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Morphing food: programmable surface grooving as a tool for shape transformation

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The advancement of 4D food design technologies stands out as one of the most promising innovations for fostering sustainable food systems and enhancing gastronomic applications. These emerging technologies enable precise control of dynamic transformation of food morphology and functional properties in response to external stimuli such as hydration, heat, or pH. In particular, *Morphing food* refers to the ability of food to undergo controlled shape changes upon exposure to specific stimuli offering a compelling approach to minimize the use of packaging materials and cost for transportation aligning with the goals of the Agenda 2030.

This study explores the application of surface grooving techniques to trigger programmable shape changes in both pasta and cereal-based snacks, leveraging on programmable and localized swelling and shrinkage as transformation mechanisms.

Initially, working on *morphing pasta*, the shape-change was achieved by manually impressing grooves and protrusions on one side of the samples through a digitally designed 3D printed mold. The impact of the applied pressures (ranging from 0.377 to 0.541 kg/cm²) and thicknesses of the dough (ranging from 1.0 to 2 mm) on dehydration kinetics, microstructure, water absorption, and bending behavior during cooking, was studied. Results revealed that dough thickness is the primary factor influencing dehydration rates and the kinetic of bending which can be described by a sigmoidal model. The bending during cooking in boiling water was mainly controlled by the remaining layer thickness below the grooves. Applied pressure, in contrast, showed minor but significant effects, especially on the thinner samples of 1.5 and 1 mm. A second series of experiments were dedicated to *morphing snacks*, by using an automated system to impress surface grooves with highly accurate depths between 300 and 1200 µm, with errors <41 µm. The groove design significantly affected dehydration during baking by increasing the surface area exposed to heat, thereby accelerating moisture loss and promoting controlled bending. While thinner samples (1.24 and 1.89 mm) successfully exhibited the desired shape change, thicker samples (2.60 and 3.43 mm) experienced delamination and inflation due to gas pocket formation, highlighting the critical interplay between groove depth, sample thickness, and dehydration kinetics in achieving reliable morphing behavior. The obtained results proved that the creation of designed surface grooves is an interesting approach for novel applications in food engineering and for a greater sustainability of the food system.