# 4D printing of shape-morphing foods: Control of stimulus-driven deformations through protein-starch thermal transitions

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Since its adoption in food processing, the focus on additive manufacturing or 3D printing technologies has dramatically increased due to its accuracy, precision and reproducibility in the processing of complex structures. The most common 3D food applications adopted by the scientific and research communities are the application of novel food formulations, customized textures, texture variation and modulation as well as the full sensory design. As an emerging and integral application of additive manufacturing, 4D printing presents a new approach of processing, for the first time, dynamic food structures with time- and stimuli-dependent behavior. Such behaviors include the pH-driven spontaneous color change, shape morphing and cell culturing. In particular, the structuring of food structures which exhibits thermal-driven evolving deformations presents an immense potential for integration in the textural design of foods.

Currently, for structuring of shape morphing foods using 4D printing, polysaccharide-based material systems are mainly used in the form starch-based and hydrocolloid-based foods. For achieving the shape morphing effect, two stimulation methods are used which are hydration and dehydration methods. Considering shape morphing of starch-based materials through dehydration stimulation, the behavior is elucidated in-relation to energy/mass transfer, applied design and contraction mismatch between (bi-layer) active-passive or active-active layers while the mechanistic effect of thermal transitions is under-studied. In the presented research, characterization of the effect of protein-starch thermal transitions on shape morphing kinetics was performed on a hydrated wheat starch-soy protein material system. The influence of the geometric design was eliminated by printing uniform planar active starch-based layers on a single passive layer where the simple uniform 2-dimensional bending behavior was characterized using a computer vision method. As for the thermal stimulation methods, microwave and oven drying were used. For characterization of the effect of starch gelatinization on the shape deformation, the gelatinization kinetics were manipulated thorough variation of hydration and protein concentration inducing inhibition in water-mobility and varying starch-protein interactions.

Finally, by elucidating the effect of thermal transitions on the shape morphing kinetics of 4D printed structures, the control over textural effects through shape morphing can be achievable in the assembly of complex 3D structures.