Emulsion Stability of Plant-Based Proteins under High Shear Deformation: Implications for High-Moisture Extrusion

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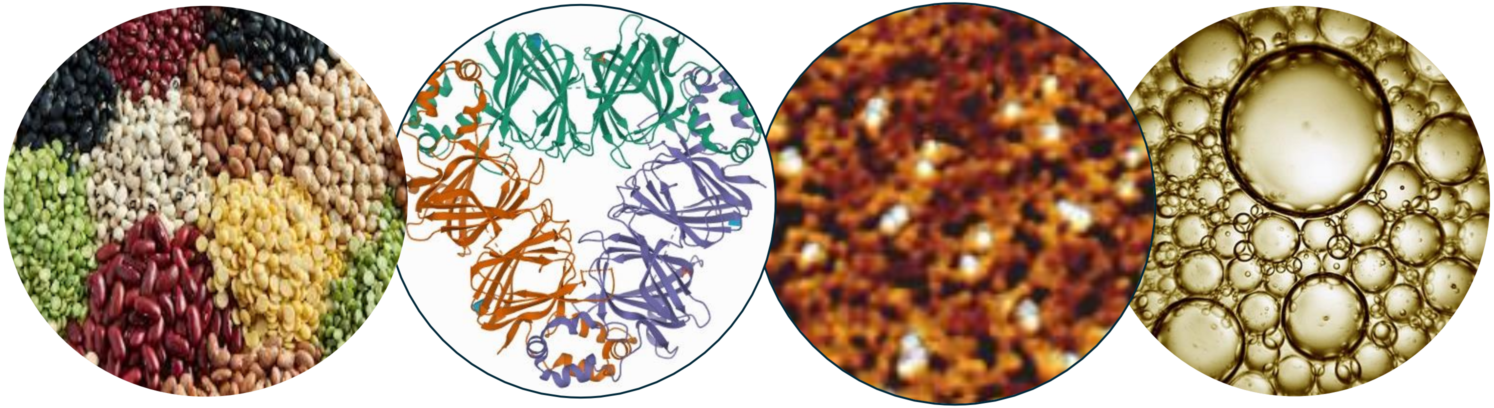

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Content

- Focus of the SIDM group
- Plant-protein sources
- Qualitative comparison plant protein with traditional sources
- Multiscale approach: nonlinear rheology
- Turbulent mixing and extrusion
- Conclusions and outlook

Focus of the SIDM group

- Foams, emulsions, films, multiphase gels
- Materials with high surface-to-volume ratio.
- Thermodynamically unstable, kinetically stable: Need appropriate stabilizer
- Our aim: link **molecular structure** stabilizer -> **microstructure** interface -> **mechanical properties** interface -> **macroscopic** stability.
- **Sustainability** : replacing dairy and meat-based proteins by plant-based proteins.
- Bridging the functionality gap.

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Plant-protein sources

- Sources of plant-based proteins: dedicated crops & waste streams

Legumes

- Soy
- Pea
- Chickpea (3 variants)
- Pigeon pea
- Fava bean
- Bambara groundnut
- Mung bean
- Lentil
- Lupin
- Kidney bean
- Black bean
- Pinto bean

Seeds

- Rapeseed
- Papaya seed
- Melon seed
- Bitter melon seed
- Jackfruit seed
- Hemp seed
- Mango seed
- Avocado seed

Leaves/peels/others

- Rubisco

Tomato leaves

Spinach

Alfalfa

Plant-protein sources

- Reasons for focusing on a wide range of sources:

Application perspective

- Sustainability:
  - **Local** sources (eliminate long-distance transport)
  - Diversity (avoid monoculture development)
  - Closing (local) production cycles (waste/side streams)
- Nutritional value

Fundamental perspective

- Compare several legumes/seed proteins: discover generic structural attributes controlling functionality

Plant-protein sources

Discover generic structural attributes controlling functionality:

Generic composition:

- 2S albumins
- 7S, 11S, 13S globulins
- Prolamins
- Glutelins

Despite similar compositions, behavior is quite different for different sources

- Different protein concentration ratios?
- Or are the main proteins slightly different?

} **Proteomics**

- Additional components (phenols, saponins, ….)?

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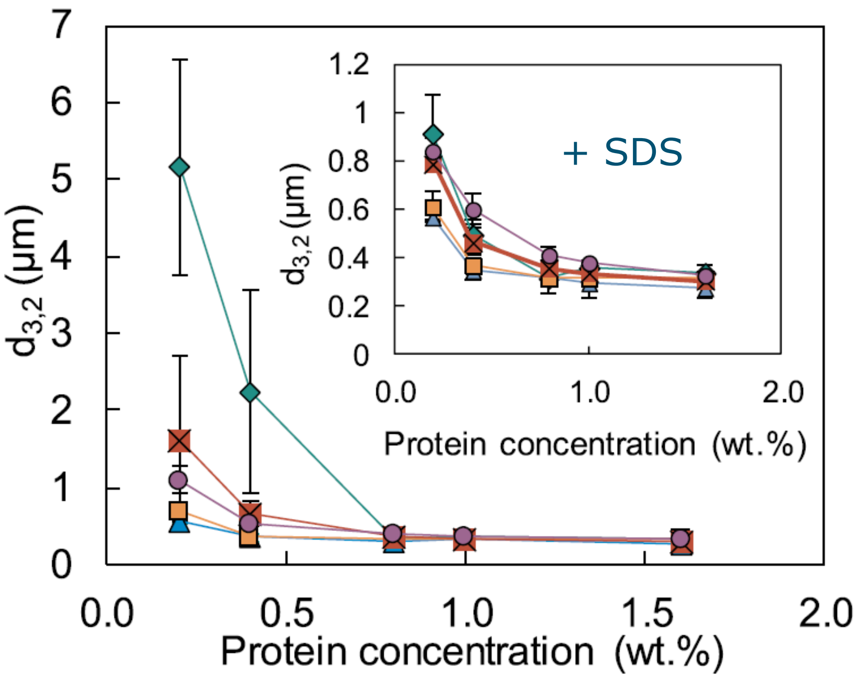
Comparison with traditional sources (in emulsions)

Droplet size versus protein concentration
(10% Oil; PPI only soluble fraction)

Comparison
- pea protein isolate (PPI)
- whey protein isolate (WPI)
- sodium caseinate (SC)



- Plant proteins in general require higher concentration
- Flocculation sometimes also a problem

Hinderink et al. Food Hydrocolloids 97 (2019) 105206

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Qualitative comparison with traditional sources

Functionality of (most) plant-proteins is less than the proteins they should replace

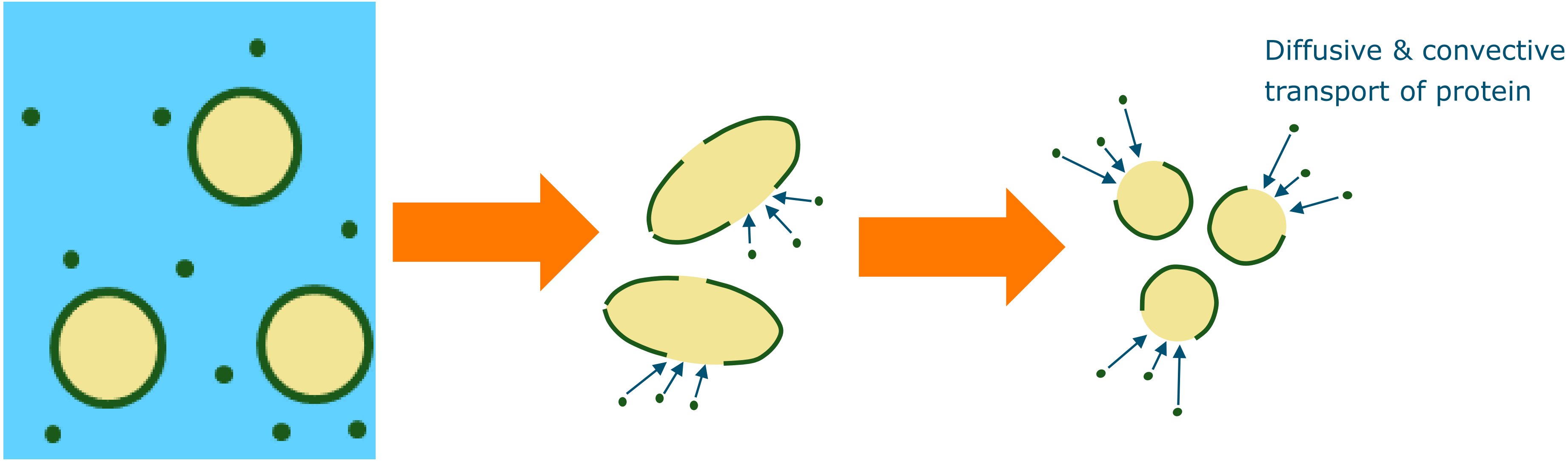
Possible reasons:

- Lower (intrinsic) solubility (storage proteins)
- Larger size and more complex structure / composition
- Non-protein impurities (e.g., lipids, polyphenols)
- Processing induced changes:
    - Hydrolysis
    - Denaturation
    - Aggregation
    - Oxidation
    - Protein-phenol interactions
    - Protein-sugar interactions

Qualitative comparison with traditional sources

How do these factors affect functionality in emulsification

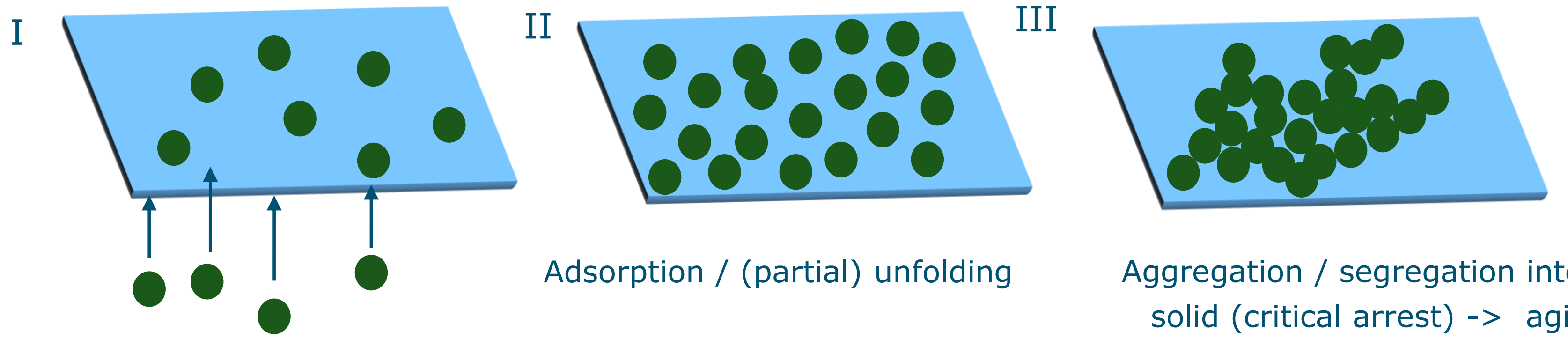
HPH step:



Deformation and break-up creates new (clean) surface

Qualitative comparison with traditional sources

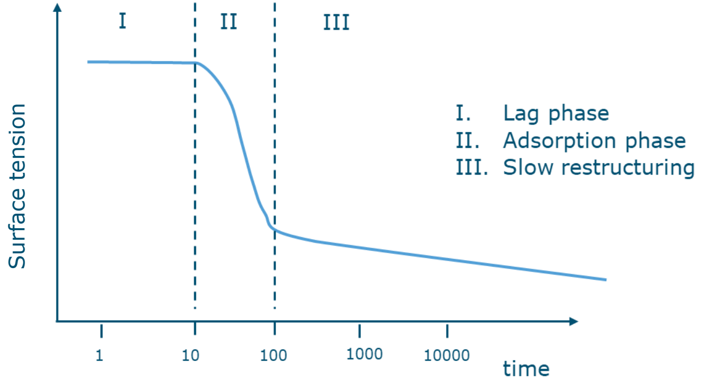
Emulsion stability is closely related to properties of the protein film

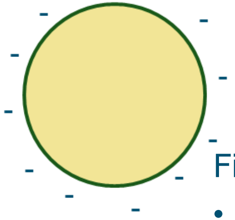


Transport towards interface

Adsorption / (partial) unfolding

Aggregation / segregation into 2D solid (critical arrest) -> aging





Film properties:

- Mechanical
- Charge density

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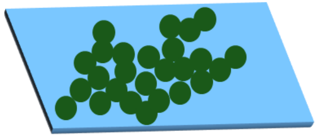
Qualitative comparison with traditional sources

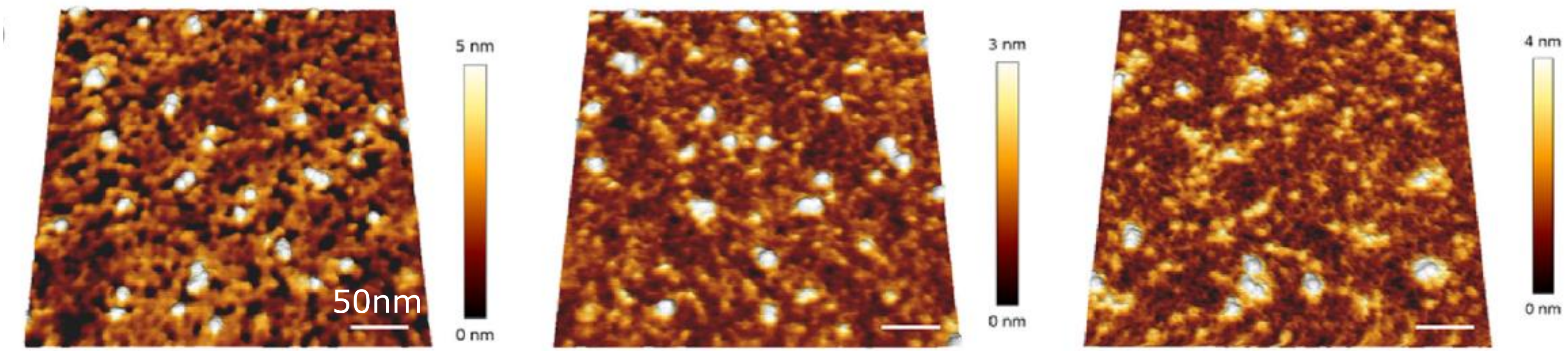
III



Aggregation / segregation into 2D solid (critical arrest?) -> aging

- Most globular proteins segregate after adsorption to interface
- They form disordered solid films with low loss tangents (~ 0.1)
- Not yet completely clear if these are 2D gels or jammed systems (soft glasses)

Lentil Faba Chickpea



A/W interface (23 mN/m)

Shen et al., Food Hydrocolloids 156 (2024) 110313

Qualitative comparison with traditional sources

Some general observations:

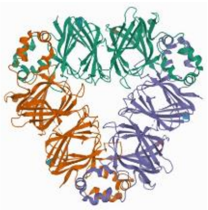
- Plant proteins in general require higher concentration to reach similar stability
- Performance does improve with higher purity
- Performance also improves with higher degree of nativity / solubility

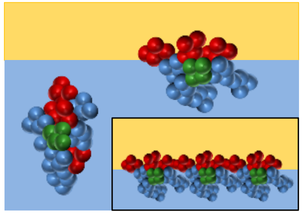
- Performance can (sometimes) by improved by further processing:
    - ➢ (Enzymatic) hydrolysis (faster adsorption, increased exposed hydrophobicity)
    - ➢ Glycosylation or other forms of modification of chemical structure
    - ➢ Heat-induced (limited) aggregation
    - ➢ HP homogenization (breakdown of clusters)
    - ➢ Ultrasound

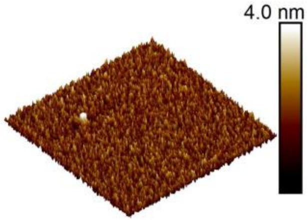
Multiscale Approach

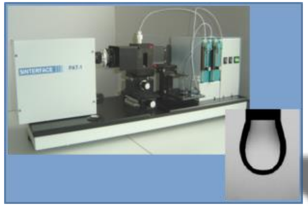
Characterization techniques:

- Molecular structure (proteomics)
- Interfacial microstructure (AFM, X-ray / Neutron scattering, ellipsometry)
- Mechanical properties (Dilatation, surface shear)
- Macroscopic stability and rheology measurements.



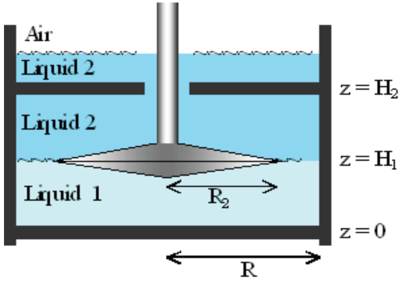




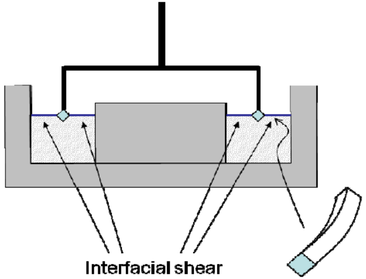


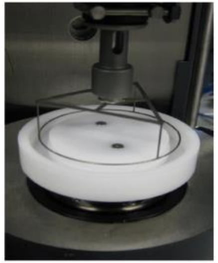
Multiscale Approach: nonlinear rheology – surface shear

Bi-cone geometry



Double wall ring geometry





Surface shear modulus

$$G_s(\omega) = G_s'(\omega) + iG_s''(\omega)$$

- Storage modulus & loss modulus
- Resistance against shear

Modes: Steady/step shear, creep, (large amplitude) oscillatory shear

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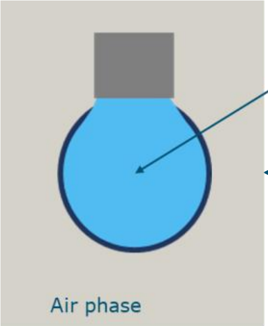
Multiscale Approach: nonlinear rheology – dilatational rheology

Oscillating drop tensiometry



Protein solution

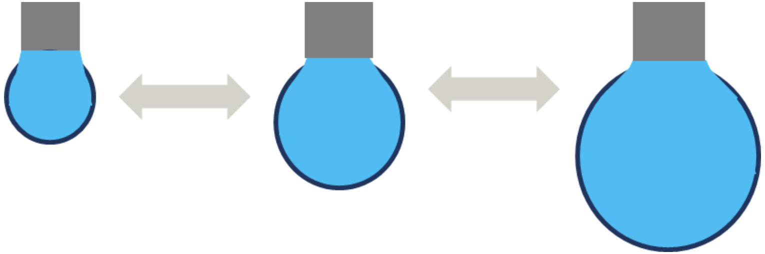
Interfacial profile
(CCD camera)

Surface pressure

Young-Laplace equation

Surface dilatational modulus:

- Resistance against compression/extension



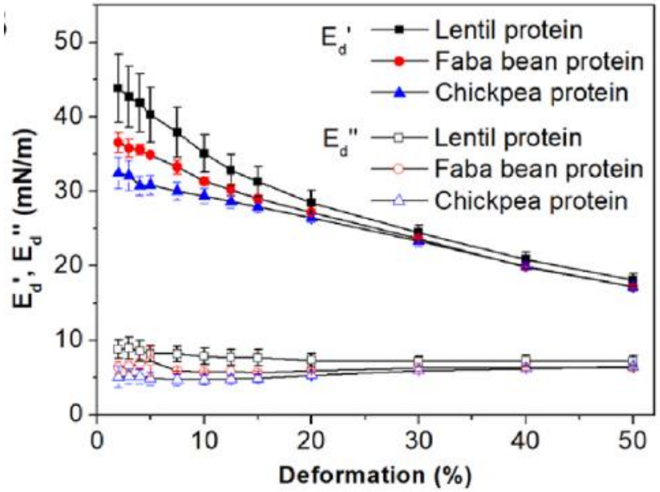
Change in surface tension

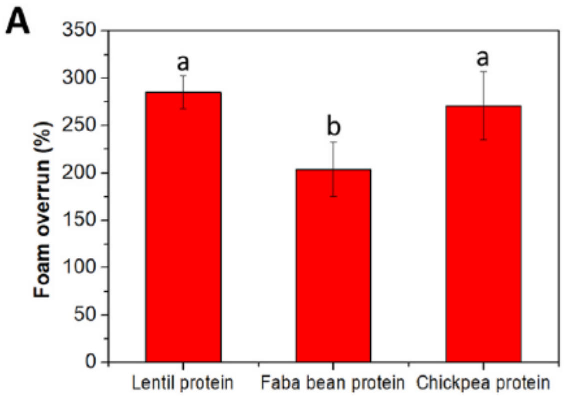
$$E_d = A\frac{\partial \gamma}{\partial A}$$

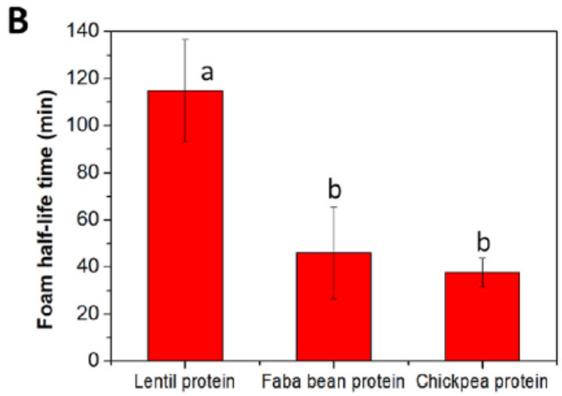
Dynamic mode: sinusoidal area changes -> sinusoidal surface pressure

Multiscale Approach: nonlinear rheology

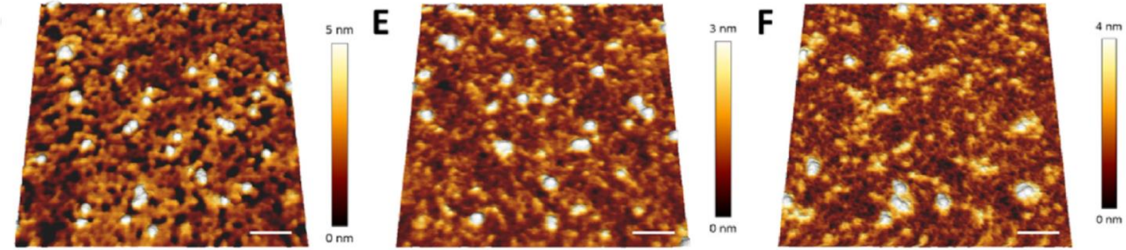
Large deformation response important in food systems: Processing, Handling & consumption







Lentil Faba Chickpea

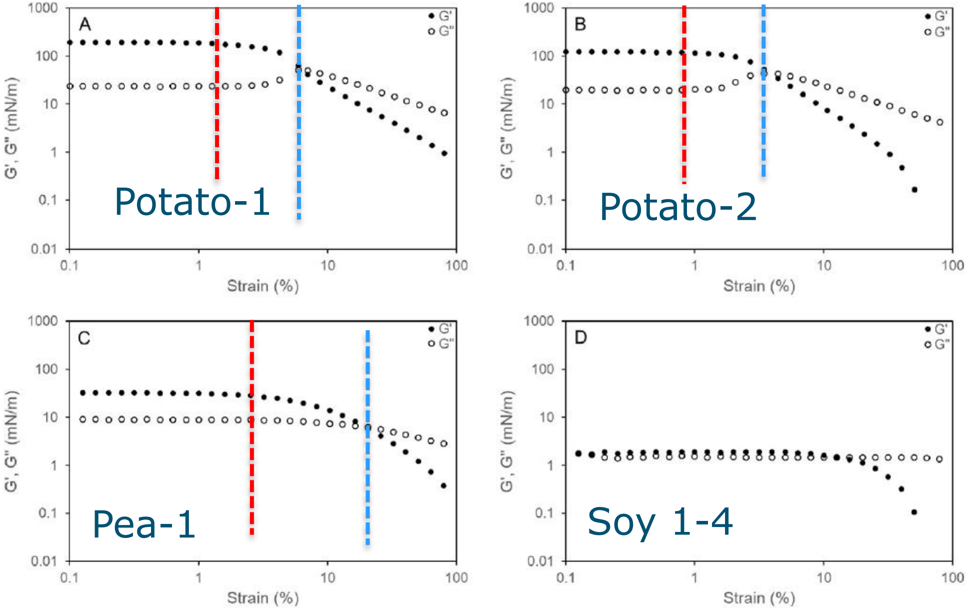


Foam systems (A/W)

Multiscale Approach: nonlinear rheology

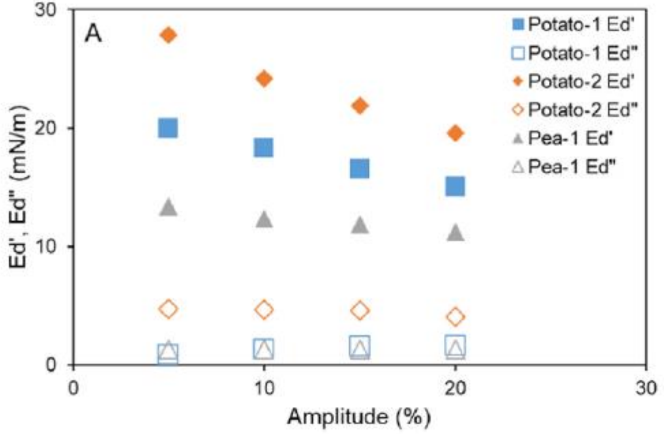
Large deformation response is important in food systems: processing

Surface shear (O/W)



- Emulsions stabilized with commercial stabilizers
- Subjected to turbulent mixing

Dilatation (O/W)



Potato-1: patatin
Potato-2: protease inhibitor

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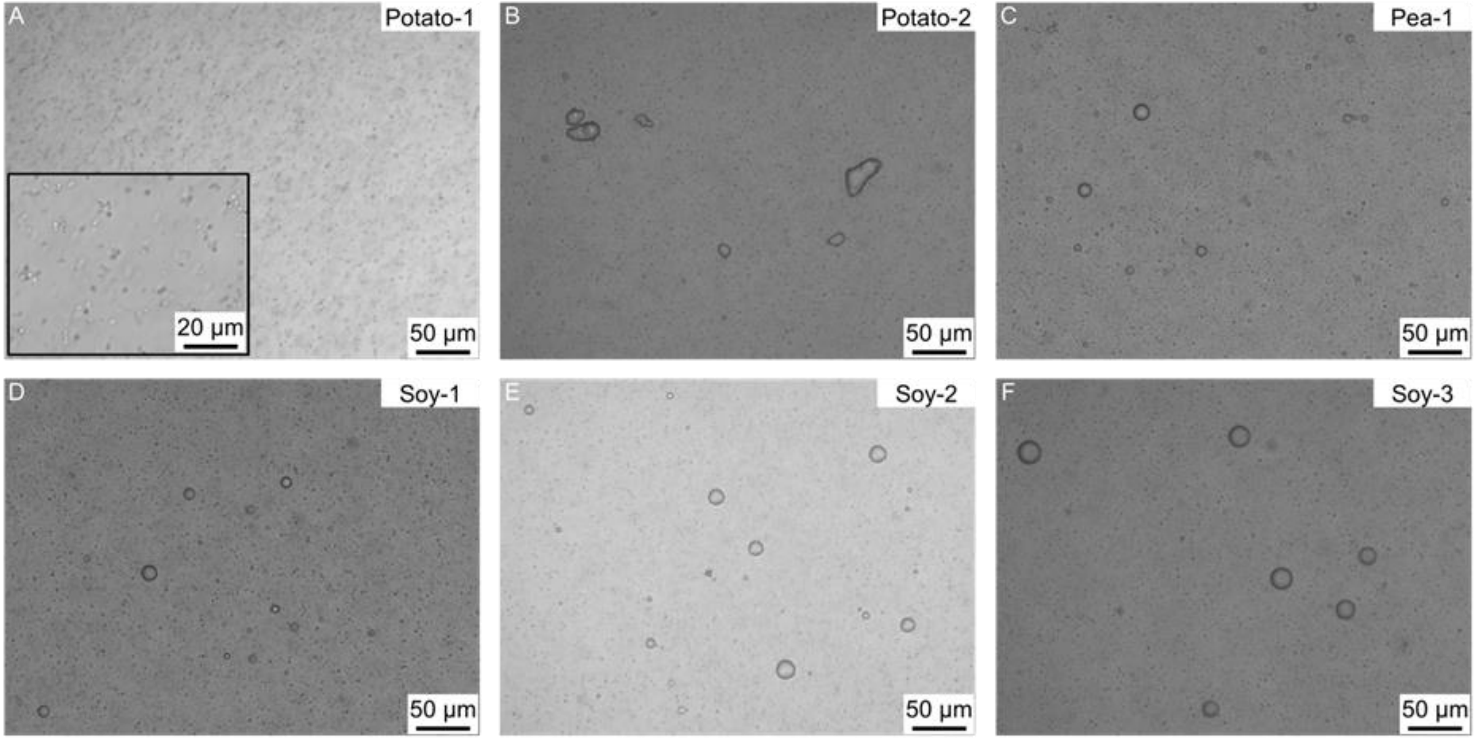
Turbulent mixing

Turbulent mixing: large and **fast** deformation

Ultra Turrax – S25N-10G dispersing tool – 13000 rpm – 15 min



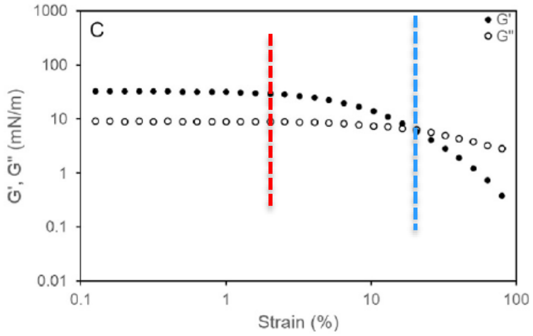
- All emulsions had droplet size ~1 μm before shearing
- Potato-1 was partially flocculated
- After shear, all showed coalescence, except Potato-1

High Moisture Extrusion

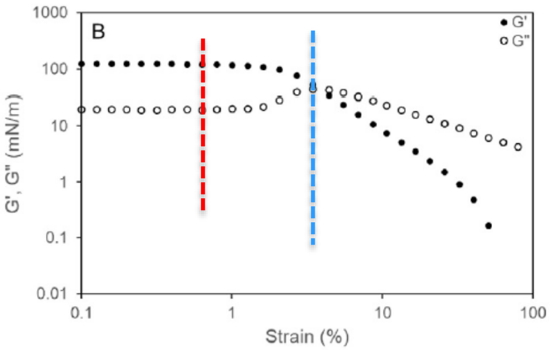
High Moisture Extrusion: **larger** and **but slower** deformation than in turbulent mixing

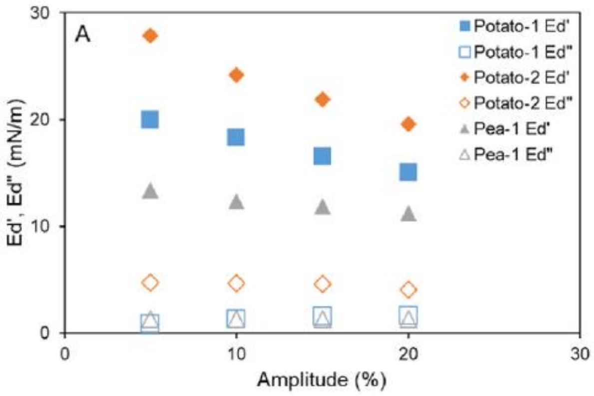
- Potato-1, Potato-2, and Pea-1
- All emulsions showed some degree of oil leakage
- **Potato-2** showed the **most leakage**, despite creating the stiffest interface
- Pea-1 had the weakest interface but was most stretchable
- It also had the lowest amount of leakage

Pea-1



Potato-2



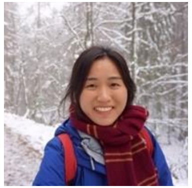


Conclusions

- Plant proteins tend to form **weaker** interfaces than animal-based ones.
- There is large variation between sources.
- For **static stability**, small strain surface rheology often directly linked to stability (stiffer = more stable)
- For processing, nonlinear behavior is more important
- Stiffer and more brittle is not always better.
- Weaker and more stretchable performs better in HME.

Ninna

Penghui



Chaya

Ziyang

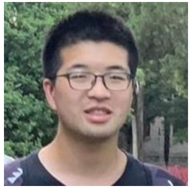
Ting

Mengyue

Anteun

Wanting

Chon



Xingfa

Ngamjit

Ployfon

Thank You

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