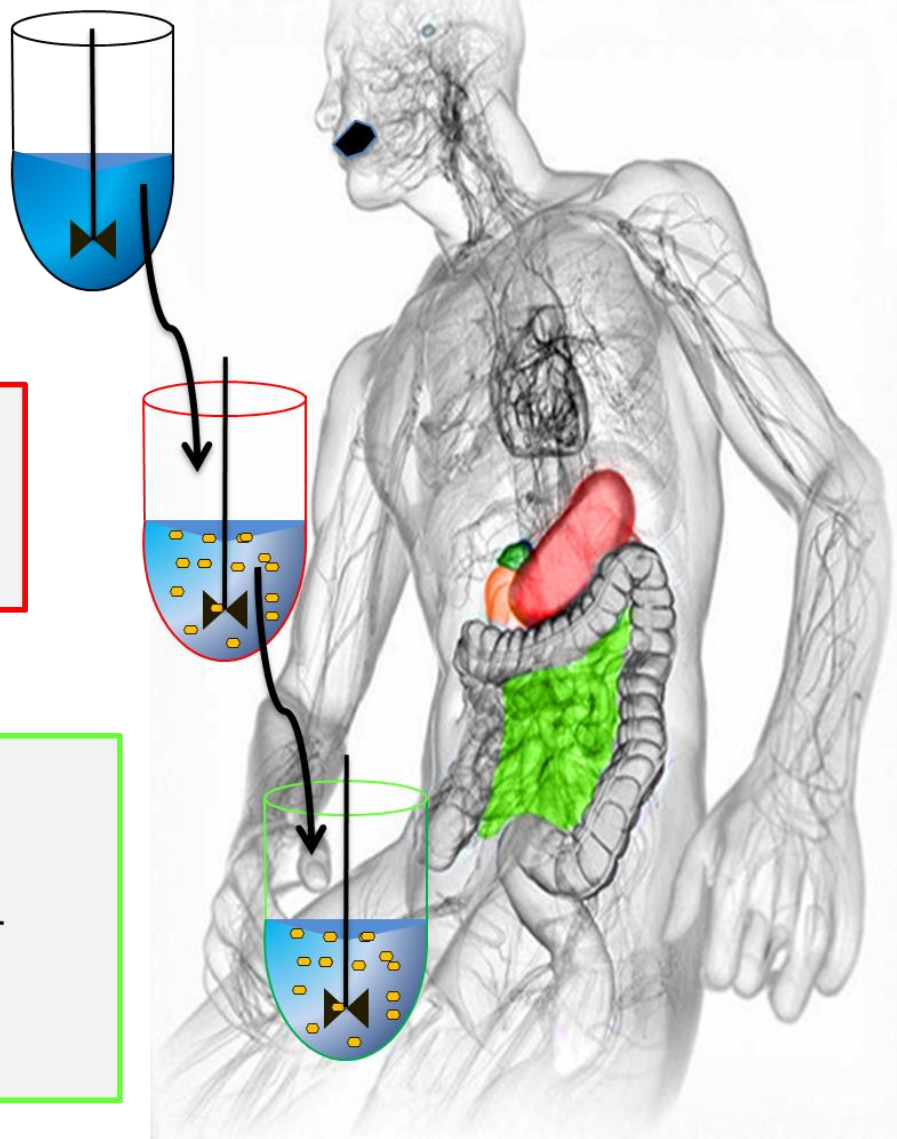
Mix 1:1 with Simulated Salivary Fluid (SSF)  
salivary amylase (75 U/mL)  
2 min, pH 7

### 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



An updated version of the protocol published last week!

nature  
protocols

PROTOCOL

<https://doi.org/10.1038/s41596-018-0119-1>

# INFOGEST static in vitro simulation of gastrointestinal food digestion

André Brodkorb<sup>1\*</sup>, Lotti Egger<sup>2</sup>, Marie Alminger<sup>3</sup>, Paula Alvito<sup>4</sup>, Ricardo Assunção<sup>4</sup>, Simon Ballance<sup>5</sup>, Torsten Bohn<sup>6</sup>, Claire Bourlieu-Lacanal<sup>7</sup>, Rachel Boutrou<sup>8</sup>, Frédéric Carrière<sup>9</sup>, Alfonso Clemente<sup>10</sup>, Milena Corredig<sup>11</sup>, Didier Dupont<sup>8</sup>, Claire Dufour<sup>12</sup>, Cathrina Edwards<sup>13</sup>, Matt Golding<sup>14</sup>, Sibel Karakaya<sup>15</sup>, Bente Kirkhus<sup>5</sup>, Steven Le Feunteun<sup>8</sup>, Uri Lesmes<sup>16</sup>, Adam Macierzanka<sup>17</sup>, Alan R. Mackie<sup>18</sup>, Carla Martins<sup>4</sup>, Sébastien Marze<sup>19</sup>, David Julian McClements<sup>20</sup>, Olivia Ménard<sup>8</sup>, Mans Minekus<sup>21</sup>, Reto Portmann<sup>2</sup>, Cláudia N. Santos<sup>22,23</sup>, Isabelle Souchon<sup>24</sup>, R. Paul Singh<sup>25</sup>, Gerd E. Vegarud<sup>26</sup>, Martin S. J. Wickham<sup>27</sup>, Werner Weitschies<sup>28</sup> and Isidra Recio<sup>29</sup>

5-year Impact Factor=15,269

INFOGEST

# The consensus model can be learned with videos on YouTube

Browser tabs: Intranet UMR STLO - Accueil, GRR (Gestion et Réservatio..., YaZiba: 30/3 - 3/4, In vitro food digestion - C...

Address bar: [https://www.youtube.com/channel/UCdc-NP9kTDGyH\\_kZCgpQWg](https://www.youtube.com/channel/UCdc-NP9kTDGyH_kZCgpQWg)

Search bar: cost infogest

Buttons: Mettre en ligne, Connexion

Left sidebar:

- Vidéos à regarder
- LE MEILLEUR DE YOUTUBE
- Populaire sur YouTube
- Musique
- Sport
- Jeux vidéo et autres
- Films
- Émissions TV
- Actualité
- Parcourir les chaînes

Main content:

## In vitro food digestion - COST action INFOGEST

Accueil Vidéos Playlists Chaînes Discussion À propos

Toutes les activités

In vitro food digestion - COST action INFOGEST a mis en ligne une vidéo. il y a 10 mois

**Alpha Amylase Activity Assay for In Vitro Food Digestion**  
de In vitro food digestion - COST action INFOGEST  
il y a 10 mois • 846 vues  
A step-by-step description of a static  $\alpha$ -amylase activity assay for an in vitro digestion method presented suitable for food; recently published and available online (open access...)

**Static In Vitro Digestion Method for Food**  
de In vitro food digestion - COST action INFOGEST  
il y a 10 mois • 723 vues  
A step-by-step description of a static in vitro digestion method presented suitable for food (international consensus); recently published and available online (open access), see ...

Right sidebar: Chaînes populaires sur YouTube


- Seb la Frite S'abonner
- MissCreatives S'abonner
- LanguedePub / M... S'abonner
- JunkFoodTasterD... S'abonner
- Madame Patachou S'abonner
- halawiyat khadija... S'abonner

<https://www.youtube.com>

Kitty Verhoeckx · Paul Cotter  
Iván López-Expósito  
Charlotte Kleiveland · Tor Lea  
Alan Mackie · Teresa Requena  
Dominika Swiatecka  
Harry Wichers *Editors*

# The Impact of Food Bioactives on Health

In Vitro and Ex Vivo Models

 COST

 Springer Open

## Some outputs

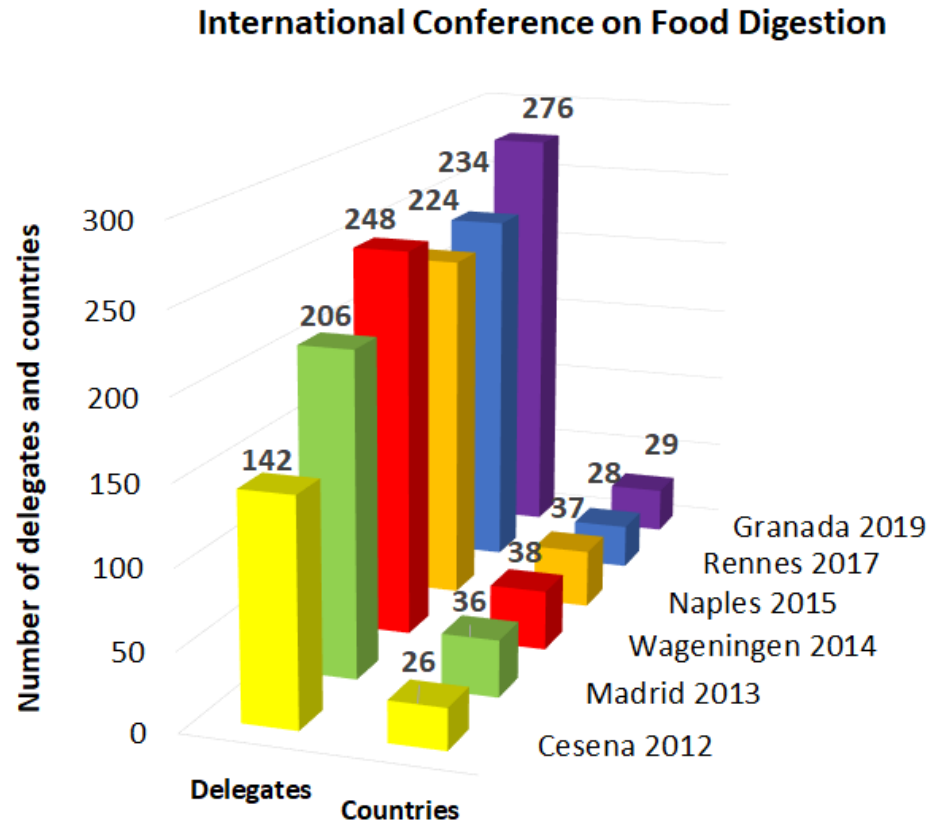
Release of a 341-page book on all the in vitro and ex vivo models to study the impact of food bioactives on health

## OPEN ACCESS

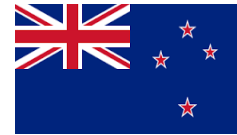
- \* More than 620,000 chapter downloads
- \* top 25% most downloaded eBooks in 2017



# The International Conference on Food Digestion



The Conference has been created by INFOGEST and is now an event regularly followed by 200 scientists







We are pleased to announce the next  
**7<sup>th</sup> International Conference on Food Digestion**



**in Cork, Ireland, 2021**