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Effect of drying method on the moisture sorption isotherms for *Inonotus obliquus* mushroom

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Abstract

Moisture sorption isotherms of *Inonotus obliquus* mushroom were studied over a selected temperature range (20–50 °C). Sigmoid sorption isotherms were observed for these samples. The sorption data were analyzed using various conventional models. The Oswin model was found to be the best model for predicting the equilibrium moisture content of mushroom in the range of water activity 0.08–0.96. The monolayer moisture content decreased as temperature increased and was affected by the drying method used. The net isosteric heat of sorption was determined using the Clausius–Clapeyron equation and the value decreased with increase in moisture content of mushroom.

Keywords: Sorption isotherms; Sorption models; Drying method; Mushroom; *Inonotus obliquus*

1. Introduction

Inonotus obliquus mushroom is a black parasite fungus that grows on birch trees in colder northern climates, at latitudes of 45°N–50°N (Cha, Jun, Kim, Park, Lee, Coh, 2006; Cui, Kim, & Park, 2005). *Inonotus* has been well known for its therapeutic effects (Vinogradov & Wasser, 2005) and has been widely used as a folk remedy in Russia without toxicity (Kim et al., 2005). Despite its substantial increase in consumption and process application, studies on mushroom dehydration are still scarce in the literature, and mainly focus on drying techniques (Gothandapani, Parvathi, & Kennedy, 1997; Yapar, Helvaci, & Peker, 1990) and functional properties (Kahlos, 1994; Kim et al., 2006; Mizuno, 1999; Mizuno et al., 1999; Solomon & Alexander, 1999).

Moisture sorption isotherms represent the equilibrium relationship between water activity and moisture content of foods at constant pressure and temperature (Kaymak-Ertekin & Sultanoglu, 2001). A sound knowledge of the relationship between moisture content and equilibrium relative humidity is essential in the formulation of foods and in their storage stability (Tsami, Krokida, & Drouzas, 1999). Extended shelf-life of foods can be achieved by reducing the moisture content to levels below those required by microorganisms. This information is also essential for modeling, designing and optimizing the drying process, evaluating storage stability and microbiological safety, determining moisture changes during storage, and selecting appropriate packaging material (Gal, 1987).

Numerous studies on the moisture sorption behavior of foods have been conducted during last two decades, resulting in several mathematical models being proposed to describe this behavior. However, information on moisture sorption characteristics of the *Inonotus* mushroom is still very limited in the literature. Choosing a mathematical model to describe integrated hygroscopic properties of various constituents of any substances to be stored is very useful; therefore, gathering more relevant *Inonotus* mushroom sorption data is necessary to improve drying processes while minimizing processing costs.

The objectives of the present study were to provide reliable experimental data regarding water vapor sorption characteristics of *Inonotus* mushroom powder prepared by different drying methods (i.e., hot-air, vacuum, and freeze

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Nomenclature

A	Chung–Pfost, Caurie, and Henderson model parameter
a	Halsey and Kuhn model parameter
a_w	water activity
B	Chung–Pfost and Henderson model parameter
b	Kuhn model parameter
c_o	GAB model parameter
c_B	density of sorbed water
c_G	GAB model parameter
K_1	Bradley model parameter
K_2	Bradley model parameter
K_O	Oswin model parameter
k_G	GAB model parameter
M	Bradley model parameter
m	equilibrium moisture content (g water/100 g solids)
m_o	moisture content equivalent to the monolayer
n	Halsey model parameter
n_O	Oswin model parameter
r	Caurie model parameter

Table 1
Isotherm equations for experimental data fitting

Model	Mathematical expression
Brunauer-Emmett-Teller, BET (Brunauer, Emmett, & Teller, 1938)	$a_w/[(1-a_w)m] = 1/(m_0 * c_B) + (c_B - 1)a_w/(m_0 * c_B)$
Oswin (Oswin, 1946)	$m = k_O(a_w/1 - a_w)^{n_O}$
Halsey (Halsey, 1948)	$a_w = \exp(-a/m^n)$
Chung and Pfost (Chung & Pfost, 1967)	$\ln a_w = -A * \exp(-B * m)$
Kuhn (Kuhn, 1967)	$m = a/\ln a_w + b$
Caurie (Caurie, 1970)	$\ln m = \ln A - r a_w$
Bradley (Boquet, Chirife, & Iglesias, 1978)	$\ln(1-a_w) = K_2 K_1^M$
Henderson (Henderson, 1985)	$(1-a_w) = \exp[A * m^B]$
Gugenheim-Anderson-de Boer, (Van den Berg, 1985)	$m = m_0 * c_0 * k_G * a_w/[(1-k_G a_w)(1-k_G a_w + c_G k_G a_w)]$

drying), to evaluate selected mathematical models to represent the experimental data, and to determine the isosteric sorption heats.

2. Materials and methods

2.1. Materials

Fresh *Inonotus* mushroom was obtained from the Korean Ginseng Corp. (imported from Baikal Herb Ltd.; harvested in March 2006) and stored at room temperature before use. Three treatments were given to the samples as follows. (1) Hot-air drying: samples were dried at 50 °C using a hot-air drying oven (DMC-122SP, Daeil Engr. Co., Korea) to a final moisture content of approximately 4–6 g H_2O/100 g solids, moisture-free basis (MFB). (2) Vacuum drying: drying at 50 °C and vacuum pressure of 0.1 MPa in a vacuum dry oven (VOS-301SD, Tokyo Rikakikai Co., Japan) to the final moisture content as stated earlier. (3) Freeze drying: samples were frozen at −45 °C for 24 h in a deep freezer (VLT 1450-3-D-14, Thermo Electron Corp., Asheville, NC, USA) prior to freeze drying using a freeze-dryer (PPU-1100, Tokyo Rikakikai Co., Japan) at vacuum pressure of 8.5 Pa.

2.2. Experimental procedure

The moisture contents of fresh and dehydrated *Inonotus* mushrooms were determined by drying in a convectional oven at 105 °C for overnight (AOAC, 1996). Dehydrated mushrooms were broken into small pieces and milled using an analytical mill (M20, IKA, Staufen, Germany) with different particle size sieves (D-55743, FRITSCH, ldar-Oberstein, Germany) to yield the particle sizes of 150–250 μm.

The equilibrium moisture content of mushroom powders was determined using a gravimetric technique in which the weight was monitored within a standard static system of thermally stabilized desiccators. Binary saturated salt solutions made using laboratory grade and at least 99.5 g/100 g pure LiCl, $MgCl_2$, K_2CO_3, $NaNO_2$, NaBr, NaCl, KCl, and KNO_3 were used to vary the water activity (a_w) from 0.08 to 0.96 (Labuza, Kaanane, & Chen, 1985; McLaughlin & Magee, 1998). To determine the sorption value, mushroom powder samples (about 2 g) were accurately weighed into a Petri dish inside a desiccator. The Petri dishes were placed in a temperature controlled chamber, with an accuracy of ±1 °C at the selected temperatures at 20, 35, and 50 °C. After 1 week, samples were weighed every 24 h until two consecutive weight changes $< \pm 0.0005$ g were recorded, at which time the sample was assumed to be at equilibrium. Experiments were done at room temperature (23±1 °C) and all measurements were done in triplicate.

2.3. Isotherm modeling

The experimental sorption data of all samples at three different temperatures was fitted to nine sorption equations