

Dynamic surfactants for biomolecular condensate stabilization

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Abstract

In biological systems, biomolecular condensates provide structurally organized microenvironment which allow condensates to precisely regulate and improve specific metabolic processes by focusing and isolating particular biomolecules from the surrounding cytoplasm. Inspired by this natural system and organization principle, synthetic condensates have become useful platforms for responsive materials, microreactor design, and molecular organization. Among the various interacting species, lipids are especially fascinating because they play crucial roles in biological organization and signaling and can interact with and alter phase-separated surroundings due to their amphiphilic nature. According to recent research, lipids can be selectively integrated into the interiors of biological systems via condensates, which affects cellular signaling pathways and reactions linked to neurodegenerative diseases. Lipid-condensate interactions are essential for droplet stability from a synthetic perspective, allowing them to be used as durable platforms for uses such as targeted drug delivery. This work utilizes an approach based on dynamically formed surfactants to investigate their mutual influence on liquid droplets and how the droplets affect them, given the importance of understanding both static interactions and the generation and distribution of lipids over time. In this work, we investigate the relationship between biomolecular condensates and a reversibly produced, temporally controlled phospholipid under aqueous conditions. We combine reversible phospholipid with phase-separated environments to study the effects of in situ-generated surfactants on condensate characteristics. Our findings demonstrate that droplet stability, size distribution, and, in certain cases, condensate morphology is strongly influenced by dynamic lipid synthesis. These results provide a framework for integrating biomolecular condensates with dynamic chemical reactions, opening up new possibilities for the development of responsive, lifelike materials and deepening our understanding of lipid-based control in complex biological systems.