

Dynamics of cake baking: A coupled multiphase poro-hygro-viscoelastic model

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Research Justification

Cake baking involves complex physics of simultaneous transport and large deformation during which a liquid batter rises and sets into a solid porous structure. Engineering understanding of the cake baking processes is limited, and the process control to obtain desired performance metrics of cakes, such as cake height, weight, porosity, and color are currently based on a trial-and-error approach.

Objective

To provide a first principle-based mechanistic understanding of the cake baking process thus providing a rational basis for optimization and novel developments in products and ovens.

Methods

A coupled multiphase, multicomponent porous media transport model with evaporation, large deformation, and material transformation (phase change from starch gelatinization) is developed for cupcake baking in a conventional oven. The equations are solved numerically to predict the evolution of temperature, moisture, large dimensional change, and color of the cupcake batter during baking. The model is validated against measured temperature, moisture, color, and height of the cake during baking. The novelty of the numerical model is the coupling of the massive change in mechanical and thermophysical properties with multiphase transport and expansion due to pressure as well as moisture loss from shrinkage.

Results

The predicted internal temperatures, moisture loss, deformation, and color formation of the cupcake during baking for different oven settings agreed well with the experiments. The average moisture at the end of the baking cycle was around 30% of dry solid mass, the average deformation was about 100%, and the average browning index was around 30-40. The model showed that the amount of internal evaporation and the onset of starch gelatinization decided the final moisture content, height, and color of the cupcakes. The model also showed that the deformation profile during baking followed the gas pressure profile inside the batter.

Conclusion

The model enables a comprehensive quantitative understanding of the effect of coupled transport and deformation on both the surface and internal physical condition of baked goods for a whole host of complex baking processes, with cupcake baking as an example. As part of computer-aided food engineering, it will greatly enhance the optimization of equipment (oven) and baked product design.