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Designing edible substrates for four-dimensional (4D) printing applications

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ABSTRACT

Additive manufacturing in food applications is driven by curiosity, the need to replace ingredients due to environmental and dietary concerns, the need to create safe textures for dysphagia patients, the need to reduce waste, and the desire to build innovative shapes in the food sector. Yet, it necessitates redesigning food manufacturing and reformulating raw materials to improve compatibility.

Film-forming solutions and emulsions based on natural biopolymers and their films are promising candidates for creating edible inks and substrates in 3D and four-dimensional (4D) printing of food. They allow tunable morphologies, matrices, textures, and nutritional profiles. The response of the edible films upon exposure to different environments determines their applicability as substrates in 3D and 4D printing settings. The response can be swelling, dehydration, and color change when exposed to stimuli (e.g., water, solutions at different pH, and heat). Film microstructure and exposure medium conditions can be altered to increase the response behavior of the edible films.

This study focuses on designing new substrates using biopolymer solutions and emulsions and repurposing their use in 4D printing applications. Film-forming solutions and emulsions were fabricated using different biopolymers at various concentrations and phase ratios. The flow and deformation of solutions and emulsions were studied. Upon drying, the films were characterized via dimensional analysis, weight, moisture content, and microstructure. The swelling rate of the films was recorded upon exposure to water for up to 60 min. Film-forming solutions and emulsions were characterized as yield stress fluids, following the Herschel-Bulkley model, with solid-like properties (storage modulus > loss modulus) in the linear viscoelastic region. The film matrix properties affected the response behavior of the samples depending on the swelling media. The swelling medium conditions significantly affected the survivability and response capacity of the films. Understanding the effects of film microstructure and swelling medium conditions on the response behavior provides insights for tailoring these films for future applications as novel substrates in 4D printing and beyond.