Modeling Flow and Deformation During Salt-Assisted Puffing of Single Rice Kernels

T. Gulati[1], A. K. Datta[1]

[1]Department of Biological & Environmental Engineering, Cornell University, Ithaca, NY, USA

Abstract

Puffing of biomaterials involves mass, momentum and energy transport along with large volumetric expansion of the porous, elasto-plastic material. Development of physics-based models that can describe heat and moisture transport, rapid evaporation and large deformations of the solid matrix can help understand the factors affecting the puffing processes. In this context, a fundamentals based study of hand operated salt-assisted puffing process of parboiled rice is described. A multiphase porous media model involving heat and mass transfer within the rice kernel undergoing large plastic deformation is implemented using finite elements. The transport model involves different phases, solid, liquid (water), and gas (air and water vapor), and multiple modes of transport (capillary flow, binary diffusion, and pressure driven flow). During puffing, intensive heating (200 degC) of the porous solid leads to rapid evaporation of liquid water to vapor resulting in large pressures to build within the kernel. At high temperatures, the rice grain undergoes a phase transformation from a rigid, glassy state to a soft and rubbery state. Development of large pressures within the soft and compliant matrix results in large volumetric expansion of the kernel causing it to puff. In order to model this complex process, a 2-D axisymmetric geometry of the rice kernel was constructed in COMSOL Multiphysics® software. Concentration of different species were solved for using the Transport of diluted species interface (for liquid water) and Maxwell-Stefan Diffusion model (for vapor and air) together with Darcy Law (to calculate Gas Pressure). Temperature of different species was obtained by solving one Heat Transfer equation assuming thermal equilibrium between different phases. Expansion and solid displacements were obtained using the Hyperelastic Material model with large strain Plasticity using the Nonlinear Structural Materials Module. The developed model was validated using 3D reconstruction of Micro-CT images that was used to determine the expansion ratio of the kernel and to visualize the microstructure development. The expansion of the kernel began from the tip of the grain and the model could successfully capture this phenomenon. The model was validated against dimension changes during puffing, moisture content and expansion ratio of the rice kernel after the puffing process. Expansion ratio, a key quality parameter associated with puffed products, was found to be sensitive to evaporation rate and intrinsic permeability of the solid matrix.

Figures used in the abstract

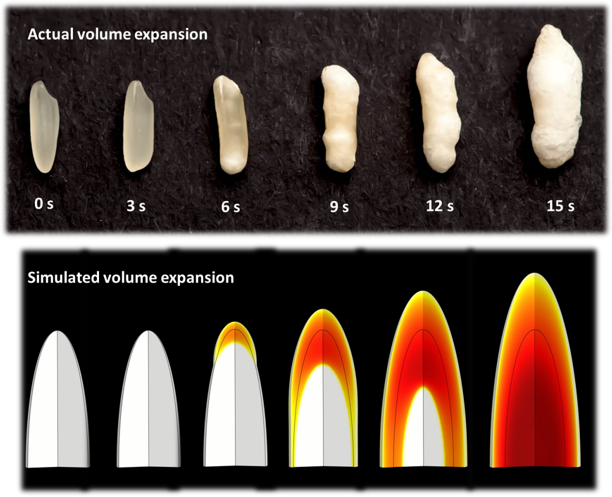

Figure 1: Actual and simulated expansion during puffing of rice.

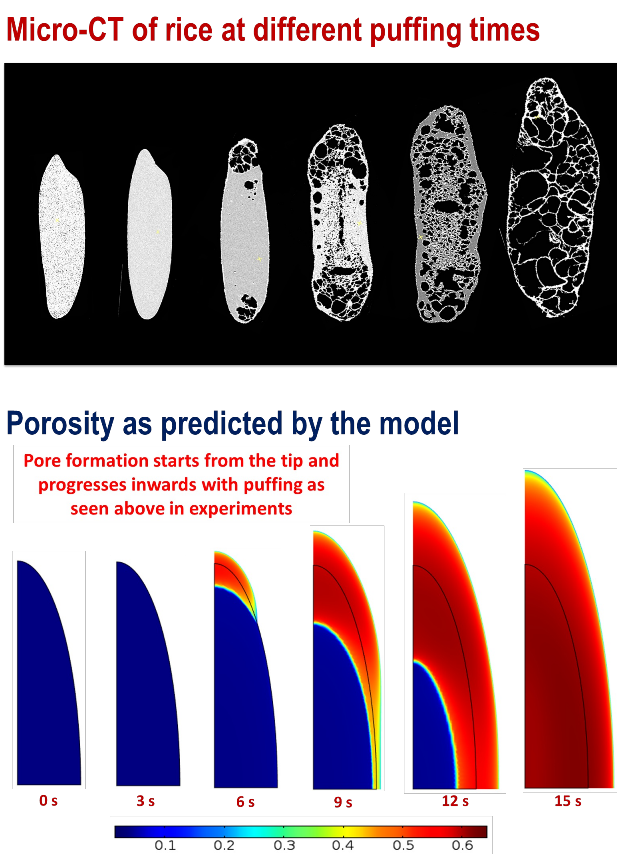

Figure 2: Microstructure development during puffing of rice kernels.