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Water vapor adsorption characteristics of starch – albumen powder and rheological behavior of its paste

T.A. Shittu[a,*], F. Idowu-Adebayo[b], I.I. Adedokun[c], O. Alade[d]

[a]Department of Food Science and Technology, Federal University of Agriculture, Abeokuta 110001, Nigeria
[b]Department of Food Science and Technology, Federal University Oye, Ekiti State, Nigeria
[c]Department of Food Science and Technology, Imo State Polytechnic, Umuagwo-Ohaji, PMB 1472, Owerri, Imo State, Nigeria
[d]Flour mills of Nigeria Plc, Apapa, Lagos, Nigeria

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ABSTRACT

This paper concerns the water vapor adsorption properties of starch-albumen powder (SAP), as a new product with many potential food processing applications. The adsorption data were generated at some practical storage temperatures (27, 35 and 40 °C) and water activities, a_w (0.11–0.86) using gravimetric method. The data were fitted to some isotherm models (GAB, Peleg, DLP and BET). The values of some thermodynamic parameters based on the Clausius–Clapeyron equation were also calculated. The rheological behavior of SAP paste was also studied at 20, 30, 45 and 60 °C. SAP was found to have type II isotherm shape and is highly hygroscopic. The adsorption data were better fitted by Peleg and DLP models (r^2=0.987–0.999). Monolayer moisture capacity ranged between 4.9 and 6.8 g/100 g solid. The water vapor sorption process in SAP is thermodynamically non-spontaneous and enthalpy-driven. SAP paste showed a characteristic shear-thinning behavior. Activation energy of flow (E_a) was found to be 31.63 kJ/mol.

Keywords: Starch-albumen powder

1. Introduction

Development of new and modified food ingredients requires certain pragmatic approaches to ensure low cost of production and optimal functionality of the ingredient in the prospected food products. Starch – albumen powder (SAP) is a new composite food powder developed by our research group as an additional way of preserving liquid egg white. Addition of starch to liquid egg white was done to increase the total solid content of the mixture prior air drying of the mixture in order to reduce drying time and energy cost. It was then hypothesized that SAP would combine the high hydration capacity of egg white proteins and high swelling capacity of starch in a single product to make a novel functional ingredient.

Thus, the functional properties of SAP as affected by drying temperature and starch content were studied and reported in a previous paper (Shittu et al., 2008). Increased starch content of the SAP significantly reduced the foaming, water absorption, and emulsifying capacities of SAP whereas the gelation capacity was increased. On the other hand, increasing air drying temperature from 40 to 60 °C resulted in SAP with higher foaming capacity. The study further established that it is possible to preserve egg white in powdered form using a simple and low-cost convective air drying technology compared with the conventional spray drying technology. Also, the product's characteristics indicate that it may be useful as functional ingredient in diverse food product applications such a breading material in fried food, as basal weaning food and as ingredient in some baked products.

Food powders experience gradual or rapid water vapor adsorption when packaged and stored under highly humid conditions. This further brings about various deteriorative changes such as microbial degradation, reduced flowability (or caking) and dissolution depending on their physical property and composition. These changes greatly affect the acceptability of the products by their consumers and end users.

*Corresponding author.
E-mail address: staofeek0904@yahoo.com (T.A. Shittu).
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Water vapor sorption isotherms are graphical plots of the equilibrium moisture content achievable by food materials when kept under a constant temperature but different relative humidity condition of food material. Sorption isotherms have been used as tools to determine the shelf stability of food materials. Therefore, to design an appropriate packaging and storage facility for food powders, their water vapor adsorption characteristics must be understood.

The water vapor adsorption by solid materials is due to binding of water molecules to the hydrophilic, charged and polar groups present in them. The hydroxyl groups in the glucose units of starch molecules serve as the binding sites for water molecules via to hydrogen bonding (Van den Berg et al., 1975; Kulik et al., 1994). The water vapor adsorption capacity would therefore depend on the number of free adsorptive sites present in the starch molecule. The ratio of the linear (amylose) to the branched (amylopectin) components of starch also affect its crystallinity which also influence its water vapor adsorption characteristics (Chaudhary and Adhikari, 2013). According to Lewicki (1997), when biopolymers (starch, sodium caseinate, and cellulose) were mechanically mixed together, the water adsorption characteristics of their mixtures followed additive law at lower a_w values. However, at higher a_w values, the adsorption mechanism became more complex and ceased to follow additive law. The complexity of water adsorption mechanism could possibly be due to anyone of molecular matrix swelling, conformational changes, polymer–polymer interactions, crosslinking, co-operative binding and multiple hydrogen bond formation or their combination.

Starch powders have been reported to exhibit type II isotherm curves (Al-Muhtaseb et al., 2004; Peng et al., 2007) while pure protein powders mainly exhibit type III isotherm curves (Ayranci and Duman, 2005; Jovanovich et al., 2003) according to BET classification (Brunauer et al., 1938). The actual sorption behavior of starch–albumen powder (SAP), which is a conjugate product but not a mechanical mixture of the two biopolymers, is however unknown. It would therefore be of practical interest to determine the water vapor adsorption behavior of this new product to assist in designing appropriate storage and packaging systems useful to extend its shelf life. A previous study had also shown that conjugation of egg white proteins with some carbohydrate polymers had varied influence on its foam forming properties (Ptaszek et al., 2014).

This study was basically conducted to generate water vapor adsorption data of SAP at three temperatures (20, 30, and 40 °C). Three mathematical models (GAB, Peleg and BET) were also tested for fitting the sorption data. Some thermodynamic properties of the product were also determined using well established thermodynamic functions. Some basic rheological properties of SAP paste were also reported.

2. Materials and methods

2.1. Production of starch–albumen powder

The albumen was obtained from freshly laid poultry eggs. The yolk was carefully separated from the albumen and then the albumen was mixed gently without foaming with native cassava starch at a weight ratio of 15/85 (w/w) for cassava starch/albumen. The mixing was continued for about 60 s in a Kenwood laboratory size blender, poured on a flat tray to spread thinly and dried in a natural convective oven preset at 40 °C. The flakes obtained were then milled into powder.

2.2. Moisture adsorption characteristics

The gravimetric method under different temperature (20–40 °C) and relative humidity conditions ($a_w \approx$ 0.11–0.86) was used in generating the adsorption data. Saturated solutions of lithium chloride, potassium acetate, magnesium chloride, calcium nitrate, magnesium nitrate, sodium nitrite, sodium chloride and potassium chromate were used to maintain the respective relative humidity in the desiccators. Duplicates of each sample were presented for analyses. The temperature regulation was achieved using an incubator at accuracy of ±1 °C. About 2 g of starch substituted egg white powder samples (dried at different temperature) were accurately weighed into the petri dishes and left above the saturated salt solution. After equilibrium weight was reached, each sample was dried at constant temperature of 105 °C for 4 h to determine the equilibrium moisture content.

2.3. Modeling of adsorption isotherms

Data obtained from the above were fitted into four isotherm models, namely, Peleg (Peleg, 1993), Double Log Polynomial (DLP) (Nurtama and Lin, 2010), Brunauer–Emmett–Teller (BET) (Brunauer et al., 1938) and Guggenheim-Anderson-de Boer (GAB) (Van den Berg and Bruin, 1981). Parameters k_1, k_2, n_1, and n_2 are constants in Peleg model (Eq. (1)) while b_0, b_1, b_2 and b_3 are constants in DLP model (Eq. (2)). Parameter M_0 in BET (Eq. (3)) and GAB model (Eq. (4)) is the monolayer moisture content, C and k are constants akin to the temperature effect on adsorption process. Model's predictive accuracy was evaluated using two statistics, namely, deviation modulus (E %) and the root mean square error (RMSE) as shown respectively in Eq. (4) and (5). Residual plots of the equilibrium moisture content were also used as additional diagnostic for testing the degree of fit of the two long range isotherm models used. M_e and M_p are the experimental and predicted values of equilibrium moisture content at the set temperature and water activity conditions.

Peleg Model : $$M = k_1 a_w^{n_1} + k_2 a_w^{n_3} \quad (1)$$

DLP Model : $$M = b_0 + b_1[\ln(-\ln a_w)] + b_2[\ln(-\ln a_w)]^2 + b_3[\ln(-\ln a_w)]^3 \quad (2)$$

BET Model : $$M = \frac{M_0 C a_w}{((1-a_w)(1+(C-1)a_w))} \quad (3)$$

GAB Model : $$M = \frac{M_0 C K a_w}{((1-K a_w)(1-K a_w + C K a_w))} \quad (4)$$