A Model Coupling Water Transport with Local Deformation and Polymer Phase Transition

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Abstract

Describing and predicting the extent of the physicochemical processes as well as geometrical deformation taking place during food transformation is of major importance to control food functional properties. Unfortunately, only a few food-matrix models consider deformation particularly because of large deformation. In the case of a starchy product such as rice, water transport and swelling together with starch gelatinization occurring during water cooking (figure 1) have a strong impact on its texture.

The 1D model, assuming the grain as a sphere, was built with COMSOL Multiphysics® software using the "coefficient form PDE" interface. Water transport associated with local deformation (swelling) was implemented by coupling three Partial Differential Equations, two based on Fick's law of diffusion written in Lagrangian coordinates and another one on Eulerian-Lagrangian transformation. One originality of this work relies on the fact that it considers two water populations according to starch state: native or gelatinizing. The extent of starch gelatinization τ (from native state ($\tau = 0$) to fully gelatinized state ($\tau = 1$)), which locally depends on both temperature and water content, was expressed through a composite variable based on a double-sigmoid approach. Each water population was characterized by its proper water absorption capacity and transport properties depending both on cooking temperature and the extent of starch gelatinization (figure 2). Thanks to the use of an adaptive Neumann boundary condition taking into account the dynamic status of the water cooking medium, the model has the capacity to represent several cooking modes: excess-water, limited-water and post-cooking holding phase (figure 3).

Model adjustments were carried out based on experimental water uptake and gelatinization front kinetics (microscopy) data collected on Chil-Bo Korean milled round rice cultivar at different temperatures ranging from 50 to 100 °C. Apparent water diffusivities in gelatinized starch were found to be lower (2.8×10−10 m2.s−1) than in native starch (3.6×10−10 m2.s−1) due to water binding and viscosity effects. Concerning deformation, the model adequately reproduces swelling as its extent corresponds to the amount of water absorbed (± 4% v/v). After 240 min at 75 and 95°C, kernel volume gain was of 4.9 and 8.4 m3.m-3, respectively.

As input parameters, the resulting validated cooking simulator can consider both varietal and cooking parameters such as chemical composition, grain geometry, temperature as a function of time as well as water-to-rice ratio. Both simulated radial water and gelatinization profiles in the

grain at the end of cooking would be of tremendous benefit to select a set of cooking scenarios for the optimization of cooked rice properties such as texture. Its use could also be extended to other starchy products.

Reference

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