



## 3<sup>rd</sup> Edible Soft Matter Conference

7 – 10 July 2025

# ABSTRACT BOOKLET

# Oral presentations

Sponsors :



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## Tuesday 8<sup>th</sup> - Program

Time	Speaker's name	Title
9:00 - 9:45 a.m.	<b>Marta Martínez</b>	Edible architectures: Linking multi-scale structure to digestibility in seaweed-based food systems
9:45 - 10:00 a.m.	<b>Francois Boue</b>	Monitoring food structure during digestion: small-angle scattering, neutron and microscopies imaging, rheology, and computer simulation
10:00 - 10:15 a.m.	<b>Thomas Gibaud</b>	Time temperature superposition in carrageean gels
10:15 - 10:30 a.m.	<b>Lennard Schulte</b>	Tuning Cellulose Microfibrill Containing Plant-Protein Gels by Shear
10:30 - 11:15 a.m.		<b>Break</b>
11:15 - 11:30 a.m.	<b>Carolina Gomez</b>	In-situ crystallised lipid stabilisation of oil-in-water nano emulsions
11:30 - 11:45 a.m.	<b>Hanna Demchenko</b>	Starch-based Pickering emulsion added food-grade films: development and characterization
11:45 - 12:00 a.m.	<b>Nirzar Doshi</b>	Coacervation generality in systems involving leguminous-plant protein
12:00 - 12:15 a.m.	<b>Lena Vincent</b>	Stabilization of water-in-water emulsions by complex coacervate core micelles
12:15 - 12:30 a.m.	<b>Koen Wetterauw</b>	Towards a generic, predictive method for air classification of pulses illustrated on adzuki bean for functional protein ingredients
12:30 - 2:30 p.m.		<b>Lunch</b>
2:30 - 2:45 p.m.	<b>Laurence Ramos</b>	Shear start-up to probe and tune the network structure of model gluten
2:45 - 3:00 p.m.	<b>Gabriele D'Oria</b>	Edible microgel particle suspensions: what is the relationship between microgel particle elasticity and bulk rheology?
3:00 - 3:15 p.m.	<b>Jack Yang</b>	Predicting emulsion viscosity by encoding neural networks with physics; slowly removing the A from AI
3:15 - 3:30 p.m.	<b>José Bonilla</b>	Quantifying Microscopic Droplets in Colloidal Systems through Machine Learning-Based Image Analysis
3:30 - 3:45 p.m.	<b>Freya Knaggs</b>	Applying the Scaled Particle Theory to the problem of kafirin solubilities
3:45 - 4:30 p.m.		<b>Break</b>
4:30 - 4:45 p.m.	<b>Francesca Bot</b>	Evaluating liquid foam properties of plant protein isolates as egg replacers
4:45 - 5:00 p.m.	<b>Laura Scheldewaert</b>	Removing isolation process-induced aggregates improves the foaming properties of faba bean proteins
5:00 - 5:15 p.m.	<b>Rui Ouyang</b>	Understanding stratification during evaporation of colloidal dispersions (dairy and model)
5:15 - 5:30 p.m.	<b>Gijs Konings</b>	Mimicking the melting profile of adipose tissue through a controlled coalescence in dense emulsions
5:30 - 8:30 p.m.		<b>Afterwork &amp; Poster session</b>

# Monitoring food structure during digestion: small-angle scattering, neutron and microscopies imaging, rheology, and computer simulation.

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**Keywords:** digestion, gels, proteins, SAXS, Microscopy

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**Abstract:** Proteins digestibility depends not only on their composition but also on their structure, which in turn can be influenced by digestion processing.

Our model solid-like food was plant protein gels from rapeseed (napin and cruciferin) and potato (patatin). The solutions were gelled at different concentrations and pHs. By the use of UV fluorescence imaging (DISCO) and X-ray scattering (SWING) at SOLEIL synchrotron, we expected to obtain structural information at different length scales: 20-200 mm and 1-500 nm, respectively, during simulated gastro-intestinal digestion.

For SAXS using a narrow beam, we observed enzyme's reaction on the gel surface, progressing over several hours downward the capillaries, limiting the gastric digestion of the protein gels by the enzyme's diffusion. We could observe for different couples of depths and times the same states, in other words master curves revealing protein unfolding, refolding /aggregation, re-unfolding and finally cleavage. Both SAXS and neutron imaging and confocal microscopy showed progressive destruction of protein aggregates. The time-resolved evolution of the gel rheology can then be discussed.

The fluorescence imaging microscopy of gel pieces under digestion showed (i) probable enzyme's accumulation on the gel surface, with rather fast progression inside (several min), (ii) decrease in size and (iii) a simultaneous expel of proteins or amino-acids. An Agent Based Model software is developed for a detailed description.

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The results were different but compatible for gels synthesis at different pHs, showing convincingly that protein digestion is determined by the effect of food microstructure, influencing the diffusion and hydrolysis rates.

# Time temperature superposition in carrageean gels

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**Keywords (5 max):** Carrageenans, rheology, Time–Temperature Superposition

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**Abstract :** Carrageenans, extracted from red seaweeds, are bio-based, biodegradable, and edible sulfated polysaccharides. Their use has recently gained attention as a sustainable alternative to environmentally harmful materials. One promising application is the development of carrageenan-based gels, which are rich in proteins, vitamins, minerals, and essential fatty acids. Due to their excellent gelling properties, these polysaccharides present a viable substitute for traditional dairy-based yogurts, potentially reducing reliance on livestock farming in the food industry.

To better understand their mechanical behavior, I will apply Time–Temperature Superposition (TTS [1]) to compare the gelation properties of iota-, kappa-, and mixed iota/kappa-carrageenan gels with newly extracted kappa/iota-hybrid carrageenans from *Mastocarpus stellatus* (Loic Hiliou [2-3]). Unlike commercial carrageenans, hybrid carrageenans naturally incorporate both kappa- and iota-like sequences within a single molecular backbone, leading to distinct gelation properties that differ from simple kappa/iota mixtures.

TTS is a rheological principle that allows for the extension of the observable timescale of a material's mechanical behavior by shifting viscoelastic data collected at different temperatures onto a single master curve. This approach relies on the assumption that molecular relaxation is thermally activated—higher temperatures accelerate molecular motion, while lower temperatures slow it down. In thermoreversible gels like carrageenan, TTS provides critical insights into gelation dynamics, relaxation behavior, and the evolution of mechanical properties over time and temperature.

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# In-situ crystallised lipid stabilisation of oil-in-water nano emulsions

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**Keywords** (5 max): O/W emulsions, in-situ crystallisation, monoglyceride, triglyceride, core-shell droplets.

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## Abstract : (250 Words Max)

The overall aim of this research was to formulate oil-in-water nano emulsions stabilised solely via crystallising lipid additives in the oil phase. It was motivated by the coalescence stability of lipid crystal stabilised droplets due to the Pickering effect, and the prospect of introducing a nano emulsion which does not require surfactant-active additives in the aqueous phase. The imagined emulsion system will only be stable if crystallisation is initiated at the interface, avoiding protrusion of large crystals and thereby the creation of an interconnecting network of lipid droplets. Saturated monoglycerides are the obvious material choice. Exploiting the cooperative behaviour with a triglyceride of the same chain length was hypothesised to enhance the stability of the interface. To produce the nano emulsions, coarse emulsions with fully melted oil phases were passed through a microfluidizer equipped with quench cooling. Variables included overall amount and ratio of lipid additives, pressure, and post-processing temperature profile. Differential scanning calorimetry, dynamic light scattering, stability analysis, and cryo-scanning electron microscopy (SEM) were applied for material and emulsion characterisation. Processed emulsions were only partially stable against coalescence due a micrometre-sized droplet size population found for all emulsions, in addition to a submicron-sized population which showed no signs of creaming. The larger droplets are the result of re-coalescence prior to kinetic trapping of the microstructure via crystallisation. Creamed droplets formed clusters upon exposure to temperature above a minor low temperature thermal transition of the monoglyceride. Cryo-SEM micrographs revealed a core-shell droplet morphology, with shell thickness depending on formulation.

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# Starch-based Pickering emulsion added food-grade films: development and characterization

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**Keywords** (5 max): Bio-based films, Pickering emulsion added films, Water vapor permeability, Oxygen permeability

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**Abstract:** Pickering emulsions have gained increased relevancy for food applications. Adding Pickering emulsions into biopolymer films is a way to impact their mechanical properties such as hardness and tensile properties as well as water-vapor and oxygen permeability. This opens a discussion towards various applications including food packaging and microencapsulation and other areas. We report on coatings and free-standing starch-based Pickering emulsion added films. Medium-chain triglyceride oil and rapeseed oils are chosen as oil phase with deionized water being aqueous phase. Phase behavior and stability are studied and ternary phase diagrams formed for different starches – dehydrated potato starch, dehydrated rice starch, dehydrated maize starch and dehydrated sodium-octenyl succinate (E1450) modified waxy maize starch. These results allowed us to identify fully emulsified/uniform and stable phase regimes that are chosen to form films, which are then solidified by pectin in aqueous phase using electrospraying and solvent-casting techniques. Tensile properties, Vickers hardness and surface energies are investigated and shown how the added emulsions determine mechanical properties of free-standing films. Water permeability is measured using thermogravimetric analysis, resulting in decreased permeability values as compared to reference films that contain only pectin. Regulatory affairs and safety regulations are also discussed.

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## References:

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# Coacervation generality in systems involving leguminous-plant proteins

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**Keywords** (5 max): Liquid-liquid phase separation, Plant protein coacervation, legume proteins, protein droplets

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**Abstract :** (250 Words Max) The growing interest in plant-based foods has spurred research into liquid-liquid phase separation (LLPS) for structuring plant proteins. LLPS results in distinct biopolymer-rich and biopolymer-poor phases, influenced by various environmental factors, as highlighted in our article on coacervation involving plant proteins. The article discusses the potential applications in microencapsulation, microgel production, and food structuring. While LLPS has been well-studied with purified plant proteins and their mixtures with polysaccharides, its use in minimally processed plant protein sources remains largely unexplored. Additionally, we show that the hydrophobic amino acid composition of plant storage proteins, such as albumins and globulins, is comparable to animal proteins like whey and gelatin (often well-studied for coacervation).

In more recent work, we demonstrate the generality of pH-induced LLPS in commercial legume flours (soybean, pea, and fava bean) without ultra-purification of protein fractions. Unlike conventional salt-induced methods, our approach relies solely on acidification. Upon acidification, protein dispersions for all legumes transition through three distinct pH-dependent regimes: soluble proteins at high pH, coacervate droplets at intermediate pH, and clustering at lower pH. CLSM further confirms the formation of homogeneous, spherical protein-rich droplets with a Gaussian-like size distribution. Observations indicated that these coacervates do not coalesce at low centrifugal forces and can be redispersed after centrifugation. Interestingly, the resistance against coalescence strongly suggests the presence of proteins (or a mixture of proteins) at the interface. The investigation has reinforced LLPS as general behaviour in minimally processed legume flours, providing an opportunity for food industries.

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# Stabilization of water-in-water emulsions by complex coacervate core micelles

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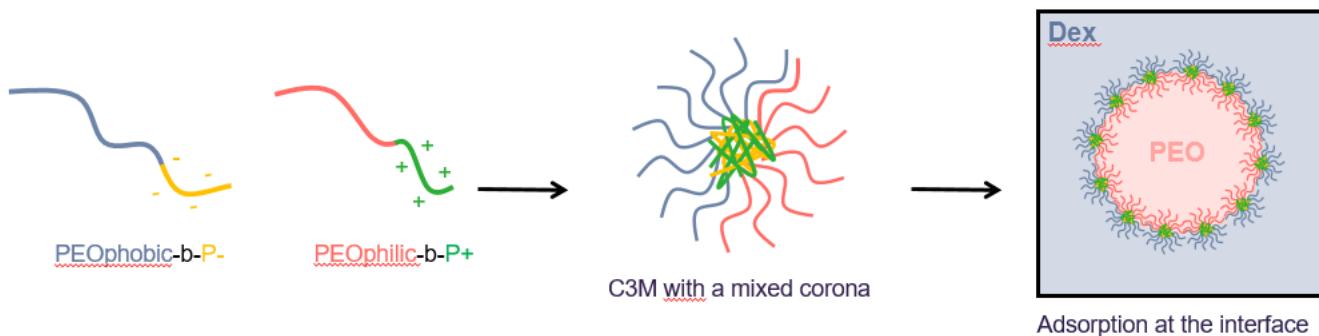
**Keywords** (5 max): Water-in-water emulsions, polyelectrolytes, complex coacervate core micelles, stabilization

## Abstract : (250 Words Max)

Water-in-water emulsions (WWE) form when aqueous solutions of incompatible polymers are mixed. These emulsions, that do not contain any organic phase, are of growing interest, particularly in the food industry as they allow texturation without fat. However, they possess a large interface and low interfacial tension, making the adsorption of molecular stabilizers, such as surfactants, difficult. Moreover, these all-aqueous systems require fully hydrophilic stabilizers displaying affinity for both phases. Therefore, using particles such as protein microgels or protein-polysaccharide complexes as stabilizers, namely Pickering effect, has proved effective in improving WWE stability. [1] [2] However, the relationship between the stabilizers' chemical composition and their ability to stabilize WWE is poorly understood. A recent work showed that poly(ethylene oxide) (PEO)/dextran WWE in the presence of dextran-derived microgels displaying affinity for both phases had an excellent stability. [3]

In this context, complex coacervate core micelles (C3Ms), consisting of polyelectrolyte complexes stabilized by a neutral hydrophilic polymer segment attached to one of the polyelectrolytes, appear as promising candidates. Indeed, their size and surface chemistry (thus, affinity for both phases) can be tuned by varying the copolymer composition. [4]

In this study, we will present PEO/dextran emulsions in the presence of C3Ms with a PEO corona. We will highlight the role of the core in C3Ms partitioning. Also, we will show that their performance varies with the length of the neutral block and ionic strength. We will also present results with Janus C3Ms that have both PEO-philic and PEO-phobic polymer segments in their corona.



## References

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# Towards a generic, predictive method for air classification of pulses, illustrated on adzuki bean for functional protein ingredients

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**Keywords** (5 max): air classification, predictive method, adzuki bean, novel ingredients, gelation

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**Abstract :** Sustainable plant-based protein ingredients are required to facilitate the protein transition, and dry fractionation is an energy efficient approach to create pulse protein concentrates. Dry fractionation of pulses is commercially done by milling and air classification, in which it is key to optimize the protein enrichment and yield. In research, this often requires trial-and-error optimization approaches per raw material. This hinders the commercial expansion to less known pulses, even though less explored pulses may potentially have interesting functional properties. Therefore, we propose a simple physics-based air classification model that predicts the protein enrichment and yield from any desired pulse. The method incorporates both operating settings and pulse characteristics, hence it is generic to a large extent. It has the potential to pinpoint optimal operating settings prior to experiments, and to judge the intrinsic suitability of raw materials for air classification. The proposed approach should aid the efficient production of novel pulse protein concentrates.

The method is illustrated for the case of adzuki bean, which has not been dry fractionated before. After producing a protein concentrate according to the optimal operating settings, its gelling properties were tested as well, and compared to those of isoelectrically precipitated adzuki bean protein isolates.

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# **Shear start-up to probe and tune the network structure of model gluten**

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**Keywords** (5 max): rheology, gluten, polymer

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## **Abstract : (250 Words Max)**

Gluten is a plant protein network that is responsible for the viscoelastic properties of bread dough. Studying the rheological behavior of gluten gels under large shear stresses is a way to probe the network structure and to better understand how gluten develops during the kneading process.

To mimic the dough kneading process, several consecutive large strain start-up shear experiments, followed by stress relaxation after flow cessation, were imposed to model gluten gels. Unexpected double stress overshoots are measured during the initial start-up shear for samples approaching the critical gel state. The disappearance of the second stress overshoot during the subsequent start-up shear could be attributed to the destruction of a loose network. Of note, following a rest period, the double stress overshoot may reappear, indicating the self-healing characteristics of these gels. Furthermore, when samples are subjected to successive shear start-up protocols with short relaxation periods, the gluten network undergoes progressive reorganization and densification over time. Our results show that the state of a gluten gel is not solely dependent on its composition and the ageing process, but also on the mechanical shear history.

This work demonstrates that gluten networks adapt significantly throughout the kneading process. Given the distinctive rheological properties of gluten gels, the emergence of specific behaviors in the nonlinear regime may facilitate a more comprehensive understanding of gluten.

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# **EDIBLE MICROGEL PARTICLE SUSPENSIONS: WHAT IS THE RELATIONSHIP BETWEEN MICROGEL PARTICLE ELASTICITY AND BULK RHEOLOGY?**

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**Keywords (5 max):** Microgel, Suspension, Rheology, Microfluidics

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## **Abstract:**

Foods made of soft particles in suspension are ubiquitous e.g. smoothies, soups, yogurt, starch pastes. Depending on the nature of particle interactions, they exhibit interesting rheological behaviors like shear thinning, continuous and discontinuous shear thickening. The investigation of soft particle systems is important as in this case, particle interactions, like adhesion or friction, will have important consequences on the flow.

Leveraging on previous work done in our team, we present an innovative system of soft particles which elasticity can be tailored at will. These spherical microgels with tunable elasticity were obtained from non-Brownian W/O droplets of controlled size ( $\sim 50\mu\text{m}$ ) using a microfluidic T-junction chip. The dispersed phase consisted of a whey protein isolate (WPI) solution and the continuous phase was made of sunflower oil. The W/O emulsion was then heated to induce the gelation of the dispersed phase forming the microgel particles. The elasticity of the microgels was systematically varied by tuning the concentration of the WPI, and investigated by measuring the elastic modulus in the linear viscoelastic region of bulk WPI gels at different concentrations. The microgels were centrifugated and subsequently dispersed in water. Dense suspensions at volume fractions ranging from  $\phi \sim 50\%$  and the jamming limit were studied, where microgel interparticle contacts is dominant. The rheology of the resulting suspensions was investigated with a shear stress sweep.

In conclusion, this study brings new insights into the rheology of suspensions of soft particles. This study also introduces an innovative technological platform to produce particles with controlled microscopic properties.

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# Predicting emulsion viscosity by encoding neural networks with physics; slowly removing the A from AI

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**Keywords** (5 max): Neural networks, Machine learning, Quemada model, emulsion viscosity, prediction

AI is proposed as a tool to improve the predictability of food soft matter systems. A major problem in using AI is the data scarcity, consequently, still the huge laborious experimental efforts to collect them. Another problem is the statistical character of AI, which neglects causality. We report on a novel route that addresses these two problems at the same time.

We have addressed a specific problem of predicting emulsion viscosity. We have encoded a neural network with physics based information, namely a Quemada model. This physics information resembles the existing physical hierarchical structure within the system. After this encoding with physics information, we optimized this so called Physics encoded Neural Network (PeNN). The model predicts emulsion viscosity over shear rate based on oil volume fraction.

We show that the mean squared error (mse) of the PeNN is always smaller than that of the NNs, in the order of a factor of thousand. Furthermore, the PeNNs capture extrapolation and interpolation very well, contrary to the NNs. This is most probably due to the inherent higher causality in the network by means of encoding it with physics information. It is furthermore shown that PeNNs need a much smaller data set size for training than the NNs to achieve a similar mse. This extraordinary finding shows the potential to use PeNNs when data is scarce or laborious to collect. The newly presented PeNNs are the next generation of predictive AI models for food soft matter systems.

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# Quantifying Microscopic Droplets in Colloidal Systems through Machine Learning-Based Image Analysis

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Mathias P. Clausen<sup>2</sup>, & Jose C. Bonilla<sup>1,2</sup>, Speaker: José C. Bonilla

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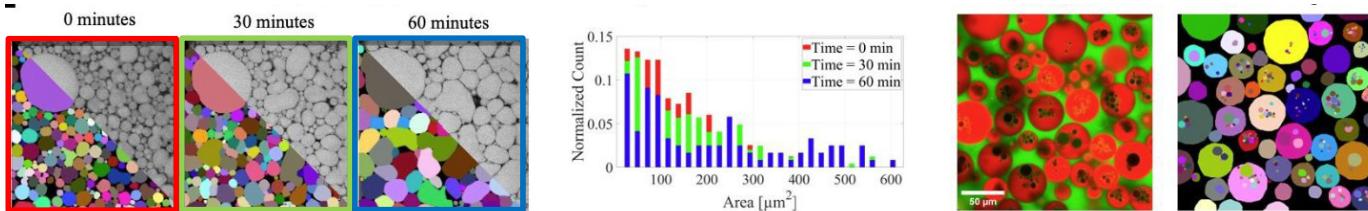
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**Keywords** : Image analysis, Machine Learning, Microscopy, Colloids

New microscopic imaging techniques provide data at unprecedented length and time scales that allow us to visualize food and soft matter at the microscopic scale helping us understand their organization and structure. Each image, or micrograph, can represent millions of data points (pixels). As the visualization techniques become available, the challenge has shifted from visualizing to extracting and analyzing meaningful data from the micrographs. Advances in data science, including machine learning, are crucial for progress in image processing and analysis. This talk will show various image analysis techniques to quantify microstructures in food and soft matter (e.g., droplets, fibrils, networks), focusing on our image analysis workflow, MIDAS (Microscopic Droplet Analysis), developed from cell segmentation software (Saalbrink et al., 2025). MIDAS segments droplets in microscopy images across a wide range of droplet sizes within the same image. Its segmentation performance is compared to other methods for segmentation of cells like Cellpose and StarDist and discussed based on the intrinsic approach each algorithm is set up to follow. Besides segmentation, MIDAS also extracts quantitative data from all droplets in the image (e.g., droplet packing and shape data). Analyzing microscopic images allows us to bring data from direct visualizations enabling us to quantify droplets within droplets, as in the case of double emulsions. The MIDAS workflow is available as open-source code in online repositories. Implementing accurate image analysis will provide new data that can be correlated with data at different length scales (e.g., rheology), advancing our understanding of food structures.



# Applying the Scaled Particle Theory to the problem of kafirin solubility

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**Keywords** (5 max): Solvation; Hydrophobicity; Scaled Particle Theory; Sorghum Kafirin; Cost cavity creation

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## Abstract: (250 Words Max)

Proteins have multiple functionalities such as structuring ability (aggregation-gelation, coacervation) and surface properties (emulsification, foaming, solid surface adsorption). Our working hypothesis is that protein solubility is the key to controlling these functionalities, through the Gibbs free energy of cavity creation ( $\Delta G_C$ ), one of component of solvation free energy. In order to better rationalise the solvation process of plant proteins, we used the Scaled Particle Theory, SPT, to compute  $\Delta G_C$  and chose to work with proteins known for their particularly low solvation rate in water, sorghum kafirin.

Kafirin, sorghum's storage proteins, are known for their high content of hydrophobic amino acids (60-65 %) in comparison to other prolamins, like wheat gluten proteins or corn zeins (about 50-55%). The resulting high hydrophobicity and self-assembling properties of kafirins lower their solubility.

We aim to compute the energy needed to solvate these hydrophobic proteins by focusing on the structure of solvent molecules around non polar residues based on cavity formation. Cavity creation is pointed out to be an entropy driven process. In this study, we calculated  $\Delta G_C$  by SPT [1], [2], [3], using the characteristics of kafirin, in *tert*-butanol, isopropanol, ethanol and water.

Following an experimental design, we showed that  $\Delta G_C$  is one of the main factors influencing kafirin solubility, along with temperature. The  $\Delta G_C$  for the different solvents tested varies from 0.157 to 0.317  $\text{kJ}\cdot\text{mol}^{-1}\cdot\text{\AA}^{-2}$ . The solvents' ranking of cost of cavity creation is  $\Delta G_C(\text{tert-butanol}) < \Delta G_C(\text{Isopropanol}) < \Delta G_C(\text{Ethanol}) < \Delta G_C(\text{Water})$ . Finally, solvents with high packing density and low density fluctuations, decrease the energy of cavity creation resulting in increased protein solubility.

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## Acknowledgements

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# Enhancing the thermal and colloidal stability of lentil protein-stabilised emulsions using high pressure homogenisation pre-treatment

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**Keywords:** Lentil protein isolate, high pressure homogenization, emulsion, colloidal stability, thermal stability

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## Abstract:

This study investigates the enhancement of thermal and colloidal stability of lentil protein-stabilised emulsions through high-pressure homogenisation (HPH) pre-treatments. Lentil protein dispersions were homogenised at pressures ranging from 0 to 150 MPa and subsequently used to formulate emulsions with 29% w/w total solids. Results indicated that HPH significantly improved protein solubility, increasing from 55.7% at 0 MPa to 93.2% at 50 MPa. Particle size distribution analysis showed a reduction in oil globule size, with volume-weighted mean diameters of 1.4 and 1.19 µm for the 0 and 150 MPa samples, respectively. Emulsions prepared from HPH pre-treated dispersions exhibited greater physical stability, with separation rates decreasing from 16.75%/h (0 MPa) to 2.05%/h (150 MPa). Rheological analysis showed that HPH pre-treatments led to low initial apparent viscosities (28.30 and 22.56 mPa·s at 0 and 150 MPa, respectively) as well as lower final viscosity (60.52 and 34.88 mPa·s at 0 and 150 MPa, respectively) after thermal treatment at 90°C for 2 min, compared with the untreated samples. Confocal laser scanning microscopy images showed a more homogeneous distribution of oil globules, and reduced flocculation, after the thermal treatment in emulsions prepared from HPH-treated dispersions. The results indicated an enhancement of the thermal stability of the HPH pre-treated samples, and this has been linked with the improved solubility of lentil protein following HPH treatment. These findings highlight the potential of HPH as an effective pre-treatment to enhance the techno-functional properties of lentil protein-stabilised emulsions, supporting the development of stable and sustainable plant-based food products.

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# Removing isolation process-induced aggregates improves the foaming properties of faba bean proteins

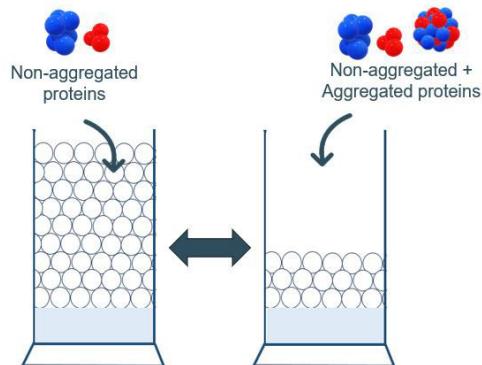
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**Keywords** (5 max): Faba bean protein; Protein aggregates; Foam stabilization mechanisms

**Abstract :** Faba beans (*Vicia faba*) are a promising protein crop in the context of the (partial) shift from animal to plant protein<sup>1,2</sup>. Protein isolates are typically obtained through wet isolation, often resulting in partial protein aggregation<sup>3</sup>. However, the impact of such aggregates on the foaming properties of the isolate remains poorly understood. This study investigates the effect of aggregates in faba bean protein isolates, obtained by aqueous extraction (pH 7.0) followed by isoelectric point precipitation (pH 5.0), on their foaming properties. Ultracentrifugation (183 800 g, 30 min) was applied to protein solutions to effectively remove isolation process-induced aggregates (25% of the proteins). Comparing protein solutions with and without aggregates, at equal soluble protein content (0.4% w<sub>soluble protein</sub>/v), revealed significantly lower foaming capacities in presence of aggregates (27% reduction), indicating their negative impact on foaming formation. Interestingly, foam stability was not affected by aggregates. The lower foaming capacity could not be explained by protein adsorption dynamics analyses, with no significant difference between solutions with and without aggregates observed. Since foaming through whipping is a dynamic process, we hypothesize that aggregates, brought through motion to the air-water interface, interfere with bubble formation or disrupt bubbles at an early stage, thereby reducing foam formation. This will be further researched with alternative foaming methodologies (e.g. monolayer bubbling equipment), and thin liquid film analyses. These findings highlight the importance of understanding the influence of protein colloidal state on foaming properties for the efficient use of plant proteins in food products.



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# Understanding stratification during evaporation of colloidal dispersions (dairy and model)

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**Keywords** (5 max): colloidal drying; Hele-Shaw cell; crack formation; drying kinetics; dairy colloids

## Abstract:

Producing biomimetic dairy powders with nutritional benefits passes through the challenging control of their physical properties, such as shape and mechanical response of the dry particles. Recent studies highlighted colloid stratification in the skin of drying droplets of dairy protein mixes, which influence their final morphology. However, unraveling the stages of protein stratification remains an unsolved question, limiting the control of the drying process<sup>1-6</sup>.

To fill this gap (Figure 1), in this study we investigate the evaporation of colloid suspensions in Hele-Shaw cells with different height under controlled environmental conditions<sup>7-8</sup>. The drying dynamics of silica colloids (HS40, TM50) and dairy proteins (whey proteins and casein micelles) were explored by digital microscopy. We characterized the formation and propagation of parallel cracks in the setup to deduce how interfacial colloid self-arrangement influences the mechanical properties of the matrices. Our preliminary findings show good agreement with existing models, though the influence of colloid size remains to be validated. The evaporation rate seemed to decrease throughout the evaporation, as underlined by the cyclical slowdown of crack propagation and the emergence of transversal cracks delimiting regions with increasing width. This specific behavior can be explained by the different internal stress distribution moving inward the cell, closely linked to the predicted variation in terms of evaporation rate.

To corroborate our hypothesis and quantify the drying kinetics for single colloids and mixes, the drying-induced mass loss is currently monitored by ultraprecision balance. Coupling microscopy and mass measurements we aim at modeling the the drying process at the micron-scale and predict powder properties.

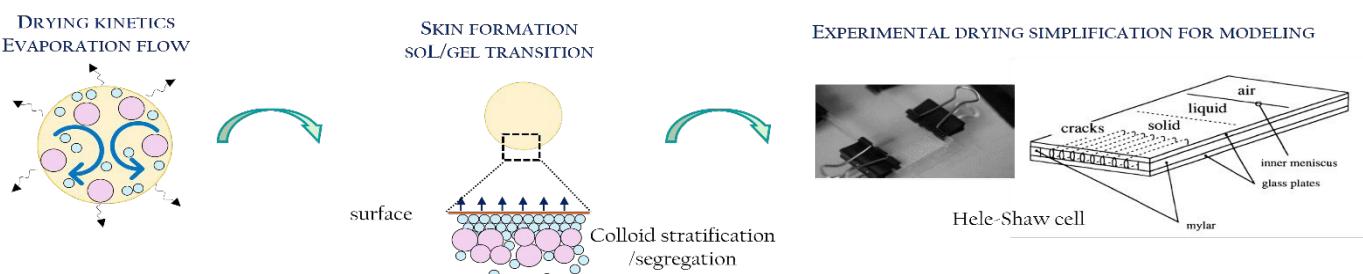


Figure 1: Strategy for exploring colloid drying dynamics

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# Mimicking the melting profile of adipose tissue through a controlled coalescence in dense emulsions

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**Keywords** (5 max): adipose tissue, rheology, crystallisation, HIPE

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**Abstract :** The adipose tissue is a densely packed system of fat cells around and in between muscle tissue. In meat products this adipose tissue is responsible for the flavour and the perceived juiciness of meat. Mimicking these properties is essential to create meat analogues with good sensory quality. We could mimic the structure and mechanical properties of adipose tissue at elevated temperatures by binding oil droplets with pea proteins. However, the challenge is to mimic the system hardness at ambient temperatures and melting behaviour during heating. When liquid oil was used in the oil droplets, no melting profile was observed, while when crystalline fat was used, we could mimic the melting profile of animal fat, as measured with rheology. Using laser diffraction and confocal microscopy, it was found that after a heating-cooling-heating cycle, fat crystals protrude from the oil droplet interface, bridging neighbouring droplets and leading to arrested coalescence. Thus, we could trigger a decrease in viscoelasticity by increasing the temperature beyond the melting point of the crystalline fat to obtain a behaviour similar to melting. By changing the crystalline fat content we could influence the extent of coalescence either by reducing the crystal protrusion into the continuous phase or by modulating the cluster size of aggregated crystal droplets. Controlling this coalescence rate of the oil droplets in dense emulsions yields melting profiles similar to those of animal fat, which can be the key to creating accurate adipose tissue mimics.

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## Wednesday 9<sup>th</sup> - Program

Time	Speaker's name	Title
9:00 - 9:45 a.m.	<b>Clément de Loubens</b>	Aggregation and gelation of whey proteins under flow
9:45 - 10:00 a.m.	<b>Ruifen Li</b>	Structure characterization of faba bean protein stabilized foams under processing
10:00 - 10:15 a.m.	<b>Margot Grostete</b>	Miniaturization of the fouling of whey proteins in falling film evaporators by microfluidics
10:15 - 10:30 a.m.	<b>Tatiana Porto Dos Santos</b>	Microfluidic EDGE chip to assess interfacial protein adsorption at very short time-scales
10:30 - 11:15 a.m.		<b>Break</b>
11:15 - 11:30 a.m.	<b>Mhammad Fahim Hussain</b>	Investigating Thermomechanical Structuring of Protein Networks Using closed cavity Rheometer
11:30 - 11:45 a.m.	<b>Gireeshkumar Balakrishnan</b>	Carageenan Gels Formed Through Crosslinking with Rapeseed proteins
11:45 - 12:00 a.m.	<b>Gökhan Uğur Atıl</b>	Temperature-Dependent Structural Evolution of Defatted and Non-Defatted Pea Globulins: A Small Angle X-ray Scattering (SAXS) and Synchrotron Radiation Circular Dichroism (SR-CD) Study
12:00 - 12:15 a.m.	<b>Vien Monterde</b>	Air/water interfacial properties and thin film drainage dynamics of compositionally diverse wheat flour water extracts
12:15 - 12:30 a.m.	<b>Claire Berton Carabin</b>	The competition between endogenous phospholipids and proteins from pea protein isolate rules their interfacial properties
12:30 - 2:30 p.m.		<b>Lunch</b>
2:30 - 2:45 p.m.	<b>Ghazi Ben Messaoud</b>	Less for More: Reducing initial Protein Content to Enhance the Viscoelasticity of Heteroprotein Coacervates
2:45 - 3:00 p.m.	<b>Vivek Narsimhan</b>	Predicting the swelling of starch granules using Flory-Rehner theories
3:00 - 3:15 p.m.	<b>Maria Mouktane</b>	Formation of Microcapsules using Rapeseed Proteins
3:15 - 3:30 p.m.	<b>Sylvie Clerjon</b>	Quantitative Magnetic Resonance Imaging to characterize food process. A focus on sodium diffusion
3:30 - 3:45 p.m.	<b>Alexy Brunel</b>	Gelled waters for swallowing disorders: from rheological, tribological and structural characterizations to sensory perception
3:45 - 4:30 p.m.		<b>Break</b>
4:30 - 4:45 p.m.	<b>Ekaterina Garina</b>	High-moisture extrusion of soy proteins: pH-dependant structure formation mechanism: pH-dependant structure formation mechanism studied by Small-Angle Scattering
4:45 - 5:00 p.m.	<b>Mehdi Habibi</b>	Normal Force Rheology as a New Tool to Characterize Anisotropic Food Structures
5:00 - 5:15 p.m.	<b>Marco Ramaiolli</b>	On the influence of the rheology of beverages on texture perception and consistency
5:15 - 5:30 p.m.	<b>Luisa Azevedo-Scudeller</b>	Oleofoams based on dairy proteins as fat replacer
from 7:30 p.m.		<b>Gala Dinner - <u>Origines</u> - <u>Maps link</u></b>

# Structure characterization of faba bean protein stabilized foams under processing

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**Keywords** (5 max): faba bean isolate; plant protein; heat-set foam; foam microstructure

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**Abstract :** Foams are important in creating appealing structures in food. A large amount of research is available on the mechanisms of structure formation which impart stability of animal-derived proteins (dairy, egg, and gelatin) foams. However, much less is understood on the functionality of plant proteins. This study investigated the changes in the microstructure and rheological properties of faba bean protein stabilized foams induced by pH changes, sugar addition and heat treatment, with egg white protein as control.

For faba bean protein, the protein solubility is highly dependent on the pH, and results illustrate how such changes can impact foam stability, with foams at pH 4 having higher overrun, stability and a more rigid structure, compared to those at neutral pH 7, which was related to stabilization of the air bubbles by larger protein aggregates surrounding at the lamella structure. Upon heating, the faba bean protein stabilized foams at pH 7 was nearly unaffected, whereas at pH 4 heating induced formation of very large structures of aggregated proteins and merging of air bubbles with the resulting impact on rheological properties depending strongly on the heating methods. Surprisingly, sugar addition decreased the overrun of the foams and the storage modulus of the resulting foam, but hindered liquid drainage to some extent. Upon heating, sugar could contribute to maintaining of the spherical bubbles and either provide comparable or higher storage modulus. The toughest foams are the faba bean foams at pH 4 with/without sugar addition after microwave heating.

This study highlights that an introduction of plant proteins for stabilizing food foams requires not only an understanding of the foaming properties, but also an understanding of what happens during processing, such as during the heating, pH changes and interaction with other ingredients.

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# Miniaturization of the fouling of whey proteins in falling film evaporators by microfluidics

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**Keywords** (5 max): Deposits, Aggregation, Kinetics, Microscopy

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## Abstract: (250 Words Max)

Fouling remains an unsolved challenge in the dairy industry, affecting operational efficiency and product quality. While extensive research has focused on fouling dynamics in heat exchangers, falling-film evaporators (FFE) have received less attention. There is scientific consensus that heat-induced protein denaturation is the main reason for fouling development, neglecting other potential mechanisms especially at relatively low temperatures.

In a recent study [1], we demonstrated that increasing shear rates foster the formation of whey protein deposits and enhance their structural complexity even at temperatures below the denaturation one. While highlighting the role of shear rate, this work does not shed light on the surface and bulk mechanisms leading to deposit formation.

In this context, we characterized in real-time the stages of dairy fouling development using microfluidic devices simulating FFE conditions. We aimed at discriminating the effects of shear ( $0\text{-}200 \text{ s}^{-1}$ ) and temperature (50–75 °C) on the kinetics of deposit growth during the flow of whey protein solutions (10 wt. %). The key findings of this analysis can be summarized in two points:

1. At low (50 °C) and high temperatures (75 °C), no deposit formation and fast channel clogging are observed, respectively, thus underlining the strong influence of heat-induced protein denaturation.
2. At intermediate temperatures (65 °C), shear is a limiting factor controlling the accumulation of solids at the surface.

These results provide a new insight on fouling mechanisms at the micron-scale and underline the coupled effect of shear and temperature under the typical FFE operational range of temperatures.

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## References.

- [1] M. Grostete et al., "Exploring the formation of surficial whey protein deposits under shear stress by rheofluidic approach," *Int J Biol Macromol*, vol. 274, p. 133291, 2024, doi: 10.1016/j.ijbiomac.2024.133291.

# Microfluidic EDGE chip to assess interfacial protein adsorption at very short time-scales

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**Keywords:** Dynamic interfacial tension, droplets, bubbles, microfluidics, whey protein isolate.

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**Abstract :** Proteins have been extensively employed to stabilize two-phase systems: oil-in-water (o/w) emulsions and air-in-water (a/w) foams. During the formation of such systems, droplets or bubbles are generated and proteins continuously move towards the interface, rapidly reducing the interfacial tension (i.e., in sub-second time-scale), and stabilizing these small objects against coalescence. Therefore, understanding these early effects is of great importance. In traditional analytical methods, such as automated droplet tensiometry (ADT), the dynamic interfacial tension can be acquired only in the second time-scale, meaning that protein adsorption at the interface generally takes place before the measurement initiates. Besides, the ADT does not allow measurement of highly concentrated systems. These challenges can be mitigated when using our microfluidic partitioned Edge-based Droplet Generation (EDGE) tensiometer that allows measurement of highly concentrated protein solutions (whey protein isolate, WPI, 2.5 - 10 wt.%) at the interface with either oil or air. Small channels allow for precision formation of droplets and bubbles in the micrometer scale. Measurements are performed in the (sub) milli-second time range, which is in line with typical time-scales that would occur in large scale processes, and the results line up with those obtained by ADT at much longer time scales. This implies that the EDGE device can distinguish very early-on effects of proteins at fluid interfaces. Additionally, the EDGE tensiometer enables assessing the impact of high protein concentrations on the formation of emulsions and foams, which is highly pertinent for designing stable food systems.

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# Synergetic Effect of Plant Proteins Mixtures for increasing foams formulations and properties

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**Keywords:** Interfacial rheology, Bulk rheology, Plant proteins mixtures, Foam quality.

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## Abstract:

Plant-based proteins have gained more attention in various industrial sectors including food due to their health benefits and environmental advantages. They become an option to replace classical Petro sourced surface-active agents for gellification, emulsification, and foaming applications.

Plant proteins from oilseeds that originated from France were used. The proteins were extracted from sunflower and linseed. Each protein isolate is able to produce and stabilize foams. Sunflower proteins isolate leads to a high foamability but low stability (6 hours). Linseed proteins isolates are able to produce weak foamability but the foams are stable for a long period (3 day).

The idea here is to mix the 2 plants proteins in order to enhance the foam properties. To this extent, mixture of two proteins with proportions of sunflower-linseed proteins of 50%-50%, 75%-25%, and 25%-75% were used.

The interfacial properties (surface tension and interfacial rheology) were studied in order to be correlated to the foam properties. The foam properties and the interfacial properties depend on the proportion of both proteins. All the mixtures produce better foam than each protein alone. The synergetic effect is highlighted for mixture containing 75% sunflower and 25% linseed proportion. In that case, a high foamability coupled to a very high foam stability are obtained. In particular, the foam remains stable during 7 days. This result is very impressive since most of proteins are only

able to stabilize foams for a couple of hours. This work paves the way for the development of bio-based materials stabilizers of foam products.

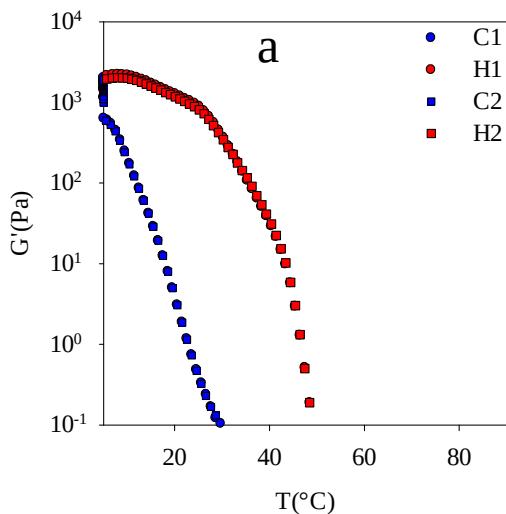
# Carrageenan Gels Formed Through Crosslinking with Rapeseed proteins

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**Keywords** (5 max): Thermoreversible gels , Rheology, Confocal microscopy, Hydrogen bonding  
Opposite charge interactions

**Abstract:** Recently, rapeseed proteins, mainly cruciferin and napin, have gained attention due to sustainability considerations. In this study, we examine aqueous mixtures of the anionic polysaccharide  $\kappa$ -carrageenan ( $\kappa$ -car) with cationic napin or anionic cruciferin as well as with rapeseed protein isolate (RPI), which contains equal amounts of napin and cruciferin. A synergistic interaction between  $\kappa$ -car and rapeseed proteins leads to thermoreversible gel formation upon cooling without inducing the coil-helix transformation of  $\kappa$ -car. Figure 1a shows the evolution of  $G'$  during heating and cooling cycles of  $\kappa$ -car/napin mixtures. Both opposite charge interactions and hydrogen bonding play significant roles, with the former causing formation of dense complexes leading to a decrease of the gel strength. Unlike napin, RPI and cruciferin form irreversible gels upon heating at 90°C, further reinforced by  $\kappa$ -car during cooling (Figure 1b). The effects of varying the protein and  $\kappa$ -car concentrations, the pH and ionic strength on the rheological properties and microstructure before and after heating will be discussed.



**Figure 1:** Evolution of  $G'$  as a function of temperature for  $\kappa$ -car/napin (a) and  $\kappa$ -car/RPI (b) mixtures during different cooling (C1 and C2) and heating cycles (H1 and H2).

## Temperature-Dependent Structural Evolution of Defatted and Non-Defatted Pea Globulins: A Small Angle X-ray Scattering (SAXS) and Synchrotron Radiation Circular Dichroism (SR-CD) Study

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Pea protein isolates are functional ingredients which contain lipid contaminants. The objective of this study was to evaluate if the presence of these lipids affects the structure of purified legumin and vicilin fractions. Pea proteins were extracted from a pea protein concentrate (Veskorn, Norway) "as is" or defatted using a chloroform and methanol solvent mixture in a 2:1 volume ratio. Pea globulins were extracted through alkali solubilization followed by isoelectric precipitation with hydrochloric acid. Legumin-rich and vicilin-rich fractions were then obtained by selective precipitation using a 0.2 M borate buffer containing 0.5 M NaCl at pH 8.

The proteins' structure and their stability were investigated between 25°C and 85°C, by applying *in situ* heating. NanoDSC was employed to follow the thermal transitions of protein fractions and combined with structural analysis using small angle x-ray scattering (SAXS) and synchrotron radiation circular dichroism (SR-CD), to elucidate how the protein structure evolves across the temperature range. SAXS intensities as a function of  $q$  were evaluated using high resolution models based on AlphaFold 3 (Google Deep Mind, London, UK) structural prediction of legumin and vicilin, based on the amino acid sequences which were taken from UniProt database.

SAXS analysis revealed that the defatting process did not significantly influence the structure of either legumin or vicilin fractions. At 25°C, both defatted and non-defatted vicilin exhibited hexameric structures. A clear transition to dimeric structures was observed for both defatted and non-defatted vicilin fractions. Legumin maintained hexameric structures at lower temperatures but transitioned to trimeric structures at temperatures exceeding 65°C. These results were well in agreement with the thermal transitions measured by NanoDSC, whereby legumin exhibited a higher denaturation temperature compared to vicilin. Synchrotron CD data showed a specific spectral change for vicilin between 187 nm and 197 nm at higher temperatures, which indicate heat-induced conformational adjustments in secondary structure. This was not the case for legumin.

In summary, this high resolution structural study combining SAXS and SR-CD analyses provide a detailed understanding of the thermal behavior and self-assembly mechanisms of pea protein fractions, revealing that the defatting process did not affect nor compromise the legumin's and vicilin's structure as well as their heat-induced structural changes.

# Air/water interfacial properties and thin film drainage dynamics of compositionally diverse wheat flour water extracts

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**Keywords** (5 max): Air/water interface, Wheat extract, Thin film balance, Interferometry, Foaming properties

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**Abstract:** The role of water-extractable wheat flour constituents and their interactions in determining the stability of wheat-based foam-type foods, such as bread doughs, remain largely unexplored. Furthermore, the influence of drainage dynamics of the thin liquid films (TLFs) between gas bubbles to food foam stabilization is often overlooked. In this study, air/water (A/W) interfacial, TLF drainage, and foaming properties of compositionally diverse wheat flour aqueous extracts were investigated. Such extracts were either used as such or modified by dialyzing out (i) low molecular mass constituents or (ii) both low molecular mass constituents and enzymatically hydrolyzed carbohydrates. This approach resulted in extracts with progressively increasing protein contents and distinct carbohydrate compositions. Wheat extract constituents created highly elastic A/W interfaces, regardless of the type of extract modification, suggesting a significant contribution in this regard from water-extractable wheat proteins. Notably, TLFs stabilized by wheat extracts with high levels of arabinoxylan (AX) with high molecular mass had significantly greater stability, implying a positive role of large AX molecules in TLF stabilization. This was further confirmed in TLF experiments where AX was enzymatically degraded. All extracts showed similarly good foaming properties, implying a dominant role for water-extractable wheat proteins in determining foaming. The strongly elastic A/W interfaces formed by these proteins, optionally supported by large AX molecules, likely reduced liquid drainage to such an extent that coalescence and disproportionation were largely delayed. The findings of this study could facilitate further investigations on the possibility of tuning protein-AX interactions toward improved foam stability.

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# The competition between endogenous phospholipids and proteins from pea protein isolate rules their interfacial properties

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**Keywords** (5 max): Dilatational rheology; Interface; Pea proteins; Phospholipids; Competitive adsorption

**Abstract:** Sustainable incentives foster the use of plant-based ingredients as emulsifiers, but their composition, functionality and interfacial properties deserve more attention. Our group recently highlighted high contents of endogenous phospholipids in pea protein isolate (PPI), as well as the potential of high-pressure homogenization (HPH) to release submicron lipid structures in aqueous suspensions [1]. These findings raised the pivotal question of the interfacial properties of this widespread ingredient, suggesting a competition between endogenous proteins and phospholipids for interfacial adsorption. Dilatational interfacial rheology measurements were conducted using either the soluble fraction of the ingredient as such, lipids extracted from PPI, or purified pea proteins (7S fraction). Oscillatory deformations of the oil-water interfacial layers were analyzed using Lissajous plots, which substantiated the interactions between proteins and lipids by deciphering their respective contributions. The formation of mixed interfacial films according to the protein-to-lipid ratio was demonstrated, with a prevalent influence of pea polar lipids on the rheological signature of the films. Atomic force microscopy confirmed the formation of mixed interfacial films where lipid domains coexist with protein aggregates. These insights advance the current knowledge regarding the complexity and functionality of plant protein ingredients, which is important to promote the rational formulation of plant-based food products.

[1] Keuleyan, E. et al. (2023) Pea and lupin protein ingredients: New insights into endogenous lipids and the key effect of high-pressure homogenization on their aqueous suspensions, *Food Hydrocolloids*, 141, 108671.



# Less for More: Reducing initial Protein Content to Enhance the Viscoelasticity of Heteroprotein Coacervates

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**Keywords:**  $\beta$ -lactoglobulin, Lactoferrin, Linear viscoelasticity, Time temperature superposition, Water content

**Abstract:** Heteroprotein complex coacervation holds significant potential for food applications, but its functionality depends on rheological properties. This study investigates the linear viscoelasticity of heteroprotein coacervates formed from oppositely charged whey proteins,  $\beta$ -lactoglobulin ( $\beta$ LG) and lactoferrin (LF), at a fixed molar ratio ( $\beta$ LG:LF = 10:1), while varying the initial protein concentrations ( $\beta$ LG: 5-40 g/L; LF: 2.5-20 g/L). The viscoelasticity of six systems was analyzed at different temperatures (5-40 °C), revealing a dominant liquid-like character with moduli decreasing as the temperature increased. Interestingly, lower initial protein concentrations produced stiffer coacervates, likely due to changes in water content as a function of the protein concentration. Time-temperature superposition (TTS) was successfully applied, and the data fit well with the Fractional Maxwell model, indicating temperature-independent interactions in the coacervate network, with activation energies ( $E_a$ ) increasing with decreasing water content. Finally, rehydrating freeze-dried coacervates while controlling the water content enabled fine-tuning of their viscoelastic properties. These findings enhance our understanding of complex coacervates and provide new strategies for tailoring their properties.

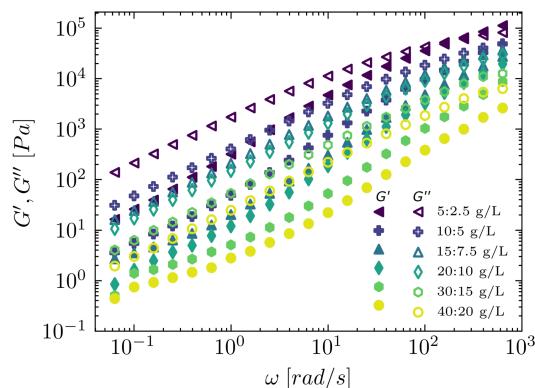


Figure 1: Viscoelastic properties of  $\beta$ LG-LF heteroprotein coacervates as a function of initial protein concentrations at 5 °C

# Predicting the swelling of starch granules using Flory-Rehner theories

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**Keywords** (5 max): Starch pasting, polymer swelling, microscopy

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**Abstract :** Starch pasting, i.e., the process by which aqueous dispersion of starch granules thicken upon heating, greatly influences the texture of a variety of consumer products. The current industrial paradigm is to use trial-and-error approaches to manipulate starch mechanics, which requires significant testing/investment when formulating new materials for the food and bioprocess industries. Here we discuss recent progress on developing physics-based models to predict the initial swelling of starch granules. We show that the dynamics of starch granule swelling can be captured by a diffusion equation of water into the granule, with the equilibrium water content captured by a Flory-Rehner theory of a crosslinked network that has the fraction of crosslinked chains varying as an empirical function of temperature. Having the cross-link density vary with temperature is important to capture equilibrium swelling at temperatures near and far away from gelatinization, although a single value of cross-linking can be used at high temperatures. The theory is compared against microscopy data of individual granule swelling for red bean, chickpea, green lentil, and yellow pea starches. We find that the experimental data for granule size versus time is able to be captured onto a master curve with appropriate shift factors. We use the Flory theory to understand how these shift factors are related to microstructural properties of the granules. At the end of the talk, we will discuss recent work on how to extend the Flory theory to include multiple ingredients (e.g., gums, sugars, etc.), with preliminary experimental data provided.

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# Formation of Microcapsules using Rapeseed Proteins

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**Keywords** (5 max): Rapeseed, microgels, napin, cruciferin, microcapsules

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## Abstract :

Rapeseed is mainly used for oil extraction, with the remaining material often discarded or used as animal feed. However, it contains 30% to 45% high-quality protein, primarily composed of cruciferin and napin. While napin was found to be heat-stable, cruciferin is more sensitive. Remarkably, it forms stable suspensions of well-defined microgels (MG) when a suspension at 0.8 wt% is heated at 80°C for only 5 min. The diameter of the microgels varied between 0.1 and 0.4 µm depending on the pH. In the presence of 0.1 M NaCl such microgels could also be formed by a rapeseed protein isolate that contains both proteins in equal amounts. These cruciferin MG have potential applications in beverages and food products.

Additionally, the MG effectively stabilize water in water emulsions by adsorbing at the droplet surface thereby preventing coalescence. Interestingly, the MG spontaneously slowly form permanent crosslinks within the layer leading a microcapsule (MC) that resists dilution. This crosslinking can be accelerated by heating the emulsion at 80°C for only 5 minutes. The size of the MC can be controlled by adjusting the volume fraction of the dispersed polymer phase or the concentration of the microgels (see fig). The MC can be washed to remove polymers and excess protein. They were found to be stable between pH 3 and pH 10 and after addition of up to least 0.1 M NaCl. They also resist mechanical stress such as vortex mixing, making them suitable for use as texturizers or carriers for encapsulation.

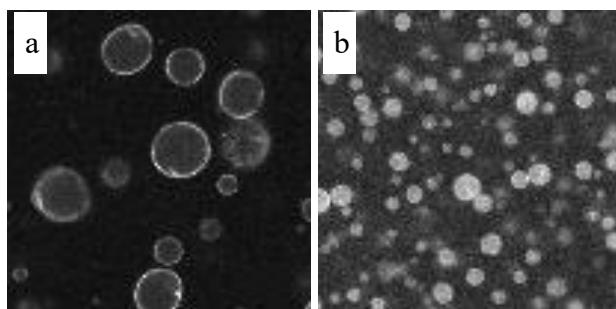


Fig. CLSM images ( $40 \times 40 \mu\text{m}$ ) of a PEO (10 vol%) in dextran emulsion containing (a) 3 g/L, (b) 14g/L cruciferin MG. The protein microgels were fluorescently labelled.

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# Quantitative Magnetic Resonance Imaging to characterize food process. A focus on sodium diffusion.

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**Keywords:** quantitative MRI, salt, water, diffusion, food

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**Abstract:** On one hand, Magnetic Resonance Imaging (MRI) stands out for its versatility, offering a wide range of analytical methods. Notably, it enables the characterization of the spatial arrangement of matter at different scales and the quantification of small-molecule dynamics. On the other hand, food processing is a crucial step in enhancing the nutritional and sensory quality of food while reducing its environmental impact. Key processes, such as cooking, drying, and salting, involve deformations, solute transfer, and dynamic changes in water and sodium interactions with the matrix. Understanding these phenomena is essential for optimizing processes.

Focusing on salt diffusion in carrots, we demonstrate how quantitative sodium MRI can explain variations in saltiness based on different seasoning practices. We compared two salting methods: i. adding salt to the cooking water and ii. sprinkling salt on the plate after cooking, using different salt crystal sizes. The results show greater salt heterogeneity when salting on the plate and a continuous diffusion of sodium within the carrot for several hours after salting, regardless of the salting conditions.

This study addressed three main challenges of sodium MRI: i. detecting the weak sodium signal, ii. obtaining quantitative images, and iii. achieving good temporal resolution.

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# Gelled waters for swallowing disorders: from rheological, tribological and structural characterizations to sensory perception

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**Keywords** (5 max): Edible gels; Rheology; LAOS; Structure; Sensorial perception

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## Abstract:

In order to prevent the risk of penetration-aspiration in dysphagic patients, aqueous edible gels are one of the possible options for providing water under a non-liquid form. However, these gels can still be optimized, both from a sensorial and/or nutritional point of view.

In practice, we have focused on ten different soft gels, obtained by mixing standard gelling polysaccharides of different natural sources, with or without calcium carbonate. The concentration of the polysaccharides is all set at the threshold of gelation.

To fully characterize their gelation, viscoelastic, slipping, flow, fracture and aging properties, we performed various shear and compressional rheological tests. The impact of the processing conditions was also examined. To better mimic the deformation during oral processing, we conducted an in-depth analysis of the large amplitude and non-linear regimes in oscillatory shear. As well, a custom-built tribometer, including a deformable artificial tongue, was also employed.

All these tests demonstrate that, despite being formulated at their onset of gelation, the different polymeric gelling agents and their mixtures allow for a wide range of rheological properties. These differences in rheology are then discussed in terms of structural organization within the gels.

In parallel, we performed a sensorial analysis on 17 healthy people trained to quantify 18 descriptors, covering perceptions before, during and after the oral phase. We then discuss the correlations between rheological and sensory features, and how formulations could be optimized. Moreover, emulsion gels – with oil droplets – have been formulated and characterized, opening the prospect of nutritional enrichment.

# High-moisture extrusion of soy proteins: pH-dependant structure formation mechanism studied by Small-Angle Scattering

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**Keywords (5 words max):** Soy proteins, Structure formation, pH effect, Small-Angle Scattering, Extrusion

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**Abstract (250 Words Max):** There is a growing societal awareness that shifting toward plant-based diets is crucial for mitigating the adverse effects associated with animal meat consumption. Novel plant-based meat alternatives that closely replicate the anisotropic structure of animal meat offer a promising solution. High-moisture extrusion (HME) is a well-established industrial processing method for producing fibrous meat alternatives from plant proteins in an efficient and scalable manner<sup>1</sup>. So far, most attempts to control plant protein structure formation have relied on variations in HME process conditions. Recently, pH shifting has also been proposed as a cost-effective processing aid. However, the complex mechanisms that determine the impact of pH-shifting on the final fibrous texture of plant protein extrudates have not been fully understood. The main obstacle is the lack of multiscale studies that could help elucidate the principles governing structure formation from the nano- to the macro-structural level.

This talk will present how Small-Angle Scattering (SAS) methods can address these challenges. The primary focus will be on how the pH-shifting of soy protein concentrate through water feed influences anisotropic structure formation during HME<sup>2</sup>. It will be demonstrated that pH-shifting has a non-monotonic effect on the extrudate anisotropic structure at the nm-scale, as determined by SAS. These results will be compared to the sub-mm information provided by Magnetic Resonance Imaging (MRI). Proposed mechanisms will be underpinned by SAS measurements on pH-shifted gelated glycinin and  $\beta$ -conglycinin as the two dominant soy proteins.

Acknowledgments: NWO OTP-TTW program and “Measurement and Modelling of Multiscale Processed Protein Products” (MP3) project (18744).

References:

1. Ruud van der Sman & Atze-Jan van der Goot. *Current Res. Food Sci.*, 6 100510 (2023).
  2. Sam Kuijpers & Ekaterina Garina *et al.* Submitted to *Food Hydrocoll.*
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# Normal Force Rheology as a New Tool to Characterize Anisotropic Food Structures

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**Keywords** (5 max): Normal Force, Rheology, Normal Stresses, Anisotropic Structure

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**Abstract :** (249 Words) Complex fluids often exhibit normal stresses perpendicular to the shear induced by shear deformation. This phenomenon has been studied extensively in polymer physics. However, it is often ignored for other soft materials including foods. Despite conventional rheological measurements being widely used to investigate food hydrocolloids, normal force induced by shear is a completely new subject in food science. The normal force induced by shear could give lots of information about the nonlinear rheological properties of food materials. We know that the normal force response of foods contributes to the mouthfeel, therefore, understanding the normal response induced by shear in edible materials is a new factor, important for understanding the sensory perception better. In this talk, I introduce several examples that normal stress rheology can be used to characterize the nonlinear response of complex food systems from highly anisotropic soft solids (meat and fibrous meat analogs) to structured multiphase systems such as liquid foams, emulsions and slurries. Shear-induced normal force rheology reveals differences in these highly anisotropic systems that can not be clearly observed based on the results of conventional shear rheology. This new characterization method could provide a deeper understanding of the structure-function relation in complex anisotropic food materials. For the meat(alternative) samples, this approach shows that fiber orientation, fiber strength and fiber micro rearrangement under deformation govern the normal response. Understanding the normal force behavior of complex food materials is also essential to predict their die-swell after extrusion with diverse applications from food 3D printing to food processing.

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# On the influence of the rheology of beverages on texture perception and consistency.

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**Keywords (5 max):** Flow, Texture, Protorheology, Thickeners

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## Abstract (250 Words Max):

Texture is an important food sensory attribute, influenced by the mechanical properties of food which can be perceived in mouth and by the interaction of food with the oral environment. In this study, we discuss quantitatively the links between the rheological and tribological properties of some beverages and their texture perception, focusing on thickness, graininess and sliminess. The results obtained in this study will be interpreted in the context of the recent scientific literature, considering the shearing and squeezing action of the tongue against the palate.

Consistency classifications are commonly used to sort food and drink in view of inferring their behaviour during consumption. In the second part of this contribution, a theory is proposed to interpret the effect of beverages physical properties (rheology, density and surface tension) on the consistency classification of thickened beverages to manage swallowing disorders. Clear differences are observed between perceived texture and consistency classification. These discrepancies can be interpreted in light of their sensitivity to different rheological properties.

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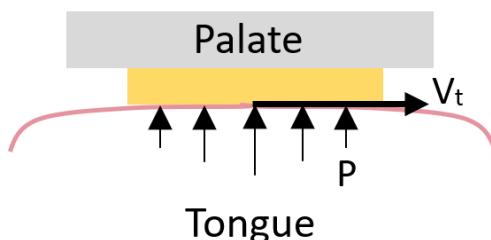


Figure 1: Tongue-Palate Compression and Shearing

# Oleofoams based on dairy proteins as fat replacer

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**Keywords:** oleofoam, dairy proteins, surfactant, edible particles

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## Abstract: (250 Words Max)

In food applications, fat is a key component influencing texture, mouthfeel, and stability. However, traditional solid fats contain a high amount of saturated and trans fats, which are associated with health risks. The food industry needs to replace saturated fat by unsaturated fat or by lowering the fat content on the final product. One solution is the use of oleogels which is a promising alternative, offering the functionality of solid fats while incorporating healthier unsaturated fats. Another promising solution is the use of oleofoams. However, oleofoams are currently produced by using high amount of saturated fatty components forming crystalline particle, which could be considered undesirable for use in nutritional products. The aim of this study is to produce and stabilize oleofoams by using a mixture of food-grade surfactant and dairy proteins as particles. Different types of dairy proteins particles were used to prepare oleofoams with Span80. We compared the effect of the nature and concentration of the proteins inside the powder, oil type and temperature on the oleofoam properties. The results showed that the addition of dairy proteins particles increased the oleofoam stability. The key parameter influencing the oleofoams was particle concentration, rather than protein concentration. The specific type of protein appeared to have minimal impact; however, the composition of the dairy powder played a crucial role. When fat or lactose was present, the oleofoams lost their stability. Thus, by incorporating protein particles, it may be possible to enhance foam stability and improve the nutritional profile of the product.

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## Thursday 10<sup>th</sup> - Program

Time	Speaker's name	Title
9:00 - 9:15 p.m.	<b>Thiemo van Esbroeck</b>	Decoding meat analogues: insights into ingredient structure function relationships
9:15 - 9:30 p.m.	<b>Laura Román</b>	Understanding Plant Proteins Interplay with Starch in Mixed Hydrogels: The Role of Protein Composition and Colloidal State
9:30 - 9:45 p.m.	<b>Elie Matta</b>	Effect of Melting Salts on the Texture of Dense Casein Micelle Suspensions
10:00 - 10:15 p.m.	<b>Julien Bauland</b>	Two step aging dynamics in enzymatic milk gels
10:15 - 11:00 a.m.		<b>Break</b>
11:00 - 11:15 a.m.	<b>Marjorie Ladd-Parada</b>	Influence of chemo-enzymatic processing on the multi-scale structure and composition of wheat bran
11:15 - 11:30 a.m.	<b>Carolina Ugarte-Pereyra</b>	Design of oleofoams from citric acid esters of monoglycerides
11:30 - 11:45 a.m.	<b>Emmanouil Chatzigiannakis</b>	Interfacial Stresses in Foams: From Microscale Film Dynamics to Macroscale Stability
11:45 - 12:00 a.m.	<b>Wanting Yin</b>	Common bean proteins: similar interfacial rheology, distinct interfacial structures and functionalities
12:00 - 12:30 a.m.		<b>Closing Ceremony</b>
12:30 - 2:00 p.m.		<b>Lunch</b>

# Decoding meat analogues: insights into ingredient structure-function relationships

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**Keywords:** meat analogues; textured vegetable protein; oil release; methylcellulose; tribology

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**Abstract:** Meat analogues play a pivotal role in the transition to more sustainable protein sources. Most meat analogues are primarily composed of textured vegetable protein (TVP), oil and binding agents. Each of these ingredients is crucial in defining the functional properties of the meat analogue, including texture and serum release. Understanding the structure-function relationships of the ingredients is essential for optimising the sensory quality of meat analogues.

This presentation delves into the intricate interplay between ingredient structure and functionality in meat analogues. For various TVPs, we quantified structural characteristics such as porosity, pore size and wall thickness using X-ray tomography. Our findings reveal how these characteristics influence water release, mechanical properties and protein digestibility of meat analogues. Oil release is less dependent on TVP structure, but is governed by oil droplet characteristics. We will demonstrate how modifying the interfacial characteristics and interactions between oil droplets and the meat analogue matrix can help tune oil release dynamics. The structural cohesion of meat analogues is achieved through the gelation of binding agents, predominantly using methylcellulose. We will present how methylcellulose gelation is influenced by proteins, and how this depends on methylcellulose molecular weight and protein characteristics. Additionally, we will discuss the tribological properties of meat analogues and the serum released, offering insights into how different ingredients contribute to the lubrication of meat analogue surfaces.

Overall, this presentation provides a comprehensive overview of the complex relationships between structure and functionality, offering insights to advance the design and quality of meat analogues.

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# Understanding Plant Proteins Interplay with Starch in Mixed Hydrogels: The Role of Protein Composition and Colloidal State

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Speaker's email: lroman@uva.es

**Keywords:** phase separation; starch retrogradation; strongly bound water; protein-starch interactions; gelation

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## Abstract

The transition from animal-based to plant-based proteins is essential for sustainability, but incorporating plant proteins into carbohydrate-rich matrices can affect food structuring and the characteristics of the formed network. This study examines plant protein-starch interactions in mixed hydrogels during hydrothermal processing. Protein concentrates (50% protein) and isolates (80-90% protein) from sunflower and lupin were selected and characterized for molecular weight, secondary structure, gelation, nativity, and surface charge. To explore protein-starch interactions, wheat (WS) and potato starches (PS) were chosen due to their different molecular architectures and swelling. Protein-starch mixed hydrogels were processed under high moisture, high temperature, and low shear conditions and the mixed gels were analyzed for microstructure, oscillatory rheology, thermal transitions, and water distribution (LF-NMR). Protein isolates delayed starch swelling due to water competition during denaturation. Furthermore, phase separation occurred in sunflower protein mixed gels, likely due to its higher 11S fraction, while all proteins reduced starch retrogradation by limiting moisture redistribution. Proteins richer in 7S globulins and native-less purified concentrates, due to their fiber content, improved water retention. Rheological experiments suggested starch-starch interactions primarily drove storage modulus ( $G'$ ), with variations dependent on protein and starch type. In PS gels, lupin protein addition increased  $G'$  more than sunflower, while in WS gels, sunflower proteins had a higher  $G'$  than lupin, regardless its purity. All protein-mixed gels increased  $\tan(\delta)$ , forming weaker viscoelastic gels. These findings highlight the importance of protein-starch-water interactions in food structuring and underscore the need of understanding protein characteristics to optimizing network formation.

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# **Effect of Melting Salts on the Texture of Dense Casein Micelle Suspensions**

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**Keywords:** Casein micelles; Trisodium Citrate; Trisodium orthophosphate; Rheology; Turbidity;

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## **Abstract:**

Casein, the predominant protein in milk, forms spherical colloidal complexes known as casein micelles. This report discusses the dissociation and textural changes of micellar casein (MC) in aqueous suspensions induced by adding trisodium citrate (TSC) or trisodium orthophosphate (TSP). Dissociation was studied by measuring the turbidity at MC concentrations between C = 1 wt% and 5 wt%. The rheological behaviour and the microstructure was investigated between C = 8 wt% and 14 wt%. The effects of the pH (5.8-7) and ageing up to 1 week were considered. It was found that TSC chelates calcium bound to MC promoting dissociation to an extent that depended on the weight ratio R of TSC over MC independent of the casein concentration. At pH 5.8, the viscosity increased as the MC dissociated and became similar to that of sodium caseinate (SC). However, at pH 7 a huge increase of the viscosity adding relatively small amounts of TSC ( $R = 0.15$ ) to values much larger than that of SC. At larger R it decreased again to values close to that of SC. This remarkable increase became less important during ageing, upon decreasing the pH, or after dilution and disappeared after one week, at pH 5.8 or at C = 8 wt%.

Larger amounts of TSP were needed to dissociate the MC. An increase of the viscosity was also observed after adding TSP, but, contrary to the case of TSC, the presence of TSP at larger R led to the formation of a gel at C = 14 wt%, embedded within a viscoelastic matrix. This gel modulus appears to decrease with increase pH and time.

This study provides insights into how melting salts like TSC and TSP can induce a dissociation and textural changes in suspensions of casein micelles, highlighting their role in controlling microstructural and rheological properties. These findings have implications for designing dairy products.

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# Two-step aging dynamics in enzymatic milk gels

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**Keywords :** Colloidal gel, aging, rheology, cheese, soft colloids

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**Abstract :** Colloidal gels undergo a phenomenon known as physical aging, i.e., a continuous change of their physical properties with time. To date, most of the research effort on aging in gels has been focused on suspensions of hard colloidal particles. In this work, we tackle the case of soft colloidal “micelles” comprised of milk proteins, in which gelation is induced by the addition of an enzyme. Using time-resolved mechanical spectroscopy, we monitor the viscoelastic properties of a suspension of colloidal micelles through the sol-gel transition and subsequent aging. We show that the microscopic scenario underpinning the macroscopic aging dynamics comprises two sequential steps. First, the gel microstructure undergoes rapid coarsening, as observed by optical microscopy, followed by arrest. Second, aging occurs solely through a contact-driven mechanism, as evidenced by the square-root dependence of the yield stress with the elastic modulus measured at different ages of the gel. These results provide a comprehensive understanding of aging in enzymatic milk gels, crucial for a broad range of dairy products, and for soft colloids in general.

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# Influence of chemo-enzymatic processing on the multi-scale structure and composition of wheat bran

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**Keywords** (5 max): bran, tomography, X-ray scattering, structure

**Abstract :** Wheat bran is one of the major by-products of the wheat processing industry. It is mostly composed of structural polysaccharides (60%), from which arabinoxylan (AX) is one of the most abundant ones representing 20-40% of the total content[1,2]. AXs have different functional and nutritional properties making them a molecule of interest [3]. In previous works, different methods have been developed to extract AXs and other molecules. However, these processes usually have low extraction yields [4, 5], which is related to the recalcitrance of the cereal cell walls caused by the complex physicochemical interactions between the molecular components. To help understand the origin of the recalcitrance, we have performed a study of the changes in wheat bran after being subjected to different AX chemo-enzymatic extraction methods using a combination of chromatography techniques, fluorescence microscopy, and X-ray tomography. The integration of such biochemical and biophysical approaches contributes to a detailed understanding of the heterogeneous localisation of the wheat bran components after different wet processes, which will help us to improve wheat bran processing towards new functional and healthy food ingredients.

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# Design of oleofoams from citric acid esters of monoglycerides

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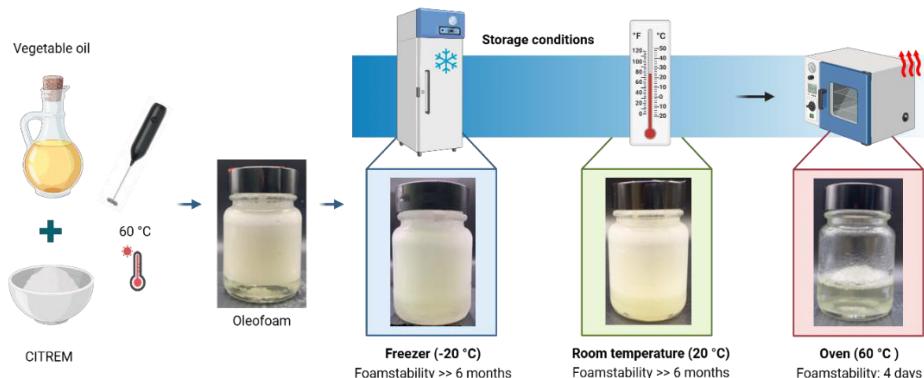
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**Keywords:** Oleofoam; edible oil; lipophilic surfactant; crystalline particles; CITREM.

**Abstract:** Citric acid esters of mono- and diglycerides (CITREM E472c) are commonly used in the food industry as emulsifiers, in products like infant formulas, beverages, seasonings, ice cream coatings, and frying margarine. Recently, CITREM has been shown to produce stable aqueous foam [1], yet its potential for oil foam production remains unexplored. Due to its unique chemical structure, which includes free hydroxyl groups and solubility in vegetable oils, CITREM is a promising candidate for this application. In this study, we evaluated the formation of foam in different vegetable oils (*i.e.*, sunflower oil, olive oil, sesame oil, flaxseed, and middle chain triglyceride oil) using CITREM as a surfactant. Initially, we determined the phase diagram of CITREM to identify the solubility limit and the temperature at which CITREM crystals form. Oil foams were then produced at a fixed temperature (60 °C) above the melting point, ensuring no crystals were present, to examine the effect of surfactant concentration on the foaming behavior. The influence of crystal formation on foam stability at different temperatures was also studied. To understand the mechanisms behind foam formation and stabilization, we combined macroscopic foam observations with optical microscopy and SAXS/WAXS to examine the self-assemblies at the nanoscale. Our results demonstrated that CITREM surfactants stabilized oil foam similarly to sucrose ester and sorbitan ester surfactants. This confirms that the key factor in forming vegetable oil foams is using a lipophilic surfactant with free hydroxyl groups capable of forming hydrogen bonds with the triglycerides in the oil.



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# Interfacial Stresses in Foams: From Microscale Film Dynamics to Macroscale Stability

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**Keywords** (5 max): interfacial rheology, thin film, foam, drainage

**Abstract :** The stability and rheology of multiphase materials, such as foams, are largely governed by the properties of their interfaces and the behavior of thin liquid films (TLFs) separating interacting droplets or bubbles. When two bubbles come into close proximity, a TLF forms between them and progressively thins through drainage. This thinning process, along with the overall stability of TLFs, is strongly influenced by interfacial stresses and intermolecular interactions driven by surface-active species. In this talk, we will discuss how experimental techniques, such as the dynamic thin film balance, shed light on nano- and micro-scale physics of these materials. Particular attention will be given to films stabilized by low molecular weight surfactants, copolymers [1], and plant proteins [2], and how they impact key foam destabilization processes: drainage, coalescence, and Ostwald ripening.

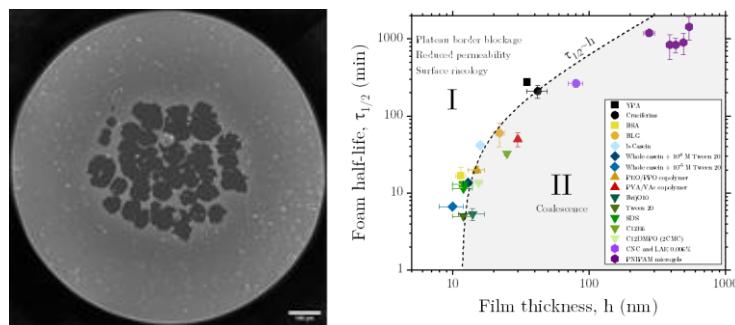


Figure 1: (Left) Microinterferometry image of a foam film stabilized by a protein (yellow-pea albumin). (Right) Correlating foam half-life with film thickness [2].

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# Common bean proteins: similar interfacial rheology, distinct interfacial structures and functionalities

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**Keywords** (5 max): common bean proteins, interfacial dilatational rheology, interfacial structures, foaming properties

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**Abstract :** In the current protein transition, plant proteins have been extensively studied; however, their compositions are typically complex, and the direct relationships between composition, structure, and functional properties remain unclear. To investigate the impact of compositional and structural differences on plant protein properties, we focused on common bean (*Phaseolus vulgaris* L.), the most widely consumed legume worldwide. Proteins were extracted from three commercially available common bean varieties—red kidney bean, black turtle bean, and pinto bean. Proteomics analysis revealed that the primary component in all three varieties was a 7S globulin, phaseolin, and extracts had nearly identical protein compositions. Interfacial rheology at the air-water interface demonstrated no significant differences in adsorption kinetics or dilatational moduli among the three proteins, indicating the formation of solid-like interfaces with similar stiffness. However, Langmuir-Blodgett deposition combined with AFM revealed that all three proteins formed a unique strand-like structure at the interface, though different surface pressures or aging times were required to achieve these structures. More surprisingly, foam stability also showed significant variation, with the foam half-life time of black turtle bean globulin reaching 25.3 hours, over 3.7 times that of the other two proteins. These findings suggest potential structural differences among the protein extracts despite their nearly identical composition, which are insufficient to cause differences in interfacial rheology but can influence the formation of interfacial structures and foamability. This study provides new insights into the link between protein structure and interfacial properties, contributing to the understanding of plant protein functionality.

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