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Journal of Food Engineering 78 (2007) 730–734

JOURNAL OF FOOD ENGINEERING

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Research note

Equivalence of the Peleg, Pilosof and Singh–Kulshrestha models for water absorption in food

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Received 8 September 2005; accepted 17 October 2005
Available online 20 December 2005

Abstract

The similarity between the Peleg, Pilosof–Boquet–Batholomai and Singh–Kulshrestha models was investigated using the hydration behaviours of whey protein concentrate, wheat starch and whey protein isolate at 30 °C in 100% relative humidity. The three models were shown to be mathematically the same within experimental variations, and they yielded parameters that are related. The models, in their linear and original forms, were suitable ($r^2 > 0.98$) in describing the sorption behaviours of the samples, and are sensitive to the length of the sorption segment used in the computation. The whey proteins absorbed more moisture than the wheat starch, and the isolate exhibited a higher sorptive ability than the concentrate.

Keywords: Whey proteins; Starch; Sorption models

1. Introduction

Various workers have studied the migration of water (liquid and gaseous) in (hydration, reconstitution) and out (drying) of food in view of the importance of sorption phenomena in food handling, processing and packaging (Abu-Ghannam & McKenna, 1997; Garcia-Pascual, Sanjuán, Bon, Carreres, & Mulet, 2005; Jovanovich, Puppo, Giner, & Añón, 2003; Pan & Tangratanavalee, 2003; Roman-Gutierrez, Guilbert, & Cuq, 2002; Sablani, Kasapis, Al-Rahbi, & Al-Mugheiry, 2002). Even, there were attempts to understand gelatinisation from the water holding capacity of starch and accompanying additives (Lupano & Gonzáles, 1999; Nashed, Rutgers, & Sopade, 2003). Also, sorption phenomenon is important in various non-food materials (Karoglou, Moropoulou, Maroulis, & Krokida, 2005). The foods and ingredients that have been studied cover a wide spectrum, and many models have been investigated to predict the sorptive behaviours of foods, and, for example, relate moisture content to time. The models are theoretical, empirical, semi-empirical, exponential, and non-exponential ones, and despite the widespread use of computers and their associated softwares, empirical equations are still widely used in view of their simplicity and ease of computation (Igelesias & Chrife, 1995; Turhan, Sayar, & Gunasekaran, 2002). The Pilosof–Boquet–Batholomai, Singh–Kulshrestha and Peleg are popular empirical non-exponential models, and some of their parameters (e.g. equilibrium moisture content, M_e, rate constant) are of immense practical significance in hydration kinetics (Peleg, 1988; Pilosof, Boquet, & Batholomai, 1985; Singh & Kulshrestha, 1987). These three models can be used independently, and Shittu, Awonorin, and Raji (2004) observed differences in their predictive ability for the hydration of African breadfruit seeds. Although the original forms of the models are differently structured, it appears that they can be rearranged to show that they are mathematically equivalent. Using the hydration of

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doi:10.1016/j.jfoodeng.2005.10.007

Nomenclature

$A_1 - A_6$	constant	M_p	predicted moisture content (%)
K	constant	n	number of data sets
M	moisture content (%)	r^2	coefficient of determination
M_0	initial moisture content (%)	RMSD	root mean square deviation
M_e	equilibrium moisture content (%)	t	time

wheat starch, whey protein concentrate and whey protein isolate as case studies, this paper examined the similarity of the three models and demonstrated their identical predictive abilities.

2. Model

The original form of the Peleg model is as in Eq. (1), which can be rearranged to yield Eqs. (2 and 3):

$$M = M_0 + \frac{t}{A_1 + A_2 t} \tag{1}$$

$$\frac{t}{M - M_0} = A_1 + A_2 t \tag{2}$$

$$\frac{1}{M - M_0} = A_1\left(\frac{1}{t}\right) + A_2 \tag{3}$$

Incorporating the initial moisture content, Eq. (4) shows the Pilosof–Boquet–Batholomai model, which can be rearranged as in Eqs. (5 and 6):

$$M = M_0 + \frac{A_3 t}{A_4 + t} \tag{4}$$

$$\frac{t}{M - M_0} = \left(\frac{1}{A_3}\right)t + \left(\frac{A_4}{A_3}\right) \tag{5}$$

$$\frac{1}{M - M_0} = \left(\frac{A_4}{A_3}\right)\left(\frac{1}{t}\right) + \left(\frac{1}{A_3}\right) \tag{6}$$

Singh and Kulshrestha (1987) found Eq. (7) to be the best for the sorption behaviours of soybean and pigeon peas, and this equation can be rearranged to the form shown in Eq. (8), while Eq. (9) shows the linear form as obtained by the authors.

$$\frac{M - M_0}{M_e - M_0} = \frac{Kt}{Kt + 1}$$

$$\text{or,} \quad M = M_0 + \frac{A_5 A_6 t}{A_6 t + 1} \tag{7}$$

$$\frac{t}{M - M_0} = \left(\frac{1}{A_5}\right)t + \left(\frac{1}{A_5 A_6}\right) \tag{8}$$

$$\frac{1}{M - M_0} = \frac{1}{K(M_e - M_0)t} + \frac{1}{M_e - M_0}$$

$$\text{or,} \quad \frac{1}{M - M_0} = \left(\frac{1}{A_5 A_6}\right)\left(\frac{1}{t}\right) + \left(\frac{1}{A_5}\right) \tag{9}$$

Therefore, it can be deduced from Eqs. (1) to (9) that $A_1 = A_4/A_3 = 1/(A_5 A_6)$, and $A_2 = 1/A_3 = 1/A_5$. Moreover, A_1, which is a measure of the rate constant in the Peleg model, is related to A_4 (time to absorb half the maximum amount of water) of the Pilosof–Boquet–Batholomai model and A_6 (rate constant) of the Singh–Kulshrestha model. The Peleg parameter A_2 (capacity constant) that measures the equilibrium moisture content ($t \to \infty$, $M_e = M_0 + [1/A_2]$) is related to A_3 and A_5, which are indicators of the water absorbing capacity or equilibrium moisture content of the Pilosof–Boquet–Batholomai and Singh–Kulshrestha models respectively. Also, in the Singh–Kulshrestha model, $M_e - M_0 = A_5$, which implies that $M_e = M_0 + A_5$, and this is the same expression for M_e in the Peleg model.

3. Materials and methods

3.1. Materials

Whey protein concentrate (WPC) and whey protein isolate (WPI) were obtained from Total Foodtec Marketing Pty. Ltd., Darra QLD 4076. From the manufacturer's data (on solids basis), WPC contains 81.5% protein, 10.2% lactose, 5.2% fat, 2.7% ash, and pH of 6.25, while WPI (ALACAN™ 894) contains 95.5% protein, 0.2% fat, 1.1% total carbohydrate, 3.2% ash, and pH of 6.80. Wheat starch (Wheaten cornflour™, ST) was purchased from Penford Australia Ltd., Lane Cove, NSW 2066. The moisture contents of the materials were measured in a vacuum oven (AOAC, 2002) to be 13.1 ± 0.28 (ST), 5.9 ± 0.39 (WPC) and 5.6 ± 0.34 (WPI).

3.2. Methods

About 1 g each of the material was put in a perforated plastic bottle, which was then put in a desiccator over 0.5% NaCl solution to obtain 100% relative humidity. An open bottle of toluene was put in the desiccator to prevent mould growth during the duration of the experiment (12 days). Samples were duplicated, and the desiccator was maintained at 30 °C throughout the experiment. The samples were periodically weighed with an electronic balance (Sartorius BP 3015; 0.1 mg sensitivity), and the moisture content was calculated using the principles of material balance with the weight gained and initial moisture content.

Linear and non-linear regression analyses were performed using the original and linear forms of the models (Eqs. (1)–(9)). In addition to the regression parameters,