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Effect of freezing temperature on rehydration and water vapor adsorption characteristics of freeze-dried rice porridge

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A B S T R A C T

Effect of freezing temperature of rice porridge on quality properties of freeze-dried rice porridge was investigated at various temperatures. Slow freezing produced porous freeze-dried rice porridges with large pores and more brittle structure than rapid freezing. All the quality properties tested were greatly influenced by both freezing temperature and temperature for the property evaluation. Both the initial rehydration ratio and the dissolution time of the freeze-dried rice porridge decreased with increase in water temperature. Results on the effect of freezing temperature on rehydration ratio and dissolution time indicated slow freezing is more preferable for the freeze-dried rice porridge. The Peleg model was fitted better than the Singh and Kulshrestha model to explain the water vapor adsorption kinetics. The activation energy for the water vapor adsorption of the freeze-dried rice porridge determined by using the Peleg model ranged 16.2–23.1 kJ/mol depending on the freezing temperature.

1. Introduction

With the advent of health-oriented well-being food and lifestyle, consumers are pursuing a so-called “slow food” as opposed to “fast food”. The trend has revived traditional foods, and among them is Korean rice porridge, which is known by the Korean name of “Jook”. Rice porridge is a traditional Korean comfort food usually for patients and old people, and it is also used for main dish, appetizer, or diet food. Rice porridge is prepared by adding six to seven times of water to rice (v/w) and cooking until the grains bloat with complete gelatinization of starch (Yang et al., 2007). Traditionally, more than 200 types of porridges were known to be developed in Korea (Lee and Jurn, 2000). Various rice porridges including ingredients such as abalone, pine nut, mushroom, and meat have been developed as healthy food and become a favorite late-night snack for mid-night oil burning students. Recently, convenient rice porridge for infant foods has been developed using freeze drying method (Kim et al., 1996). Freeze drying is a well known method for obtaining high quality dehydrated foods (Dalgleish, 1990; King, 1971). One of the most prominent factors of freeze-dried food is the structural rigidity afforded by sublimation of frozen material at the surface to produce a porous structure. Due to its porous structure, the freeze-dried rice porridge is rehydrated almost completely when water is added. However, the structure of freeze-dried foods and their rehydration properties are known to be greatly affected by the size and location of ice crystals formed during pre-freezing, which is mainly dependent on the freezing rate and final temperature of the foods (Otero et al., 2000). Usually, slow freezing forms large ice crystals while rapid freezing promotes intensive nucleation and the formation of small ice crystals. The resulting structural difference of freeze-fried rice porridge caused by freezing rate may influence the rehydration, dissolution, and water vapor adsorption properties of the final product.

Generally, freeze-dried products are rehydrated before use. The hygroscopic nature of freeze-dried products is advantageous for rapid and complete rehydration, however, adsorption of water vapor of the product during storage and distribution causes a serious problem. Since freeze-dried rice porridge is very hygroscopic in nature, it is very susceptible to adsorption of water vapor. Adsorption of water vapor may result in swelling and conformational changes of the molecular structure, thus affecting structural quality of the freeze dried product. Therefore, an understanding of the water vapor adsorption characteristics is essential for better control the quality of freeze-dried rice porridge during processing and distribution.

In the adsorption process, water molecules distribute themselves between the vapor phase and the food surface until a state of equilibrium reached. This process may be studied by measuring the rate of approach to equilibrium by means of adsorption curves which are plots of weight against time at a constant relative humidity and temperature. Usually, such plots give exponential curves, which are characteristics of the product (Peleg, 1988). It is desirable to characterize the rate of water vapor adsorption

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through a single quantity rather than using the entire curve. Understanding water vapor sorption kinetics may help in selecting appropriate packaging materials and storage conditions, and evaluating water vapor sorption during storage.

The main objective of the present study is to investigate the effect of freezing rate of rice porridge on the properties such as rehydration, dissolution in water, and water vapor adsorption of freeze-dried rice porridge.

2. Theoretical consideration

Many attempts have been directed towards analyzing the hydration data using theoretical or empirical approaches. Most of theoretical analyses were based on the Fick's second law of diffusion (Bello et al., 2010; Hayakawa, 1974; Bluestein and Labuza, 1972; King, 1968) which usually involves numerous functions and parameters, made them difficult to describe the water vapor adsorption process in simple terms. In some cases, empirical models were preferred because of their relative ease of use. Among the empirical or semi-empirical models used, a first order kinetics equation has been used to predict moisture adsorption in the wheat flour (Singh et al., 1981):

$$\frac{m_e - m}{m_e - m_o} = \exp(-kt) \tag{1}$$

where m_o and m_e are the initial and equilibrium moisture contents, respectively. m is the transient moisture content, k is the rate constant for hydration.

Peleg (1988) proposed a simple two-parameter sorption equation as follows:

$$m = m_o + \frac{t}{k_1 + k_2 t} \tag{2}$$

where k_1 is the Peleg rate constant and k_2 is the Peleg capacity constant. To determine the constants, Peleg used a linearized form of the equation as follows:

$$\frac{t}{m - m_o} = k_1 + k_2 t \tag{3}$$

Singh and Kulshrestha (1987) proposed following model to predict water sorption of grain beans such as soy bean and pigeon pea:

$$\frac{m_e - m}{m_e - m_o} = \frac{1}{kt + 1} \tag{4}$$

They used a linearized form of the above equation to determine the rate constant (k) for the water sorption process.

$$\frac{1}{m - m_o} = \frac{1}{k(m_e - m_o)t} + \frac{1}{(m_e - m_o)} \tag{5}$$

They found that constant k shows temperature dependence and can be expressed in terms of an Arrhenius type equation:

$$k = k_o \exp(-E_a/RT) \tag{6}$$

where k_o is a pre-exponential factor, E_a is the activation energy (kJ/mol), R is the universal gas constant (8.314 J/mol K), T is the absolute temperature (K).

Vega-Mercado and Barbosa-Carnovas (1989) used the following model to predict water vapor adsorption of freeze-dried pineapple pulp:

$$m = \frac{t}{a + bt} \tag{7}$$

where a and b are constants; t is adsorption time. This model differs from the Peleg model (Eq. (2)) in terms of m_o, which is not included in Eq. (7). Eq. (7) could be expressed in a linear form as:

$$\frac{1}{m} = \frac{a}{t} + b \tag{8}$$

Among the above models, some models such as the first order kinetic model (Eq. (1)) requires an equilibrium moisture content (m_e) to apply to the moisture adsorption process. Generally, determination of the equilibrium moisture content requires relatively long period of time. On the contrary, Peleg model (Eq. (2)), Singh and Kulshrestha model (Eq. (4)), and Vega-Mercado and Barbosa–Carnovas model (Eq. (7)) do not require the equilibrium moisture content for application. It is of interest to note that Eqs. (3) and (5) can be simplified into Eq. (8) when using completely dried sample (i.e., $m_o = 0$). In such cases, the constants a and b in Eq. (8) corresponds to k_1 and k_2 in Eq. (3), and $1/km_e$ and $1/m_e$ in Eq. (5), respectively. It is also interesting to note that Eq. (5) can be reduced to Eq. (3) when Eq. (5) is rearranged into following form:

$$m - m_o = \frac{t}{\frac{t}{m_e - m_o} + \frac{1}{(m_e - m_o)k}} \tag{9}$$

Then $1/(m_e - m_o)k$ and $1/(m_e - m_o)$ in Eq. (9) are equivalent to k_1 and k_2 in Eq. (3), respectively. In such a case, the inverse of the Peleg rate constant, k_1, is expected to show temperature dependency as the rate constant, k, in Eq. (5).

3. Materials and methods

3.1. Materials

Japonica type fresh milled rice was purchased at a local market and used for preparation of rice porridge. The moisture content of the sample was determined by AOAC method 925.10 (AOAC, 2000) in triplicate and the initial moisture content of the rice sample was 13.50 ± 0.24 g water/100 g solid. Reagent grade K_2SO_4 (Duksan Pharmaceutical Co. Ltd., Yong-In, Korea) was used for preparation of saturated salt solution for the test of water vapor sorption of freeze-dried rice porridge.

3.2. Preparation of rice porridge

Rice porridge was prepared following the method of Kim et al. (1996)). Rice (100 g) was washed and rinsed five times with tap water. Water was added to the rice with the ratio of 6:1 (v/w) in an Erlenmeyer flask and then cooked for 15 min in an autoclave (VS-1221-60, Vision Scientific Co. Ltd., Seoul, Korea) at 105 °C. After cooling the rice porridge at room temperature for 1 h, it was transferred to an ice tray, which was divided to make cube type of porridge with the size of 22 × 26 × 22 mm including about 5 g of rice porridge. And then the rice porridge was frozen for two days by using four different freezers set at temperatures of −5 °C (Refrigerator, CRF-114ED, DaeYoung E & B Co. Ltd., Seoul, Korea), −20 °C (Refrigerator, SR519HM, Samsung Electric Co. Ltd., Seoul, Korea), −40 °C (Deep Freezer, DF9014, Ilshin Lab Co. Ltd., Yangju, Korea), and −70 °C (Deep Freezer, MDF-U32 V, Sanyo Electric Co. Ltd., Osaka, Japan), respectively.

3.3. Freezing rate of rice porridge

To test the effect of freezing rate, freezing temperature of the rice porridge samples at different freezers were monitored during freezing of rice porridge. T-type thermocouples were inserted into the center of rice porridge samples in freezers set at −5, −20, −40 and −70 °C and the change in temperature was recorded every 10 s using a data logger system (HOBO® U12, Onset Computer Corporation, Bourne, MA, USA).