Designing and Understanding Thermoresponsive Shape-Shifting in 4D-Printed Pea-Based Foods and its Applications

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Food 3D printing, also known as additive manufacturing, has created new opportunities for designing reconfigurable food structures. When time is introduced as an additional dimension, printed constructs can be programmed to undergo shape-morphing transformations, a concept known as 4D printing. However, achieving precise and reproducible deformation in plant-based systems, elucidating the underlying mechanisms, and translating them into real-world applications, remains a significant challenge. In this study, we developed a high-concentration pea-based suspension tailored for 4D printing and systematically examined the influence of printing parameters (print size, infill density, and printing path) and processing conditions (heating temperature and duration) on controllable shape transformations. Rheological tuning reveals that water content governed extrudability and structural integrity. By varying baking temperature, duration, and path design, we demonstrated how these factors interact to regulate bending magnitude and direction. A key mechanism is proposed: nonuniform vapor expansion within the printed matrix generates internal stresses that drive bending aligned with the print trajectories. To validate design principles, edible prototypes such as bending plates and floral actuators are fabricated and successfully actuated under conventional baking. These results demonstrate that programmable shape changes in plant-based foods are feasible, and offer a route for designing functional, responsive food constructs with controllable morphology.

Keywords:

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