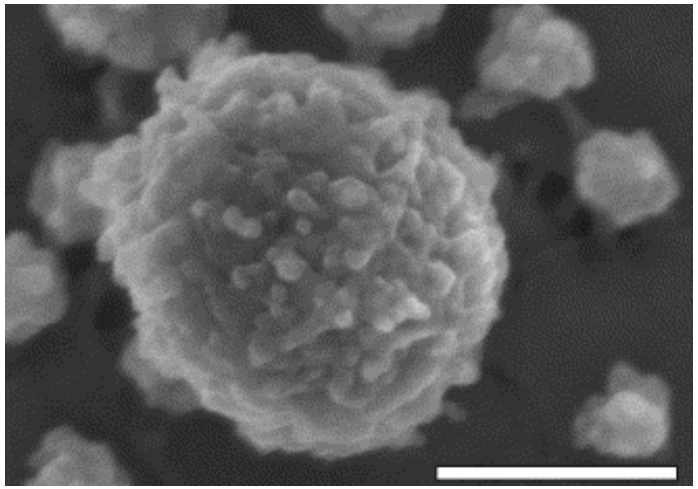
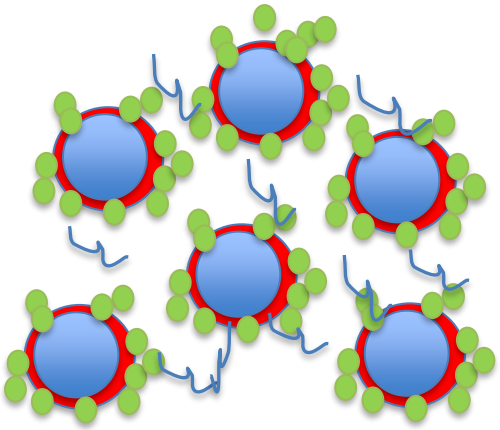
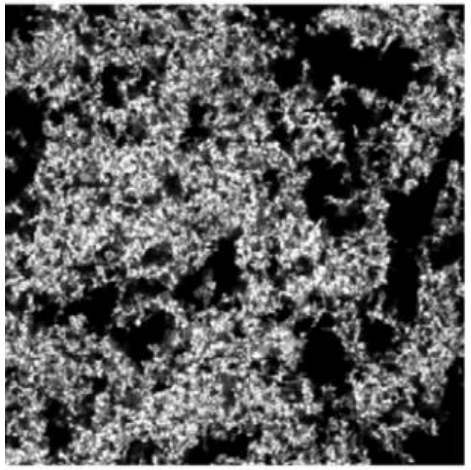
A Food Science Perspective on the Dairy Matrix: Composition, Properties and Implications of Processing







Professor Alan Kelly

School of Food and Nutritional Sciences,

University College Cork

E-mail: a.kelly@ucc.ie

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University College Cork, Ireland
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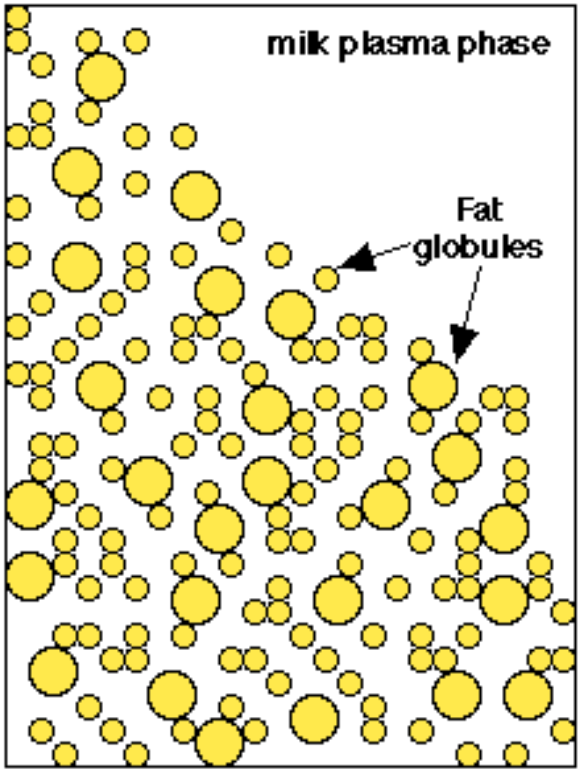
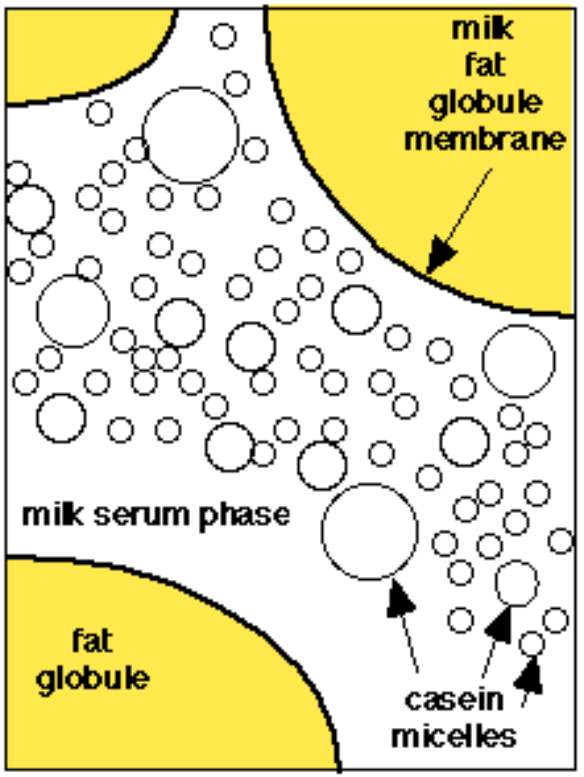
The Dairy Matrix

- Nutritional profile of food influenced both by structure and nutrient content
- Complex nutrient profile of milk
- Range of physical structures of dairy products – liquid, gel, solid
- Changes in state and interactions due to processing
- Dynamic and changing (e.g., cheese ripening)

What is milk? More than meets the eye…..

- Multicomponent (fat, protein, lactose, minerals)
- Multiphase (emulsion, colloidal suspension)
- Biologically active (e.g., enzymes)
- Physically and microbiologically unstable
- Process to stabilize/transform/diversify



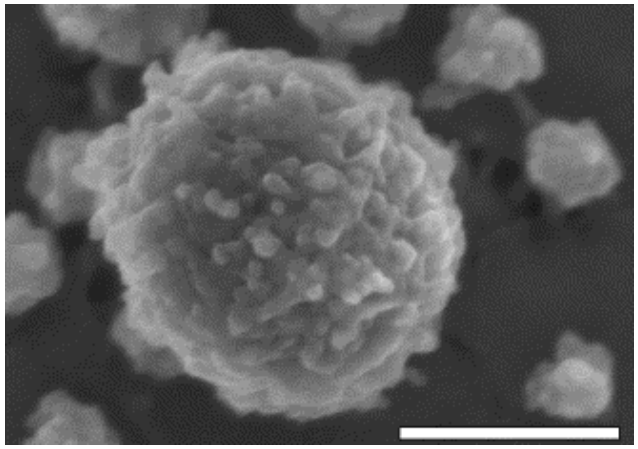


The Multiple Roles of Milk Proteins

Skim Milk

pH 4.6

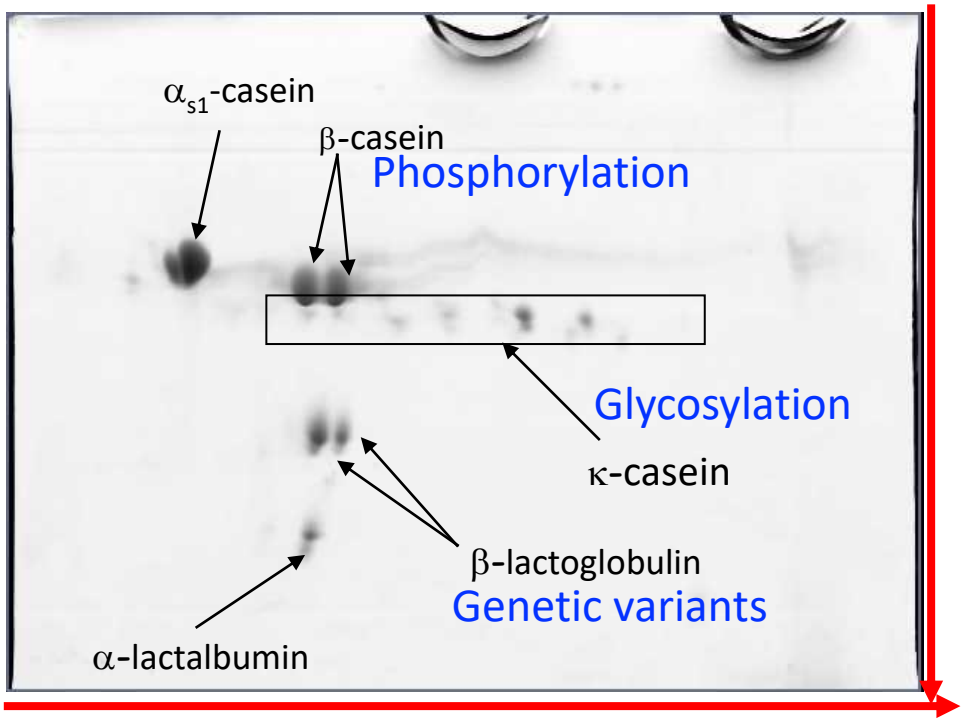
Soluble	Insoluble micelles
WHEY PROTEINS	CASEINS
~20% milk proteins	~80% milk proteins



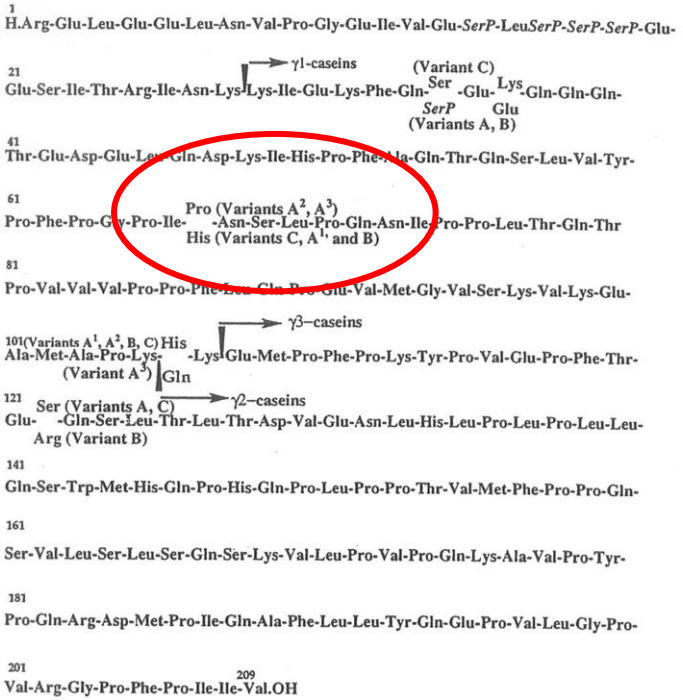
The caseins are:

- Sources of amino acids
- Mineral carriers
- Individual proteins
- Massive aggregates
- Heterogeneous
- Colloidal entities
- Dynamic entities
- Easily destabilized
- Thermally sensitive

Milk protein microheterogeneity



- Four caseins (α_{s1}-, α_{s2}, β- and κ-)
- Multiple sources of heterogeneity



Amino acid sequence of bovine β-casein

Also, precursors of peptides

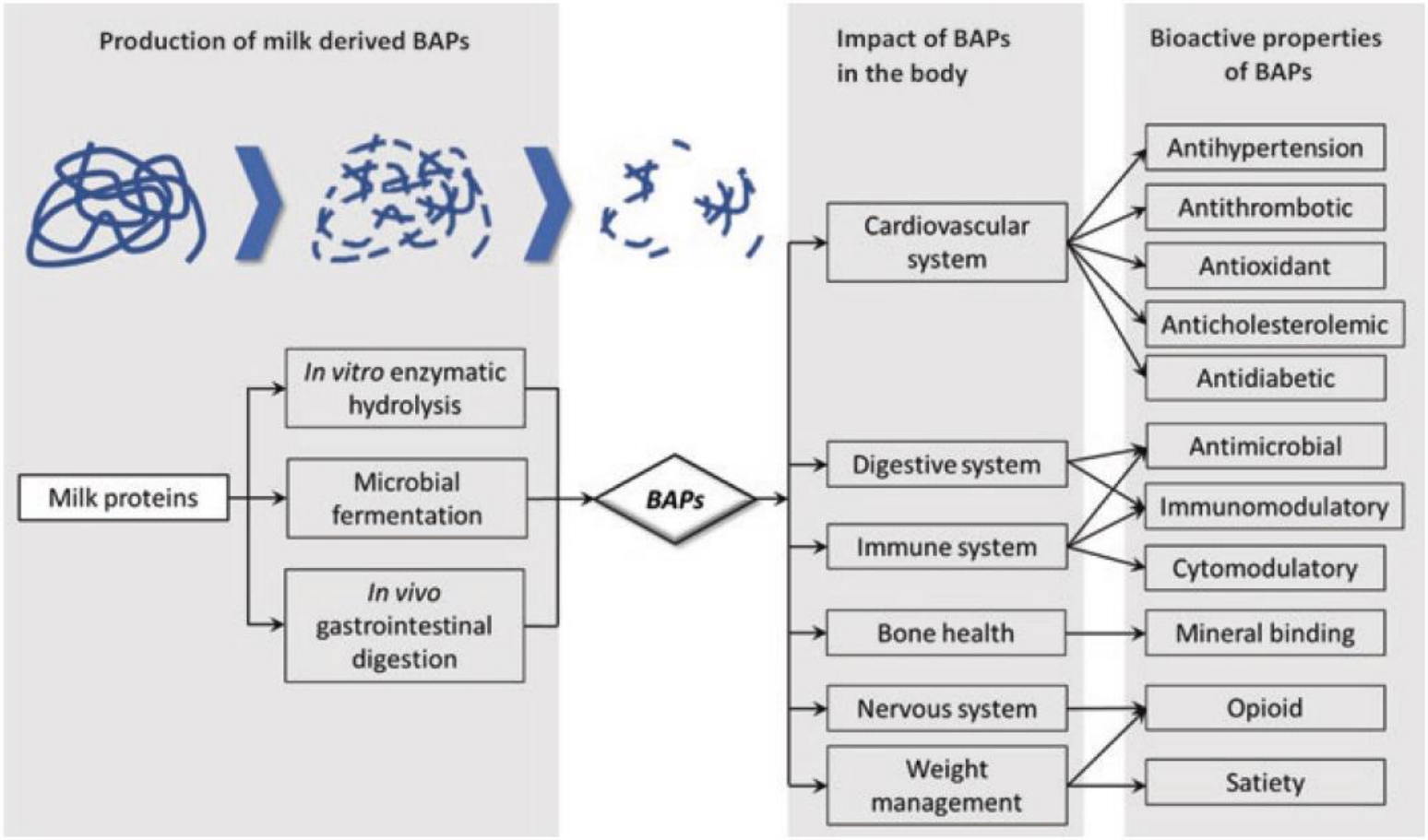


Fig. 18.1 Schematic of different approaches used for the production of milk-derived bioactive peptides (BAPs) and the impact of these BAPs on different bodily systems (adapted from Korhonen and Pihlanto (2006) and Mohanty et al. (2016b))

Kleekayi et al. 2021

The Casein Micelle: a Dynamic Matrix

Colloidal calcium phosphate (CCP) throughout

κ-casein on surface

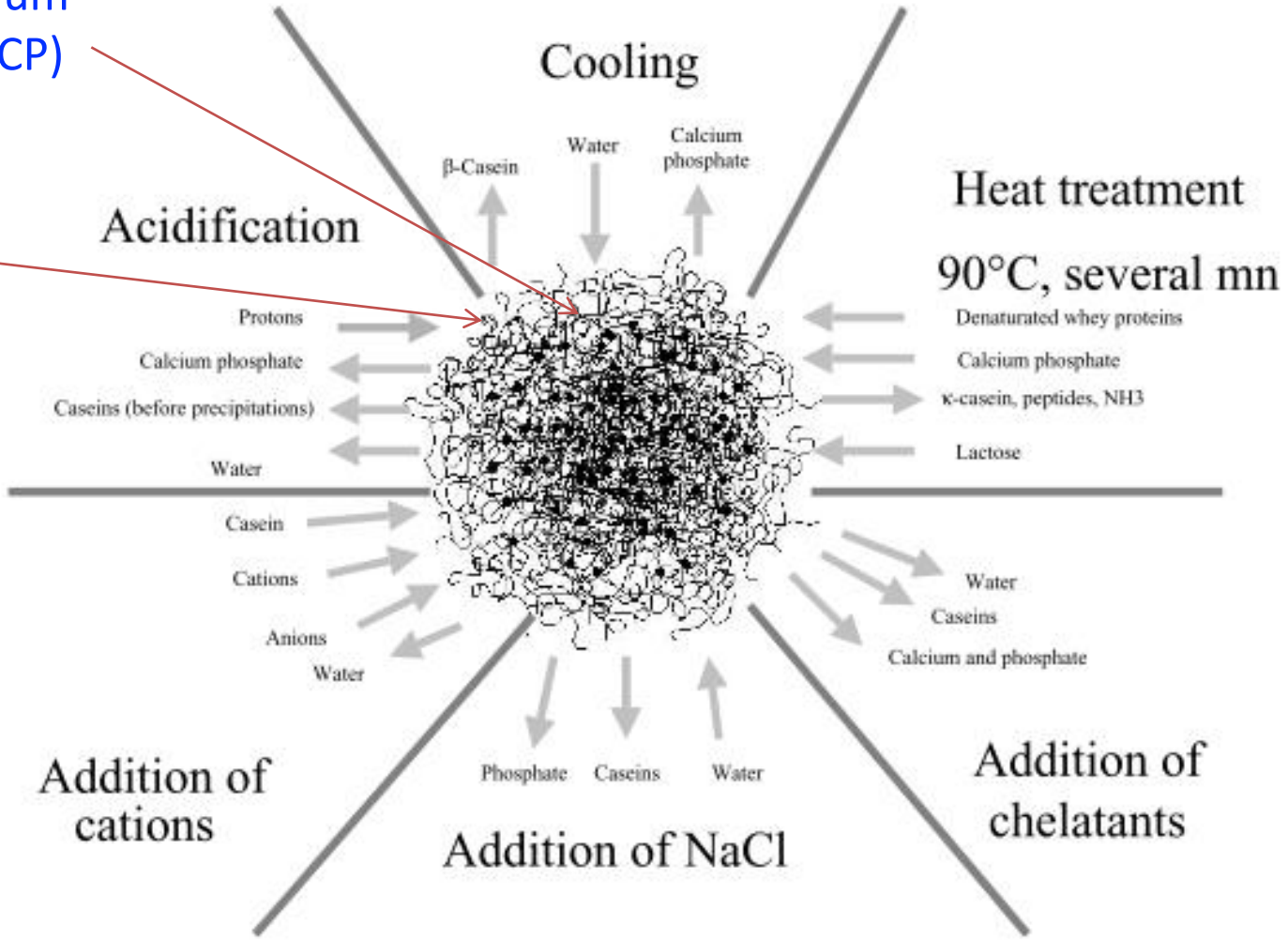


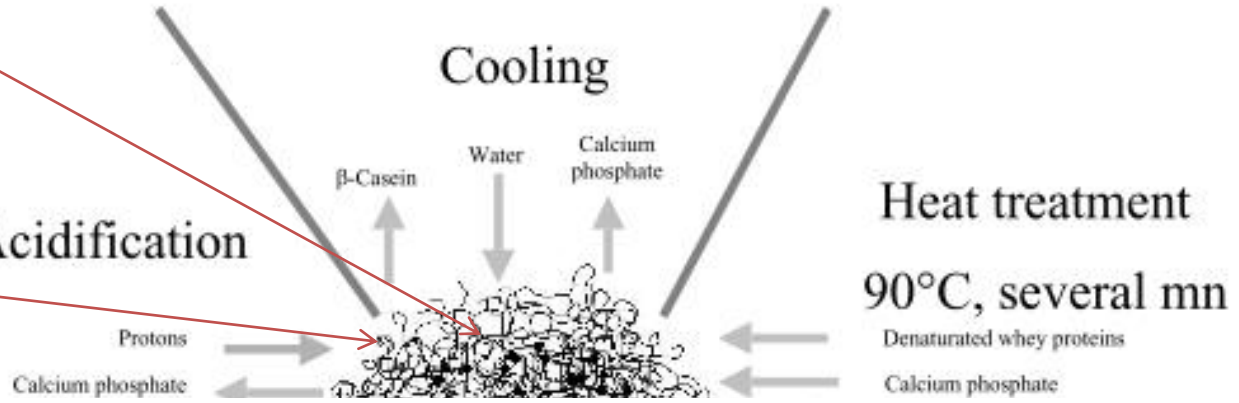
Figure 4. Modification of salt equilibrium in different physico-chemical conditions.

Gaucheron (2005)

The Casein Micelle: a Dynamic Matrix

Colloidal calcium phosphate (CCP) throughout

κ-casein on surface



The Evolution of Milk Casein Genes from Tooth Genes before the Origin of Mammals

Kazuhiko Kawasaki,*[,1] Anne-Gaelle Lafont,[2] and Jean-Yves Sire[2]

[1]Department of Anthropology, Pennsylvania State University

[2]UMR 7138-Systématique-Adaptation-Evolution, Université Pierre et Marie Curie, Paris, France

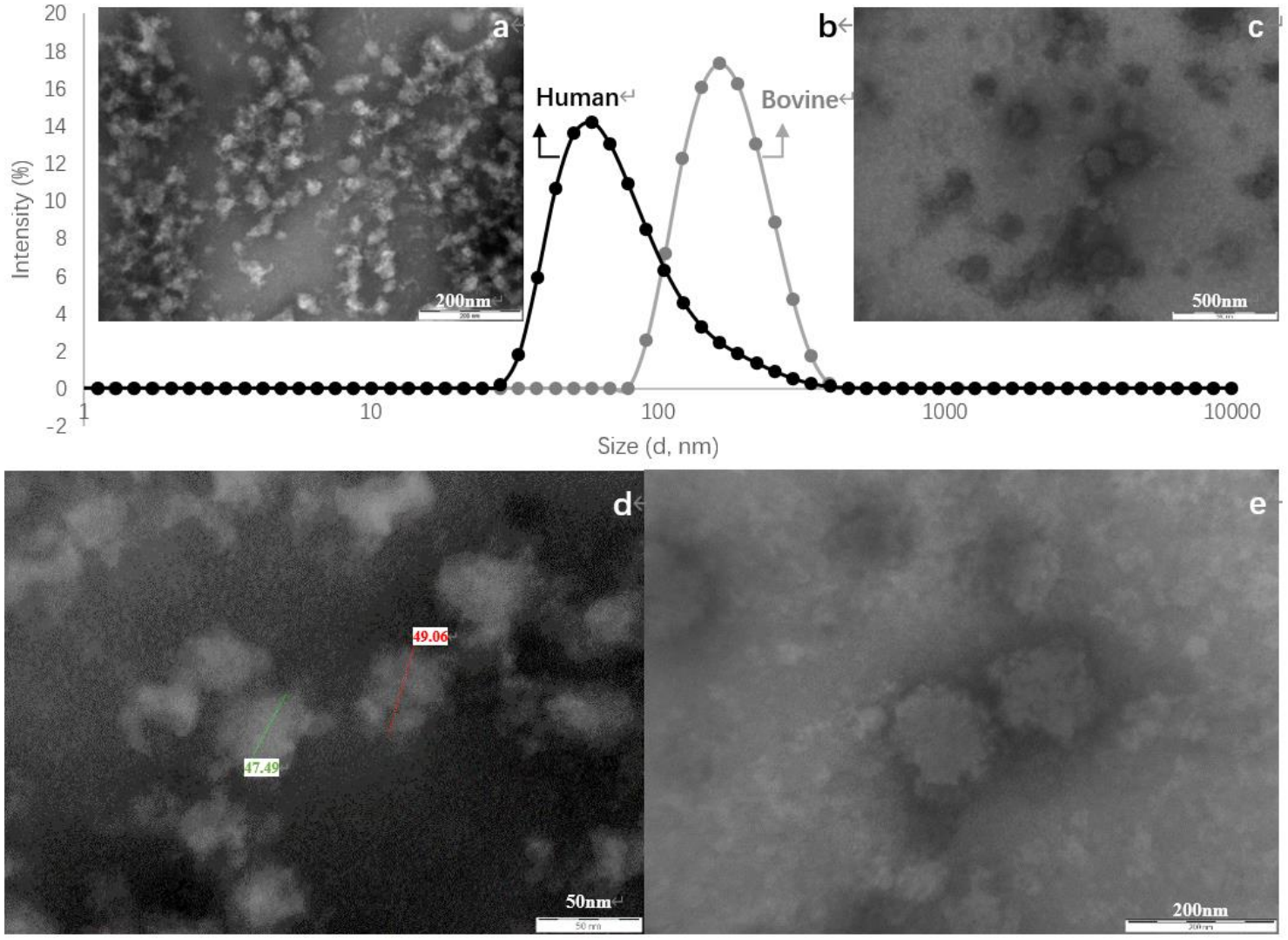
***Corresponding author:** E-mail: kuk2@psu.edu.

Associate editor: Yoko Satta

In milk, caseins and calcium phosphate (CaP) form a huge complex called casein micelle. By forming the micelle, milk maintains high CaP concentrations, which help altricial mammalian neonates to grow bone and teeth.

05)

Inter-species differences



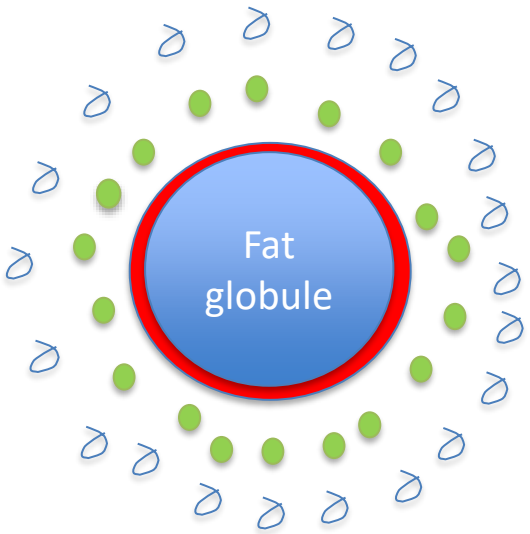
Observation of human (a, c) and bovine (d, e) casein micelles from TEM and representative size distribution profiles of human (black line) and bovine (grey line) casein micelles (b) from Zetasizer analysis. Magnification: a, e: 120 K; c: 60 K; d: 400 K

Meng and Uniacke, UCC

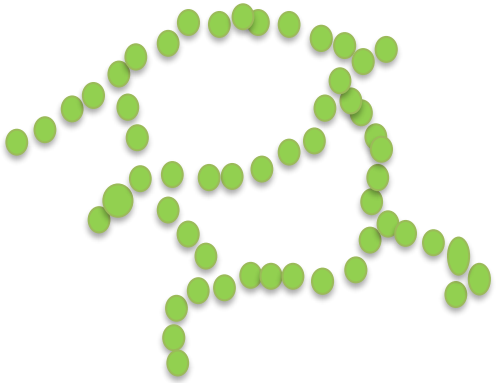
Controlled destabilisation of casein micelles

- Basis of many dairy products
- Fast acidification: isoelectric precipitation of caseins to make acid casein
- Slow quiescent bacterial acidification: yogurt, acid-coagulated cheeses
- Rennet coagulation: rennet casein, most cheeses
- Fractionates the matrix (proteins, fats, minerals)

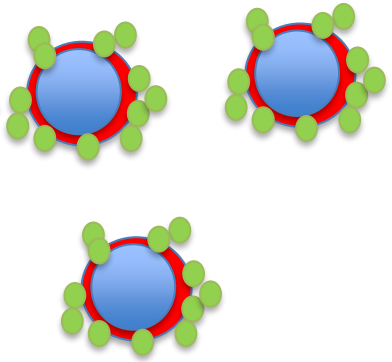
Transforming the matrix



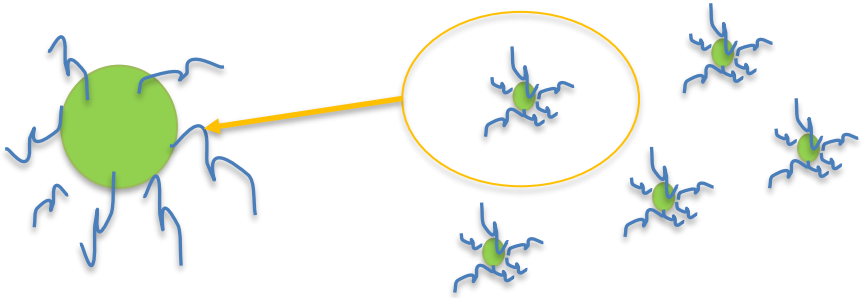
Destabilisation (acid, rennet)



Homogenisation

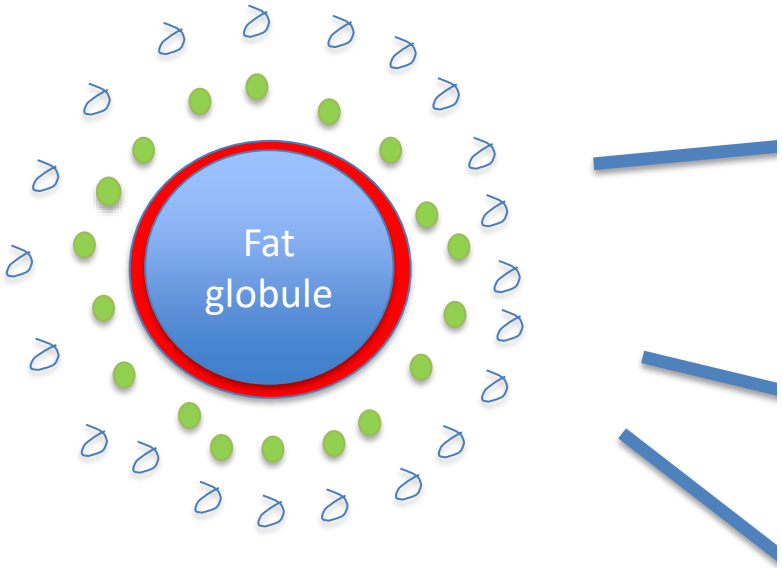


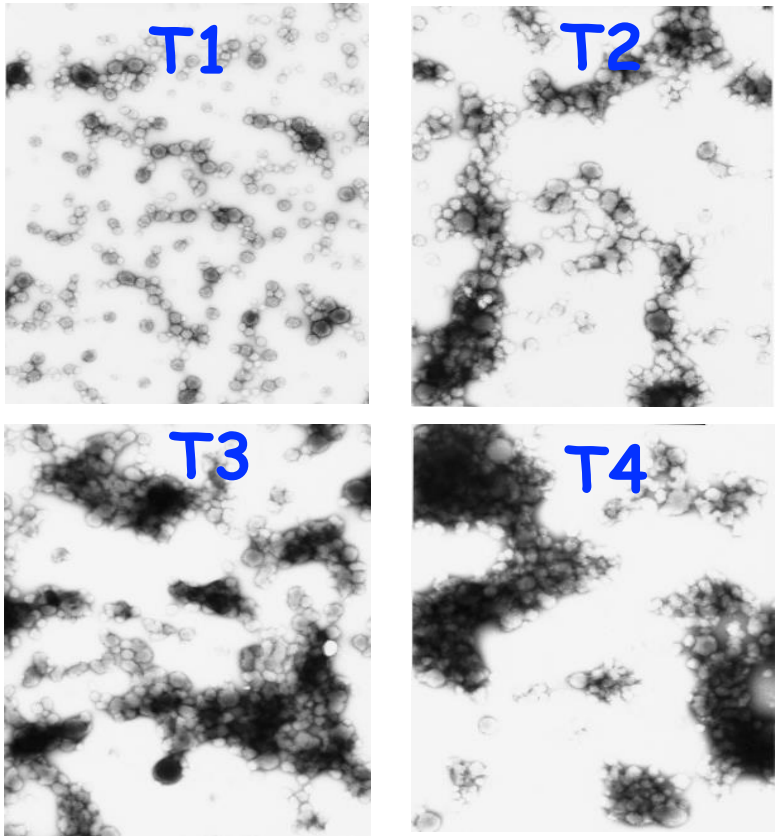
Heat Treatment



- Milk fat globule membrane (MFGM)
- Native whey proteins (β-lg)
- Denatured whey proteins (β-lg)
- Casein micelles

Transforming the





Milk fat globule membrane (MFGM)

Native whey proteins (β-lg)

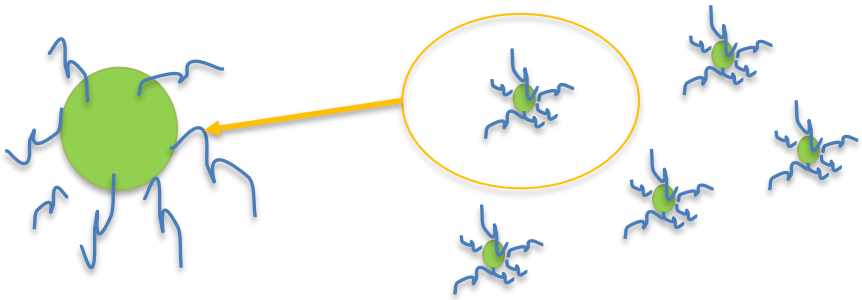
Denatured whey proteins (β-lg)

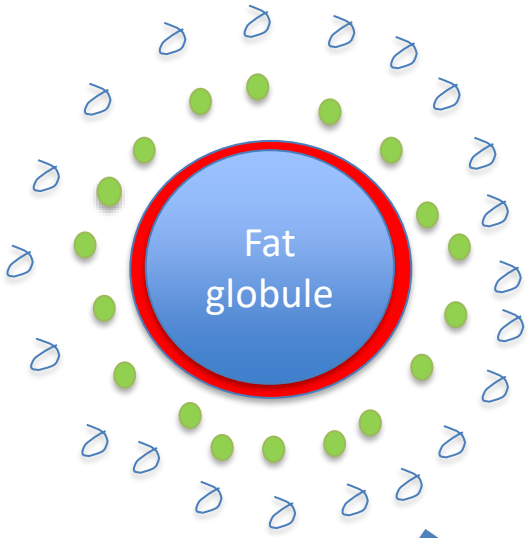
Casein micelles

H

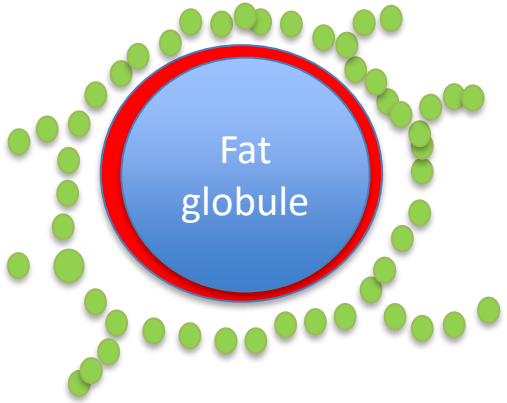
Trea

Gel assembly during cheese-making

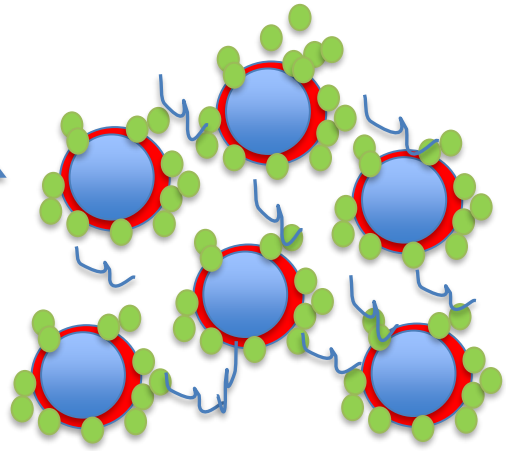




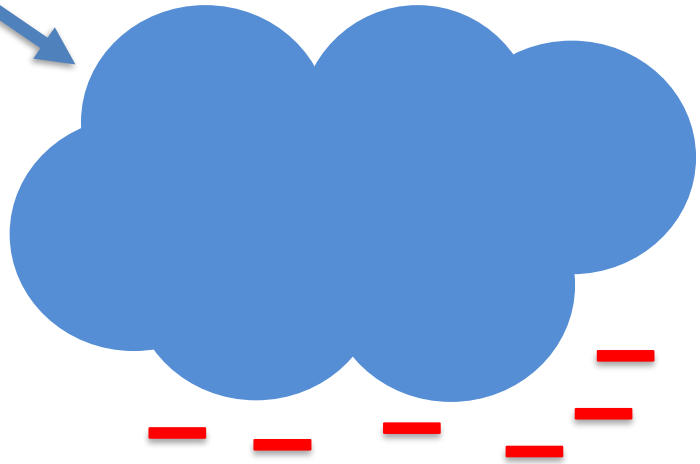
Cheese



Yoghurt

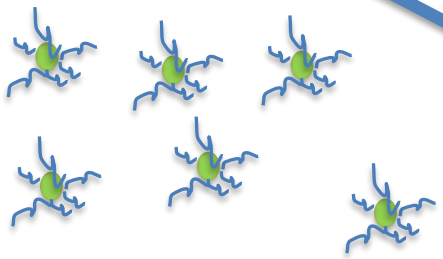


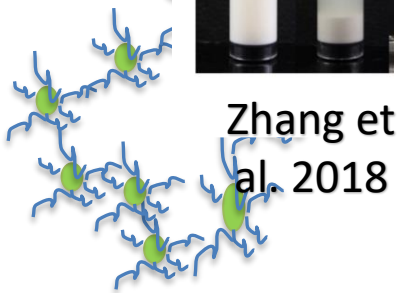
Butter

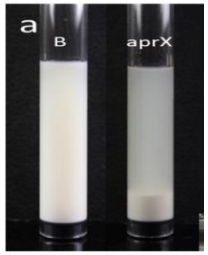


UHT milk
(fresh)

Gelation







Zhang et
al. 2018

The duality of calcium: both a nutrient……

Review

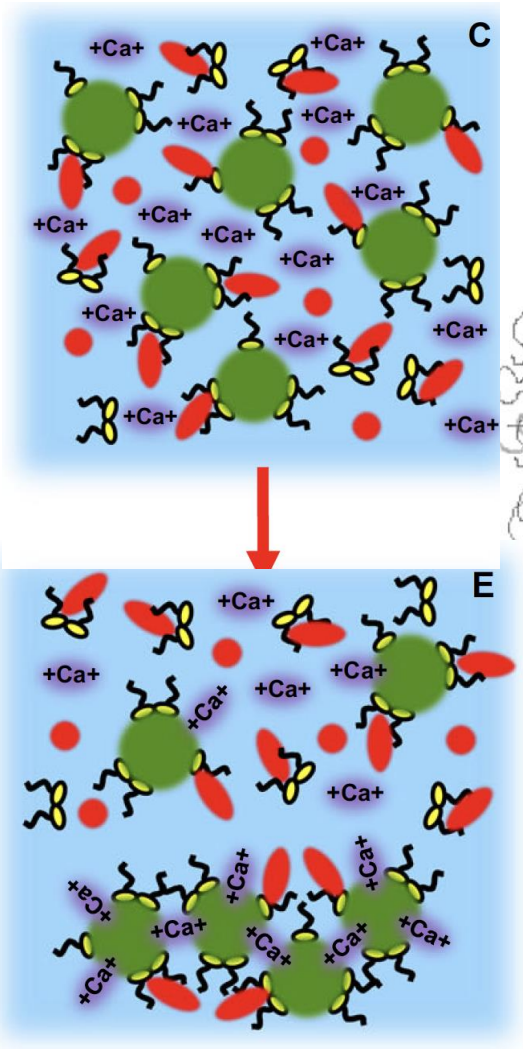
Milk minerals (including trace elements) and bone health

Kevin D. Cashman*

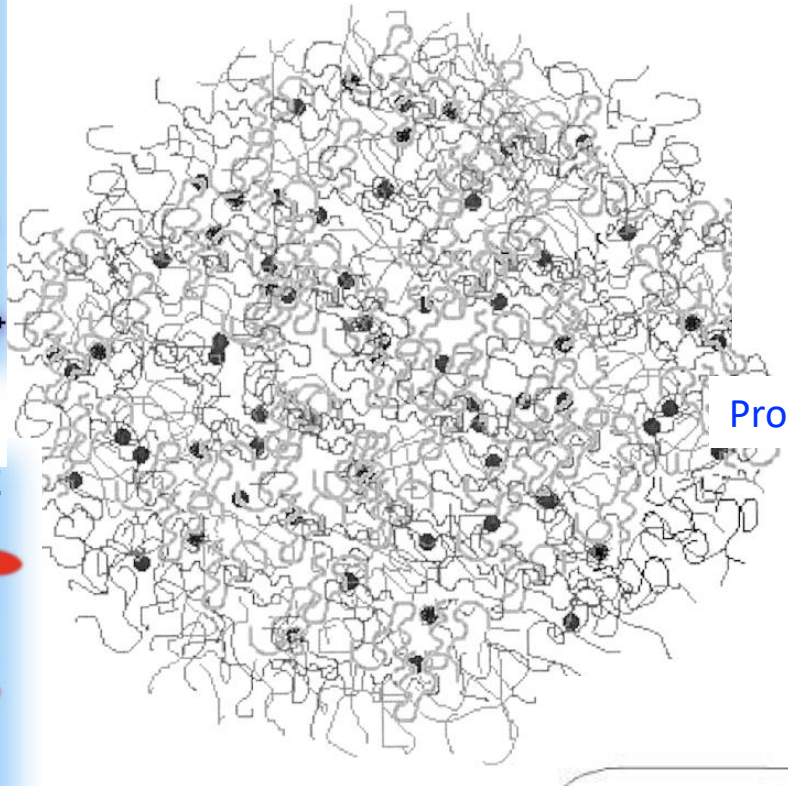
Department of Food and Nutritional Sciences, and Department of Medicine, University College, Cork, Ireland

Received 12 September 2005; accepted 31 May 2006

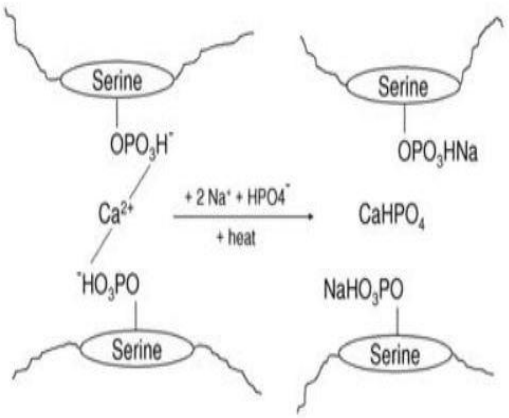
……and a major influence on dairy products



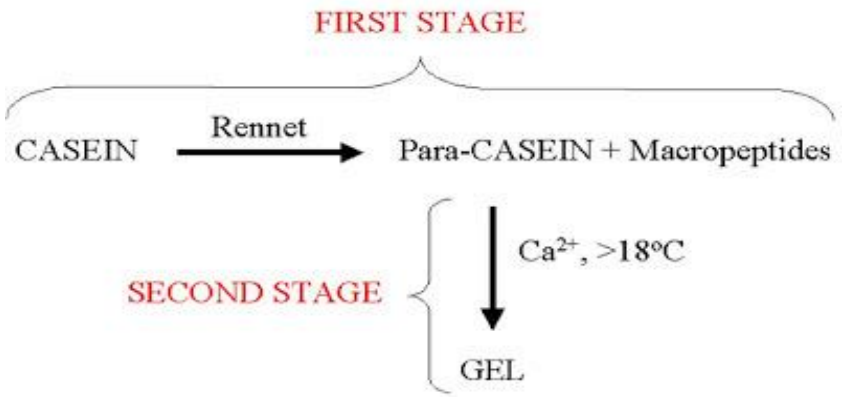
UHT milk:
Anema, 2019



DeKruif, 2003



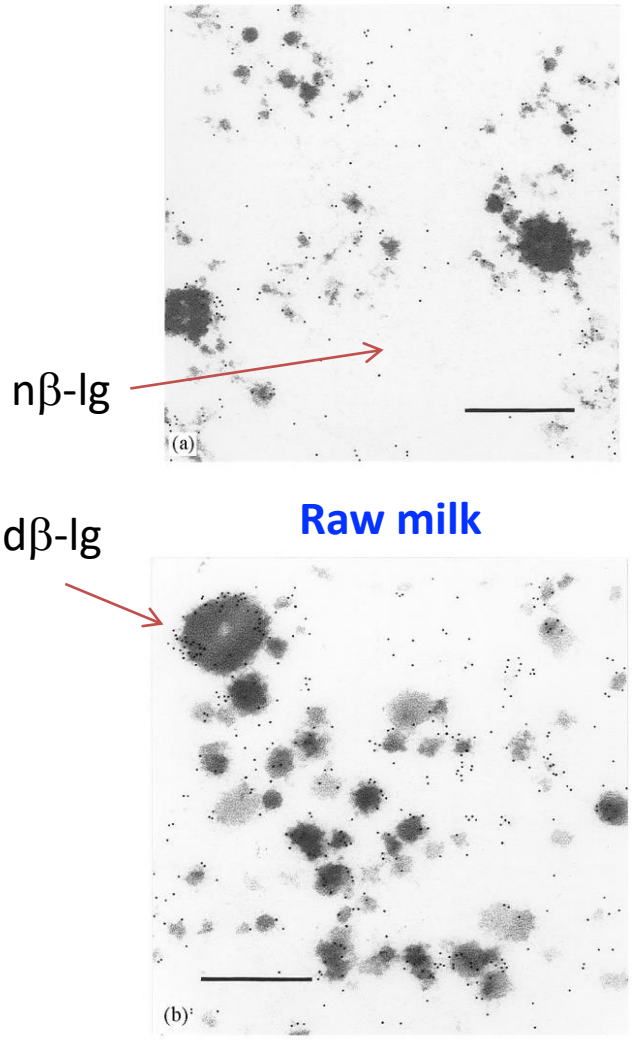
Processed cheese: Guinee et al. 2004



Rennet coagulation: Cheesescience.net

Heat treatment and the matrix

- Heat treatment results in denaturation of β-lactoglobulin and structure formation
- Whey protein-whey protein and whey-protein-casein interactions possible
- Fundamentally affect behavior of both protein types and product characteristics
- Minimal at pasteurization conditions (72-75℃ for 15-30 sec), extensive at UHT conditions (135-140℃ for 2-5 sec)



Raw milk

UHT milk

Enright et al. 1999

Heat treatment enhances digestion

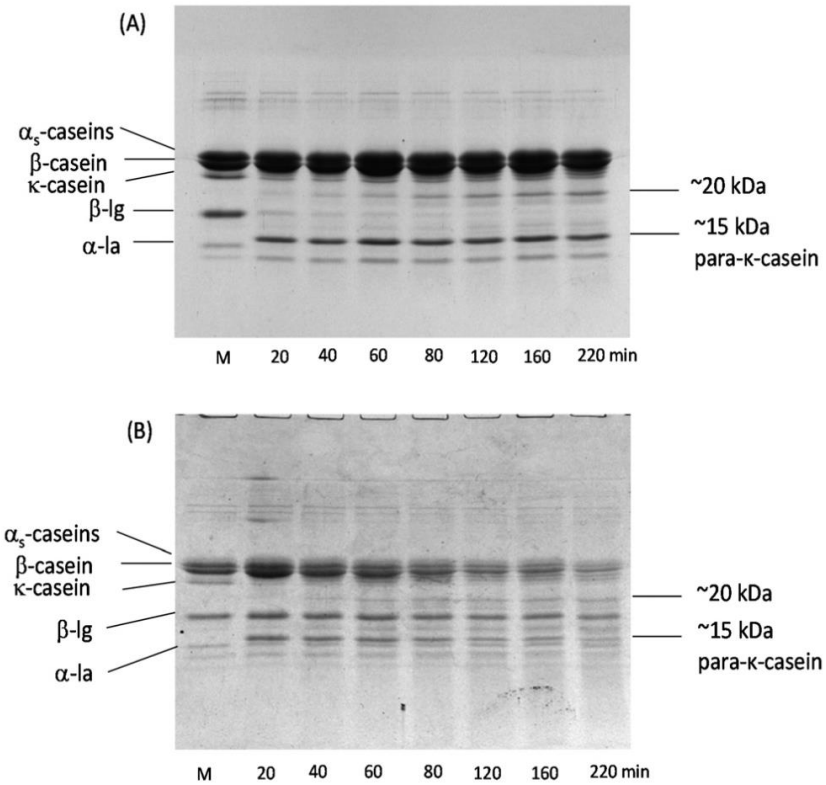
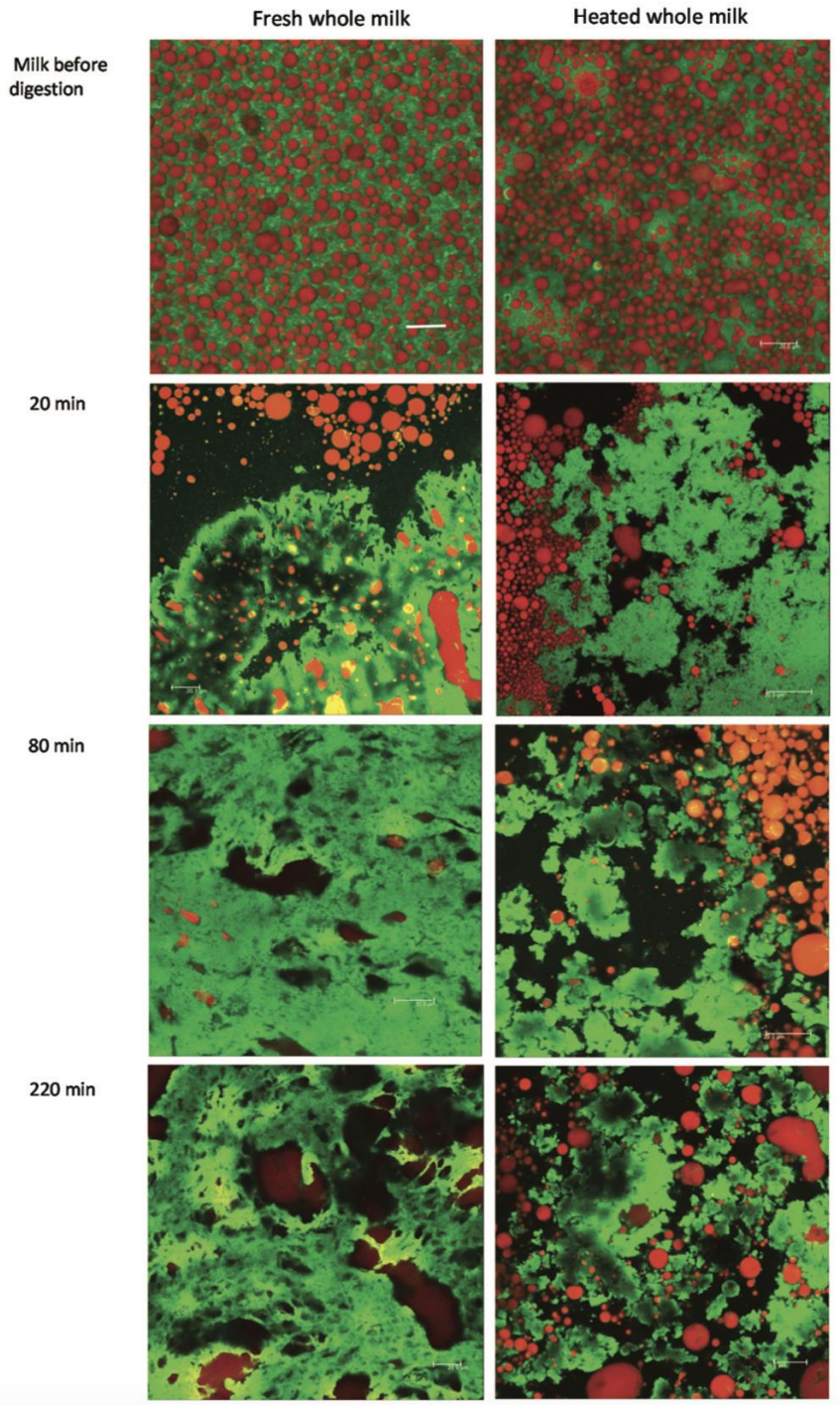


Fig. 3 SDS-PAGE patterns under reducing conditions of the clots obtained during the gastric digestion of unheated whole milk (A) and heated whole milk (90 °C for 20 min) (B) in the HGS at different times. M, unheated milk.

Ye et al. 2016



JOURNAL OF AGRICULTURAL AND FOOD CHEMISTRY

Article

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Effects of Different Industrial Heating Processes of Milk on Site-Specific Protein Modifications and Their Relationship to in Vitro and in Vivo Digestibility

Yasuaki Wada[†,‡] and Bo Lönnerdal*[,†]

- Milk subjected to various commercial heat treatments
- Clear differences in levels of denaturation of whey proteins
- Major differences in digestion under adult and infant gut conditions
- But other changes too (lactosylation)

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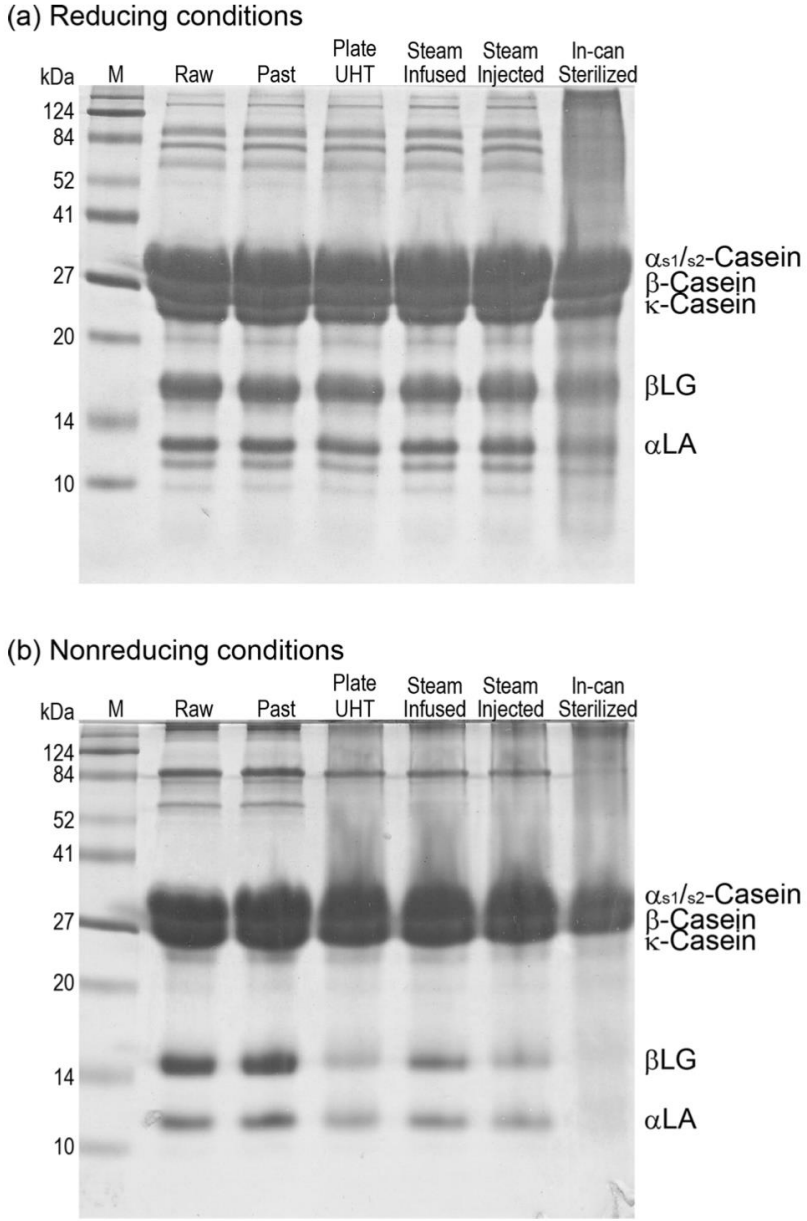

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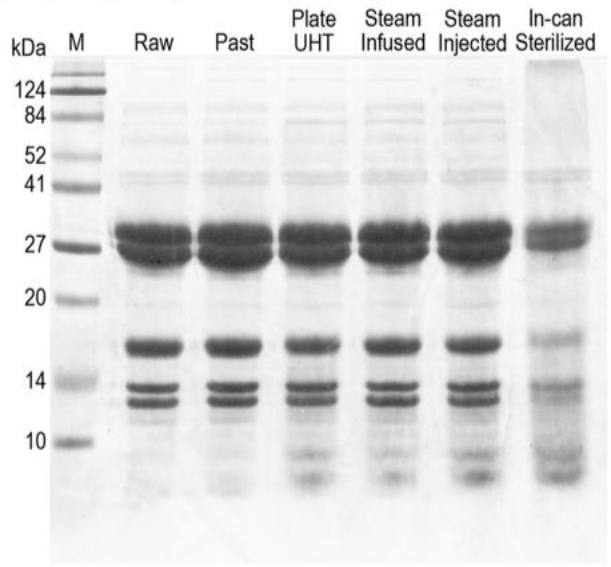
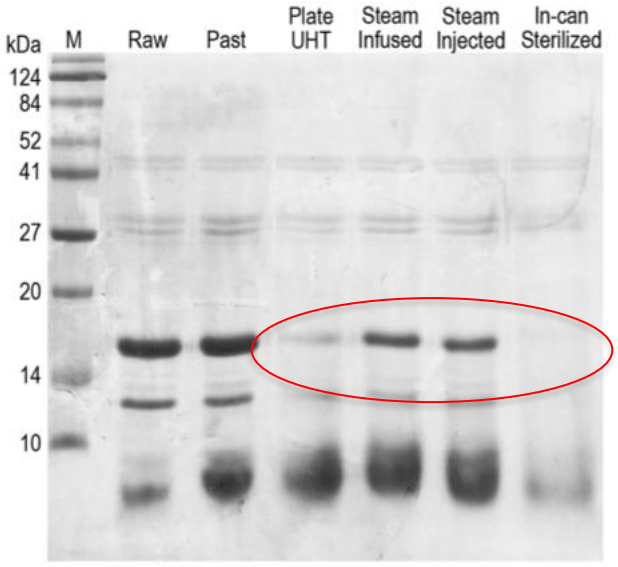
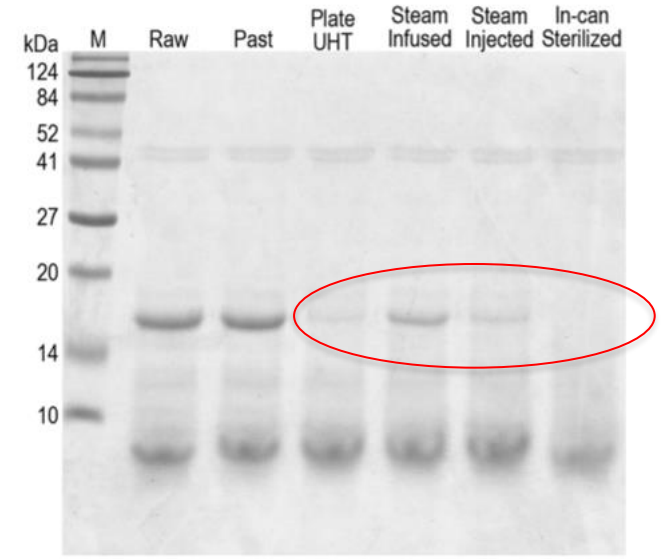
(a) Pepsin (pH 4.0) X 5 min



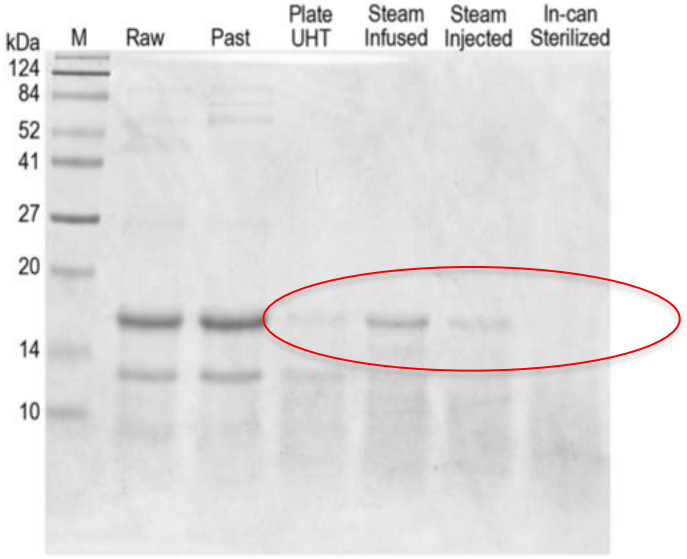
(d) Pepsin (pH 4.0) X 30 min



(l) Pepsin (pH 2.0) X 30 min

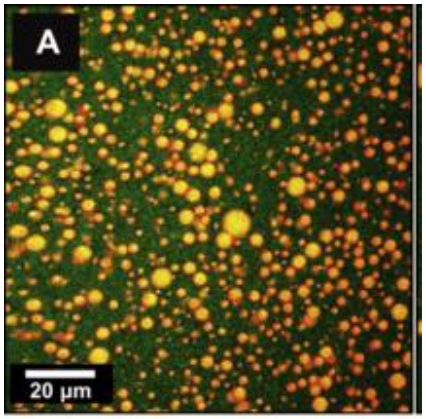


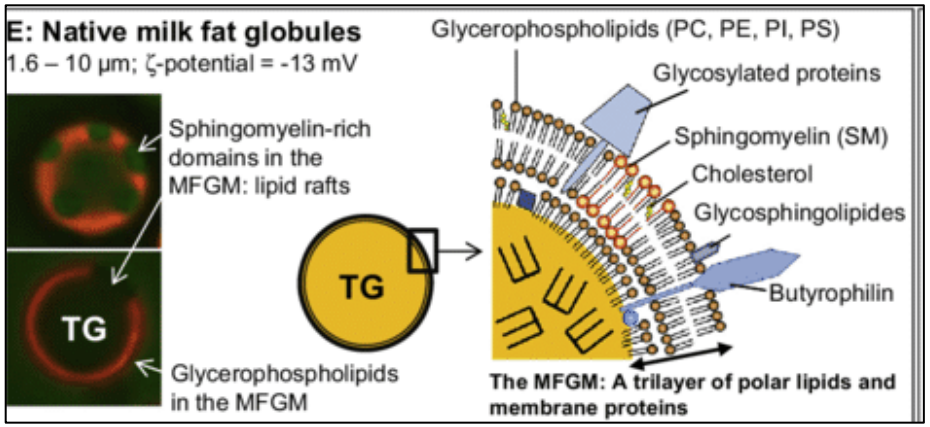
(h) Pepsin (pH 4.0) X 30 min + Pancreatin (pH 7.0) X 60 min

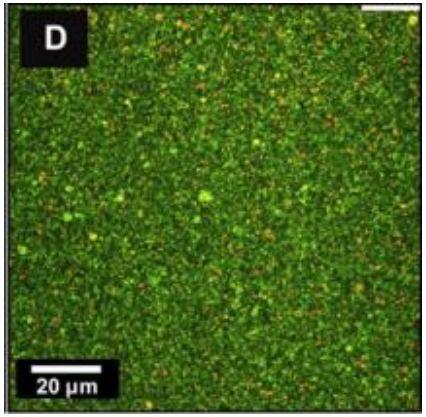


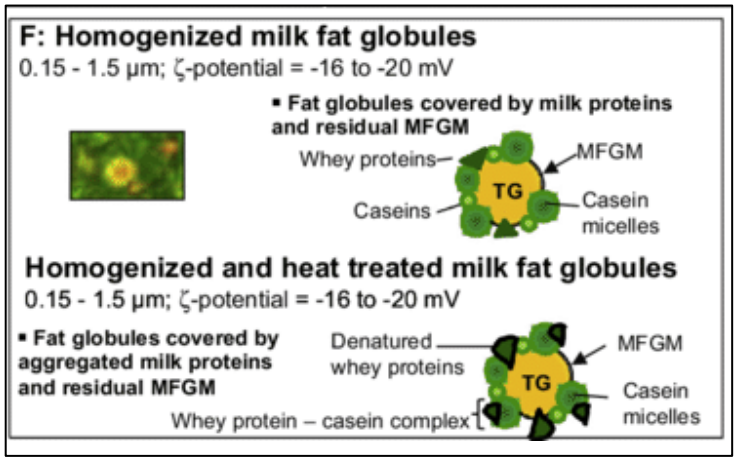
Homogenisation and the matrix

- Homogenisation has fundamental implications for the relationship between fat and protein and milk and dairy products
- Usually applied in combination with heat treatment









Garcia et al. 2014

Synergistic effects of heat and homogenisation

Different macro and micro structure of coagula formed and release of protein and fat

Ye et al. 2017

Synergistic

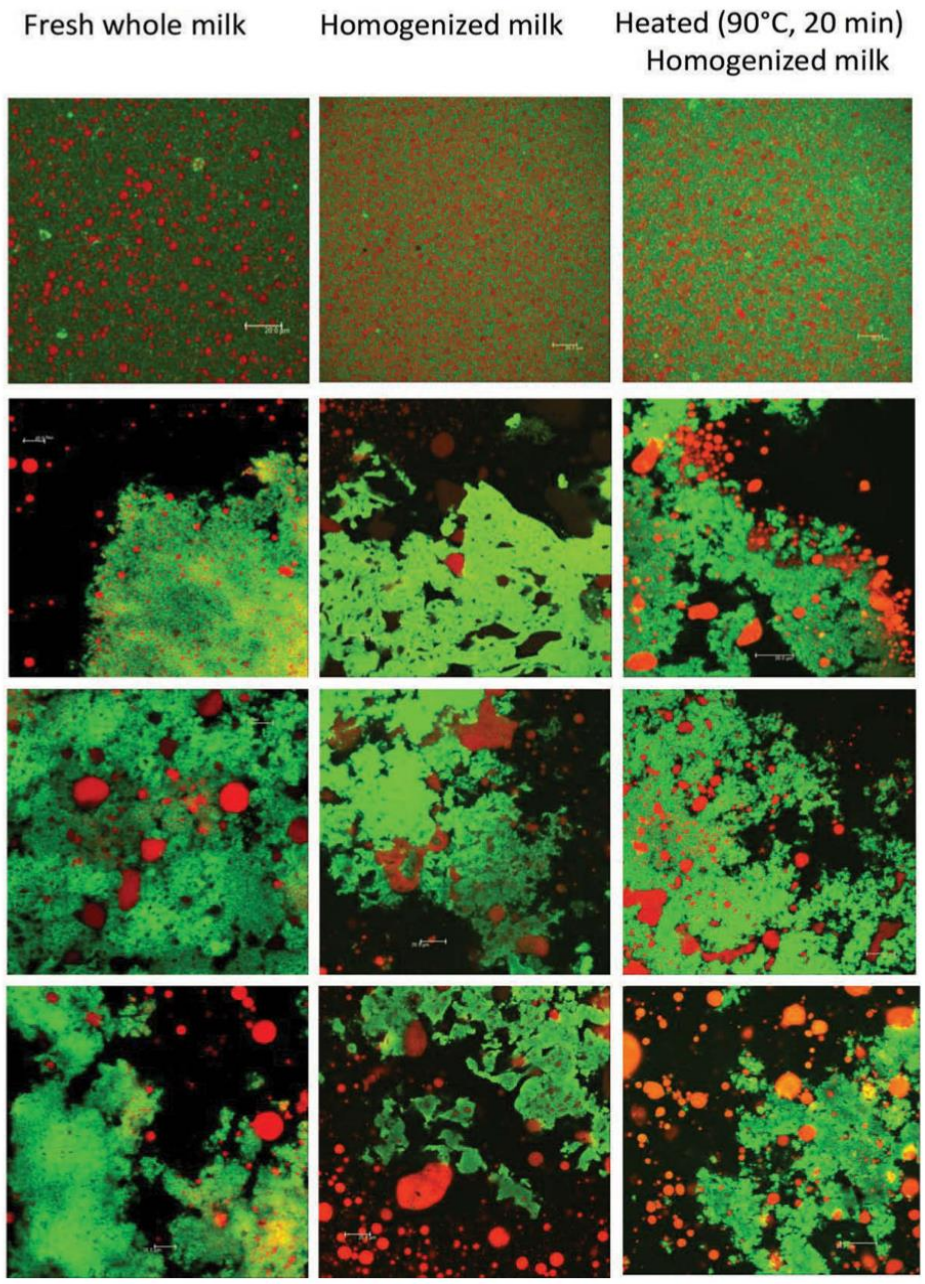
Fresh whole mi

20 min

160 min

Different macro ar
coagula formed ar

Ye et al. 2017



Synergistic effects of heat and homogenisation

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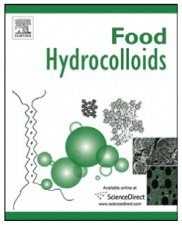

Structural mechanism and kinetics of *in vitro* gastric digestion are affected by process-induced changes in bovine milk

Ana-Isabel Mulet-Cabero [a, b], Alan R. Mackie [c], Peter J. Wilde [a], Mark A. Fenelon [b], André Brodkorb [b, *]

[a] *Quadram Institute Bioscience, Norwich Research Park, Norwich, Norfolk, NR4 7UA, UK*
[b] *Teagasc Food Research Centre, Moorepark, Fermoy, Co. Cork P61C996, Ireland*
[c] *School of Food Science and Nutrition, University of Leeds, Leeds, LS2 9JT, UK*

- Heating and homogenization of milk led to a very different type of coagulum during gastric digestion
- Caseins digested more slowly than whey proteins except when denatured
- Homogenisation and heating both increased nutrient release

Synergistic effects of heat and homogenisation

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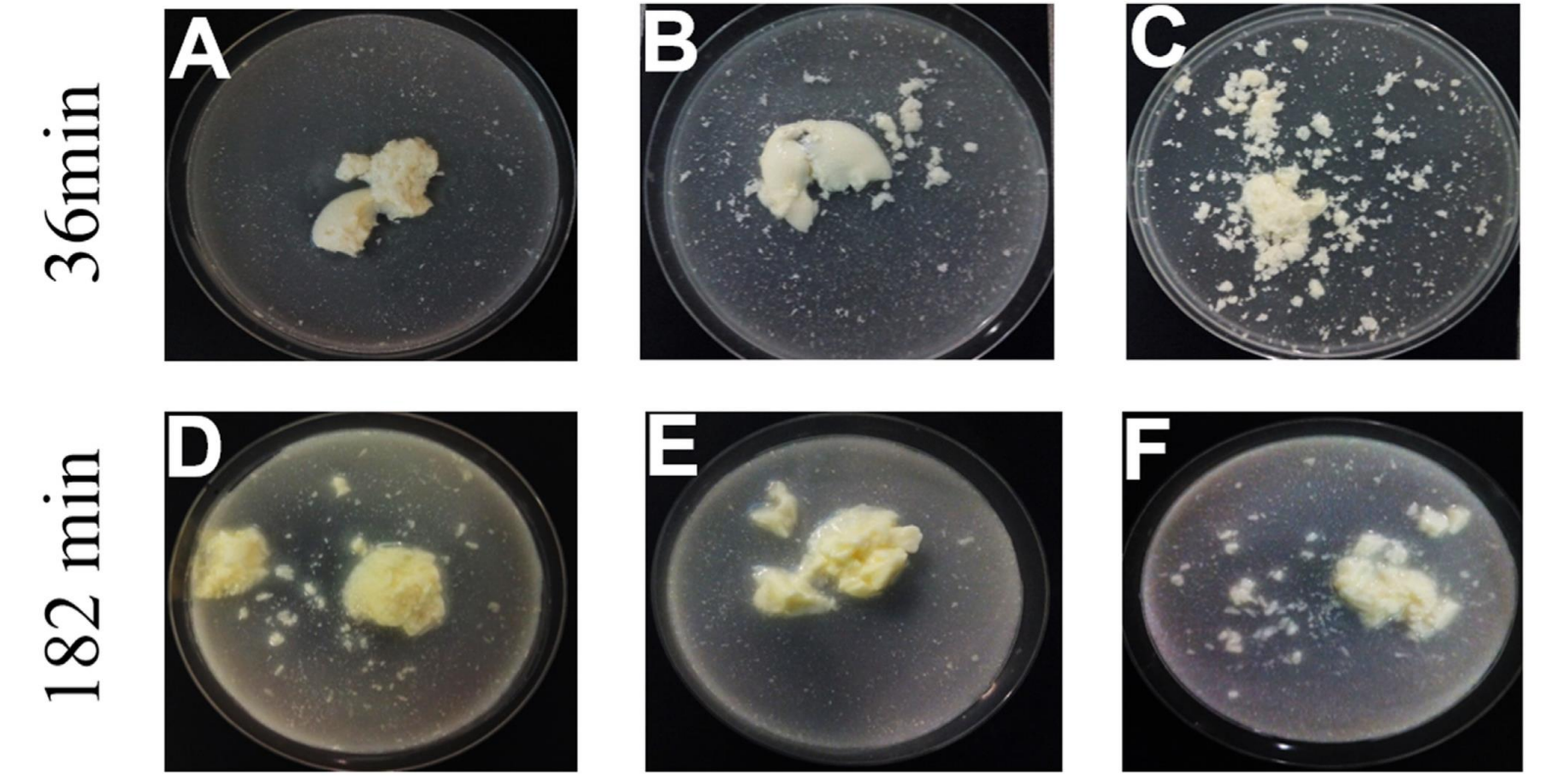

Synergistic effects of heat and homogenisation

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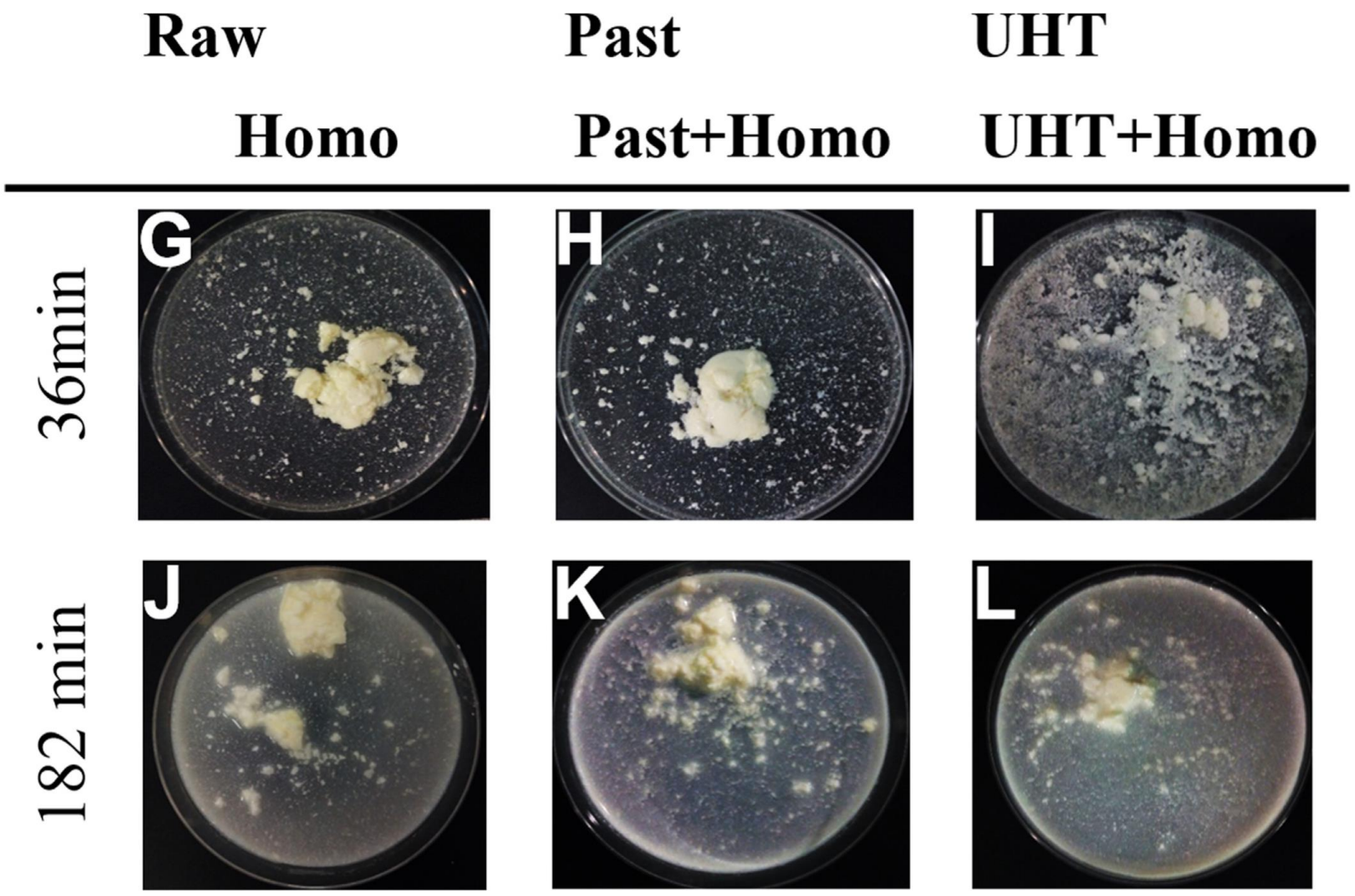
Ana-Isab
André B

[a] Quadram Ins
[b] Teagasc Fooc
[c] School of Foc



Synergistic effects of heat and homogenisation

Contents lists available at ScienceDirect

Food Hydrocolloids

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Ana-Isab
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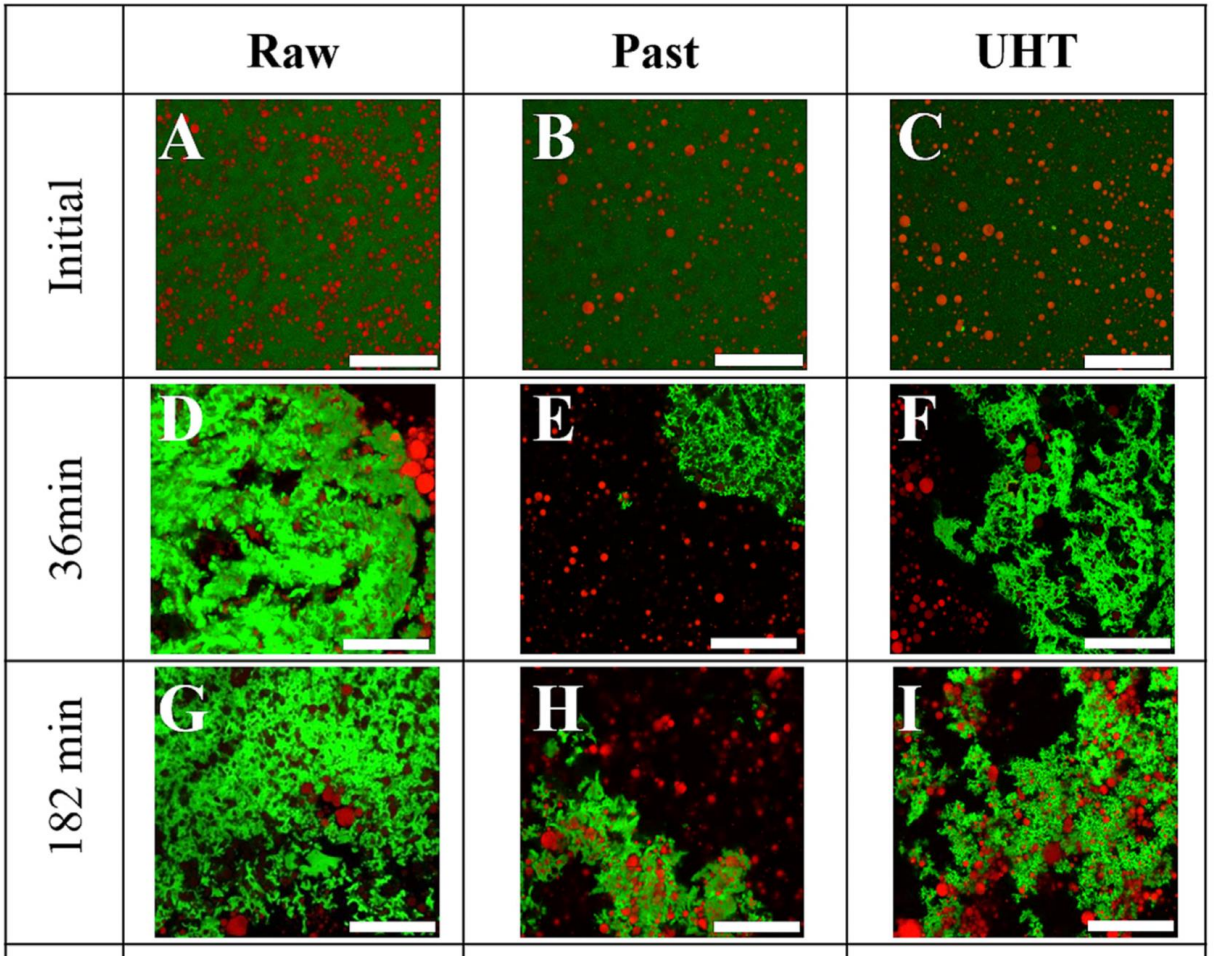
[a] Quadram Ins
[b] Teagasc Fooc
[c] School of Foc



Novel technologies and the matrix

- Ongoing interest in development of novel processing technologies for milk and dairy products
- ‘Freshness goal’ – meet raw milk demand but greater safety
- Technologies such as high pressure (HP) treatment and pulsed electric field (PEF) treatment
- More advanced for juices than milk

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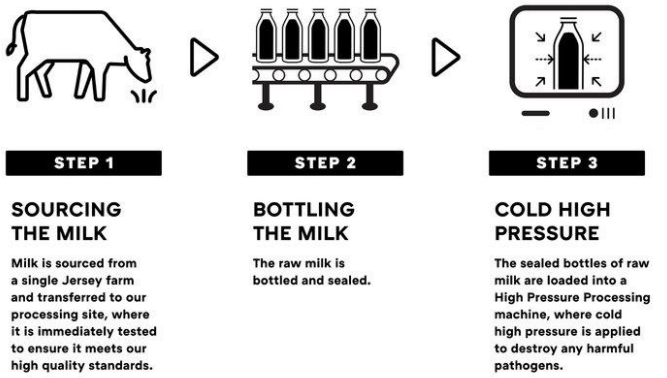
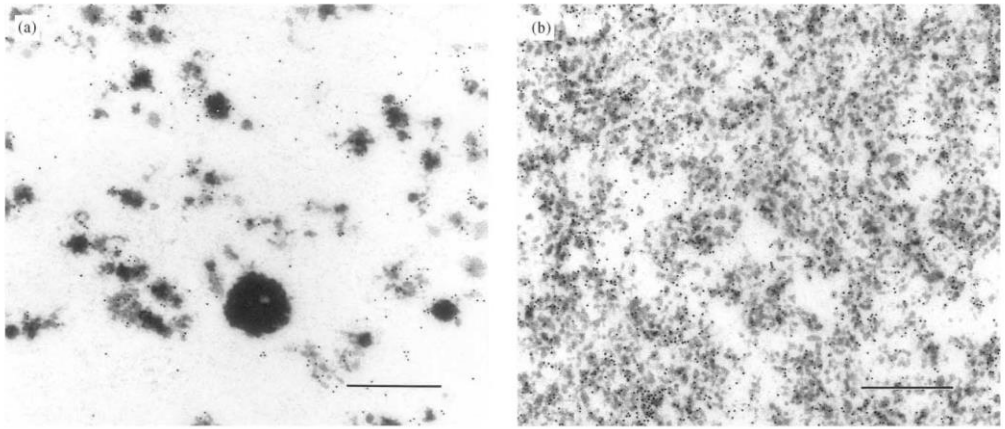


Comparative study on quality of whole milk processed by high hydrostatic pressure or thermal pasteurization treatment

Guanchen Liu[a,c], Christina Carøe[b], Zihan Qin[a,d], Daniel M.E. Munk[a], Michael Crafack[b], Mikael A. Petersen[a], Lilia Ahrné[a,*]

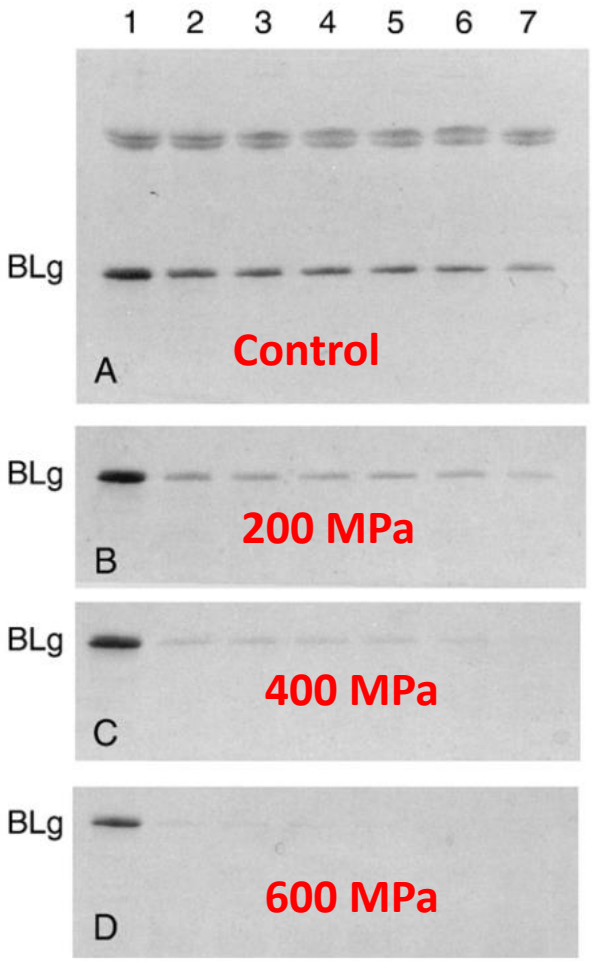
[a] Department of Food Science, University of Copenhagen, Frederiksberg C, Denmark
[b] Arla Foods Amba, Arla Innovation Center, Skejby, Denmark
[c] Hangzhou Wahaha Group, Key Laboratory of Food and Biological Engineering of Zhejiang Province, Hangzhou, China
[d] School of Food Science and Biotechnology, Zhejiang Gongshang University, Hangzhou, China

No impact of high pressure on digestibility of milk compared to heat despite significant impacts on milk proteins



Scollard et al. 2000

HP enhanced peptic digestion of β-lg, reducing allergenicity



Zeece et al. 2008

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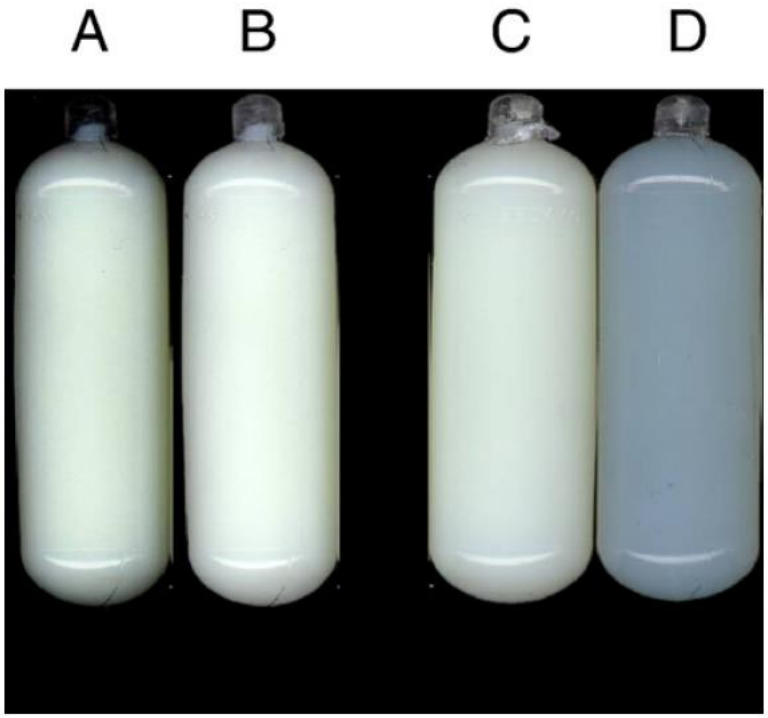
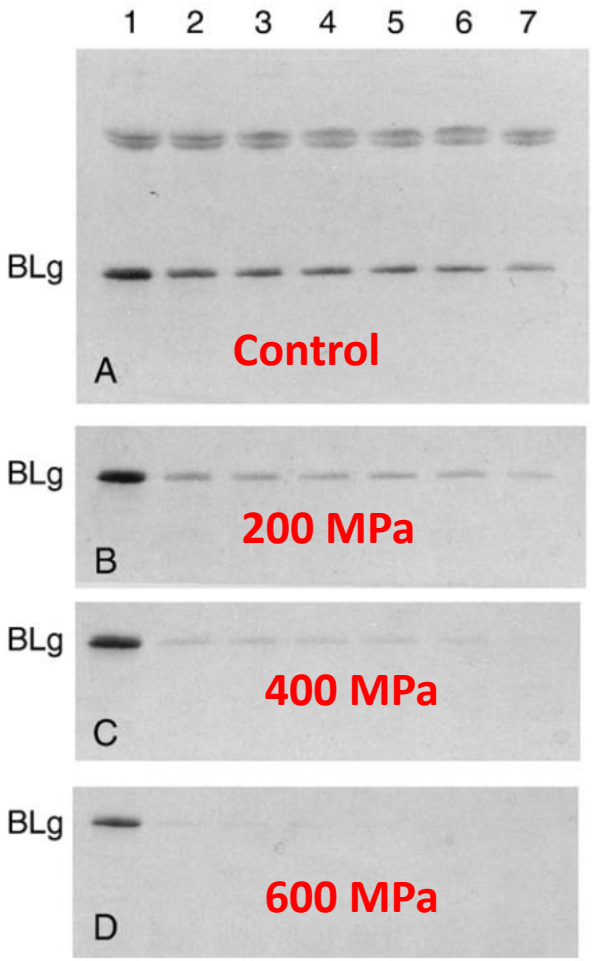
No impact of high pressure on digestibility of milk compared to heat



Considine et al. 2007

HP enhanced peptic digestion of β-lg, reducing allergenicity



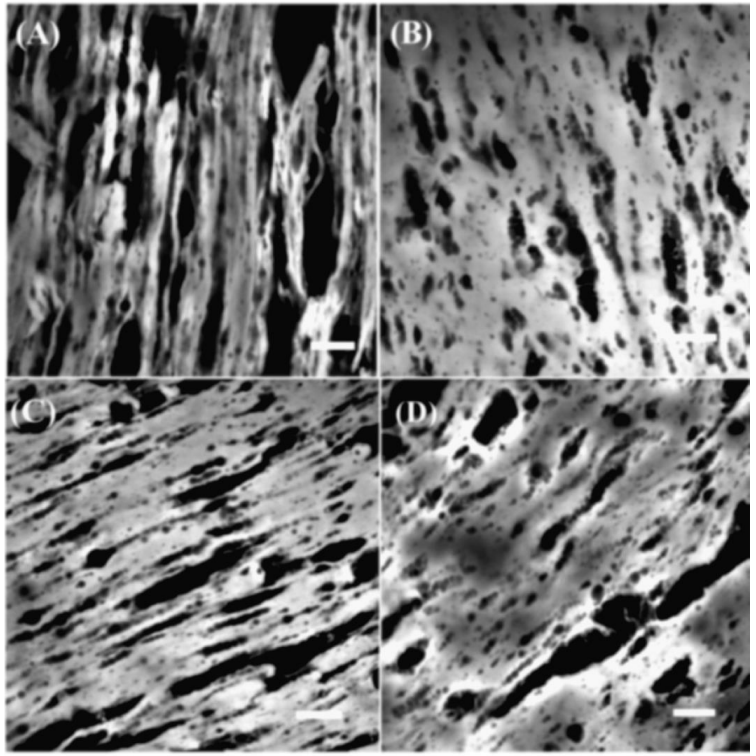
Zeece et al. 2008

Novel technologies and the cheese matrix

- Multiple technologies of interest for effects on the cheese matrix that can significantly impact on structure
- Impact on digestibility of interest for further study

Mozzarella cheese

Control 400 MPa x 10 min



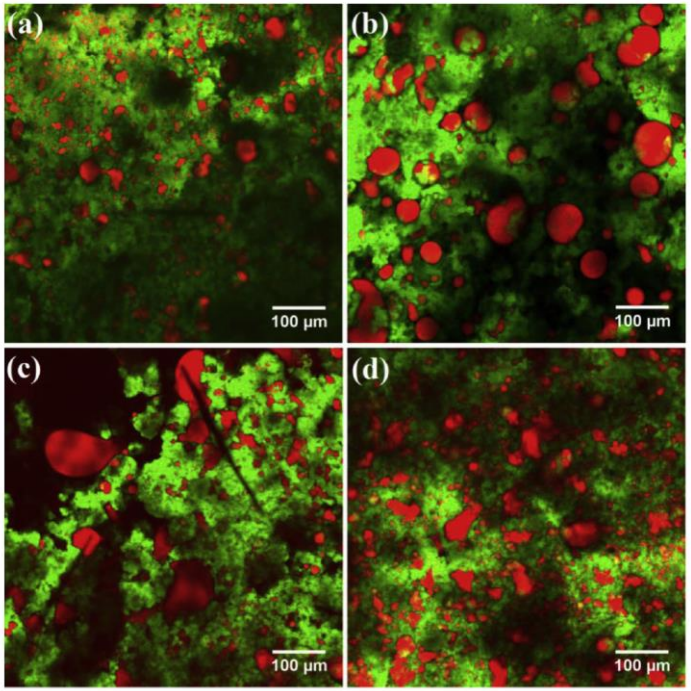
O'Reilly et al. 2002

3D printed processed cheese

Control Melted

D1

D15



Print (slow) Print (fast)

Le Touhic et al. 2018

Conclusions

- Milk is a complex matrix that processing makes more complex
- Existing processes (homogenisation, heat treatment) fundamentally alter the matrix
- Processing can enhance or alter digestion
- **Key example: the cheese matrix effect**
- Processing evolving – new structures, new opportunities