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Modelling the hydration of foodstuffs

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Abstract

The rehydration kinetics of dried foodstuffs is of critical importance to their sensory properties and delivery of flavour and functional molecules. Based on the dynamics of capillary flow in partially saturated porous media, a finite element model is developed to predict the infiltration of water into dried food products taking into account temperature effects. The finite element model is based on the mixed form of the mass conservation equation. The constitutive relationships of water retention and hydraulic conductivity are adopted from the fields of hydrology and soil science. The transfer properties of water in the porous medium depend on the moisture content and the microstructure. This is contrast to the constant transfer properties often used in the heat and mass transfer models developed for foods. Rehydration of green tea as a function of temperature has been simulated and results are compared with NMR measurements. There is good agreement.

Keywords: Rehydration; Porous media; Mass transfer; NMR measurements; Biomaterials

1. Introduction

Dried foodstuffs often need to be rehydrated before they are consumed. It is desirable that these foodstuffs hydrate as fast as possible and show adequate structural

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and chemical characteristics. Information about water absorption as a function of temperature of those food materials is critically important to their shelf life and product usage. Rehydration of food materials also has an important impact on their nutritional and sensorial properties.

A number of studies have been reported to model the hydration kinetics of foodstuffs and different types of models have been used. Two main approaches can be identified. One approach uses the empirical and semi-empirical models like for instance the Peleg and the Weibull equation [18–20,25,30,31]. The other approach employs diffusive models based on Fick's second law of diffusion [13,26–28,33]. Despite numerous studies using Fick's law to model liquid water transport in porous foodstuffs, the liquid water movement cannot be simply defined as a diffusion process. Hydration occurs by capillary flow, driven by an energy potential gradient, rather than by diffusion. Some studies using capillary flow approach to model hydration and/or drying of foodstuffs have been reported recently [9,15,17,23,35]. However, the capillary flow approach is still not widely used.

The objective of this work is to show the feasibility of modelling the rehydration process of foodstuffs using the capillary flow approach applying constitutive relationships often used in soil science and hydrology. In particular, the effect of temperature is modelled. We first demonstrate that the effect of temperature on hydration can be directly taken into account in the constitutive properties. A finite element model is then proposed. As a model system of porous foodstuff, we use dried green tea leaf material (Sencha). Hydration behavior of green tea at various temperatures is investigated using time domain NMR. Consequently we compare our model predictions with the experimental data of green leaf tea hydration. For a range of temperatures studied, we find good agreement between the model prediction and the experimental data. More details of this work can be found in [37,38].

2. Theory

2.1. Capillary flow model

For fluid flow in a capillary body, we can write the continuity equation as follows [3]

$$\nabla \cdot \rho_{\mathrm{w}} J + \rho_{\mathrm{w}} \frac{\partial \theta}{\partial t} = 0 \tag{1}$$

where ρ_{w} is the density of water (1000 kg/m^3), J is the volumetric mass flux and θ is the volumetric moisture (water) content. This equation is a mass balance statement. The first term describes the divergence of the mass flux in the control volume and the second term describes the change of mass in that volume in time.

Normally in capillary flow theory the flux of water is considered to be governed by Darcy's law:

$$J = -\frac{k k_{\mathrm{r}}}{\mu_{\mathrm{w}}} (\nabla P_{\mathrm{c}} - \rho_{\mathrm{w}} g) \tag{2}$$