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Quality characteristics and moisture sorption isotherm of three varieties of dried sweet potato manufactured by hot air semi-drying followed by hot-pressing

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ABSTRACT

This study compared the quality and moisture sorption properties of dried sweet potato prepared from three varieties (two yellow types and one purple type). Semi-dried sweet potato was subjected to a hot-pressing, which led to a final moisture content of 0.14–0.22 kg/kg solid (dry weight basis). The textural properties of the dried product depended on the sugar content of raw materials. In addition, the sugar content also influenced the MSI properties of the dried product. Based on the mathematical models, the GAB equation was revealed as the best model to explain the MSI properties of dried sweet potato. Among the varieties, *Annou-beni* (AB) showed the highest sugar content and would be the best variety from a taste point of view. *Beni-haruka* (BH) showed similar qualities to AB, while the less sugar content of this variety reflected that curing was essential for BH to improve consumers' preference. *Shin-jami* (SJ) had a weak point in sweetness since it possessed the lowest sugar content. However, the low sugar content of SJ with an attractive color trait induced an acceptable crispy texture and made the product healthier, and SJ could serve as a good sweet potato variety to make dried snack products.

1. Introduction

Recently, sweet potato has been recognized as a healthier food due to its large content of edible fiber and phytochemicals. In general, sweet potato snacks are manufactured by an oil-frying process; however, an increase in consumer demand for healthier and additive-free products has triggered the development of dried sweet potato products (Oh, Ramachandraiah, & Hong, 2017). Sweet potato is rich in starch, and sweetness is an important characteristic of sweet potato products. It is known that heating (steaming or baking) sweet potato improves the sweetness mainly due to the degradation of starch and sugars (Oh et al., 2017; Owusu-Mensah, Oduro, Ellis, & Carey, 2016). Therefore, heating sweet potatoes has the potential to produce a dried snack, and various novel drying techniques, such as ohmic heating with vacuum drying and thin layer hot air drying, have been introduced to improve the drying rate and efficiency of sweet potatoes (Fan, Chen, He, & Yan, 2003; Zhong & Lima, 2003).

Our previous study demonstrated that hot-pressing enabled the production of a dried sweet potato snack with a preferable crispy texture (Oh et al., 2017). In this process, sweet potato was semi-dried until the moisture content of the sample reached 0.3–0.4 kg/kg solid (dry weight basis). Thereafter, the crispy texture could be developed by hot-pressing (HP) at 180 °C for 3 s, which resulted in instant drying with a moisture content lower than 0.2 kg/kg solid and greatly increased the consumers' preference for the product compared with commercial products (Oh et al., 2017).

The drying process of sweet potato produces accumulation of sugars, which reduces the water activity (a_w) of the dried product. One can expect that the dried final product has a very long shelf-life due to the prevention of microbial growth (Choi et al., 2015). However, the complete drying of foods causes side effects including oxidative deterioration, which is responsible for the browning discoloration of dried sweet potato during long-term storage. In addition, the very low moisture content of dried sweet potato makes the product vulnerable to moisture sorption, which is connected with a stale texture during storage. The moisture sorption isotherm (MSI) is a useful tool for predicting the quality characteristics and for designing the processing operational conditions for dried foods (Yanniotis & Blahovec, 2009). The BET (Brunauer-Emmett-Teller) equation has been a representative model to interpret multilayer sorption isotherms; however, this model is only useful within a narrow a_w range of 0.05–0.35 (Al-Muhtaseb, McMinn, & Magee, 2002). To explain the moisture sorption isotherm more accurately, various modified kinetic models and empirical models have been suggested. Nevertheless, the accuracy of the models closely

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depends on the type and composition of foods (Al-Muhtaseb et al., 2002). Consequently, this study aimed to evaluate the physicochemical properties of dried sweet potato snacks prepared from three varieties and to compare the moisture sorption characteristics of the dried products.

2. Materials and methods

2.1. Materials

Three varieties of sweet potato (*Ipomoea batatas* Lam) including *Beni-haruka* (BH), *Annou-beni* (AB) and *Shin-jami* (SJ, purple color) immediately after harvesting were obtained from a local farm (Haenam, Korea). After being washed in running water, all materials were steamed at 100 °C for 30 min and mashed by a food processor (KMX51, Kenwood Ltd., Havant, UK) for 5 min. To form a shape, the mashed materials were placed into a mold (210 × 140 × 140 mm) and pressed manually. Finally, the materials were cut into a cubic shape (25 × 25 × 6 mm) for snack preparation and for use as samples. To analyze the sugar compositions, sucrose and fructose were purchased from Sigma-Aldrich Co, (St. Louis, MO, USA), and glucose and maltose were obtained from Junsei Chemical Co., Ltd. (Tokyo, Japan), all of reagent grade (> 99% purity).

2.2. Dried snack preparation

The preparation procedure of dried sweet potato snack consisted of a two-stage process as described in our previous study (Oh et al., 2017). In the first stage (semi-drying), cubic samples were dried at 60 °C until the moisture content reached 0.4 kg/kg solid using a hot air drier (LD-918H5, Lequip, Seoul, Korea). Estimated drying rate was 0.127 kg/kg·h, 0.102 kg/kg·h and 0.238 kg/kg·h for BH, AB and SJ, respectively. In the secondary stage (final drying), hot pressing was applied at 180 °C for 3 s using a lab-assembled ohmic-heat presser. The collected product from each sweet potato variety was placed in a desiccator prior to use (within 2 h).

2.3. Quality characteristics

The moisture content of the snack was determined by the hot air drying method at 105 °C for 24 h. The total solid content was estimated in brix (Oh et al., 2017). Five grams of snack sample were homogenized with 45 mL of distilled water, and the suspension was gently stirred at ambient temperature for 2 h. The suspension was centrifuged at 15,000 × *g* for 5 min under ambient temperature, and the brix of the supernatant was measured using a refractometer (RHB-55, Lumen Optical, Seoul, Korea). The total brix was calculated by multiplying a diluting factor of 10. Compositions of the sugar in the supernatant were estimated using an HPLC system (Dionex Ultimate 3000, Thermo Fisher Scientific, Waltham, MA, USA) equipped with a reflective index detector (Shodex RI-101, Shodex, Tokyo, Japan) and a Sugar-pak column (300 × 6.5 mm, Waters Technologies Corporation, Milford, MA, USA) maintained at 70 °C. Degassed distilled water was used as the mobile phase, and the flow rate was set to 0.5 mL/min. The supernatant was filtered through a membrane filter (0.45 μm) and diluted 5 and 30 times for the raw materials and dried snack, respectively. The injection volume of the dilute was 10 μL. For standards, sucrose, glucose, fructose and maltose were used. The color of the snack was obtained on a random surface using color reader (CR-300, Konica-Minolta Sensing Inc., Tokyo, Japan) calibrated with a standard white board ($L^* = 101.2$, $a^* = 0.4$, $b^* = 4.5$). CIE L^*, a^* and b^* were obtained as indicators of lightness, redness and yellowness, respectively. The texture of the snack was estimated using a texture analyzer (CT-3, Brookfield Engineering Laboratories, Inc., Middleboro, MA, USA) equipped with a three-point bend fixture (TA-TBP, Brookfield Engineering Laboratories, Inc.) and a blade (TA7, Brookfield Engineering Laboratories, Inc.). The breaking force at failure was recorded under a 0.5-g trigger load and 60-mm/min head speed (Oh et al., 2017).

Table 1
Models adopted to fit the moisture adsorption isotherm data of dried sweet potatoes.

Model	Equation	Reference
BET	$X_e = X_m C a_w / [(1 - a_w) + (C - 1)(1 - a_w) a_w]$	Brunauer et al. (1938)
Smith	$X_e = A + B\log(1 - a_w)$	Smith (1947)
Oswin	$X_e = A[a_w/(1 - a_w)]^B$	Oswin (1946)
Halsey	$a_w = \exp(-A/X_e^B)$	Halsey (1948)
GAB	$X_e = X_m CK a_w / [(1 - K a_w)(1 - K a_w + CK a_w)]$	Van den Berg and Bruin (1981)

A, *B*, *C* and *K* indicate the experimental constants of each model. X_e and X_m are equilibrium moisture content and monolayer moisture content, respectively.

2.4. MSI and comparison of models

The MSI of dried sweet potato snack was estimated according to Cost-project 90 (Wolf, Spiess, & Jung, 1985). In total, three sets of six saturated salt solutions were prepared using LiCl, $MgCl_2$, K_2CO_3, NaBr, NaCl and KCl, which generated specific a_w conditions of 0.112, 0.327, 0.438, 0.577, 0.753, and 0.843, respectively (Min, Choi, & Lee, 1998). For sample preparation, dried sweet potato snack product was coarsely pulverized (562-1325 μm in size) using a homo mixer (JC15MR, Shin-Il Co., Seoul, Korea) for 1 min. Aliquots of 1 g of ground powder were placed in glass tubes (15 mm in diameter), and three tubes were placed into each glass containing saturated salt solution. Each set of the six salt solutions was moved to incubators in which the temperature was maintained at 30, 40 and 50 °C, respectively, and kept until the samples reached a constant weight. The equilibrium moisture content (EMC, X_e) of the sample was plotted as a function of a_w and the data were fitted by five models (Brunauer, Emmett, & Teller, 1938; Halsey, 1948; Oswin, 1946; Smith, 1947; Van den Berg & Bruin, 1981) as depicted in Table 1. The goodness of fit of the selected models was evaluated by the mean relative percentage deviation modulus (*P*) defined by the following equation (Lomauro, Bakshi, & Labuza, 1985):

$$P = \frac{100}{n} \sum_{i=1}^{n} \left| \frac{X_i - X_{ip}}{X_i} \right|$$

where n is the number of experimental data, and X_i and X_{ip} indicate experimental and predicted moisture contents, respectively.

2.5. Statistical analysis

A completely randomized design was adopted to evaluate the effect of sweet potato variety on the qualities and MSI pattern. Means from the three entirely repeated experiments (n = 3) were analyzed by one-way analysis of variance (ANOVA) using SAS (ver. 9.1, SAS Institute Inc., Cary, NC, USA). When the main effect (variety of sweet potato) was significant ($p < 0.05$), Tukey's honest significant difference (HSD) test was conducted to separate the means.

3. Results and discussion

3.1. Quality characteristics

The moisture content and brix of raw sweet potatoes revealed that SJ was identical to the BH and AB varieties (Table 2). SJ had a higher moisture content than those of BH and AB ($p < 0.05$), while the dried product did not show a difference in the moisture content. It should be noted that different semi-drying times were applied for each variety to adjust the same moisture content in the semi-dried samples prior to HP. The actual semi-drying times of each variety were 10 h for BH, 14 h for