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Adsorption behaviour of bulgur

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ABSTRACT

The aim of this research was to determine the adsorption behaviour of bulgur. Three different particle sizes (2 < coarse < 3.5, 1.6 < medium < 3.0, 0.5 < fine < 2.0 mm) of bulgur, purchased from market, were kept in nine different equilibrium levels of relative humidity (8.2–97.3%) at 20, 30 and 40 °C. The data obtained were evaluated using BET (Brunauer–Emmett–Teller) and GAB (Guggenheim, Anderson and deBoer) sorption equations. The equilibrium moisture content of bulgur increased both with decreasing temperature and bulgur size. The constants m_0 and C of BET and GAB equations were determined to be between 2.54 and 5.03 g water per 100 g of dry matter and 4.96–16.57, respectively. Constant k was between 0.85 and 0.93, and GAB equation was determined to fit very well for bulgur adsorption, because of $\%E$ values lower than 10%. Bulgur must be stored below 70% relative humidity and with less than 10 g water per 100 g of dry mater.

1. Introduction

Bulgur has mostly been known in Central Asia, the Middle East, Balkans and Turkey for a long time. After it was recognised by the WGC (Whole Grain Council) as a whole grain, bulgur was more available to the USA and European countries. Bulgur is commercially manufactured from durum wheat (*Triticum durum* ssp.) through boiling in water until whole grain gelatinises, drying under sunlight or in drying-towers about 12% moisture content, slightly debranning, breaking with mill to different particle sizes, sifting and classifying (Bayram, 2007; Kahyaoglu, Sahin, & Sumnu, 2010; Koca & Anıl, 1996; Köksel, Edney, & Özkaya, 1999; Ranum, 1996; Toufeili et al., 1997; Turhan, Oymael, & Ekiz, 2003). More than 1 million tons per year are produced in Turkey alone (Bayram & Öner, 2007; Caba, Boyacıoğlu, & Boyacıoğlu, 2012), bulgur is a pre-gelatinised traditional and functional wheat product that is available as ready and half-ready to eat; it is used to prepare more than 250 meals (Yildirim, Bayram, & Öner, 2008) such as pilaf, soup, bulgur balls and salads.

Currently, the demand for functional food, defined as food containing good bioactive components for health, is increasing in direct response to health consciousness and health-care costs (Charalampopoulos, Wang, Pandiella, & Webb, 2002). Bulgur can be evaluated as a functional food (Caba et al., 2012) because of its nutritional components, especially with respect to B vitamins, minerals, dietary fibre and its low glycaemic index (Jenkins et al., 1986). Bulgur is an important dietary fibre source because it contains 18.3 g of dietary fibre content per 100 g. Its dietary fibre content is 3.5, 6.8, 2.3 and 1.8 times higher than rice, wheat flour, whole wheat bread and oat meal, respectively (Bayram & Öner, 2007; Dreher, 2001). Also, bulgur contains resistant starch type III, and because wheat is cooked, the starch becomes gelatinised and when the wheat is dried, the gelatinised starch becomes retrograded. Furthermore, bulgur is used for food aid in famine regions by the WFP (World Food Programme), because of its nutritional value and long-term storage ability, even in improper conditions, owing to resistance to insect and mould activity (Bayram, 2007; Robinson & Mills, 1971).

Moisture sorption isotherms describe the relationship $[m = f(a_w)_T]$ between the equilibrium moisture content (m) referred to dry matter and its corresponding water activity (a_w) at a constant temperature (T). Moisture sorption isotherms are important in food as a useful thermodynamic tool for specifying the conditions of storage and stability, packaging, drying, predicting shelf life and understanding the physicochemical changes of dried foods (Bell & Labuza, 2000; Carter & Schmidt, 2012; Erbas, Certel, & Ertugay, 2005; Lewicki, 1997; Osundahunsi, Seidu, & Mueller, 2014; Shih, Daigle, & Champagne, 2011). The isotherms are described as five types according to Brunauer–Emmett–Teller (BET) analysis. Type I is a monolayer adsorption isotherm of water vapour to a porous solid, which is the typical isotherm of anticaking agents in food. Type II (sigmoid isotherm or S-type) is a multilayer adsorption isotherm, which is caused by the combined effects of colligative capillaries and surface–water interactions. Type III is an adsorption isotherm of a pure crystalline substance like sugar or salt. Type IV is the adsorption isotherm of a swellable

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hydrophilic solid to achieve maximum hydration. Type V is adsorption of water vapour on charcoal and is related to type II and type III (Bell & Labuza, 2000; Mathlouthi & Rogé, 2003).

A number of papers have been published on the equilibrium sorption properties of wheat and its products, but only few adsorption data (Turhan et al., 2003) are available for bulgur. The aim of this study was to determine the adsorption isotherms of bulgur with different particle sizes at different storage temperatures, and to calculate sorption data from BET and Guggenheim, Anderson and de Boer (GAB) sorption models.

2. Materials and methods

2.1. Materials

In this research, commercial bulgur of three different particle sizes (2 < coarse < 3.5, 1.6 < medium < 3.0 and 0.5 < fine < 2.5 mm), produced from durum wheat in accordance with number 2009/24 of the Turkish Bulgur Codex (Anonymous, 2009), were obtained from a market in Antalya. Before the determination of adsorption isotherms, the bulgur samples were dried under 0.266 bar vacuum at 40 °C, which were stored in sealed glass jars in the fridge until needed.

All salts (Sigma, Germany) used in the preparation of saturated salt solutions were of analytical grade. The saturated salt solutions used in this study were prepared at 50 °C one week beforehand, and allowed to gain stability by mixing every day.

2.2. Determination of adsorption isotherms

A static gravimetric method was used to determine the adsorption behaviour of the bulgur. The samples were kept in nine different desiccators containing saturated salt solutions, providing different equilibrium relative humidity levels (NaOH 8.2%, CH_3COOK 22.5%, $MgCl_2$ 33.1%, K_2CO_3 43.2%, NaBr 57.6%, KI 68.9%, NaCl 77.5%, $BaCl_2$ 90.7% and K_2SO_4 97.30%) at three different temperatures (20, 30 and 40 °C) for 7 days (Bell & Labuza, 2000; Erbaş, Certel, & Ertugay, 2005). Approximately 1 g of each sample was weighed (±0.1 mg) into small glass dishes as a thin layer and they were put into the different relative humidity desiccators at the studied temperature; then, their weight change was controlled every day to determine the equilibrium time. The samples reached a constant weight after 5 days, but they were kept in desiccators for 7 days for affirmation. Then, the samples were taken from the desiccators and their weight gains were determined by weighing.

The initial moisture contents of samples were determined by drying at 105 °C for 24 h. The moisture contents of coarse, medium and fine bulgur were determined to as 2.99, 2.97 and 2.96 g/100 g dry matter, respectively. Moisture contents that occur during the sorption were determined from the weight change.

The obtained data were evaluated using two different sorption models, that is, the BET [Eq. (1)] and GAB [Eq. (2)] models (Timmerman, Chirife, & Iglesias, 2001) and GAB model [Eq. (2)] (Lewicki, 1997). Where a_w is water activity, m is moisture content in 100 g dry matter, m_0 is monolayer moisture content in 100 g dry matter, C is energy constant related to heat of sorption and k is constant. To inhibit mould growth in the samples, a small dish containing 1 mL of toluene was also placed into the desiccators that had relative humidity levels higher than 0.70 (McMinn & Magee, 1999)

$$\frac{a_w}{(1-a_w)m} = \frac{1}{m_0 C} + \left(\frac{C-1}{m_0 C}\right) a_w \qquad (1)$$

$$\frac{a_w}{(1-ka_w)m} = \frac{1}{m_0 C k} + \left(\frac{C-1}{m_0 C}\right) a_w \qquad (2)$$

2.3. Fitting of adsorption data to the BET and GAB equations

Experimental data were applied to BET and GAB isotherm equation models. The constants of the equations were calculated using data from 8.2–57.6% relative humidity with linear regression for the BET model and data from all relative humidity levels with non-linear regression for the GAB model.

The fit of data from the obtained bulgur adsorption to the BET and GAB models was used the mean relative percentage error (%*E*) equation [Eq. (3)]. It evaluates goodness of fit between experimental and calculated moisture contents. Where m_{ei} is experiential moisture content, m_{ci} is calculated moisture content and N is the number of observations (Bejar, Mihoubi, & Kechaou, 2012; Lomauro, Bakshi, & Labuza, 1985).

$$\%E = \frac{100}{N}\sum_{i=1}^{N}\left|\frac{m_{ei}-m_{ci}}{m_{ei}}\right| \qquad (3)$$

2.4. Statistical analysis

Three samples were used to determine the moisture content at each measurement point and all the research was replicated twice. The data were analysed by ANOVA using the SAS statistical software package (v.7.00, SAS Institute Inc., Cary, NC, USA) to compare the means with respect to the research factors, temperature and bulgur particle size.

3. Results and discussion

3.1. Adsorption isotherms

The adsorption isotherms and equilibrium moisture content of the bulgur samples were significantly ($p < 0.01$) affected by both the temperature and the bulgur particle size, according to analysis of variance; the results are given in Table 1.

The moisture adsorption isotherms obtained from sorption data of the bulgur depend on both temperature and bulgur size, as presented in Fig. 1 together with their standard deviations. The adsorption isotherms of bulgur correspond to the characteristic of the type II isotherm, generally referred to as sigmoid isotherms or S-type, according to IUPAC classification (Rouquerol, Rouquerol, & Sing, 1999). Physical adsorption on microporous food particles can result in type II isotherms, and corresponds to multilayer moisture formation (Adamson, 1990). These adsorption isotherms for the bulgur samples indicate that sorption occurred in the bulgur particles, creating starchy products with multilayer adsorption. In general, wheat and its products have type II isotherms (Hébrard et al., 2003).

When the adsorption temperatures were increased, the equilibrium moisture content significantly decreased (Fig. 1). In other words, the bulgur samples adsorbed more water at low adsorption temperatures than at high temperatures. Actually, this event is expected, because water molecules are bound to the polar sites of food components, such as starch and proteins, via hydrogen bonding. Increasing the temperature makes the formation of

Table 1
Analysis of variance for equilibrium moisture content in bulgur samples.

Source	Freedom Degree	Mean square	*F*
Bulgur particle size	2	65.69	35.96**
Temperature	2	50.49	27.64**
Error	68	1.82	

** $p < 0.01$