Modelling of water transport and swelling in a single rice grain during cooking: impact of starch gelatinization

Starchy food texture has a strong dependency on gelatinization and water content distributions (1). A physically-based model was designed to predict cooked rice sensory attributes.

Keywords: modelling, swelling, gelatinization, starch, texture.

Mathematical model (COMSOL Multiphysics™)

The present binary model (1: water; 2: anhydrous starch) includes (figure 1):

Water transport with two water populations: in native \( X_{1n} \) and gelatinized starch \( X_{1g} \) (kg/kg db):

\[
\frac{\partial X_{1n}}{\partial t} = \frac{\partial}{\partial r} \left( D_n \frac{\partial X_{1n}}{\partial r} \right) \quad (r < r_g)
\]

\[
\frac{\partial X_{1g}}{\partial t} = \frac{\partial}{\partial r} \left( D_g \frac{\partial X_{1g}}{\partial r} \right) \quad (r_g \leq r < r'_g)
\]

where \( r \) and \( \xi \) are the Lagrangian and Eulerian coordinates respectively (m), \( D_i \) are the apparent diffusivities (m².s⁻¹), \( X_{1c}^{cr} \) is the water content threshold for gelatinization starting-up (kg/kg db) and \( \rho_i \) are the densities of the species \( i \) (kg.m⁻³).

Starch gelatinization: local degree of starch gelatinization \( \tau \) is a function of temperature and local water content within rice (figure 2).

Swelling using an Arbitrary Lagrangian−Eulerian method: \( \rho_3 r^2 dr = \rho_2 \xi^2 d\xi \)

Model validated for 3 steeping temperatures (50, 75 and 95°C), through 3 independent ways:

- Water uptake (gravimetry) (figure 3)
- Volumetric change
- Gelatinization front kinetic (polarized light microscopy) (figure 4)

Model application: Texture prediction from simulated profiles

Four limited-water rice cooking programs (namely 1, 2, 3 and 4; figure 5) were run with a rice cooker (picture) and subjected to sensory evaluation (firmness and crunchiness).

Cooking programs also simulated to obtain the final degree of starch gelatinization and water content profiles. Programs 1 and 2 resulted in remaining low-hydrated native regions whereas programs 3 and 4 led to highly-hydrated and fully gelatinized grain (figure 6). The native and low-hydrated core may confer more firmness and crunchiness.

Conclusion

This new “mechanistic” modeling approach can predict the local extent of two major phenomena (water transfer and gelatinization) involved in rice cooking process. This opens new ways for cooking process optimization.