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Water desorption isotherm and drying characteristics of green soybean

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ABSTRACT

There is very little published information on green soybean about moisture sorption and drying. Water desorption isotherms were determined by the static gravimetric method using saturated salt solutions at 20, 30, and 40 °C. By comparing the index of goodness of fit, the isotherm for green soybean seeds could be better described by the Halsey equation with the desorption isotherm parameters A and B estimated to be 5.612 and 1.538 respectively. The net isosteric heat of water desorption calculated by Clausius–Clapeyron equation was from 208.8 to 3627.9 kJ/kg. Thin layer drying of green soybean seeds in a range of 25–45 °C and relative humidity from 0.2 to 0.4 dec were carried out with a heat pump dryer. The Page model was the most suitable model for describing the thin layer drying process of green soybean seeds compared with the Lewis, Henderson and Thompson models. The drying characteristics of green soybean seeds were tested and analyzed under various temperature and humidity conditions, and the results will be useful for the drying and storage of green soybean seeds.

1. Introduction

Green soybean (*Glycine max* (L.) Merr.) is one of the most important economical crops grown worldwide, especially in China. The seeds are rich in healthy and anti-cancer ingredients (Redondo-Cuenca et al., 2006; Trock et al., 2006). Usually green soybean seeds are consumed as a vegetable (Mateos-Aparicio et al., 2008), snack food and soy milk. The nutrient composition of green soybean is of special interest mainly because it is characterised by high protein and edible sugar content (Redondo-Cuenca et al., 2006). High sugar content could influence the bean's moisture isotherms, glass transition temperature and drying characteristics. The drying characteristics of green soybean seeds can reflect some integrated drying information of agricultural materials. Therefore, knowledge of physicochemical properties of green soybean seeds will provide useful information on drying of beans and can lead to improvement of the drying process (Miranda et al., 2012; Argyropoulos et al., 2012).

Moisture content of harvested green soybean seeds can reach 20% or more, with higher moisture content enhancing physiological activities, increasing enzyme activity and lipid oxidation, leading to higher nutrient consumption and eventually resulting in quality degradation in storage and transportation. Using effective artificial drying technologies to dehydrate seeds to a safe moisture content (10–12%) could assure good storage quality (Abalone et al., 2006; Parde et al., 2002). Quality stability of green soybean seeds requires a good knowledge of the relationship between water activity and equilibrium moisture content at a particular temperature, which is known as water sorption isotherm (Martins et al., 2008; Roopesh et al., 2009; Maskan and Göğüs, 1997; Timmermann et al., 2001). Knowledge of the drying kinetics of green soybean is essential in designing and optimizing the quality control during drying process. Considerable research has been carried out on the drying kinetics of seeds, such as tomato, amaranth, pumpkin, safflower coriander seeds (Sogi et al., 2006; Sacilik et al., 2007; Sacilik, 2007), but research on green soybean seeds has been very limited. Heat pump drying is an effective drying method, because it has more technology advantages such as energy conservation, environmental protection and easy to realize automatic control (Hawlader et al., 2006; Prasertsan and Saen-saby, 1998, Chin and Law, 2010; Minea, 2012). To the authors' knowledge, no comprehensive study on the water sorption and drying characteristic of green soybean with a heat pump dryer has been reported, so experiments were carried out with the aim of providing this information.

The objectives of this work were to (1) measure desorption isotherms and thin layer drying curves, (2) find the best model to describe desorption isotherms, drying characteristics of green

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soybean, and (3) estimate the numerical solutions of equilibrium moisture content and of net isosteric heat.

2. Materials and methods

2.1. Experimental

Samples were obtained from Heilongjiang Province in northeast China. Initial moisture content of the samples used for determination of desorption isotherms and thin layer drying was tested before experiments. Sample moisture content was determined in an air oven at a fixed temperature of 103 °C for 8 h (State Bureau of Technical Supervision, 1995). The required moisture content was adjusted by adding water to the samples, then sealing in double plastic bags and stored in refrigerator at 3–4 °C for 5 days. Before the experiments began, samples had been taken out of the refrigerator and kept in double-layer polyethylene bags at room temperature for about 24 h.

The desorption equilibrium moisture content was determined at 20, 30, and 40 °C using the static gravimetric method (Corzo and Fuentes, 2004; Tarigan et al., 2006; Cruz et al., 2010), which is based on the use of saturated salt solutions to maintain a fixed relative humidity at a particular temperature while the equilibrium is reached.

Eleven saturated salt solutions were prepared corresponding to a wide range of water activities from 0.112 to 0.946 at different temperatures as shown in Table 1 (Lahsasni et al., 2002; Zhang, 2005; Mark et al., 2011; Cassini et al., 2006). Samples (10 g) were placed into a plastic basket hanging above the saturated salt solution in each bottle, and the bottles were placed in a temperature controlled chamber (±0.5 °C). Measurements were made at 20, 30, and 40 °C for desorption. Early stage measurements were made every 2 days, later stage was every day. Once three consecutive weight measurements showed a difference within 0.001 g, the sample mass was considered to be stationary and the experiment was ceased. At least three replicates of each experiment were made.

A heat pump dryer was used with an auxiliary condenser in this study, which is illustrated schematically in Fig. 1. The dryer can be run at two stages: warming or cooling. The function of the auxiliary condenser is to discharge the redundant heat from the dryer when the temperature is higher than the set temperature limit.

The heat pump dryer allows drying air to remain at a constant temperature and relative humidity. When the heat pump dryer is in heating mode, the refrigerant in the heat pump system follows a sequential path: 1→2→3→4→5→6→7→8→9→1. If the process temperature is higher than set point, heat pump dryer will run in a cooling mode and the refrigerant will follow a different path: 1→10→11→4→5→6→7→8→9→1. The transition between the heating and cooling modes can keep the drying air at a constant temperature. Drying air is circulated by the main and the auxiliary fans. The drying air flows through 3→12→13→14→15→8→3. The drying air in the chamber is circulated horizontally at a constant speed over the samples. A continuous weight recording system was designed to weight the samples so as to monitor moisture content change in the drying process without removing them from the chamber. A tray of metallic mesh was used to hold the green soybean sample.

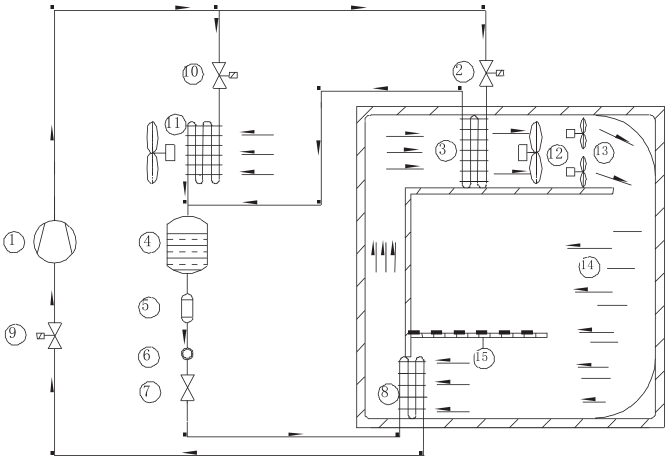

Fig. 1. Schematic diagram of the laboratory heat pump dryer: 1 – compressor, 2 – solenoid stop valve, 3 – condenser, 4 – liquid storage tank, 5 – filter dryer, 6 – liquid viewing glass, 7 – expansion valve, 8 – evaporator, 9 – main solenoid stop valve, 10 – solenoid stop valve, 11 – auxiliary condenser and fan, 12 – main fan, 13 – auxiliary fan, 14 – air baffle, 15 – material screen.

Table 1
Saturated salt solutions and water activities used in measuring the sorption isotherms of green soybean at 20, 30 and 40 °C.

Salt	Values of activities		
	20 °C	30 °C	40 °C
LiCl	0.113	0.113	0.112
CH_3COOK	0.231	0.216	0.230
$MgCl_2$	0.331	0.324	0.316
K_2CO_3	0.432	0.432	0.400
$Mg(NO_3)_2$	0.559	0.514	0.484
NaBr	0.591	0.560	0.570
$CuCl_2$	0.680	0.670	0.670
NaCl	0.755	0.751	0.745
$(NH_4)_2SO_4$	0.813	0.806	0.790
KCl	0.851	0.836	0.823
KNO_3	0.946	0.923	0.891

2.2. Mathematical modelling

Many models have been used in describing adsorption and desorption in foodstuffs and agricultural materials in the range of water activities from 0.05 to 0.95. Seven commonly used models

Table 2
Seven mathematical models used to describe the desorption isotherm of green soybean.

Models	Equations	
Henderson	$a_w = 1 - \exp\left[-A\cdot T\cdot M_e^B\right]$	(1)
Modified Henderson	$a_w = 1 - \exp\left[-A\cdot (T+C)\cdot M_e^B\right]$	(2)
Modified Chung-Pfost	$a_w = \exp[-A/(T+C)\cdot \exp(-B\cdot M_e)]$	(3)
Halsey	$a_w = \exp\left[(-A/R\cdot T)\cdot M_e^{-B}\right]$	(4)
Modified Halsey	$a_w = \exp\left[-\exp(A+C\cdot T)\cdot M_e^{-B}\right]$	(5)
Oswin	$M_e = (A+C\cdot T)(a_w/1-a_w)^{1/B}$	(6)
Modified GAB	$M_e = \dfrac{A\cdot B\cdot C/T\cdot a_w}{(1-B\cdot a_w)(1-B\cdot a_w+C/T\cdot B\cdot a_w)}$	(7)