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Moisture distribution in broccoli: measurements by MRI hot air drying experiments

X.Jin[a]*, R.G.M.van der Sman[b], E.Gerkema[c], F.J.Vergeldt[c], H.van As[c], A.J.B.van Boxtel[a]

[a]*Systems and Control Group, Wageningen University, P.O.Box 17, 6700AA, Wageningen, The Netherlands. Contact: Xin.Jin@wur.nl*
[b]*Food Process Engineering Group, Wageningen University*
[c]*Laboratory for Biofysics, Wageningen University*

Abstract

The internal moisture distribution that arise in food products during drying, is a key factor for the retention of quality attributes. To reveal the course of moisture content in a product, internal moisture profiles in broccoli florets are measured by MRI imaging during drying experiments with controlled air flow and temperature. The 3D images concern a matrix size of 64×64×64 elements. Signal intensity is converted to product moisture content with a linear relationship, while taking a minimum detectable moisture content of 0.3 kg water/ kg dry matter into account. Moisture content as a function of time is presented for a 2D cross sectional area in the middle of a broccoli sample.
The average moisture contents for the cross sectional area obtained from the MRI imaging are compared with spatial model simulations for the moisture distribution. In that model the effective diffusion coefficient is based on the Free Volume Theory. This theory has the advantage that the changed mobility of water in the product during drying is taken into account and the theory also predicts the moisture transport in the porous broccoli floret. Key parameters for the Free Volume Theory are estimated by fitting to the experimental MRI results and the effective diffusion coefficient is given as a function of the product water content.

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Keywords: MRI; convective drying; moisture profiles

1. Introduction

Drying is a main technology for food preservation. The low moisture content and water activity allow safe storage of food products over an extended period of time. Due to the heat load and dehydration, quality attributes of food products change during drying; for example structure, colour, healthy components and nutritional value. The changes in quality attributes depend on the local, time varying

* Corresponding author. Tel.: +31-0-317-482014.
E-mail address: xin.jin@wur.nl.

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moisture content and temperatures in the product rather than the average moisture content. As a result, the internal moisture distribution and moisture diffusion are important in studying the influence of drying on quality attributes of the product.

Drying of food particles process is controlled by diffusion and is often described by Fick's law. However, food products behave more complex during drying. The product goes from a rubbery state to a glassy state, and the changes in water mobility, resulting in different diffusion properties, may not be ignored. To meet the changes in diffusivity, the free volume theory is applied to predict moisture transport during drying[1]. This theory is based on the physical properties of foods, and takes the mobility of the water molecules into account. Moreover, the free volume theory can be applied in porous media, like vegetables (for example the floret of broccoli).

Moisture transport and distribution in products are key factors for the development of the product quality. To control the quality development, knowledge of the moisture content as a function of place and time in the product is required. For that purpose spatially distributed moisture profiles can be measured with destructive methods by taking slices from the product or non-destructive methods such as γ-ray densitometry. Drawbacks of these methods are the requirements on the size of the sample, a limited resolution or they can only be applied in a one dimensional direction[2,3,4].

As an alternative, magnetic resonance imaging (MRI) is a powerful method to study complex materials as food products. The pioneer technique allows the imaging of the products' interior non-destructively. With continuous and controlled drying conditions, moisture transport during drying can be recorded. MRI has been applied in food applications to study the rehydration of extruded pasta[5], dying of potatoes[6], drying of apple slabs[2], and drying of food gels[7].

In this work moisture profiles in broccoli during drying are obtained from MRI imaging data. Experimental results of the moisture profiles and the effective diffusion coefficients are compared with simulation of the Free Volume theory and key parameters are tuned.

2. Theory and Modeling

Fick's second law for diffusion controlled particle drying, is given as:

$$\frac{\partial W}{\partial t} = \frac{\partial}{\partial r}\left(D_{eff}\frac{\partial W}{\partial r}\right) \quad (1)$$

with D_{eff} is the effective diffusion coefficient($m^2.s^{-1}$), W the moisture content($kg_{water}.kg_{dry\ matter}^{-1}$), r the position(m) and t the time(s).

According the Maxwell-Eucken relationship, the diffusion coefficient for water in porous products is a combination of the diffusion coefficient of water in the continuous phase(D_c ; product) and in the dispersed phase(D_d ; air):

$$D_{eff} = D_c\left(\frac{D_d + 2D_c + 2(1-\varepsilon)(D_d - D_c)}{D_d + 2D_c - (1-\varepsilon)(D_d - D_c)}\right) \quad (2)$$

with D_d($m^2.s^{-1}$) is the water diffusion coefficient in air which is given by Olek (2003)[15]:

$$D_d = 23 \times 10^{-6}\ \frac{98100}{P}\left(\frac{T}{273.15}\right)^{1.78} \quad (3)$$

where P is the pressure(Pa), and T the temperature(K).