Comparative Interfacial Stabilization by β-Lactoglobulin and Cruciferin in Protein-Stabilized Oil-in-Water Emulsions Using a Microfluidic Approach

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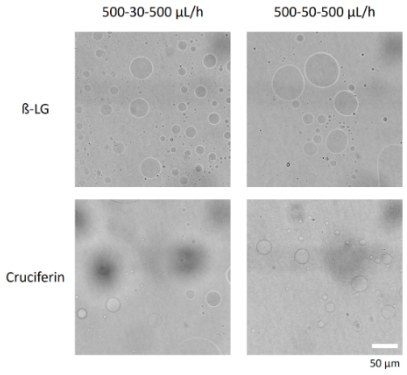
Emulsions used in plant-based milk alternatives are frequently formulated with relatively low protein contents, where interfacial crowding is limited and adsorption kinetics become critical for long-term stability and sensory quality. In this regime, it is still unclear how animal- and plant-derived globular proteins differ in their ability to stabilize freshly formed oil–water interfaces under well-defined flow conditions. Here, we employ a microfluidic 3D flow-focusing geometry to generate well-defined oil-in-water emulsions and directly compare the interfacial stabilization provided by the dairy protein β-lactoglobulin (β-LG) and the plant storage protein Cruciferin.

Medium chain triglyceride (MCT) oil droplets are produced in a single flow-focusing chip while keeping the flow-rate ratio fixed and varying only the protein identity and its bulk concentration between 0.25 and 0.75 wt%. This design yields monodisperse droplets whose formation history and residence time after pinch-off are precisely controlled, allowing hydrodynamic effects to be decoupled from compositional ones. Confocal laser scanning microscopy is used as a real-time probe of droplet size, spatial organization and coalescence dynamics during the first minutes after emulsification, when interfacial films are still developing.

Across the investigated concentration range, Cruciferin-stabilized emulsions displayed smaller droplet diameters and improved resistance to coalescence compared to β-LG at identical bulk concentrations, which consistently yielded larger, less stable droplets. The contrasting droplet size and stability suggest differences in the efficiency with which plant- and dairy-derived proteins stabilize freshly formed interfaces at low concentrations. This hypothesis will be examined in ongoing work by correlating microfluidic data with small-angle X-ray scattering and Raman microscopy to resolve interfacial nanostructure and molecular organization.

Keywords:
protein-stabilized emulsions, Cruciferin, β-lactoglobulin, microfluidics



Bright-field micrographs of MCT oil-in-water emulsions stabilized by 0.5 wt% β-lactoglobulin (top) and Cruciferin (bottom), produced in a microfluidic device at the flow rate of 500–30–500 and 500–50–500 µL h−1. Scale bar: 50 µm.