Numerical modelling of deformation and rupture of gas cell walls in bread dough during baking

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Objective:
During bread-making, the gas cells undergo continuous expansion and, consequently, the gas cell walls (GCW) separating them thin from several hundreds to a few ?m, until their rupture. It is well accepted that the GCW rupture moment is crucial for a good quality bread. In contrast, the understanding of stress concentration on the GCW scale, and the role played by the starch granules in it, has received little attention. Therefore, the aim of this work was to model this thinning process occurring at small scale, as a preliminary step to multiscale modelling of bread baking, and in complement to other higher-scale modelling tools available in the research team.
Methods:
For the model, a GCW was represented by a single wheat starch granule surrounded by gluten, and the possible rupture points were localized through the analysis of von Mises stress fields under unidirectional extension. This model was fed with Young's moduli values coming from the literature for gluten and from dedicated experiments for starch. Compression-relaxation tests were carried out at different temperatures for different starch types (varying in terms of botanical origin and variety), and two extreme water contents depending on the starch type.
Results:
Simulated stress concentration within the GCW was highly dependent on the characteristics of starch granules, and was the highest close to the edge of the starch granules. Flattening of starch granules was simulated when Young modulus of starch was lower than that of gluten. In such case, stress distributes more uniformly through the GCW thickness, lengthening extension and delaying rupture. Likewise, mechanical tests showed that Young modulus decreased with temperature whatever the starch type. Under the range of water content under study, Young modulus of starch was higher than that of gluten, except for waxy wheat starch.
Conclusions:
This work illustrates an example of modeling at small scale (µm) and highlights the lack of experimental data at these scales but also the need of experimental strategies to be developed to obtain them. This is illustrated here with the mechanical properties of starch; that of gluten and the gluten/starch interface constitute perspectives to this work.