The structure of dairy products at different length scales drives the bioavailability bioavailability of nutrients

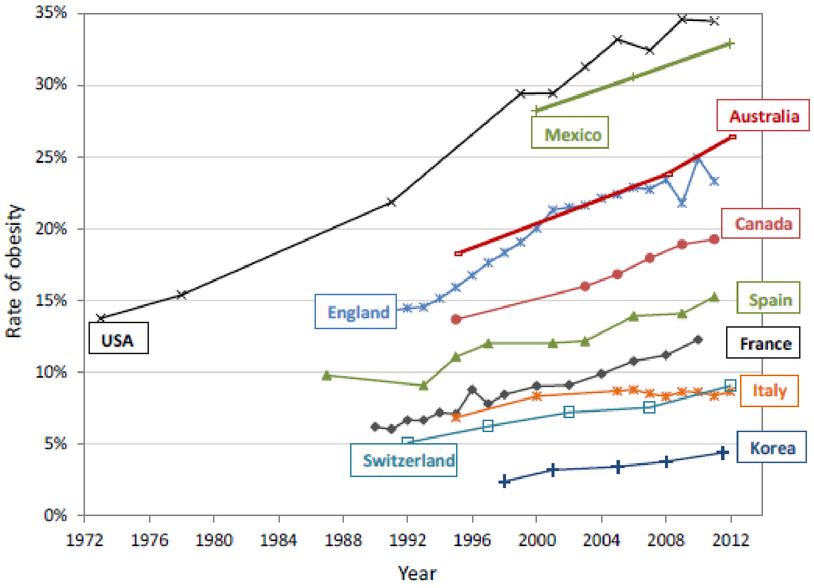
Didier Dupont

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

INRA
SCIENCE & IMPACT

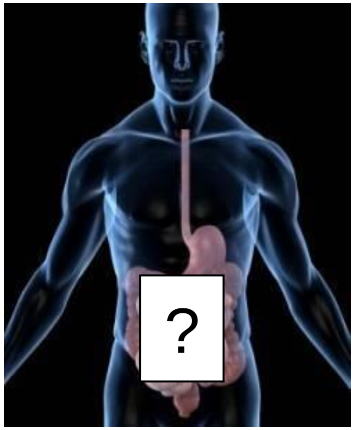
Dr Didier DUPONT, INRAE, STLO, Rennes, France

Food and human health: the key role of digestion



Diet-related diseases ↑

Prevent these pathologies rather than cure them



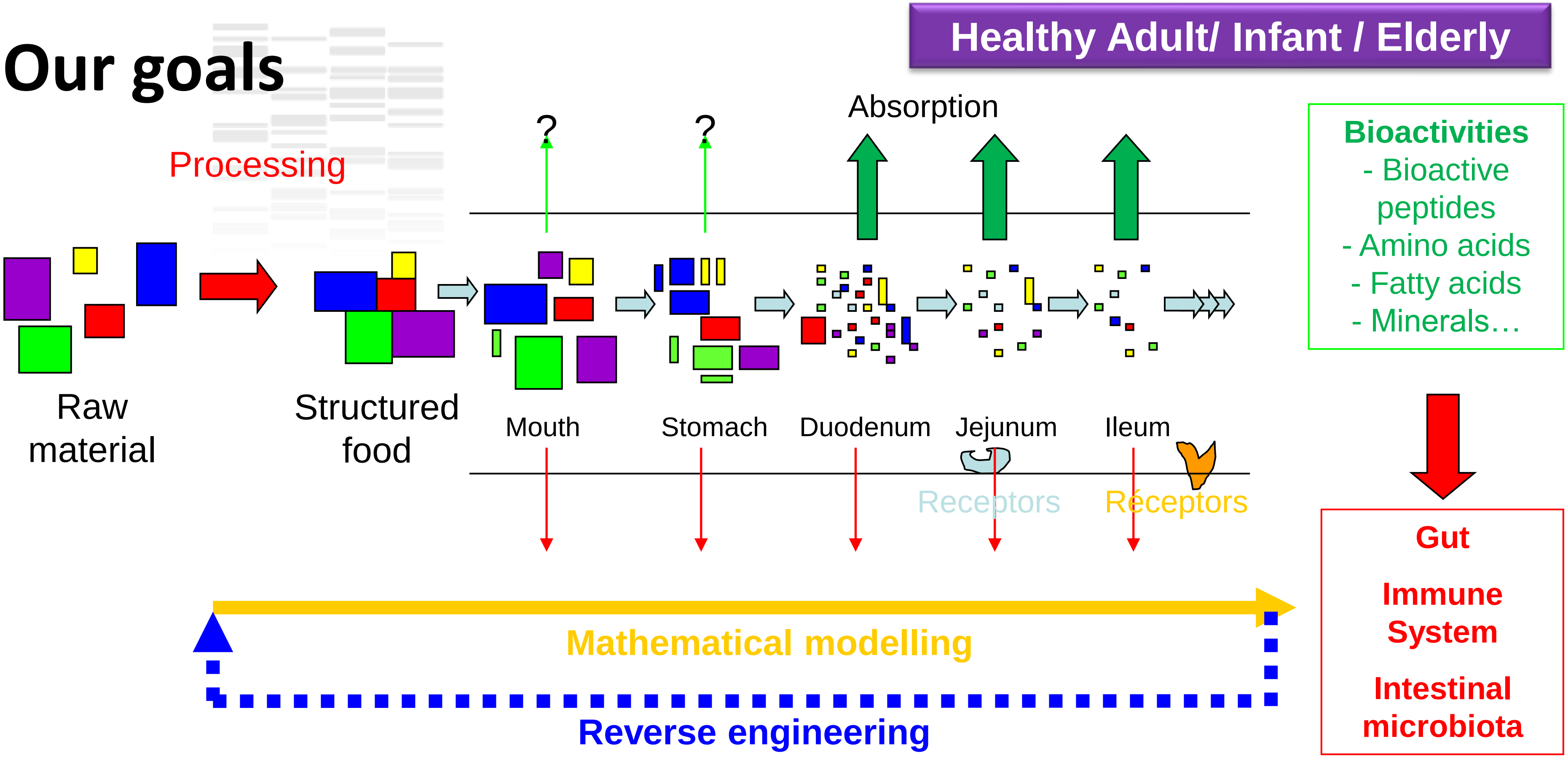
GI tract = interface between food and human body

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

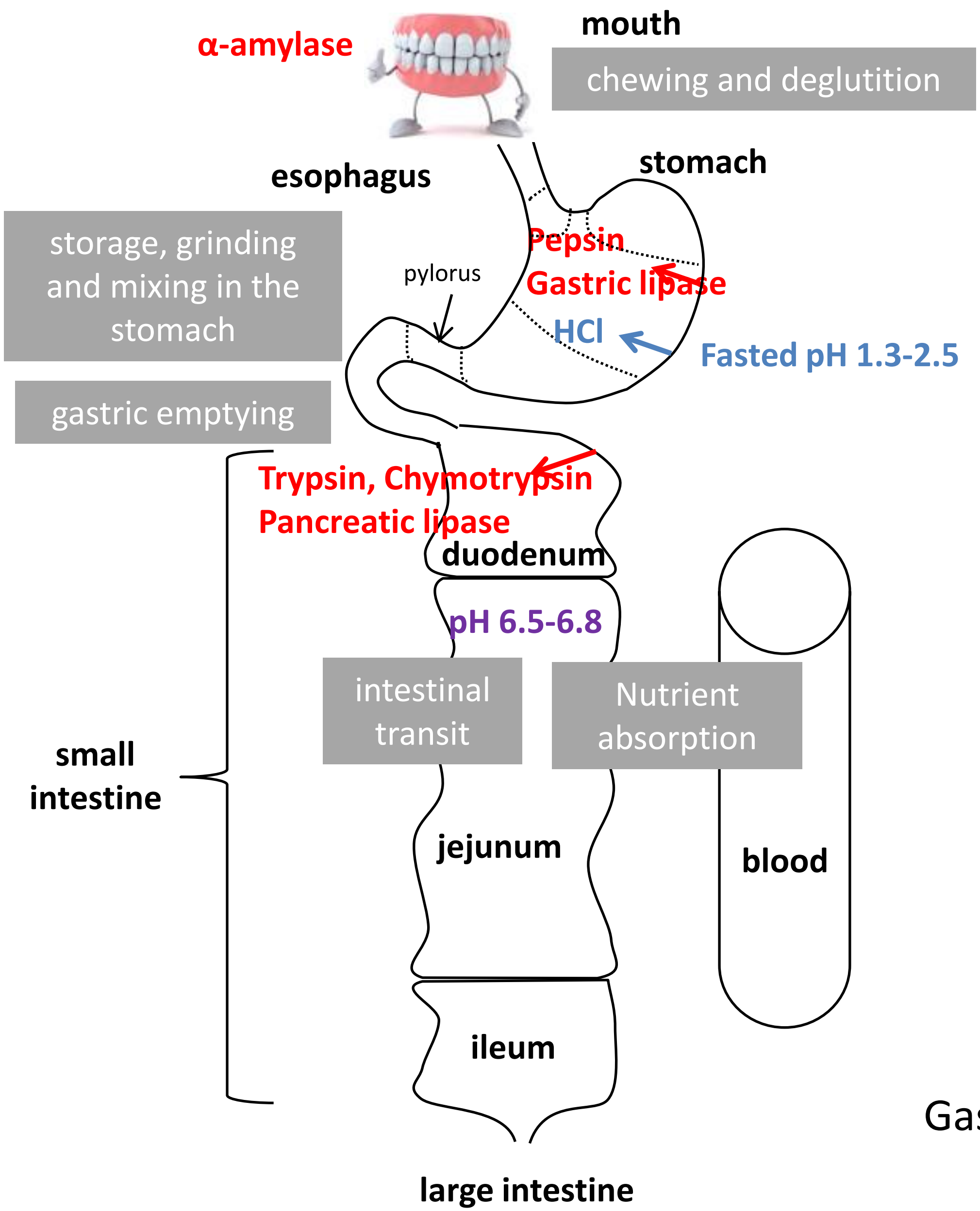


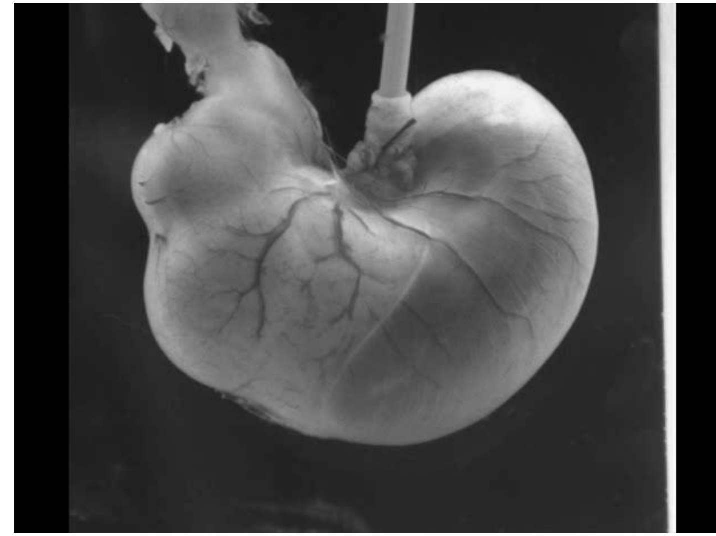
☞To understand the mechanisms of breakdown of food matrices and their constituents in the gut and identify the beneficial/deleterious food components released during digestion

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

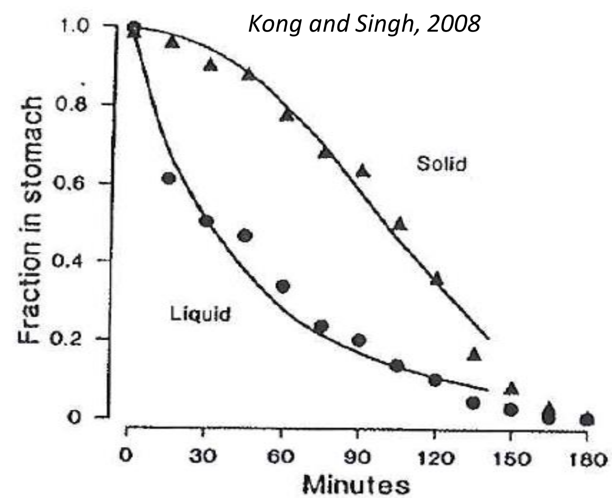
☞To model these phenomena in order to develop a reverse engineering approach

The digestive process





From Roger Lentle, Massey Univ. NZ



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

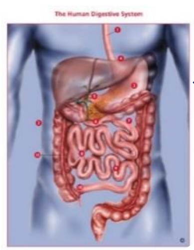
Models available at INRAE for simulating digestion

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

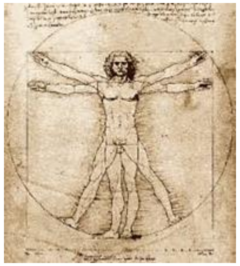
In vitro dynamic models
(infant, adult, elderly)



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

Animal models

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

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

STLO

NERDT™ : the NEar Real Digestive Tract

Xiao Dong Pro-Health
Smart Digestion
Suzhou University

SOOCHOW UNIVERSITY
UNTO A FULL GROWN MAN

INRAE

L'INSTITUT agro Rennes Angers

INSTITUT CARNOT QUALIMENT

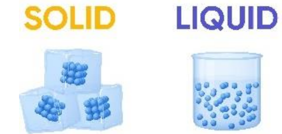
Food structure as modified by processing affects the kinetics of food digestion

SCIENCE & IMPACT

Dupont D.

INRAE, Rennes, France

Comparison of 6 dairy products of identical composition but different structure



Macroscopic scale

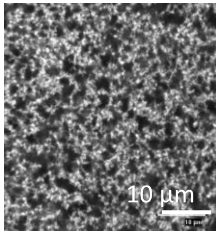
Ultra Low Heat powder

rehydration in water 14.5%

unheated milk ("raw" milk)

macrostructure

24h-20°C, rennet 0.003 % v/w → rennet gel



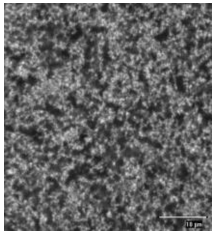
pH 6.6

heat treatment 90°C-10 min

microstructure

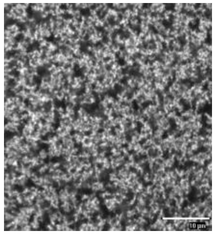
heated milk

24h-20°C, rennet 0.3 % v/w → rennet gel



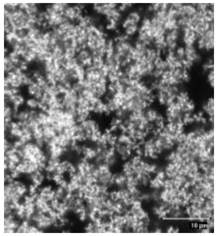
pH 6.6

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:

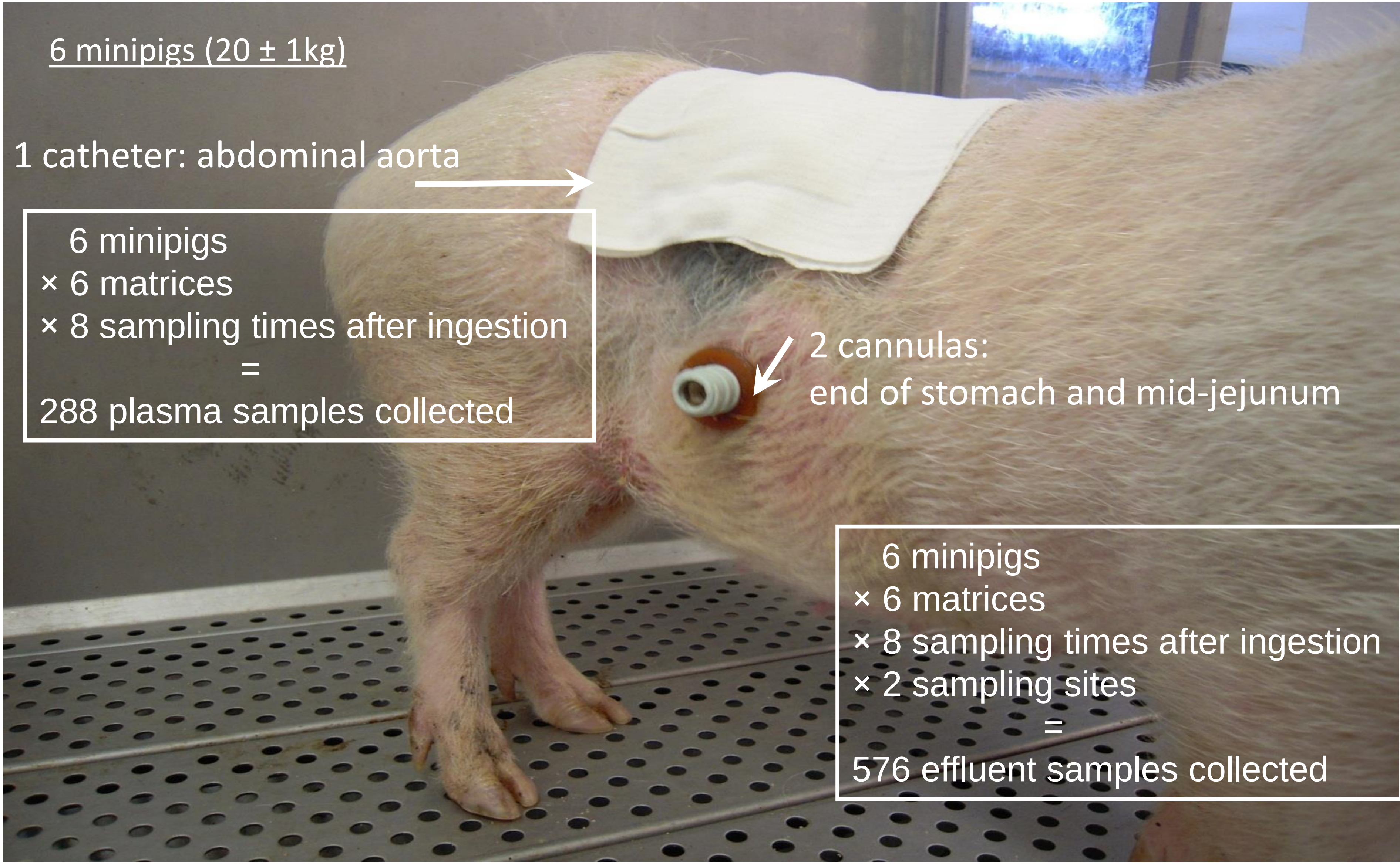
40 g/L caseins, 10 g/L whey proteins,
95 g/L lactose and minerals

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

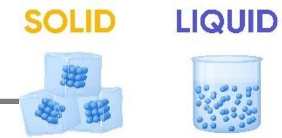
The multi-canulated mini-pigs

SOLID LIQUID

Macroscopic scale



Gastric emptying half time



Macroscopic scale

Ultra Low Heat powder

unheated milk ("raw" milk)

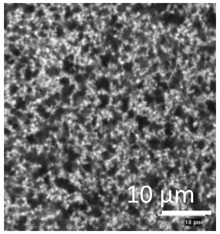
96 min

heated milk

96 min

? min

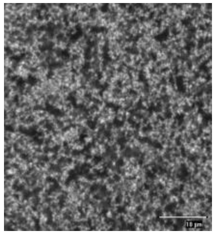
rennet gel



pH 6.6

352 min

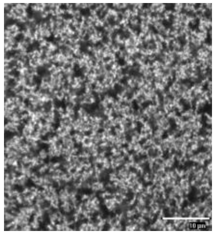
rennet gel



pH 6.6

148 min

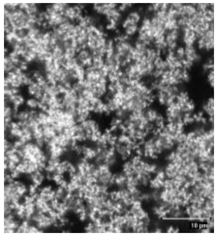
acid gel



pH 4

stirred acid gel

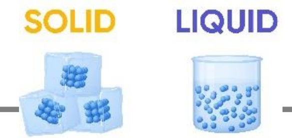
124 min



pH 4

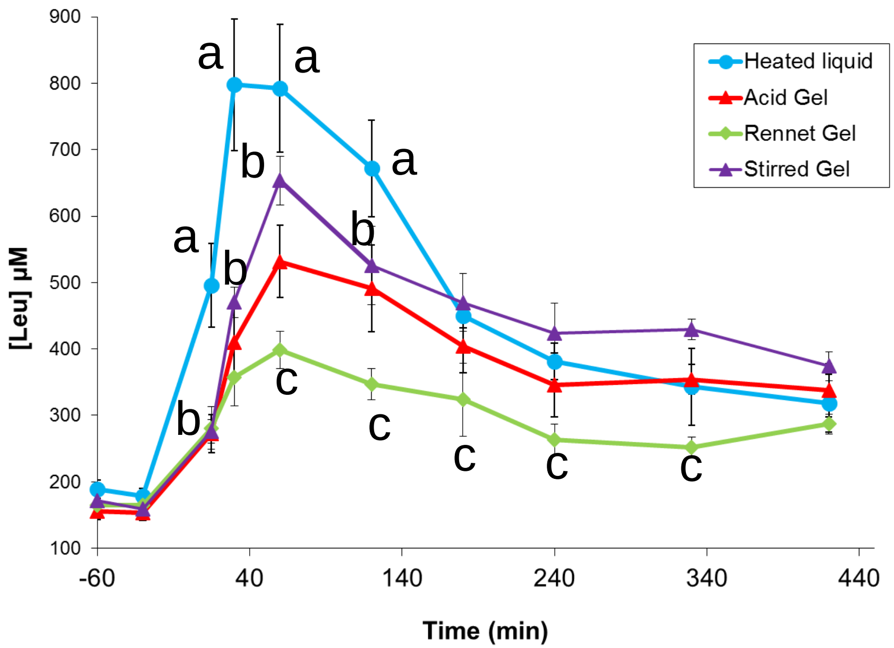
The liquid-gel transition

Barbé *et al.* Food Chem 2013



Macroscopic scale

Effect on absorption



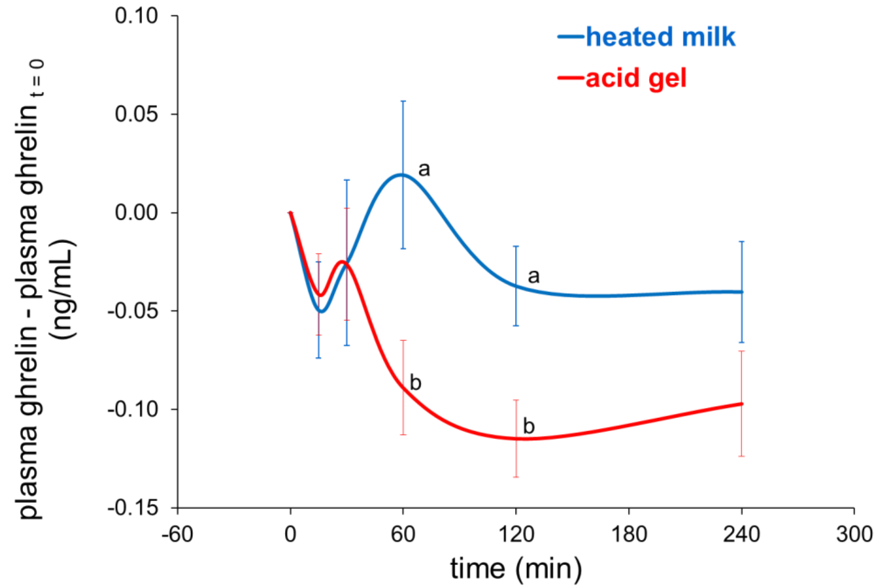
milk gelation:

→ delayed proteins transit → delayed AA absorption

↘ maximal AA concentration in the plasma

Potential effect on satiety

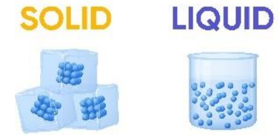
ghrelin (gastrointestinal hormone → appetite stimulation)



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

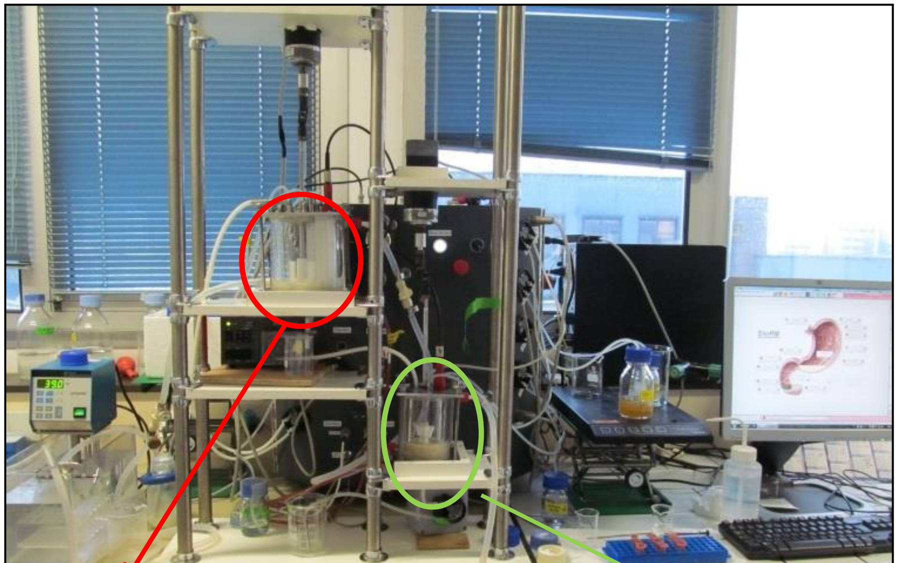
- More bioactive peptides identified during digestion of acid gel than rennet gel
- Nature of peptides is identical (clearly defined by the digestive enzyme specificity)
- Kinetics of release are different

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

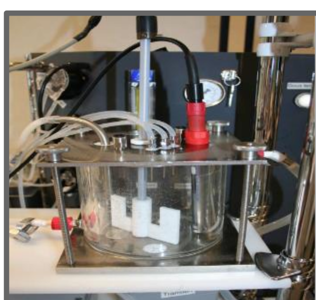


DIDGI®

StoRM® software

Stomach

- Pepsine
- Gastric lipase
- Simulated gastric fluid
- HCl



Emptying : Elashoff's model

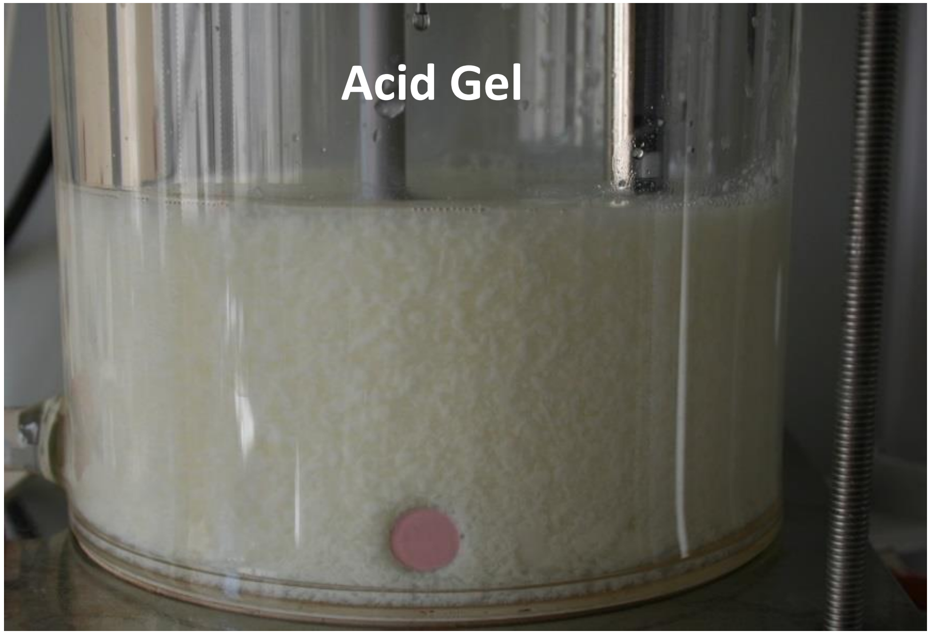
Small intestine

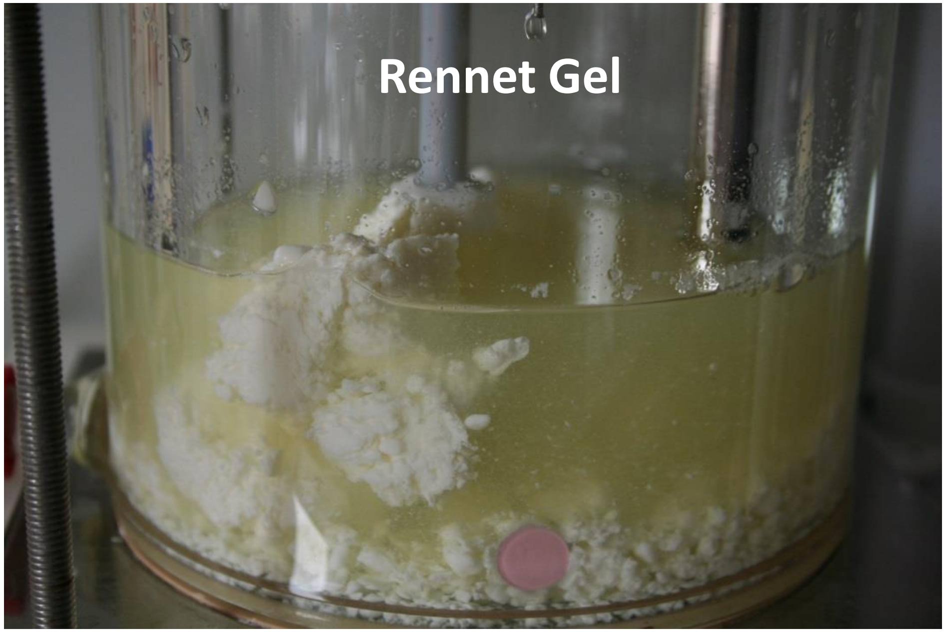
- Pancreatin
- Bile
- Simulated intestinal fluid
- $NaHCO_3$

Emptying : Elashoff's model

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

Barbé et al.
Food Chem. 2014

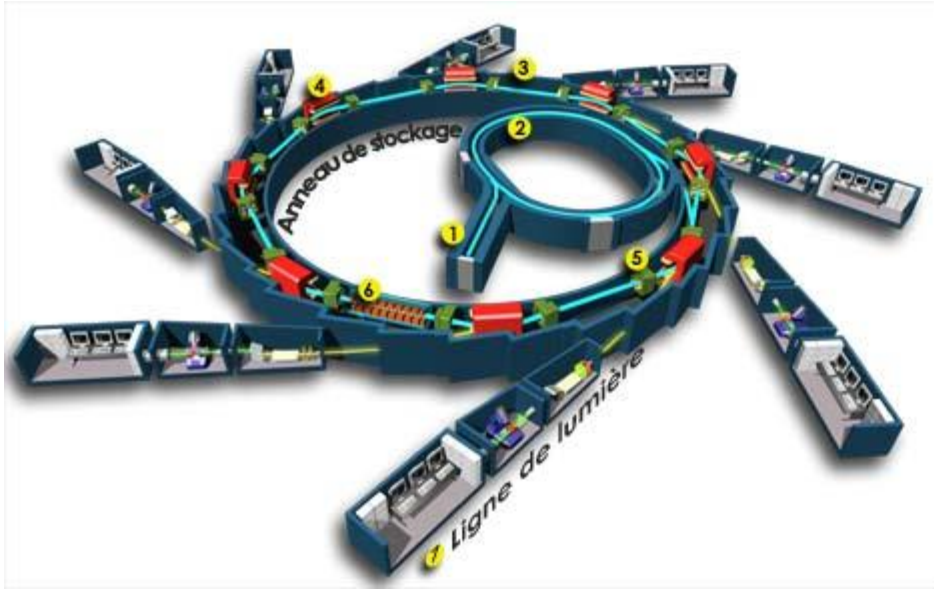




Formation of a strong coagulum with rennet gel → slow down the gastric emptying of caseins

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

SOLEIL SYNCHROTRON



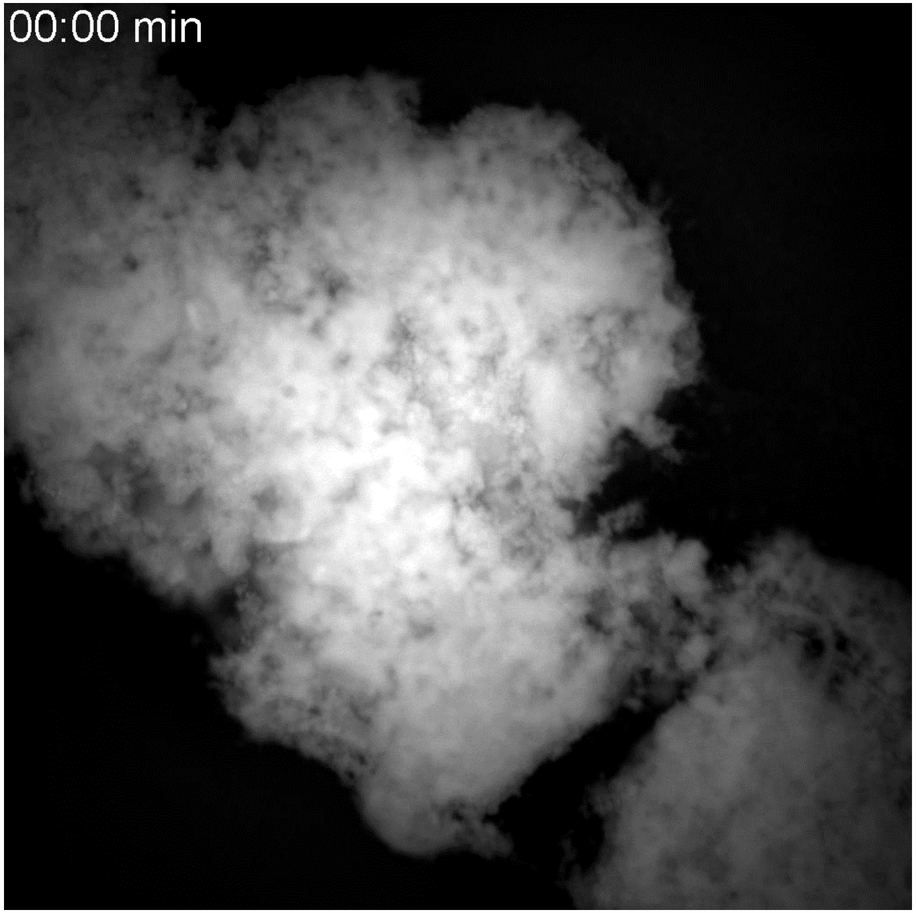
Soleil is a particle (electron) accelerator that produces the synchrotron radiation, an extremely powerful source of light that permits exploration of inert or living matter

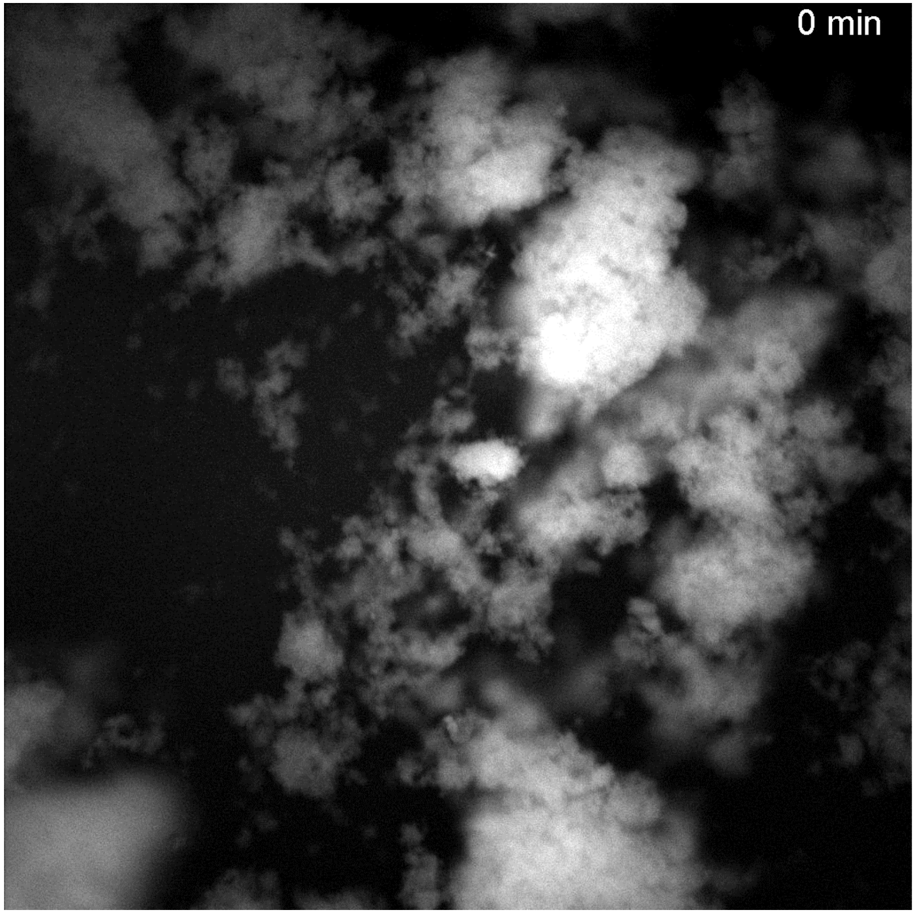
DISCO

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

Development of whey-based cheese for helping elderly people to fight against sarcopenia

Anais Lavoisier, Olivia Menard, Stefano Nebbia, Martine Morzel, Didier Dupont

Science & Technology of Milk & Eggs (STLO)
Rennes, FRANCE

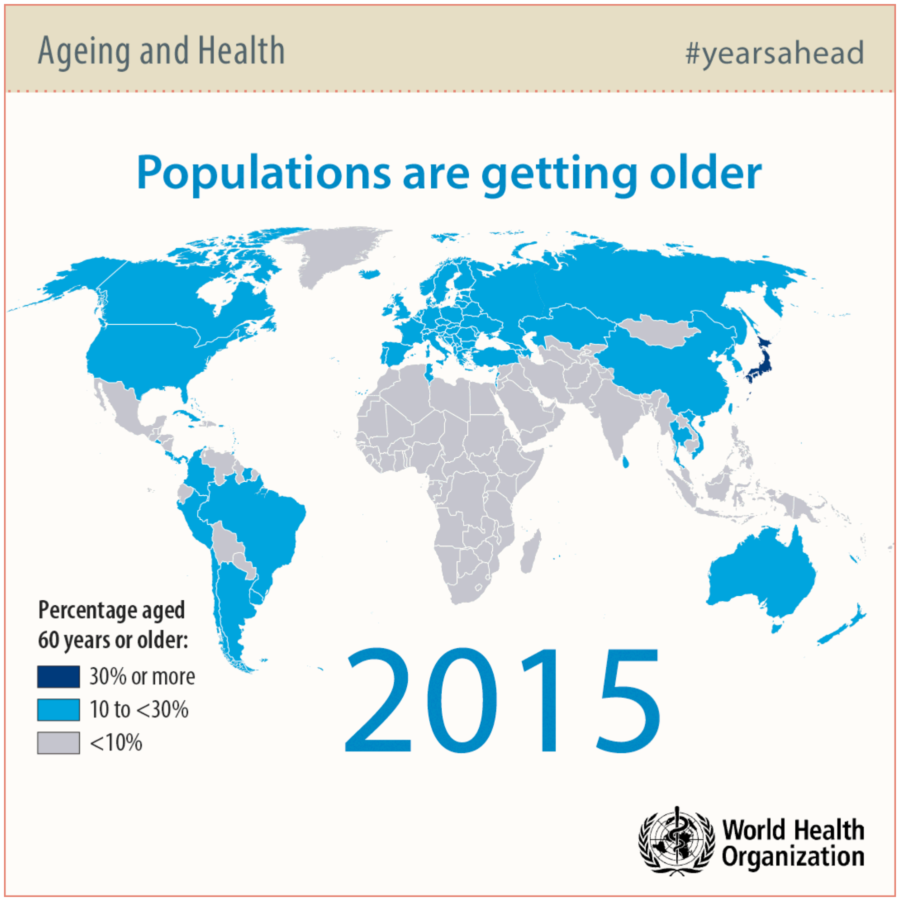
EAT4AGE

AGEING = a world problem…

The EU population over 65

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

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



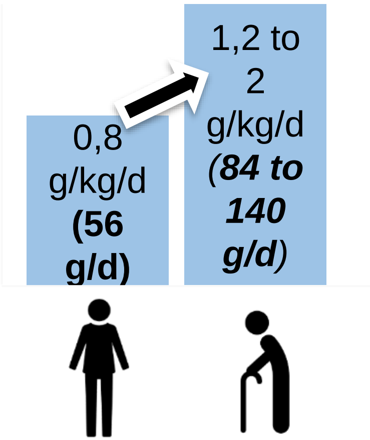
Challenge : healthy ageing

=

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

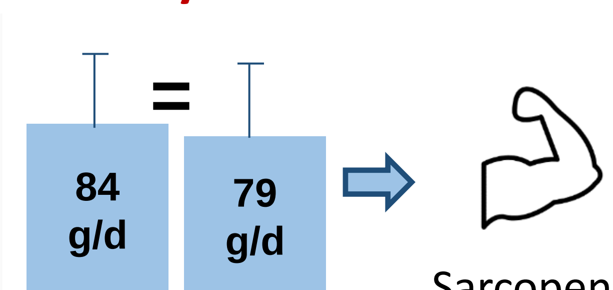
The nutritional needs of elderly people

Proteins



(Baum et al. 2017)

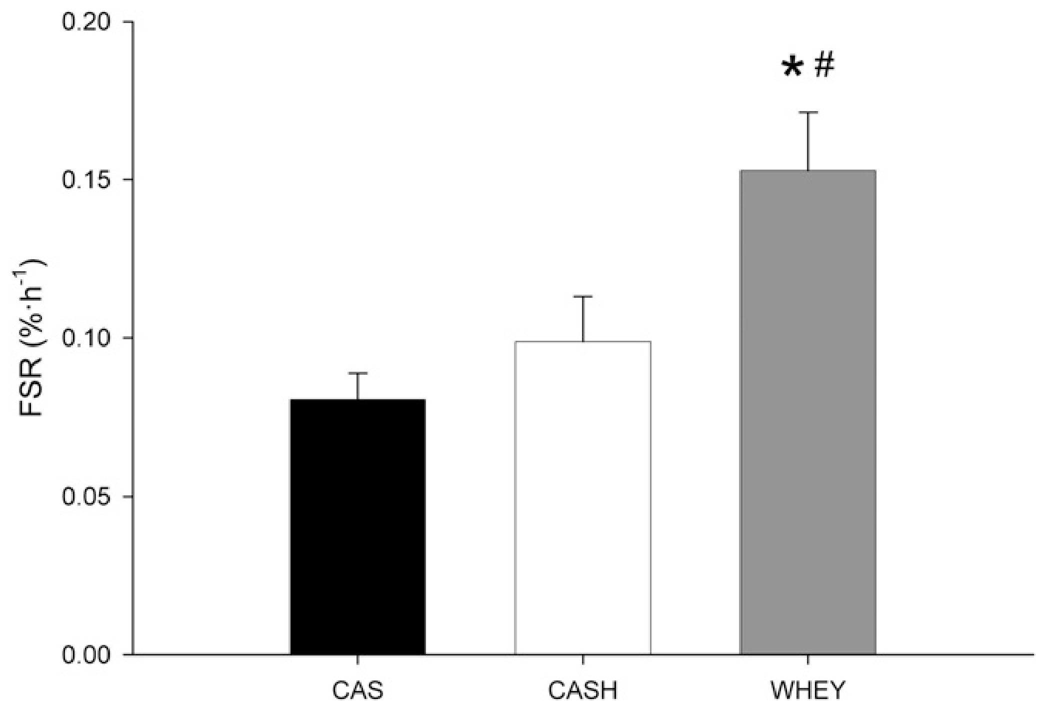
Mean daily intake



Sarcopenia

(INCA 3, 2017)

FSR= protein fractional synthesis rate

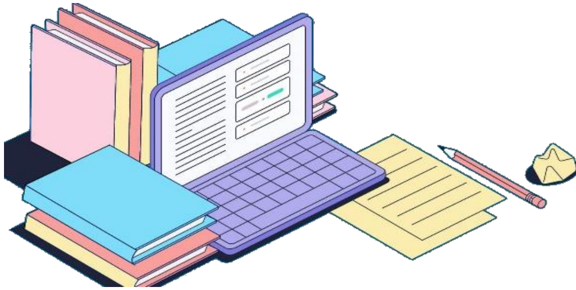


Pennings et al. 2013

Objectives of the EAT_4AGE project

Ageing leads to a decrease in the oro-gastrointestinal capacities (Rémond *et al*. 2015)
In vitro models simulating the altered conditions in the GI tract are needed to study food digestion in elderly

1. Exhaustive literature review



Oro-gastrointestinal tract physiological parameters

Healthy older adults ≤ 65 y.

In vivo data

2. Consensus static *in vitro* digestion model

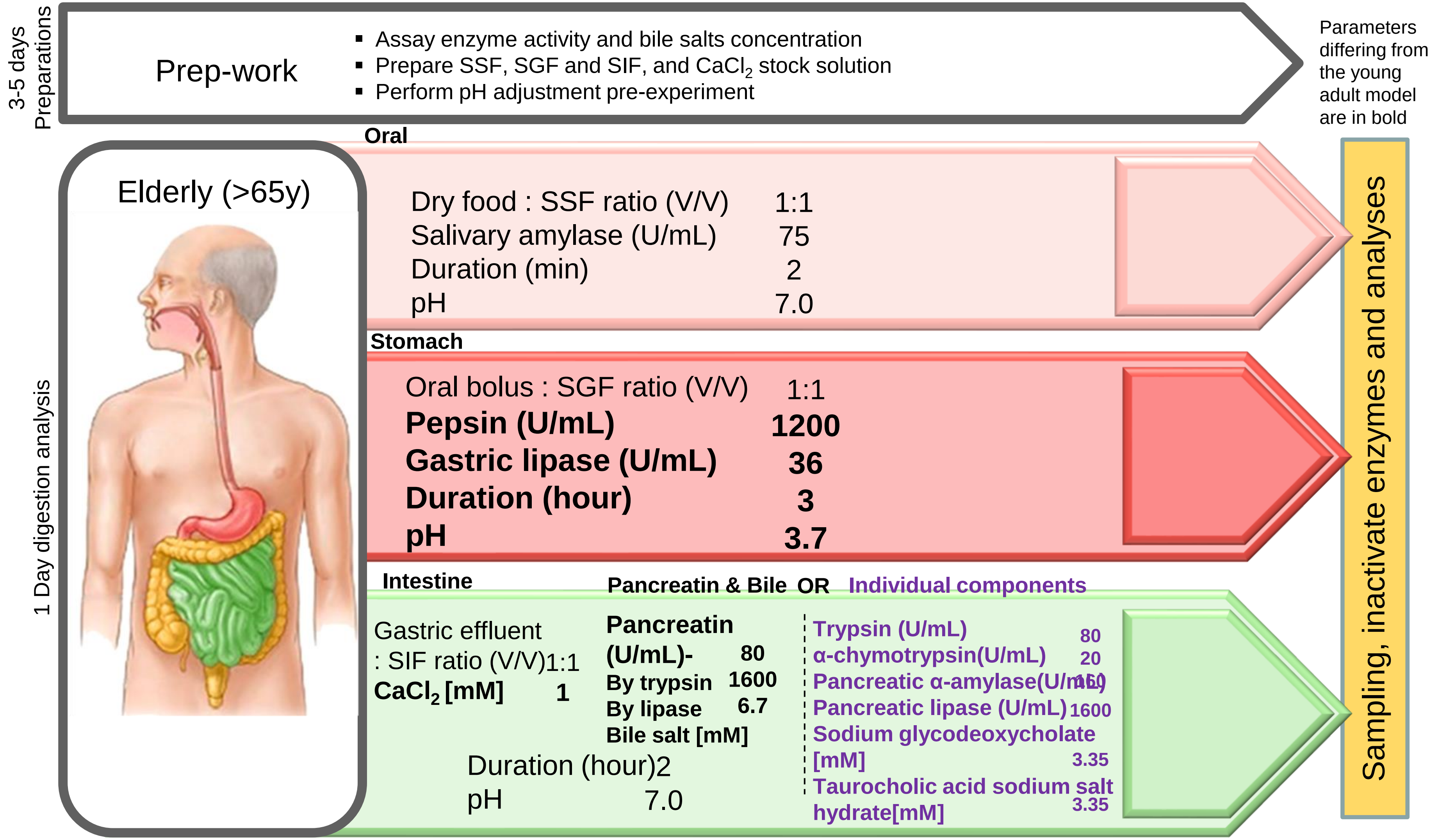
Adaptation of the INFOGEST 2.0 digestion method

Brodkorb et al. *INFOGEST static in vitro simulation of gastrointestinal food digestion.* Nat Protoc 14, 991–1014 (2019)

EAT4AGE consortium & International workshop

WP 3: *In vitro* digestibility and nutrient bioaccessibility of age-tailored food products

Overview of the *in vitro* digestion model for adults over 65



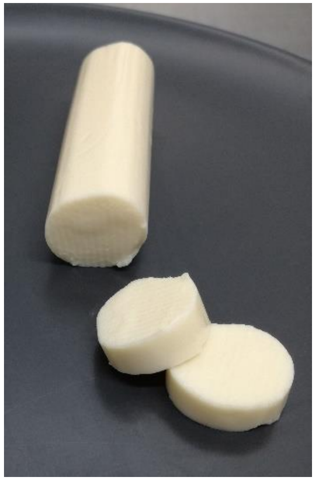
From the journal:
Food & Function

Menard et al. 2023, Food & Function, Highly Cited Paper

Cream cheese

Whey-based cheese

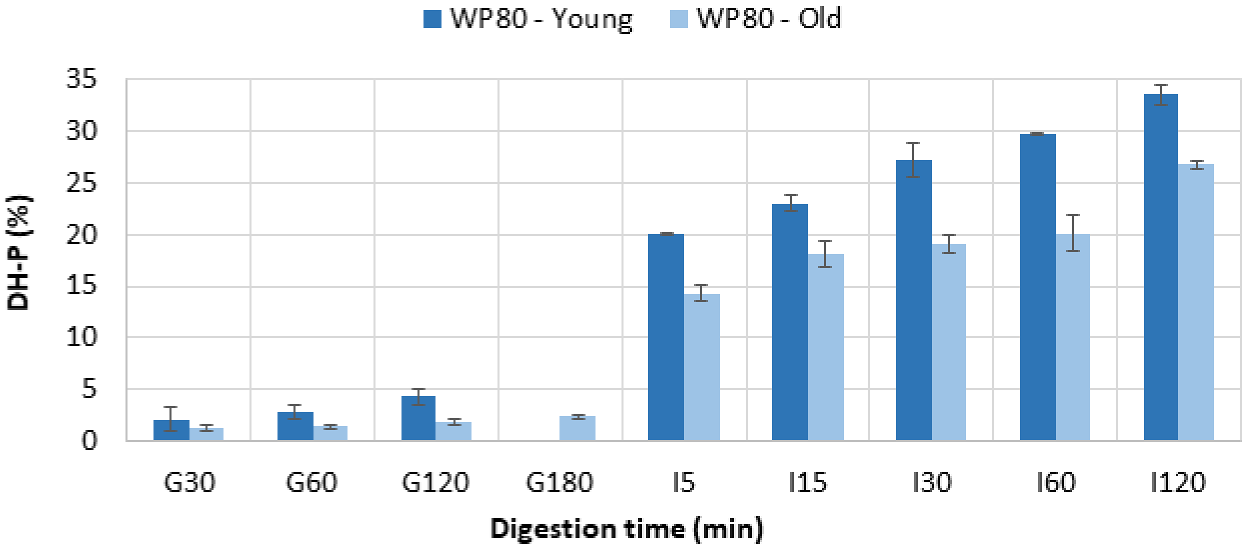
- Liquid emulsion: 24 % proteins, 20 % lipids, 0.6 % NaCl, 0.5% $CaCO_3$
- 80% whey proteins + 20% casein
- Heat treatment at 70°C for 35 min
- Emmental-cheese flavoured
- Texture: spreadable
- Corresponds to **≈ 0.93 g of leucine** /serving (= 30 g of cheese), ≈ 37 % of the recommendations /meal for the elderly



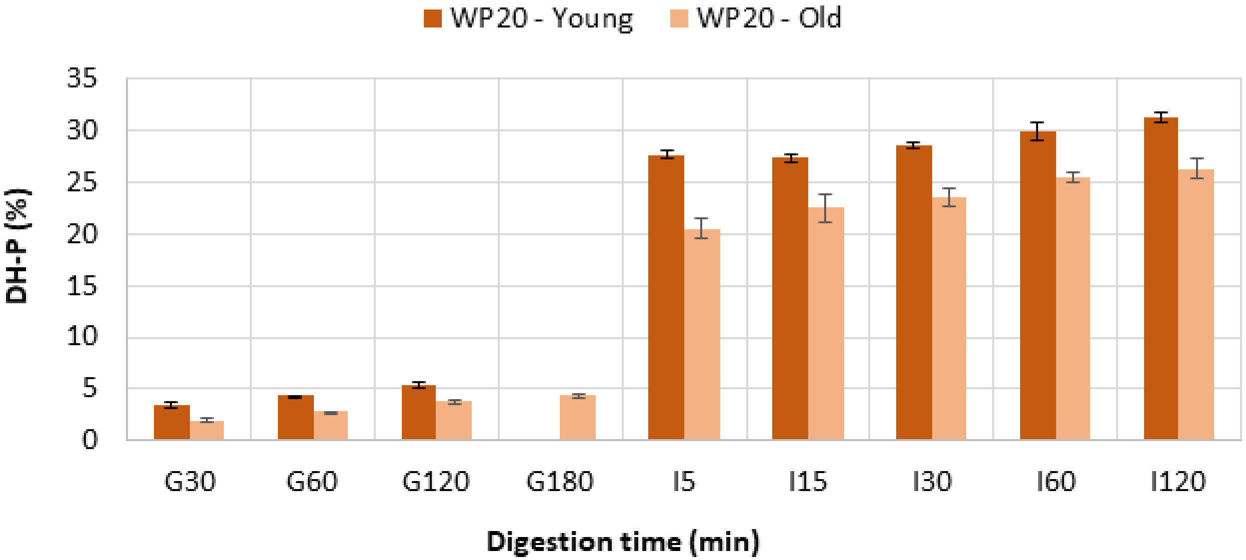
Control Casein-based cheese

- Liquid emulsion: 24 % proteins, 20 % lipids, 0.6 % NaCl, emulsifying salts
- 80% casein + 20% whey proteins
- Emmental-cheese flavoured
- Texture: spreadable
- Corresponds to **≈ 0.70 g of leucine** /serving (= 30 g of cheese), ≈ 28 % of the recommendations /meal for the elderly

Ageing results in a slower digestion of cheese proteins



Lavoisier *et* al.
Food Res Int. 2014



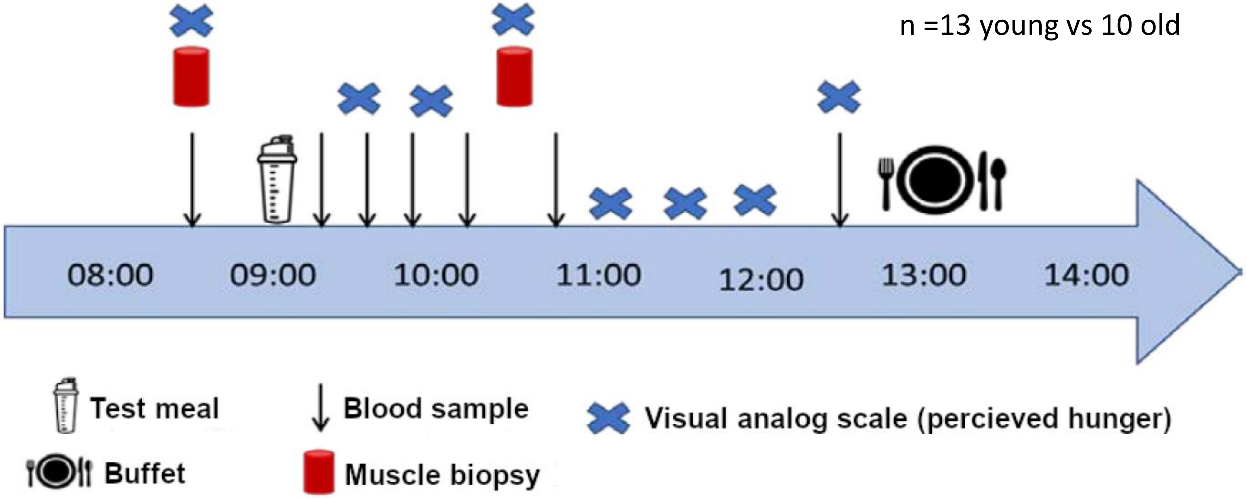
Clinical study to assess aminoacidemia and acute anabolic response in young and old adults after cheese consumption

- Control spreadable cheese: 80% casein + 20% whey proteins
- Modified spreadable cheese has switched the ratio of whey and casein (Whey 80%, casein 20%)
- Portion size: 45 g

	Portion size	Protein	CHO	Fat	Energy	
Modified	45	10,8	2,7	9	135	kcal
Control	45	10,8	2,7	9	135	kcal

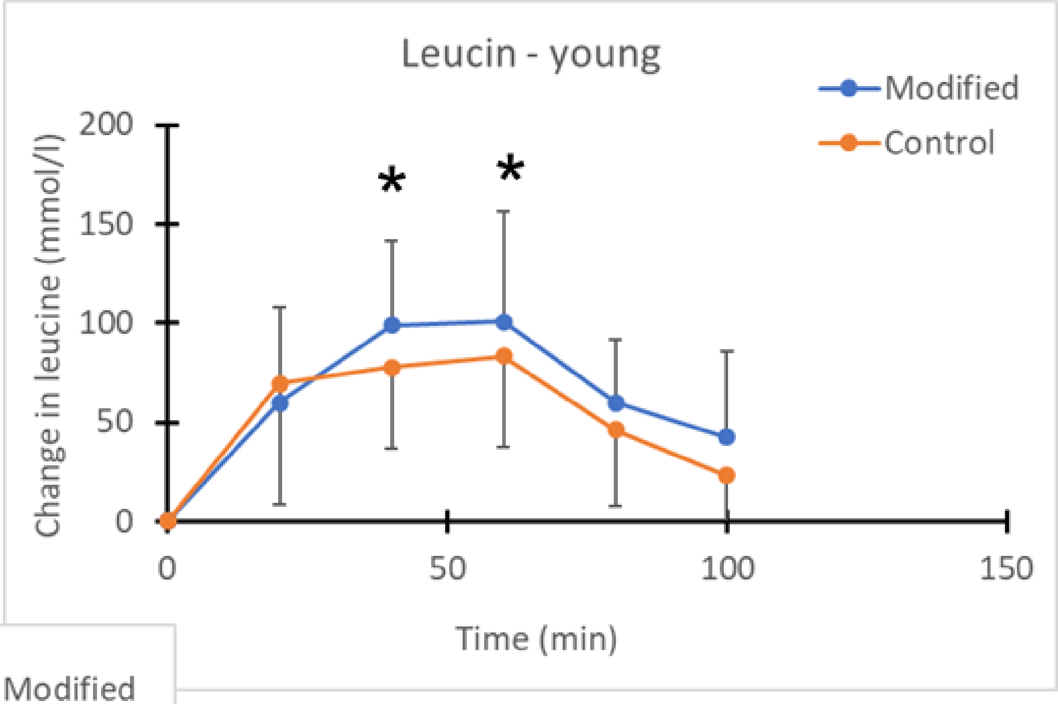
- Served on melba toast (23 g)

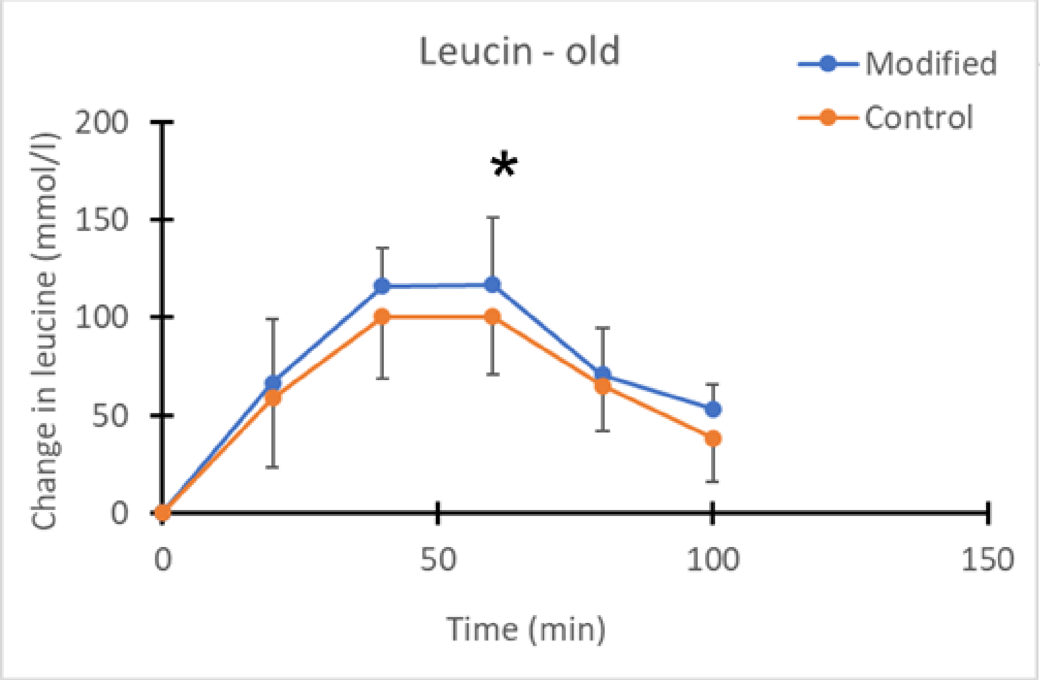
n =13 young vs 10 old



Whey-based vs. Casein-based cheese – Plasma [leucine]

By courtesy of
Pr Truls Raastad





* Limited effect on elderly people
* Data on the acute anabolic response released over the summer

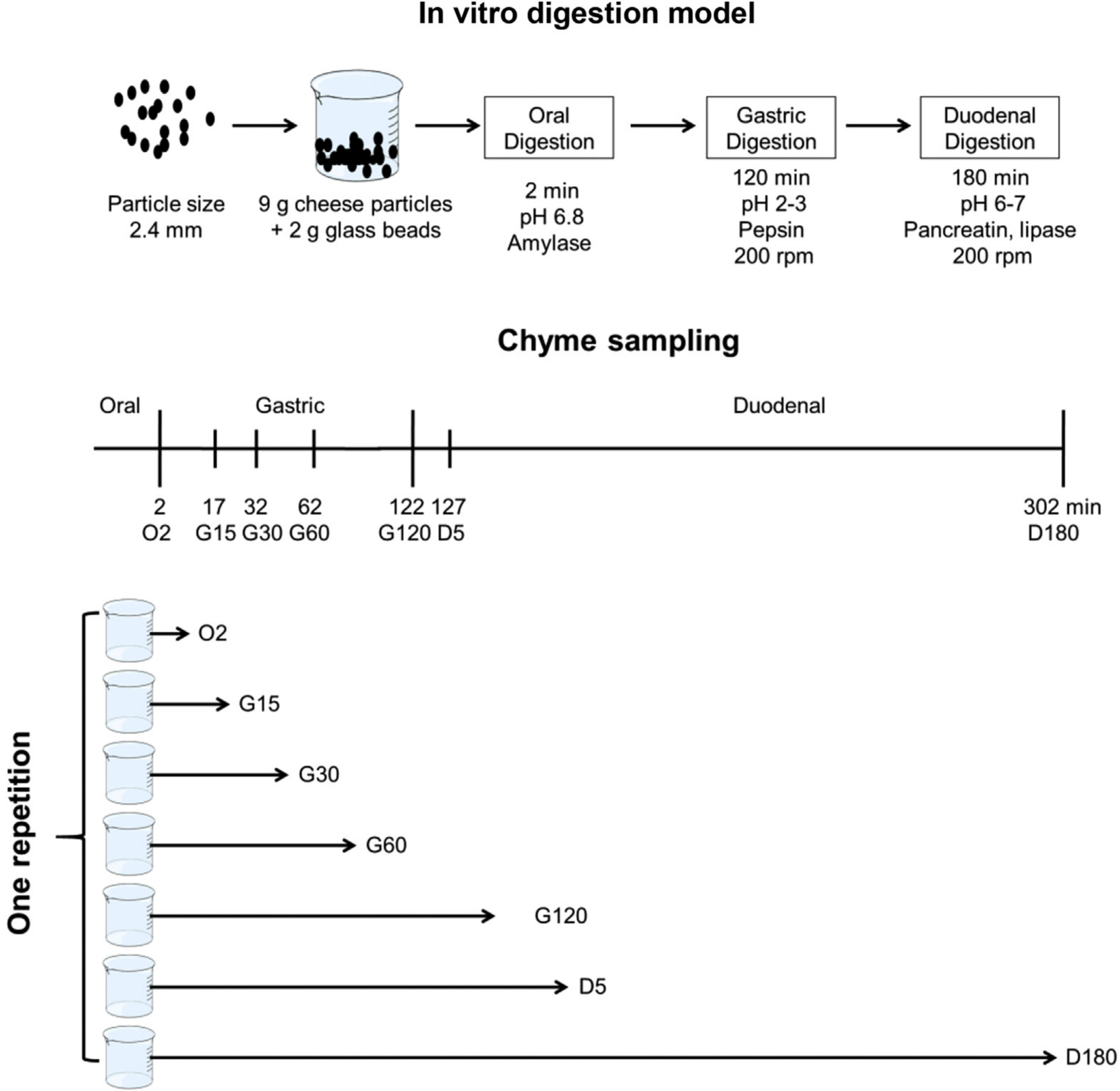
NORGES IDRETTSHØGSKOLE
NORWEGIAN SCHOOL OF SPORT SCIENCES

Does cheese texture affects its digestion?

Xixi Fang, Laurie-Eve Rioux, Steve Labrie, Sylvie L. Turgeon

STELA Dairy Research Centre, Institute of Nutrition and Functional Foods, Université Laval, Québec City, Qc, G1V 0A6, Canada

- Camembert
- Smear cheese
- Young Cheddar
- Aged Cheddar
- Mozzarella



Main findings of the study

Camembert showed a fast release of proteins/peptides in the gastric phase with a full hydrolysis in trhe stomach

Mozzarella exhibited a very slow digestion process with several proteins remaining intact at the end of the gastric phase

But all the cheese proteins were quickly hydrolyzed when entering the small intestine showing that cheese is a highly digestible food

Cheese disintegration at the end of gastric phase was higher when initial cheese hardness, cohesiveness, and chewiness were lower.

We have demonstrated that solid and elastic foods can limit the diffusion of acidic secretions and digestive enzymes in food particles (Nau et al. 2019, 2022).

Texture and composition of cheese are keys parameters that drive the digestion process

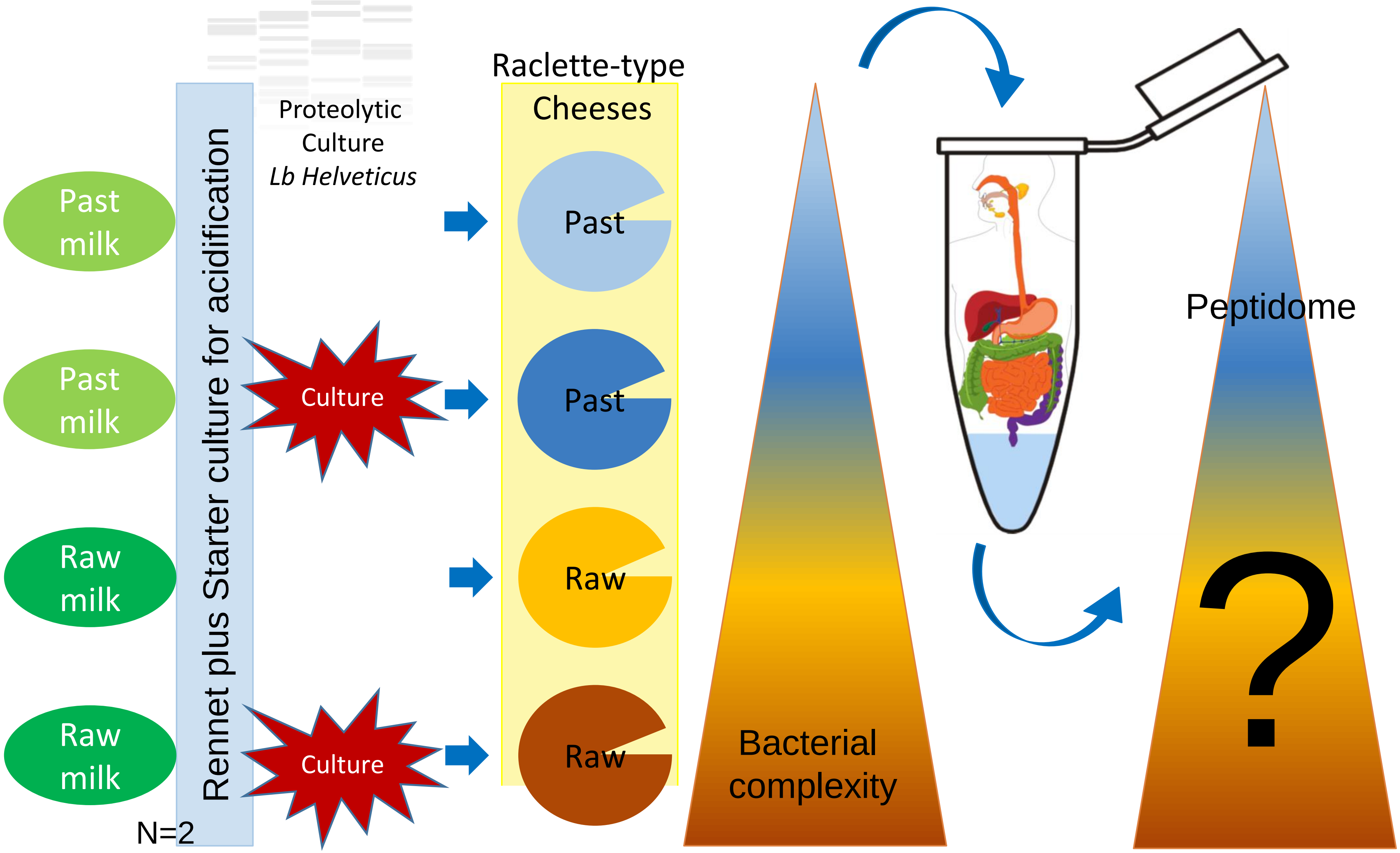
Does cheese microbiota has an impact on protein hydrolysis during digestion?

INRA SCIENCE & IMPACT

Egger L., Menard O., Portman R. & Dupont D.

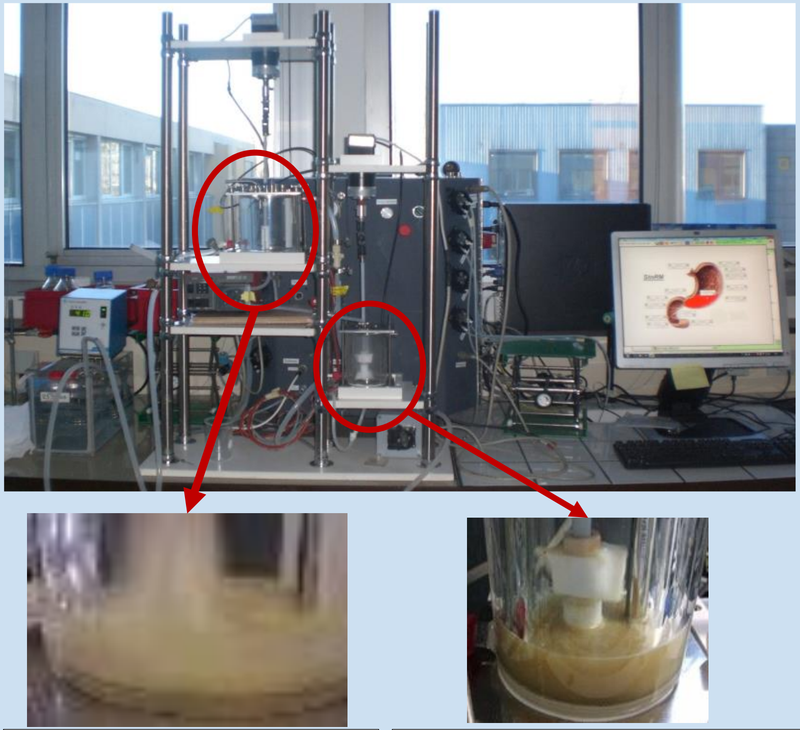
Agroscope, Bern, Switzerland
INRAE, Rennes, France

Experimental Setting



In vitro digestion methods

Dynamic (DIDGI®)



Gastric :

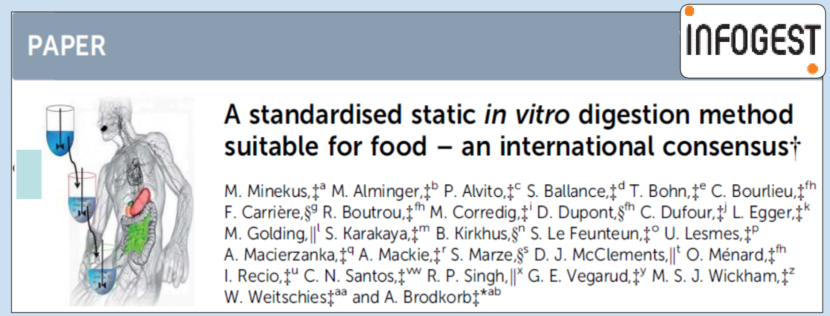
- Pepsin (2000U/ml) 0.5ml/min
- HCL 1M to acheive $pH=1.68+3.52^{(-t/42)}$
- Emptying $t_{1/2}$=85min β= 1.8
- duration: 150min

Intestinal digestion:

- Bile (2%) 0.5ml/min
- Pancreatin (7%) 0.25ml/min
- $NaHCO_3$ 1M to acheive pH=6.8
- Emptying $t_{1/2}$=250min β= 2.5
- duration: 240min

Kinetic digestions n=2, cheeses: 4 X 2

Static (INFOGEST)



PAPER

A standardised static *in vitro* digestion method suitable for food – an international consensus†

M. Minekus,‡[a] M. Alminger,‡[b] P. Alvito,‡[c] S. Ballance,‡[d] T. Bohn,‡[e] C. Bourlieu,‡[fh] F. Carrière,§[g] R. Boutrou,‡[fh] M. Corredig,‡[i] D. Dupont,§[fh] C. Dufour,‡[j] L. Egger,‡[k] M. Golding,||[l] S. Karakaya,‡[m] B. Kirkhus,§[n] S. Le Feunteun,‡[o] U. Lesmes,‡[p] A. Macierzanka,‡[q] A. Mackie,‡[r] S. Marze,§[s] D. J. McClements,||[t] O. Ménard,‡[fh] I. Recio,‡[u] C. N. Santos,‡[vw] R. P. Singh,||[x] G. E. Vegarud,‡[y] M. S. J. Wickham,‡[z] W. Weitschies‡[aa] and A. Brodkorb‡*[ab]

Gastric:

- Pepsin (2000U/ml)
- pH=3
- duration: 120min

Intestinal digestion:

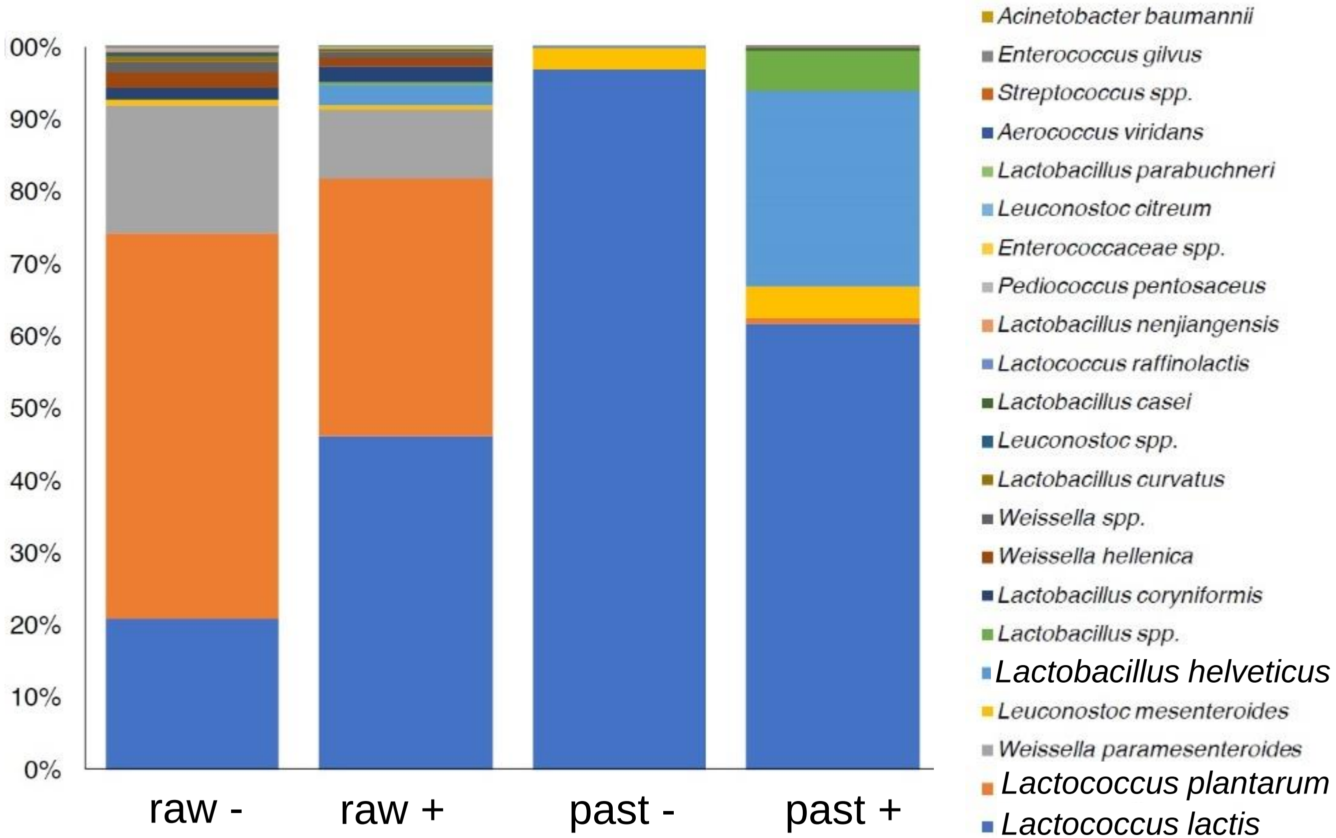
- Bile salts 10mM
- Pancreatin: to reacj100 U of trypsin/ml digesta
- pH=7
- duration: 120min

Kinetic digestion n=1, Endpoints n=3, cheeses: 4 X 2

Characterization of Cheeses

Microbial Diversity

Bacterial community based on 16S rRNA sequencing (v1v2) after 120 days of ripening:



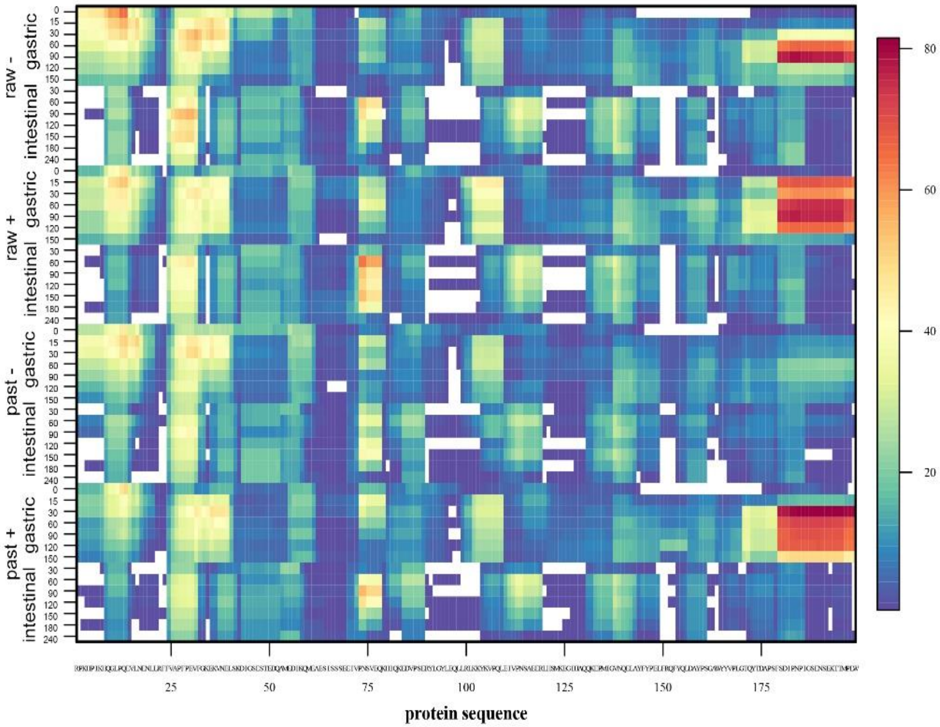
Composition

of four different (n=2) Swiss Raclette cheeses After 120 days of ripening:

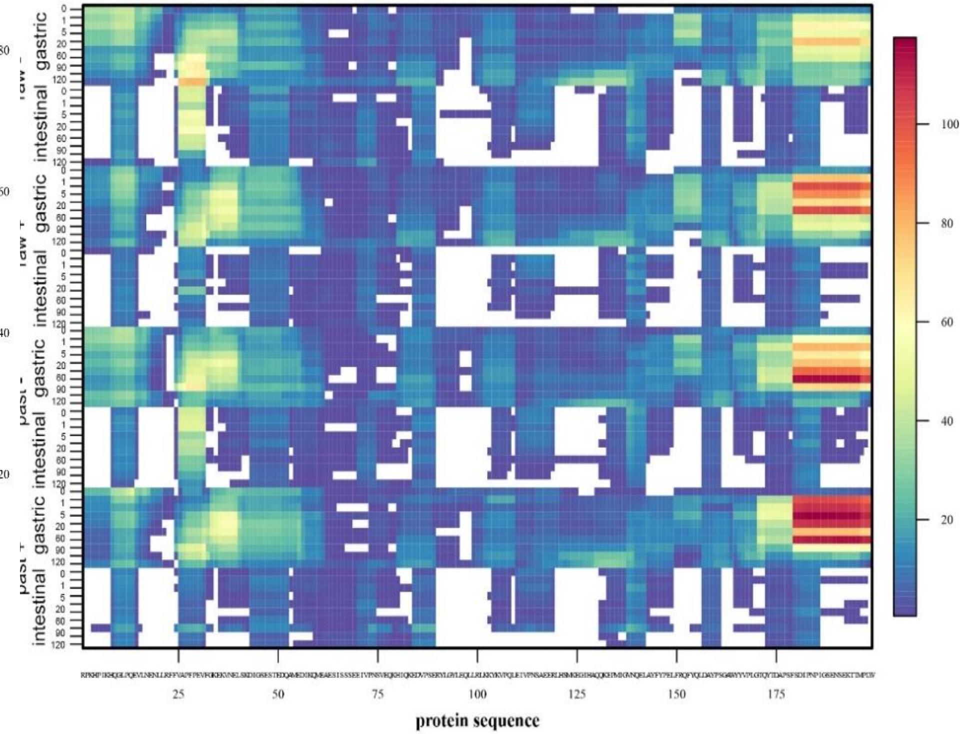
Cheese		sample	fat	NaCl	true protein	NPN	pH	Free NH_2
milk	LH		g/kg	g/kg	g/kg	g/kg		mmol/kg
raw	no	**raw -**	290.3	18.9	244.37	5.7	5.1	151.3
	yes	**raw +**	295.8	17.9	250.26	5.6	5.1	151.5
past	no	**past -**	284.8	21.0	247.41	5.7	5.1	143.2
	yes	**past +**	288.3	18.9	238.26	5.8	5.1	145.2

Peptide generation during IVD

α_{s1}-casein



Dynamic N=4



Static N=2

Gastric digestion:

- Higher number of peptides at the C-terminus of the cheese samples with the proteolytic strain (observed in all caseins)

Intestinal digestion:

- Differences have been wiped off by the action of intestinal proteases

Egger et al.
Food Chem. 2021

Bioactive Peptides

β-casein, dynamic digestion

Opioid[1]

Hypertension[2]

DPP-IV inibitory[3]

Peptide	Cheese 1 (raw -)	Cheese 3 (raw -)	Cheese 2 (raw +)	Cheese 4 (raw +)	Cheese 5 (past -)	Cheese 7 (past -)	Cheese 6 (past +)	Cheese 8 (past +)	raw / past
EELNVPGEI	2	2	1	0	0	0	0	0	0.04
LNVPGEI	1	1	0	0	0	0	0	0	0.13
NVPGEIVES	0	0	0	0	2	1	1	0	0.05
NVPGEIVESL	10	10	10	6	5	7	8	0	0.10
FQSEEQQQT	0	0	0	0	1	1	0	0	0.13
QTEDEL	1	1	0	3	4	6	3	1	0.11
TEDEL	18	18	20	13	11	15	11	11	0.03
TEDELQD	2	2	5	7	11	8	7	5	0.08
PFAQTQSLV	1	1	0	0	0	0	0	0	0.13
YPFPGPIPN	0	0	0	2	3	3	2	0	0.13
PFPGPIPN	5	5	5	4	1	0	3	1	0.00
PQNIPPLTQTP	1	1	0	0	0	0	0	0	0.13
PQNIPPL	1	1	0	0	0	0	0	0	0.13
NIPPL	11	11	8	5	7	7	6	3	0.13
NIPPLT	8	8	3	0	0	2	1	0	0.10
PPLTQT	0	0	0	0	0	1	0	1	0.13
PVVVPP	7	6	5	3	2	2	4	3	0.04
VVVPPFLQPEV	1	1	1	2	0	0	0	0	0.00
PPFLQPE	7	7	9	13	14	16	14	18	0.01
PFLQPEV	0	0	0	2	2	4	3	4	0.01
SLTLTDVENLHLPLPLLQSWMHQPHQPLP	1	1	1	0	0	0	0	0	0.02
HLPLP	0	0	0	0	2	0	0	3	0.15
LLQSWMHQPHQPLPPT	2	2	1	0	1	0	0	0	0.11
MHQPHQPLPPT	30	30	31	18	22	15	9	1	0.03
QPHQPLPPT	0	0	0	1	3	2	3	0	0.06
FPPQSV	14	14	13	21	12	10	7	13	0.07
SVLSLSQSKVLPVPQKAVPY	1	1	0	0	0	0	0	0	0.13
LPVPQ	7	7	8	5	5	4	6	6	0.11
MFPPQ	2	2	3	2	1	2	1	1	0.03
MFPPQS	4	4	2	2	1	0	0	0	0.00
AVPYPQ	5	5	5	5	0	0	0	5	0.02

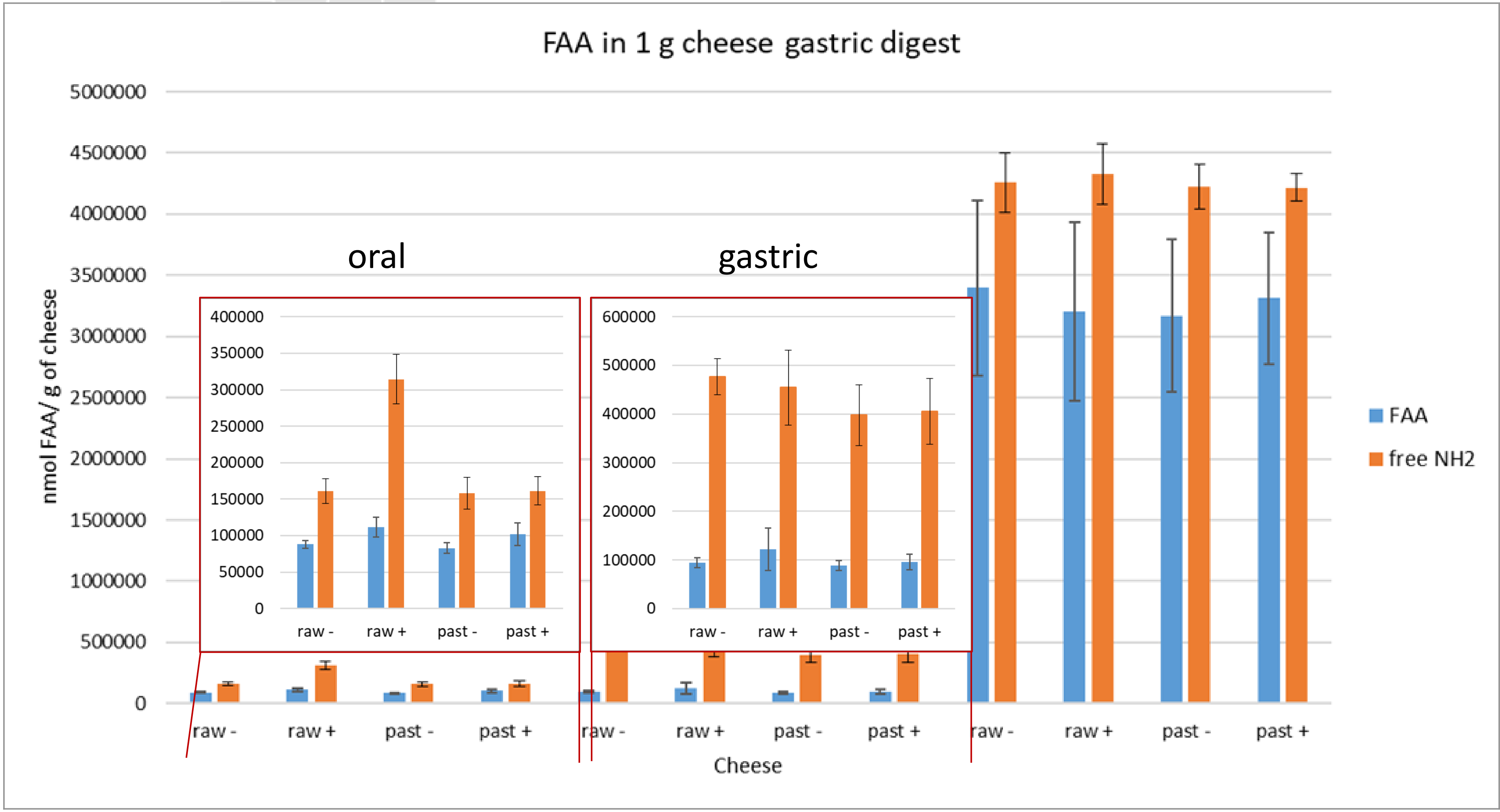
Peptide	Cheese 1 (minus culture)	Cheese 3 (minus culture)	Cheese 5 (minus culture)	Cheese 7 (minus culture)	Cheese 2 (plus culture)	Cheese 4 (plus culture)	Cheese 6 (plus culture)	Cheese 8 (plus culture)	culture +/-
YPVEP	3	3	2	4	0	1	3	2	0.10
TLTDVEN	4	4	4	3	4	1	3	1	0.11
LHLPLP	0	0	1	0	1	2	0	3	0.12
LLQSWMHQPHQPLPPT	2	2	1	0	1	0	0	0	0.11
SVLSLSQSKVLPVPQKAVPY	1	1	0	0	0	0	0	0	0.13
RDMPI	0	0	0	0	1	0	0	1	0.13
QEPVLGPV	0	0	3	2	4	2	3	3	0.09
LNVPGEIVESL	3	3	2	2	2	0	1	0	0.02
LNVPGEI	1	1	0	0	0	0	0	0	0.13
PVLGPV	3	3	5	4	8	5	3	6	0.18
FQSEEQQQT	0	0	1	1	0	0	0	0	0.13
DELQDKI	1	1	0	2	0	0	0	0	0.05
PFAQTQSLV	1	1	0	0	0	0	0	0	0.13
VYPFPGPIPN	11	11	10	10	8	9	8	0	0.09
VYPFPGPI	9	9	9	7	93	11	16	27	0.19
PFPGPI	16	16	12	14	13	10	10	11	0.03
LPQNIPPL	9	9	6	5	2	2	7	2	0.05
PQNIPPLTQTP	1	1	0	0	0	0	0	0	0.13
PQNIPPL	1	1	0	0	0	0	0	0	0.13
NIPPL	11	11	7	7	8	5	6	3	0.07
NIPPLT	8	8	0	2	3	0	1	0	0.16
TQTPVVVPPFLQPEV	0	0	1	0	1	3	0	1	0.19
TQTPV	3	3	2	1	1	2	2	0	0.19
TPVVVPP	2	2	2	0	0	0	0	0	0.02

Tendency: ↗ Bioactive Peptides

- raw milk
- without proteolytic culture

[1]Nongonierma, 2015; [2]Aluko, 2015, [3]Nongonierma, 2016

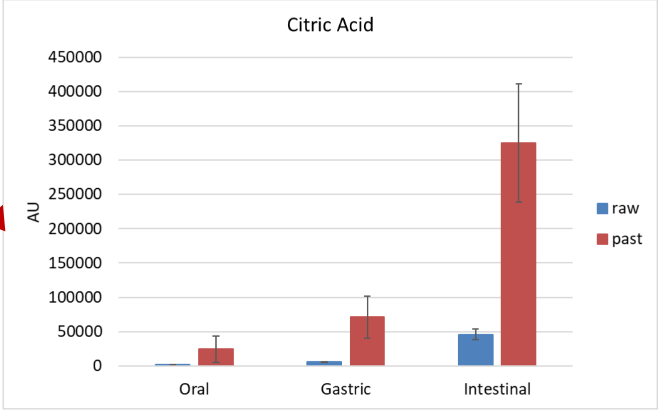
Release of free amino acids

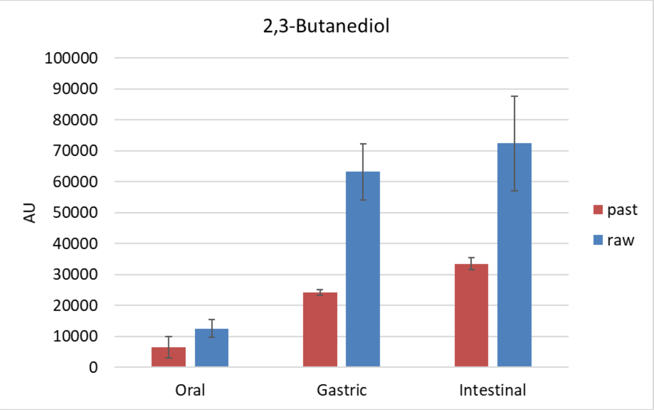


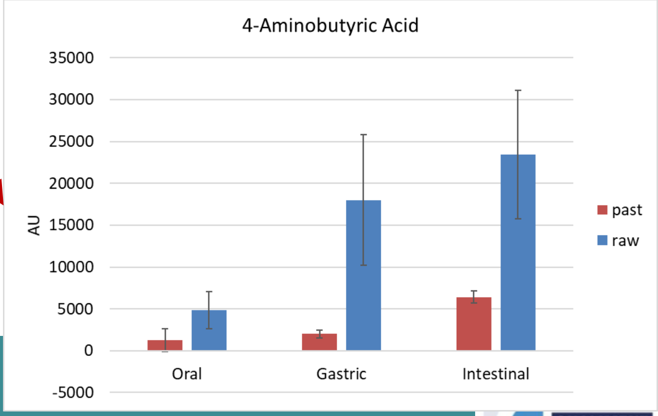
→ Some differences between cheeses are visible in the oral or gastric phase but are wiped off after the intestinal phase

Metabolome

		Gastric		Intestinal	
	Name	t-Test	Kruskal-Wallis	t-Test	Kruskal-Wallis
Increased in Past milk Cheese	L-Serine	0.007	0.003	0.748	0.753
	Glyceric acid	0.000	0.001	0.077	0.115
	L-Serine	0.000	0.001	0.021	0.016
	Malic acid	0.000	0.001	0.158	0.172
	L-Serine	0.000	0.001	0.085	0.093
	L-Arabitol	0.000	0.001	0.472	0.016
	L-Glutamine	0.001	0.003	0.749	0.753
	Citric acid	0.001	0.001	0.000	0.001
	D-Tagatose	0.000	0.001	0.000	0.002
	D-Tagatose	0.000	0.001	0.829	0.401
Increased in Raw milk Cheese	2,3-Butanediol	0.000	0.001	0.000	0.001
	2,3-Butanediol	0.000	0.001	0.000	0.001
	2-Hydroxybutyric acid	0.000	0.001	0.022	0.016
	L-Isoleucine	0.017	0.027	0.065	0.036
	Succinic acid	0.000	0.001	0.000	0.001
	L-Aspartic acid	0.012	0.006	0.010	0.012
	4-Aminobutyric acid	0.001	0.001	0.000	0.001
	Tyramine	0.017	0.001	0.034	0.027
	3-Phenyllactic acid	0.000	0.001	0.012	0.016
	L-Ornithine	0.000	0.001	0.029	0.046
	L-Glutamic acid	0.000	0.001	0.548	0.753
	5-Aminovaleric acid	0.055	0.401	0.122	0.753
	Cadaverine	0.000	0.001	0.000	0.001
	L-Tryptophan	0.000	0.003	0.058	0.046
	2-Monomyristin			0.078	0.115







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QUALIMENT

Conclusions

- Raw milk cheeses have a higher microbial diversity after 4 month of ripening, resulting in a higher content of free amino acids and differences in specific metabolites

- After gastric digestion, cheeses with higher microbial complexity have more complex peptide patterns and a slightly higher proteolysis

- All cheese digesta have only minor differences after intestinal IVD under dynamic and static conditions and these differences originate from non digestable metabolites present in the cheeses

Take home messages

The structure of dairy products regulate the kinetics of protein (and lipids as well!) digestion and the release of amino acids in the bloodstream

Gastric emptying rate and the structure that the product adopts in the stomach cavity regulates the whole digestion process.

Cheeses are food of very high nutritional quality providing all of the indispensable amino acids needed.

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
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Amélie DEGLAIRE – *Lecturer*
Juliane FLOURY – *Lecturer*
Catherine GUERIN - *Lecturer*
Steven LE FEUNTEUN – *Senior Scientist*
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Martine MORZEL – *Senior Scientist*
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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

784 scientists - 300 institutes – 60 countries

cost
EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

Industry involvement

☞ ~ 60 private companies are following INFOGEST

INFOGEST

Chair
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Vice-chair
Alan Mackie - UK

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	Imaging Technologies applied to digestion WG7

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Andre Brodkorb

Lotti Egger

Uri Lesmes

Brigitte Graf

Marion Letisse

Leslie Couedelo

Marilisa Alongi

Choi-Hong Lan

Luca Marciani

Some outputs

In vitro gastrointestinal digestion
Consensus INFOGEST protocol

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

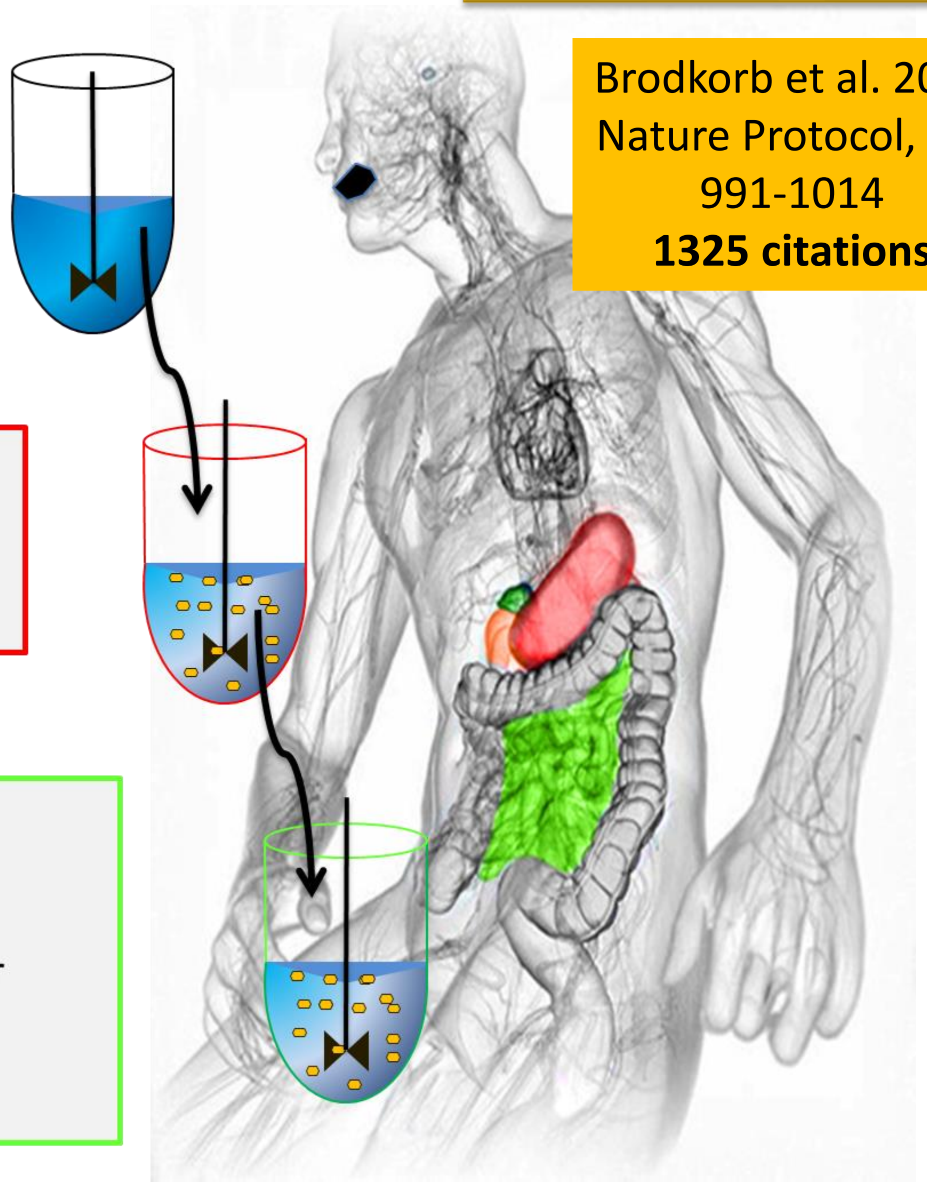
Brodkorb et al. 2019
Nature Protocol, 14, 991-1014
1325 citations

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



INFOGEST

International Conference

Gdansk, Poland
2026

We are pleased to announce the next

9th International Conference on Food Digestion

in Gdansk, Poland, 19-21 May 2026