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Sorption equilibrium moisture and isosteric heat of adsorption of Chinese dried wheat noodles

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A B S T R A C T

Equilibrium moisture content (EMC) data for dried wheat noodles of ten Chinese varieties were collected by a gravimetric method at 11–96% equilibrium relative humidity (ERH) and 15 °C, 20 °C, 25 °C, 30 °C, and 35 °C. Five models were fitted to the sorption data, namely the modified Chung Pfost equation (MCPE), modified Henderson equation (MHE), modified Guggenheim Anderson deBoer equation (MGAB), modified Oswin equation (MOE), and a polynomial equation. The best fitting equations were MGAB and the polynomial equation. At a constant ERH, the EMC decreased with increasing temperature, despite the minor effect of temperature on the sorption isotherms of dried noodles. Initially, the isosteric heats of adsorption for dried wheat noodles decrease rapidly with increasing sample moisture content (m.c.); however, after the moisture content is more than 15% of the dry basis (d.b.), they decrease slowly with increasing m.c. The heat of vaporization of Chinese dried wheat noodles approaches the latent heat of pure water at a moisture content of ~20% d.b., which is ~2500 kJ/kg. The isosteric heats of sorption of Chinese dried noodles predicted by MCPE and MHE models at lower temperatures were higher than those at higher temperatures. When the equilibrium relative humidity (ERH) is 60%, the safe-storage moisture content of Chinese dried wheat noodles are 11.74% and 11.57% d.b. at 25 °C and 35 °C, respectively. Among ten varieties of dried wheat noodles, the egg-flavoured noodle had the highest onset temperature (T_o), peak temperature (T_p), and conclusion temperature (T_c) of gelatinization, but the golden-silk egg noodles had the highest peak enthalpy of gelatinization. The gelatinization T_o, T_p, and T_c of golden-silk egg noodles were the lowest. Most of the ten varieties of dried wheat noodles demonstrated similar thermal properties and hygroscopic behaviour.

1. Introduction

Noodles are a traditional food in China and other Asian countries, and have been flavoured by the Chinese people for over 2000 years. Noodles constitute almost 40% of wheat products in Asia (Janto et al., 1998; Hu et al., 2006). Dried noodle is a hygroscopic food product made of wheat flour and salt (Huang and Lai, 2010). The water vapour transmission between a hygroscopic product and the surrounding environment is a physical phenomenon which may have adverse effects on the quality of the products during storage, as most food products are vulnerable to spoilage in high-moisture conditions (Deman, 1999). Usually a food product is manufactured in one climatic region and is sold in diverse climatic regions where the water vapour pressures (relative humidities) differ from each other. In this circumstance water vapour transmission between food products and the surrounding environment occurs at different speeds (Bruin and Berg, 1981). Therefore noodle processors must have adequate knowledge of the quality of dried noodles during storage with regard to moisture ingress, and select an appropriate packing material for dried noodles in order to prevent adverse consequences due to moisture migration (Cooksey, 2004). However, there are few reports on the moisture sorption isotherms of Chinese dried wheat noodles.

The quality of wheat noodles and instant noodles depends mainly on their physical, chemical, and microbiological stability (Menkov et al., 2005). This stability is a consequence of the relationship between the EMC of noodles and their corresponding water activity or equilibrium relative humidity (ERH) at a given temperature. Inazu et al. (2001) determined desorption isotherms of Japanese noodles (udon) at 20 °C, 30 °C, and 40 °C, and described

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Nomenclature

a_w	water activity
A,B,C,D,E,F,G	model coefficients
d.b.	dry basis
ERH	equilibrium relative humidity
EMC	equilibrium moisture content
m.c.	moisture content
m_i	experimental value
m_{mi}	the average of experimental value
m_{pi}	the predicated value
MRE	the mean relative percentage error (%)
n	the number of observations
h_s	isosteric heat of sorption (KJ/Kg)
h_v	latent heat of vaporization of free water (KJ/Kg)
h_w	differential heat of wetting (KJ/Kg)
R^2	coefficient of determination
P_s	saturate vapour pressure (Pa)
r.h.	relative humidity
RSS	residue sum of squares
SE	standard error
T	absolute temperature (K)
t	temperature (°C)
T_c	conclusion temperature of gelatinization (°C)
T_o	onset temperature of gelatinization (°C)
T_p	peak temperature of gelatinization (°C)
w.b.	wet basis
$\triangle H$	enthalpy of gelatinization

them by several isotherm models, such as the GAB, Oswin, and Smith equations. Navaratne (2013) determined the 20 °C moisture sorption isotherm of wheat noodles by a gravimetric method at 32.5–92.3% relative humidity (r.h.), and, from this isotherm, determined the maximum allowable moisture content for safe keeping. It is imperative to evaluate the allowable moisture content for longer-term storage of Chinese dried wheat noodles.

Knowledge of the energy requirement, state, and mode of moisture sorption is important in designing effective noodle drying and storage systems. The analysis of food product moisture sorption isotherms by a thermodynamic approach could supply information about energy requirements during dehydration, microstructure, surface physical phenomena, moisture properties, and sorption dynamics (Tsami, 1991; Wang and Bremman, 1991; Fasima et al., 1999; Thorpe, 2001). Isosteric heat of sorption, often referred to as differential heat of sorption (h_w), is useful in estimating the state of water adsorbed by the solid particles (Fasina et al., 1999).

Knowledge of h_w is of great importance when designing equipment for dehydration processes. The level of material moisture content at which the net isosteric heat of sorption approaches the latent heat of vaporization of water is often regarded as an indication of the amount of 'bound water' in the product (Kiranoudis et al., 1993; Öztekin and Soysal, 2000; Li, 2012). Öztekin and Soysal (2000) adopt the EMC data of durum wheat, soft wheat and hard wheat from ASAE Standards (1994) and compared the sorption isosteric heats among these wheat types. However, few reports deals with the sorption isosteric heat of wheat noodles. The objectives of this study were to collect the EMC/ERH data of Chinese dried wheat noodles at 11–96% ERH and 15 °C–35 °C, and then determine a suitable model for describing their isotherms, and calculate the maximum allowable moisture content for safe storage and the isosteric heat of sorption. The overall aim was to provide a guideline for the drying process and longer-term storage of Chinese dried wheat noodles.

2. Materials and methods

2.1. Dried noodle samples and experimental procedures

The ten varieties of dried wheat noodles used in this work were collected from two major food plants in China in July 2014. Their moisture contents and nutritional sign are shown in Table 1. Their average moisture content (m.c.) was 10.81% d.b. For the sorption experiment, all noodle threads were cut to 4 cm.

The equilibrium moisture contents of each species of dried noodle at five constant temperatures (15 °C, 20 °C, 25 °C, 30 °C, and 35 °C) over an equilibrium relative humidity of 11.3–96.0% were determined as described in our previous reports (Li et al., 2011; Li, 2012) using the static gravimetric method. Briefly, 27 wide-mouthed glass bottles (250 mL), each containing 65 mL saturated salt solution, were kept in a temperature-controlled cabinet to maintain nine groups of different ERH levels in the range 11.3–96.0%. The salt solutions included lithium chloride, potassium acetate, magnesium chloride, potassium carbonate, magnesium nitrate, cupric chloride, sodium chloride, potassium chloride, and potassium nitrate. The measurement at each relative humidity condition was conducted in triplicate, and a total of 135 bottles were used in an experiment for five sorption isotherms of each noodle variety. Each sample of dried wheat noodles (~5.0000 g) was placed into a small bucket (3 cm diameter and 4 cm length) made from copper wire gauze, and hung into the wide mouth glass bottle on a copper wire pothook under a rubber plug, at 2–3 cm above the saturated salt solutions. Beyond fifteen days after exposing the samples to the saturated vapour at 35 °C, the copper wire buckets with samples were weighed every other day until the change in mass between two successive readings was less than 2 mg. When this constant stage was reached, the moisture content of the sample was defined as the EMC and was determined by the oven method (AOAC, 1980). The sample was dried to a constant weight at 103.0 ± 0.5 °C for 4 h. When the samples were exposed at a lower temperature, they were left longer to equilibrate. However, the noodles exposed to the saturated potassium nitrate and potassium chloride solutions for 3–6 days at higher temperatures were susceptible to fungal growth, and were removed immediately if any mould was visually observed.

2.2. Analysis of the sorption data

The experimental EMC/ERH data were used to make isotherm curves in Kaleidagraph for Mac 4.1.3 software, using ERH data on the x-axis and EMC data on the y-axis. Five equations were adopted to fit the EMC data of dried noodles (Table 2).

The fitting was conducted using the non-linear regression procedure in SPSS 13.0 for Windows (SPSS Inc., 2006). Determination coefficient (R^2), residue sum of squares (*RSS*), the standard error (*SE*), and mean relative percentage error (*MRE*) were used as the criteria to determine the best equation for the EMC/ERH data. The equations (1)–(4) were used for calculating R^2, *RSS*, *SE*, and *MRE*, respectively.