Oil foams stabilized by polyglycerol fatty acid esters: Linking bulk self-assembly to interfacial and foaming properties

Antoine Simon[a], Arnaud Saint-Jalmes[b], Taku Ogura[c,d], Romain Bordes[e], Anne-Laure Fameau[a]

[a] INRAE, University of Lille, CNRS, Centrale Lille, UMET, 59000 Lille, France
[b] University of Rennes, CNRS, IPR, 35000 Rennes, France
[c] Tokyo University of Science, Chiba 278-8510, Japan
[d] Euglena Co., Ltd., Tokyo 174-0046, Japan
[e] Department of Chemistry and Chemical Engineering, Chalmers University of Technology, 41296 Gothenburg, Sweden

antoine.simon@inrae.fr

Personal cleansing products must balance efficient removal of oily skin contaminants, such as sebum and makeup, with good sensory usability. As modern formulations become increasingly long-lasting and resistant, there is a growing need for systems combining high cleansing efficiency with mildness and pleasant texture. In this context, oil foams are attracting increasing interest for applications in cosmetics, food and pharmaceutical formulations, as they combine the strong solubilizing capacity of oils with the light texture and spreadability of foams [1]. However, oil foams remain poorly understood. Most reported oleofoams rely on crystalline surfactants or particles for stabilization, typically based on sorbitan esters or sucrose esters, often at high concentrations [2,3]. Although recent studies have shown that stable oil foams can also be obtained using molecular surfactants [4], the mechanisms governing foam formation and stability remain largely unclear, particularly regarding the role of surfactant self-assembly in the bulk oil phase and at the air/oil interface.

In this work, we investigate oil foams stabilized by polyglycerol fatty acid esters (PGs), a versatile class of non-ionic surfactants widely used in cosmetic formulations. Their well-defined and tunable chemical structure enables a systematic investigation of the relationship between molecular architecture and foaming properties. In particular, key structural parameters such as alkyl chain length, degree of unsaturation, and headgroup size can be independently varied.

A multiscale experimental approach is employed to elucidate the stabilization mechanisms of oil foams. Bulk self-assembly and phase behavior are characterized by small-angle X-ray scattering as a function of temperature, oil composition and surfactant structure. These results are correlated with interfacial properties probed by surface tension measurements and X-ray reflectivity, as well as with thin film stability and interfacial rheology. Finally, macroscopic foaming tests are performed to establish structure-property relationships across scales.

Our results reveal strongly contrasted foaming behaviors depending on both the oil phase and the chemical structure of the PGs. Foam formation and stability are shown to be directly governed by the nature of the surfactant self-assemblies present in the bulk oil phase, which are highly sensitive to oil composition. In particular, the size of the polyglycerol headgroup emerges as a key parameter controlling self-assembly pathways, interfacial mechanical properties and ultimately foaming performance. This work provides new insights into the rational design of oil foams and highlights the central role of bulk self-assembly in non-aqueous foaming systems.

Keywords:
Oil foams, Polyglycerol fatty acid esters, Nonionic surfactants, Bulk self-assembly

References:

[1] A.-L. Fameau, CHAPTER 13. Non-aqueous Foams Based on Edible Oils, in: A.R. Patel (Ed.), Food Chemistry, Function and Analysis, Royal Society of Chemistry, Cambridge, 2017: pp. 275–307. https://doi.org/10.1039/9781788010184-00275.
[2] Y. Liu, B.P. Binks, A novel strategy to fabricate stable oil foams with sucrose ester surfactant, Journal of Colloid and Interface Science 594 (2021) 204–216. https://doi.org/10.1016/j.jcis.2021.03.021.
[3] Y. Liu, B.P. Binks, Foams of vegetable oils containing long-chain triglycerides, Journal of Colloid and Interface Science 583 (2021) 522–534. https://doi.org/10.1016/j.jcis.2020.09.043.
[4] C. Ugarte-Pereyra, S.-M. Argyri, R. Bordes, S. Vincent-Bonnieu, J. Beaucé, B.P. Binks, C. Le Coeur, A.-L. Fameau, Design of oleofoams from citric acid esters of mono−/diglycerides, Food Research International 220 (2025) 117119. https://doi.org/10.1016/j.foodres.2025.117119.

Acknowledgements:
The project is supported by the Circular Bio-based Europe Joint Undertaking and its members. Funded by the European Union. Views and opinions expressed are however those of the author only and do not necessarily reflect those of the European Union or CBE-JU. Neither the European Union nor the granting authority can be held responsible for them.