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Sorption isotherm and state diagram for indica rice starch with and without soluble dietary fiber

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ABSTRACT

Moisture sorption isotherms and state diagrams for indica rice starch (IRS) and indica rice starch-soluble dietary fiber (IRS-SDF) were developed to investigate the effect of SDF on the stability of IRS. Sorption isotherms of IRS and IRS-SDF were determined by the static gravimetric method and the data were modeled by Guggenheim–Anderson–de Boer (GAB) model. The GAB monolayer moisture contents were calculated to be 7.43 and 8.37 g/100g (dry basis) for IRS and IRS-SDF, respectively. The state diagram was composed of the glass transition line and freezing curve, which were fitted according to Gordon–Taylor and Chen models, respectively. The ultimate maximum-freeze-concentration conditions were calculated as characteristic glass transition temperature (T_g') of −42.5 °C and −31.5 °C with characteristic solids content (X_s') being 0.71 and 0.72 g/g (wet basis), and characteristic temperature of end point of freezing (T_m') being −18.2 °C and −13.8 °C for IRS and IRS-SDF, respectively. The state diagrams and sorption isotherms of IRS and IRS-SDF have great significance for evaluating storage stability, optimizing drying and freezing processes.

1. Introduction

The storage stability of foods is significantly influenced by water content and temperature. After the concept of water activity (a_w) was put forward, a great deal of further research was reported on the relationship between water activity and food storage stability (Al-Muhtaseb et al., 2002). At present, water activity is used as a reliable assessment of the storage stability (lipid oxidation, microbial growth, non-enzymatic and enzymatic activities) and the texture of foods (Yu and Li, 2012). However, the limitations of using water activity to evaluate of foods quality and stability have been pointed out, meanwhile, the concept of the glass transition was proposed, which indicates that foods are most stable at or below the glass transition (Sablani et al., 2004). The temperature at which an amorphous system changes from a glassy to a rubbery state is considered as the glass transition temperature (T_g) (Roos and Karel, 1991a; Shi et al., 2012). The relationship between the glass transition temperature and food processing or storage stability has been described in detail (Bhandari and Howes, 1999; Rahman, 2009). In the literature, all of the experimental results could not be explained by water activity or glass transition concepts, respectively, and all foods are beyond their prediction range (Rahman and Al-Saidi, 2017). In addition, Rahman and Al-Saidi (2017) indicated that a combination of water activity and glass transition could be a powerful tool in determining food stability. The concept of water activity was added along with the complementary concept of glass transition in order to better understand the factors governing the stability of foods (Bhandari and Howes, 1999).

State diagram is a map of different states of a food as a function of water or solids content and temperature (Rahman, 2004); and it has been used as an effective tool for foods researchers to determine the best methods of food processing and storage. Moreover, state diagram provides useful information regarding storage stability and shelf life for low-moisture-content and frozen foods (Roos and Karel, 1991a). State diagram usually consists of the freezing curve, glass transition line, and maximal-freeze-concentration, and it was mainly researched by differential scanning calorimetry (DSC) (Sablani et al., 2009).

Rice is an important agricultural crop worldwide; and rice starch has received extensive attention due to its smooth texture, digestible and hypoallergenic qualities. However, rice starch also has some negative aspects, such as being susceptible to retrogradation and having a tendency to produce undesirable weak-bodied, cohesive, rubbery pastes or gels under extended cooking and high-

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shear conditions (Viturawong et al., 2008). Therefore, various types of hydrocolloids are used to overcome these shortcomings, especially soluble dietary fiber (SDF). Banchathanakij and Suphantharika (2009) and Krystyjan et al. (2013) studied the storage stability of starch-hydrocolloid composite gel. They found that the addition of SDF could increase the strength of the starch gel and decrease the aging rate during storage, as well as maintain the relative stability of rheological and textural properties. Due to the functionality of SDF, such as water-holding capacity, gel-forming ability, fat-mimetic properties, and thickening effects, the texture, shelf-life and sensory characteristics of starch-based foods can be improved by adding SDF (Lai et al., 2011). The oat hydrocolloidal fiber component was added to the formula to improve the functionality of rice noodles (Inglett et al., 2005). Furthermore, SDF could avert cardiovascular disease and colon cancer, in addition to lowing serum cholesterol and absorption of released glucose (Sowbhagya et al., 2007). Therefore, SDF is widely used in starch-based food systems. It's significant to study the stability of starch-based food systems during processing and storage. The effects of temperature and water content on the physical state and physicochemical properties during processing and storage could be obtained from state diagram, which provides the evaluation of thermal and physical changes in food systems (Rahman, 2006). In recent years, the number of studies into state diagrams for starch-based foods has gradually increased. For example, Sablani et al. (2009) studied the thermal transition properties and state diagrams of rice noodles. Additionally, the state diagram for extruded instant artificial rice (Herawat et al., 2014) has been reported. Although the effect of dietary fiber on the physicochemical properties of starch has been investigated (Lai et al., 2011), less research into phase diagrams for IRS-SDF is available.

Therefore, the aim of this work is to obtain the storage stability criteria for IRS and IRS-SDF as functions of temperature and moisture content according to the development of state diagrams and the moisture sorption isotherms.

2. Materials and methods

2.1. Materials

Indica rice starch (IRS, 0.53% protein, 0.42% fat, 0.21% ash, 8.30% moisture, 25.64% amylose and 64.12% amylopectin) was obtained from kunming Pueryongji Group (Kunming, China). Dietary fiber from soybean was provided by Zhengzhou Linuo Biotech Co Ltd (Zhengzhou, China). Soluble dietary fiber (SDF, 3.5% protein, 5.5% ash, 0.32% fat) from dietary fiber of soybean were prepared based on AOAC Official Method 991.43 and Guo and Beta (2013).

2.2. Preparation of soluble dietary fiber-rice starch blends

IRS-SDF blends were prepared by replacing IRS at 5.0% with SDF. The slurry (90% moisture content) of starch and SDF was stirred at 800 rpm for 60 min. Then, the sample was freeze-dried and immediately ground to fine powder. Finally, the powder was screened through mesh size of 100. The IRS dispersions (90% moisture content) were also prepared and freeze-dried as controls.

2.3. Measurement and modeling of water sorption isotherms

The moisture sorption isotherms for IRS and IRS-SDF were determined by a static gravimetric method and water activity ranging from 0.11 to 0.90 at 25 °C based on sorption theory (Rahman, 2006). The IRS-SDF and IRS powders were placed in airtight desiccator with phosphorus oxide. Then, dry samples (~1.000 g) were put in an weighing bottles (25 mm × 40 mm) stored in different desiccators while maintaining different relative humidity environments created using different saturated salt solutions at 25 °C. The salts maintaining equilibrium relative humidity employed were LiCl, CH_3COOK, $MgCl_2 \cdot 6H_2O$, $K_2CO_3 \cdot 2H2O$, Mg $(NO_3)_2 \cdot 6H_2O$, $NaNO_2$, NaCl, KCl, and $BaCl_2 \cdot 2H_2O$ with equilibrium relative humidities of 11%, 23%, 33%, 43%, 53%, 67%, 76%, 84%, and 90%, respectively (Greenspan, 1977). Thymol in a 5 ml beaker was placed inside the airtight containers for higher a_w ($a_w \geq 0.75$) to prevent mold growth in samples during storage. Samples were weighed periodically for approximately 5 weeks until a constant mass was reached (the weight difference of samples between two successive measurements being less than 0.001 g). The moisture content values of equilibrated samples were determined gravimetrically by drying samples placed inside an oven at 105 °C for at least 18 h. The samples with moisture contents higher than 0.2 g/g were prepared by adding pre-calculated amount of distilled water to the dried IRS and IRS-SDF powders. Then, the samples were sealed and equilibrated at 4 °C for 24 h before DSC analyses.

Water absorption data were modeled with Guggenheim-Andersen-de Boer (GAB) model. The GAB equation is:

$$X_{ws} = \frac{X_m C K a_w}{(1 - K a_w)(1 - K a_w + C K a_w)} \tag{1}$$

Where X_{ws} is the water content in dry basis (g/100 g dry-solids); X_m is GAB monolayer moisture content which was considered as secure water content of freeze-dried foods (g/100 g dry-solids); C and K are GAB parameters related to the heat of adsorption of monolayer and multilayer, respectively.

2.4. Measurement and modeling of glass transition by DSC

The thermal characteristics of samples were determined by modulated DSC (Q2000, TA Instruments, New Castle, DE, USA) equipped with mechanical refrigerated cooling system (cooling the samples to −90 °C). The distilled water (melting point 0.0 °C, $\Delta H_m = 333$ J/g) and indium standard (melting point 156.5 °C, $\Delta H_m = 28.44$ J/g) were used to calibrate the heat flow and temperature of the instrument. Aluminum pans of 30 μl with lid were used in all experiments and an empty sealed aluminum pan was used as a reference in each test. Nitrogen was used as the carrier gas (50 ml/min).

The sealed pans with samples (~10 mg) containing unfrozen water were cooled to −90 °C at 5 °C/min, and then equilibrated for 10 min. They were then scanned from −90 °C to 50 °C at a heating rate of 5 °C/min. Thermograms were analyzed for the initial (T_{gi}), mid (T_{gm}) and end-points (T_{ge}) of the glass transitions, and T_{gi} was considered as the characteristic temperature of the transition (Rahman, 2006). Three replicates were used for the determination of glass transition temperature at each water content/water activity.

A different procedure was used for samples with higher water content (moisture content: 0.28–0.72 g/g, web basis) and these samples contained freezable water. In order to achieve maximal-freeze-concentration conditions and eliminate the exothermic peak, the process of annealing is necessary before T_g can be measured. Optimum annealing for 30 min should be performed in order to acquire maximum ice formation (Telis and Sobral, 2001).

T_m' is the end point of freezing or the start of the melting of ice crystals (Rahman, 2004). $(T_m')_n$ was defined as the apparent maximal-freeze-concentration condition. Annealing for 30 min at $[(T_m')_n - 1]$ °C was used to obtain the annealed maximal freeze-concentration condition. The annealing procedure was as follows: Samples (~10 mg) of the powder in a sealed aluminum pan (30 μl) were cooled from 20 °C to −90 °C at 5 °C/min, and held for 10 min.