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FULL LENGTH ARTICLE

The temperature hydration kinetics of *Lens culinaris*

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KEYWORDS

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Abstract The aim of this study is to evaluate the hydration kinetics of lentil seeds (*Lens culinaris*) in water at different temperatures (25, 32.5, 40, 55, 70 and 80 °C) for assessing the adequacy of models for describing the absorption phenomena during soaking. The diffusion coefficient values were calculated using Fick's model for spherical and hemispherical geometries and the values were in the range of 10^{-6} m^2/s. The experimental data were fitted to Peleg, Sigmoidal, Weibull and Exponential models. The models adequacy was determined using regression coefficients (R^2), root mean square error (RMSE) and reduced chi-square (χ^2). The Peleg model is the suitable one for predicting the experimental data. Temperature had a positive and significant effect on the water absorption capacities and absorption was an endothermic process.

1. Introduction

The lentil is an edible pulse. The lentil is a bushy annual plant of the legume family, grown for its lens-shaped seeds. The lentils have the third-highest level of protein (about 30%) after soybeans and hemp (Callaway, 2004). The amino acids essential present in protein are isoleucine and lysine. Lentils also contain dietary fibre, folate, vitamin B_1, and minerals. Red (or pink) lentils contain a lower concentration of fibre than green lentils (11% rather than 31%). The energy provided by the lentil is similar to that of cereals and other pulses. Lentils are an important source of dietary essential minerals, these include macronutrients (K, P, Ca, Mg, Na), micronutrients (Fe, Zn, Cu, Mn) and trace elements (Al, Cr, Ni, Pb, Co, Se, Mo) (Yadav et al., 2007).

The knowledge of the physical properties of lentil seeds is essential for the design of equipment such as for handling, processing and storing of it. The hydration process is, thus, an important unit operation in dried foods, as it describes and defines its properties and using during cooking, extraction, fermenting, germinating and eating. Therefore, it is important to understand the hydration kinetics of different food products, as well as the influence of process conditions (as temperature) on its rate (Oliveira et al., 2013). Abou-Samaha et al. (1985) observed that the soaking in tap water and in saline solution led to increases of the hydration coefficient, weight of seeds, inorganic phosphorus and phosphorus fraction other than phytate phosphorus, solubility of nitrogen and in vitro protein digestibility, and to reduce the cooking time and tannins and improve the seed colour of lentils. Joshi et al. (2010) observed that the same cultivar might have different water uptake

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behaviour at the same temperature in function of the seed surface area. They observed that the French-green lentil type was able to imbibe the largest amount of water which can be attributed to its highest seed surface area to volume ration and the highest protein content indicating that at elevated water uptake do not depend on their pore characteristics.

The objectives of this study were to study the temperature dependent water absorption kinetics of lentil seeds (*Lens culinaris*) and to assess several mathematical models in terms of their adequacy to describe water absorption by chickpea splits.

2. Materials and methods

2.1. Materials

Lentil samples (*L. culinaris*) were purchased from a local supermarket from the Suceava county, Romania. The lentil samples were cleaned in an air classifier to remove foreign matter. The initial moisture content of lentil was determined using a hot air oven method (Prasad et al., 2010).

2.2. Physical properties

Physical properties (dimensions, mass, bulk density, true density, porosity, geometric mean diameter, sphericity, surface area, porosity, coefficient of static friction) of lentil were determined according to standard methods (Ghadge et al., 2008).

2.3. Water absorption experiments

Soaking experiments were made up at 25, 32.5, 40, 55, 70 and 80 °C. About 20 g of lentil seeds was placed in 600 ml Erlenmeyer flaks which contained 300 ml of distilled water which was already preset to the desired temperatures in a constant temperature in a constant temperature water bath (Lauda, Germany). The flasks were covered with aluminium foil to prevent moisture loss during the study. The samples were removed at 10 min interval for up to 3 h. After the desired time, the soaked samples were quickly blotted on paper towels to remove excess moisture adhering on the surface (Vishwakarma et al., 2013), weighed and analysed immediately for moisture content.

2.4. Water kinetics

The hydration kinetics can be described using empirical and theoretical models. For describing the moisture diffusion of different seeds has been used the Fick's second law of diffusion for a spherical geometry (Prasad et al., 2010).

$$\frac{\partial M}{\partial t} = \nabla(D\nabla M) \tag{1}$$

where M is moisture content at any given instant t (kilograms per kilogram, d.b.), t is time (seconds) and D represents moisture diffusivity (square metres per second. In 1975, Crank gives some analytical solutions for the Fick's second law for bodies of regular shape such as sphere, cylinder and slab.

The simplified form of the infinite series diffusion equation (Crank, 1975) was used to model the water absorption process in the seeds:

$$MR = \frac{M - M_0}{M_S - M_0} = \sum_{i=0}^{\propto} A_i exp(-D\lambda_i^2 t) \tag{2}$$

where MR – moisture ratio (dimensionless), M_0 – initial moisture content (% dry basis), M – moisture content at any time of soaking, M_S –saturation moisture content, A_i – constant for a given solid shape. The infinite series of the right-hand side of the equation converges rapidly to the first term after a finite soaking period. Thus, equation could be rewritten as follows:

$$MR = \frac{M - M_0}{M_S - M_0} = A_i exp(-D\lambda_i^2 t) \tag{3}$$

where $D\lambda_i^2 = -k$ is defined as the water absorption rate constant. Nonlinear regression procedure was used to estimate the value of k; subsequently, values of D and A_1 were calculated.

Assuming that the lentil is a spherical grain, the diffusion equation can be simplified to the first term of the summation with an error of less than 0.1% (Bello et al., 2004):

$$MR = \frac{M - M_0}{M_S - M_0} = \frac{6}{\pi^2} e^{-\left(\frac{D_e \pi^2 t}{R^2}\right)} \tag{4}$$

If the lentil is being assumed to be hemispheric, Newman's solution can be given (Walde et al., 2006) as follows:

$$MR = \frac{M - M_0}{M_S - M_0} = 1 - \frac{6}{\pi^2} e^{-\left(\frac{D_e \pi^2 t}{R^2}\right)} \tag{5}$$

The values of diffusion coefficient, D, of lentil were fitted to an Arrhenius relationship of the type:

$$D_e = D_0 \cdot exp\left(-\frac{E_a}{RT}\right) \tag{6}$$

where D_0 – a constant (square metres per second), E_a – activation energy (kJ/mol), R- gas constant (8.314 J/mol K), and T_0 – absolute temperature (K).

2.4.1. Empirical models

The Peleg's equation (Peleg, 1998) is the most used model to describe the food products hydration phenomena. This equation involves two parameters and describes a continuous change from a first-order (at $t \to 0$) to a zero-order (at $t \to \infty$) kinetic. The Peleg's equation expression is as follows:

$$M(t) = M_0 + \frac{t}{k_1 + k_2 \cdot t} \tag{7}$$

where k_1 and k_2 are parameters models.

This model is one of the suitable for hydration data, but it cannot describe an initial lag phase, which is observed during the hydration of some dried grains. Kaptso et al. (2008) proposed another models which describe a sigmoidal behaviour with an initial lag phase followed by a high absorption rate phase and, finally, by a stationary phase, using three parameters: τ (that describes the function inflection point, and related the lag phase), k (the kinetic parameter) and M_{eq} (the moisture at the equilibrium, that relates the maximum water absorption). The sigmoidal model is described as follows:

$$M(t) = \frac{M_{eq}}{1 + \exp[-k_3 \cdot (t - \tau)]} \tag{8}$$

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