Supplementary materials

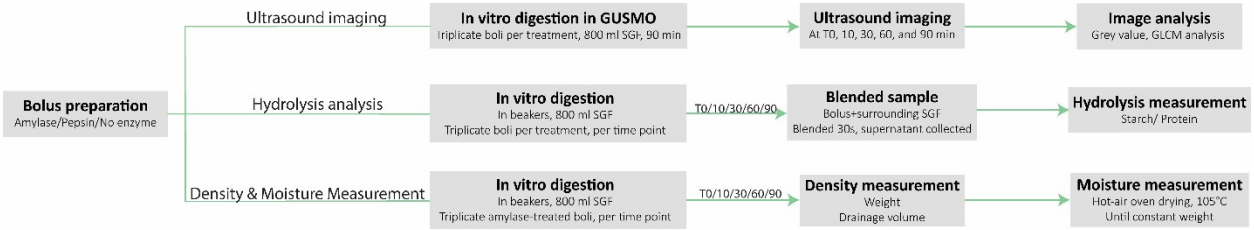

Figure S1. Workflow diagram of parallel experiments. All parallel experiments followed the same bolus preparation procedure. The upper branch represents ultrasound imaging during 90 min of digestion in GUSMO; the middle and lower branches represent separate in vitro digestion experiments, stopped after specified digestion times, for hydrolysis analysis and for density and moisture measurements, respectively.

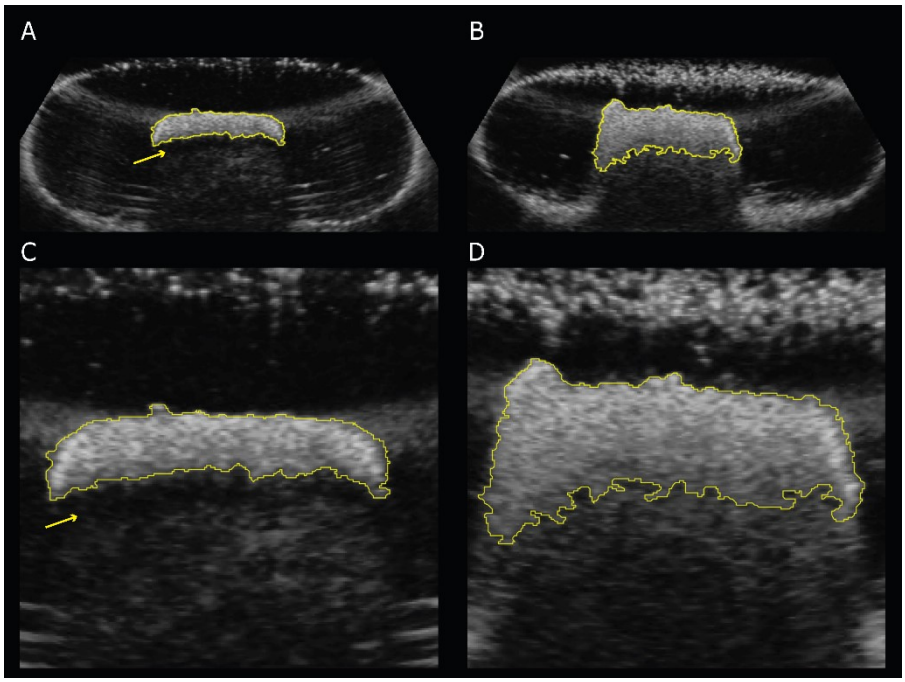

Figure S2. Representative examples of bolus boundary segmentation under different image contrast conditions. Panels A and C show a case in which the interface between the hyperechoic bolus and the surrounding background is well defined because of the high pixel-intensity contrast. The yellow outline indicates the segmented bolus region, and the yellow arrow represents the adjacent darker boundary zone. Panels B and D show a lower-contrast case in which the bolus boundary cannot be delineated reliably as a single continuous boundary from intensity differences alone. In this condition, segmentation using the wand tool is more uncertain, and adjacent darker background patches were therefore used as cues for defining bolus boundary (yellow outline). Panels C and D are zoomed-in views of A and B, respectively.

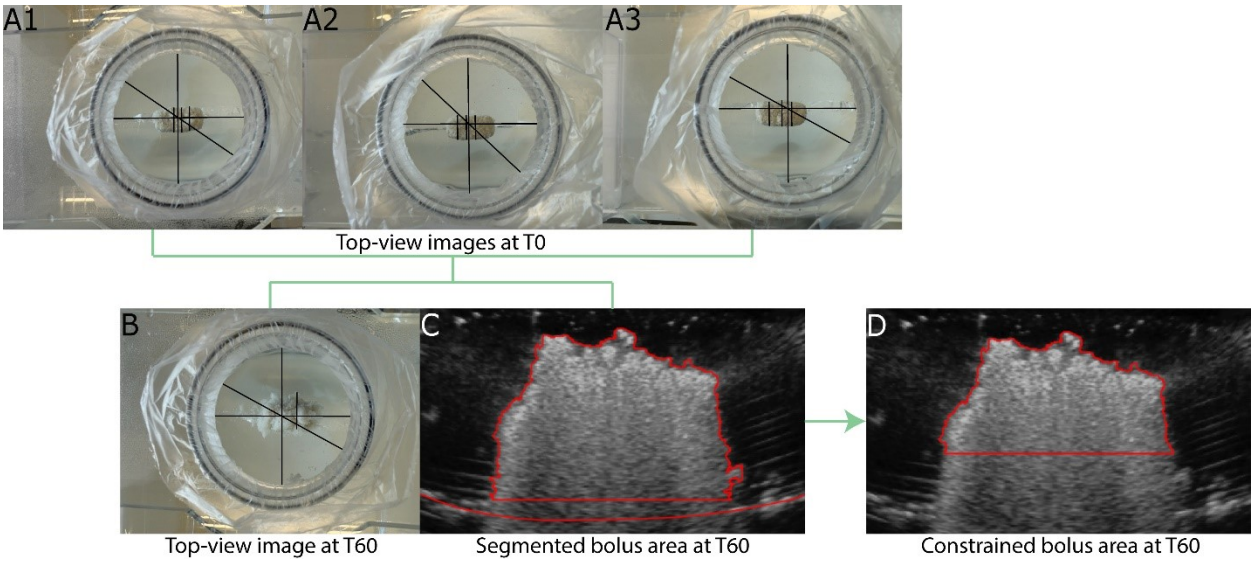

Figure S3. Estimation of bolus size and size-constrained segmentation. (A1-3) Triplicate T0 top-view images used for calibration. On each image, three black lines were drawn across the frame opening to measure its diameter in pixels, and three black lines were drawn across the bolus to measure the apparent bolus width. (B) Representative top-view image during digestion (amylase-treated bolus at T60). The frame opening diameter was measured using three black lines, and the apparent bolus width was measured using a black line drawn across the widest visible part of the bolus. (C) Bolus region segmented using the primary wand-based method. (D) Size-constrained bolus ROI obtained after trimming the segmented region in (C) according to the estimated bolus width.

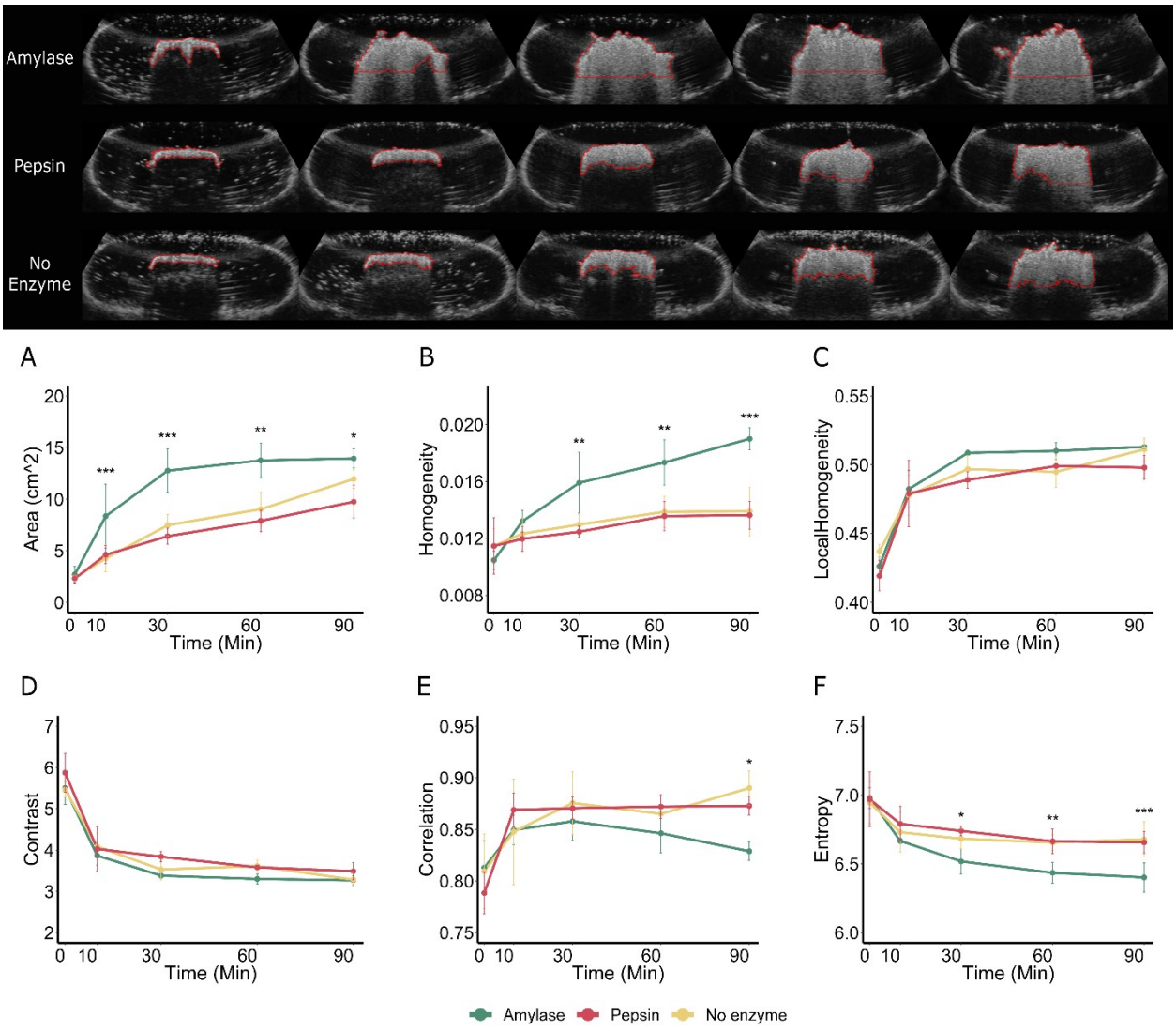

Figure S4. Representative images of bolus inserted in amylase (Top row), pepsin (Middle row) and no enzyme (Bottom row) with size constrained segmentation and results (A-F) of GLCM texture analysis for the traced regions over the 90-minute digestion. A: Size of segmented bolus ROIs B: Homogeneity measures the uniformity or orderliness of the texture. Higher values indicate less texture complexity; C: Local homogeneity represents similarity of grey values. Higher values indicate a smoother image/area; D: Contrast reflects differences in greyscale intensities. Higher contrast values indicate greater differences; E: Correlation reflects the degree to which a pixel's intensity is linearly related to its neighbor's intensity; F: Entropy represents the randomness and complexity of greyscale distribution; higher entropy values indicate more complex and disordered texture. Asterisks (*) indicate significant differences for amylase-treated boli compared to pepsin-treated and no enzyme boli. * $p<0.05$, ** $p<0.01$, *** $p<0.001$. For bolus area at t=90, the significance refers only to amylase versus pepsin.

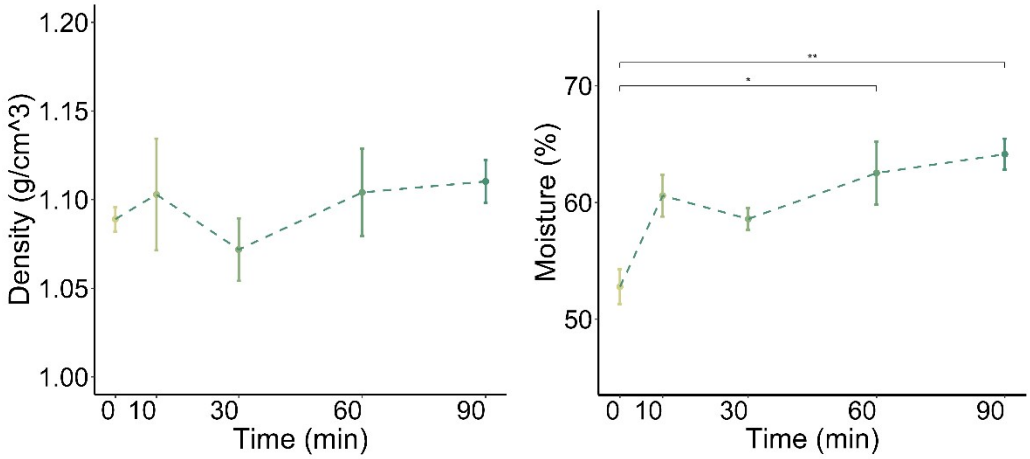

Figure S5. Density and Moisture content of boli with amylase after different digestion times. Density was calculated from the weight and drainage-measured volume of boli collected from SGF. Moisture content was measured from weight loss after drying at 110 °C. Values represent mean ± SD for three replicates.

Figure S6. Representative images showing the differences in boli immersed in gastric fluid versus after removal. In the left panel, porous bread cubes at bolus peripheral are filled with fluid. The middle and right panels show boli after removal from fluid, revealing a noticeable loss of water.

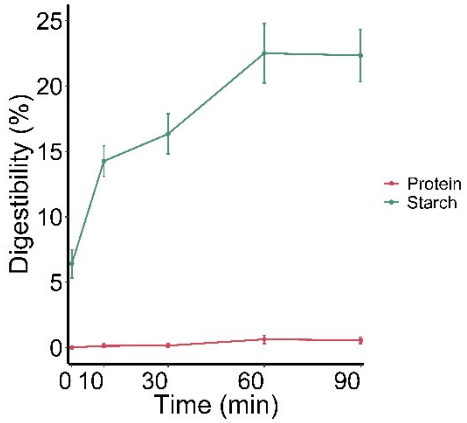

Figure S7. *In vitro* starch and protein digestibility of bread boli over 90 minutes. Values are mean ± standard deviation for three replicates of boli, supernatant sampling and hydrolysis measurements.

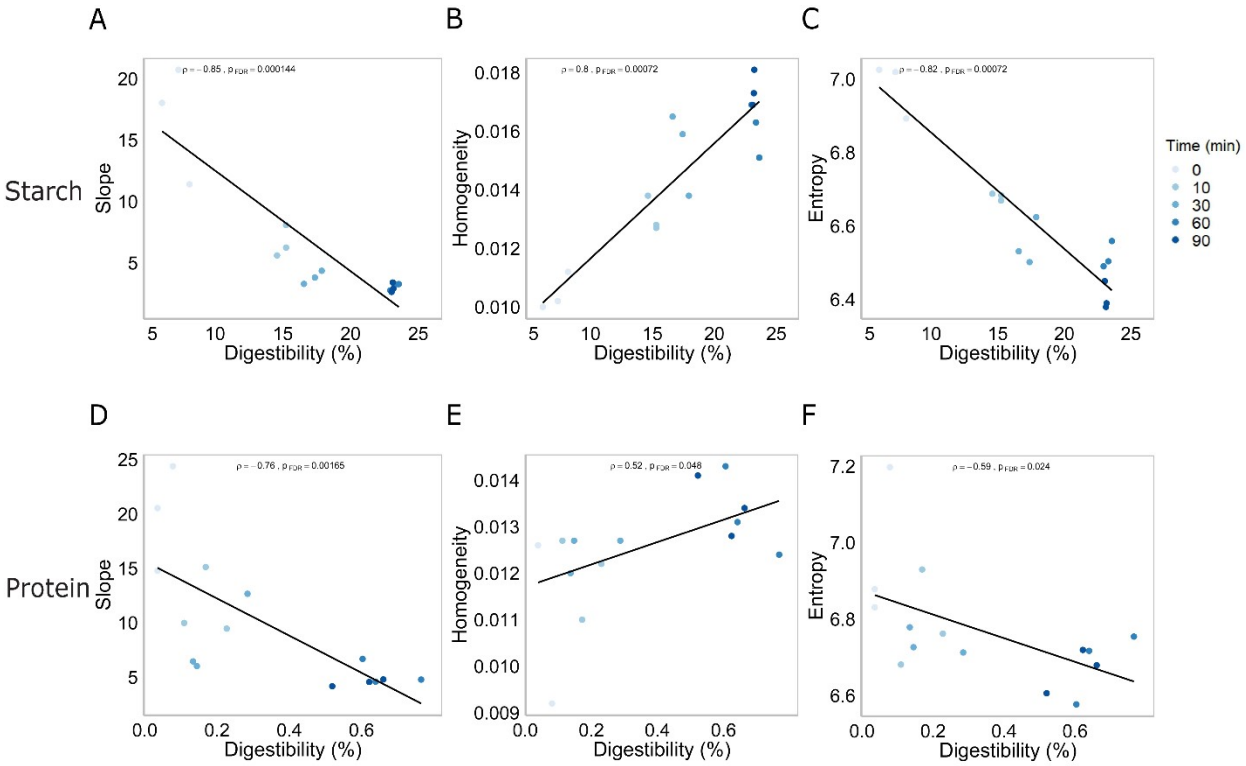

Figure S8. Correlation of degree of hydrolysis of starch with grey value curve slopes and image texture features over 90 minutes digestion. Points of the same color represent triplicate samples from the same time point.