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Shelf life prediction of packaged cassava-flour-based baked product by using empirical models and activation energy for water vapor permeability of polyolefin films

Ratchaneewan Kulchan [a], Waraporn Boonsupthip [b], Panuwat Suppakul [c,*]

[a] Thai Packaging Centre, Thailand Institute of Scientific and Technological Research, 196 Phaholyothin Rd., Ladyao, Chatuchak, Bangkok 10900, Thailand
[b] Department of Food Science and Technology (Food Engineering Major), Faculty of Agro-Industry, Kasetsart University, 50 Phaholyothin Rd., Ladyao, Chatuchak, Bangkok 10900, Thailand
[c] Department of Packaging and Materials Technology, Faculty of Agro-Industry, Kasetsart University, 50 Phaholyothin Rd., Ladyao, Chatuchak, Bangkok 10900, Thailand

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ABSTRACT

Moisture sorption kinetics and isotherms of cassava-flour-based baked product were investigated. Empirical models were tested to fit the experimental data. Textural changes of the product were investigated. In addition, activation energies (E_p) for water vapor permeability (WVP) of polyolefin films were determined. Finally, the product was packaged in low-density polyethylene (LDPE) or oriented polypropylene (OPP) pouches, and stored at 30 ± 1 °C and 50 ± 2% RH to simulate actual storage conditions and to determine shelf life. This actual shelf life was compared to the predicted shelf life by using empirical models and E_p for WVP. Moisture sorption kinetics was more rapid during the initial stage, while a lesser amount of moisture was adsorbed as adsorption time increased. The higher the relative humidity used, the more pronounced the effect. The sigmoidal moisture sorption isotherms of this product can be classified as type II. The GAB model was found to be the best-fit model for this product. Once the product hardness or work reached the maximum and began to reduce at moisture content (MC) $\approx$6%, the product texture began to be detected as becoming slightly soft. This implies that hardness and work at the maximum level could be used to identify the critical MC which causes a loss of crispness to an unacceptable degree. The predicted shelf lives – estimated by employing E_p for WVP of LDPE and OPP, and the GAB model – were close to the actual shelf lives. Therefore, the estimation by empirical models and activation energy was found to be applicable for rapid and accurate shelf life prediction.

1. Introduction

Cassava (*Manihot esculenta* Crantz) flour is used as a key ingredient in several dry crisp products such as potato chips and puffed curls. In addition, Asian and Latin American peoples are interested in its use as a partial substitute for wheat flour (Lopez et al., 2004; Mohamed et al., 2006). To consumers, high crispness of such products indicates not only good quality but also freshness (Rohm, 1990). Unfortunately, few study results have been reported on the creation and preservation of crispness for cassava-based flour products (Chang et al., 2000). Such research has been especially rare for multi-component systems.

Sorption characteristics of cassava-flour-based baked products are crucial for the design, modeling and optimization of their drying, packaging, storage and transport. Knowledge of sorption isotherms is also important for predicting moisture sorption properties of highly sensitive food products via empirical models. These isotherms provide information on the moisture-binding capacity of products at a determined relative humidity, and are a useful means for analyzing the moisture plasticizing effect and the effect on textural properties (Bell and Labuza, 2000; Al-Muhtaseb et al., 2002). Chirife and Iglesias (1978) reviewed 23 isotherm models and their use for fitting sorption isotherms of foods and food products. None of these models accurately described the sorption isotherm over the entire range of relative humidity, since water is related to the food matrix by different mechanisms in different activity regions. However, these kinetic models are still important for use in the prediction of moisture sorption properties of foodstuffs.

In the texture study, crispness was perceived as a combination of the sound generated and the fracture of the product as it was bitten completely through with the back molars (Duizer et al., 1998). Different instrumental and sensory approaches have been applied to study this quality attribute, and have generated a large amount of experimental data (Roudaut et al., 2002). Unfortunately,

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* Corresponding author. Tel.: +66 2 562 5058; fax: +66 2 562 5047.
E-mail address: fagipas@ku.ac.th (P. Suppakul).

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Nomenclature

A	test area (m^2)
a_w	water activity
a, b, c, d	constants of the Peleg modelC_B
	constant of the BET model
C_G, k	constants of the GAB model
E_p	apparent activation energy of water vapor permeability
F, G, H	constants of the Lewicki model$G$
	weight change (g)
k, c	constants of the Oswin model
k_1, k_2	parameters of Peleg kinetic model
l	thickness (mil)
M_0	initial moisture content
M_c	critical moisture content
M_t	moisture after time (t)
P	water vapor permeability coefficient ($g\,mil\,m^{-2}\,d^{-1}\,mmHg^{-1}$)
p_{sat}	saturated vapor pressure at constant temperature, mmHg
Δp	vapor pressure difference (mmHg)
RH_0	relative humidity in test dish
RH	relative humidity in desiccator
T	temperature (K)
$T_{g,m}$	mid-point glass transition temperature (°C)
t	time (d)

no conclusion can be soundly drawn for the relationship between instrumental and sensory results. This is due to the fact that many definitions of "crisp" were applied (Roudaut et al., 2002), and only a few studies of sensory data have been reported to the public (Hecke et al., 1995; Roudaut et al., 2002). The crispness of dry crisp products is controlled by product composition and structure (Roudaut et al., 2002). Process conditions affect the final moisture content which governs crispness of the finished product (Roudaut et al., 2002). During storage, water adsorption from the atmosphere or by mass diffusion from neighboring components can also cause a loss of crispness (Nicholls et al., 1995).

Moisture-sensitive products may absorb moisture during long-term storage, as the commonly used packaging materials are permeable to moisture. Moisture content can be used as the critical data for judging the quality of products that have been degraded by moisture. Water vapor permeability of packaging materials is one of the important criteria for predicting the rate of moisture uptake (Chen and Li, 2003). Recently there has been increased interest in the development of a mathematical model for optimization of flexible film packaging of moisture-sensitive foods (Del Nobile et al., 2003; Azanha and Faria, 2005; Araromi et al., 2008; Siripatrawan, 2009).

This study is aimed at: (1) investigating the moisture sorption kinetics and empirically modeling the moisture sorption isotherm of cassava-flour-based baked product; (2) determining a critical water activity of cassava-flour-based baked product based on mechanical and sensory approaches; and (3) determining the activation energy for water vapor permeability of polyolefin films, and applying this to the predicted shelf life of moisture-sensitive food products.

2. Materials and methods

2.1. Sample preparation

A cassava-flour-based baked sample was prepared using cassava flour (55.2%) (Cho Heng Rice Vermicelli Co., Ltd., Nakhon Pathom, Thailand); coconut milk (18.4%); egg yolk (1.1%); and sucrose (23%), obtained from various commercial retailers. Firstly, a mixture of coconut milk and sucrose was heated at 90 °C until 40% sample weight loss was reached. The obtained mixture, with egg yolk and cassava flour then added, was kneaded into dough using a domestic mixer (KM 410, Kenwood Limited, UK) at a minimum speed. The dough was stored in a tightly sealed container at room temperature overnight. Then the dough, after adding water (2.3%), was kneaded to obtain homogeneous distribution before being divided roll dough into small balls (~1 cm dia) using a 1 cm plain biscuit cutter. The balls were placed on a greased pan and baked at 150 °C for 20 min. After baking, they became porous and expanded to ~1.5 cm dia. The baked products were left to cool, and kept in a tightly sealed container for further use.

2.2. Proximate analysis

The sample was analyzed for moisture, protein, carbohydrate, starch, fat, ash and fiber using AOAC methods (Lane, 1998). All determinations were carried out in triplicate.

2.3. Moisture sorption kinetics and isotherm

A standard gravimetric methodology (weighing samples equilibrated in thermally stabilized desiccators) was used for determination of the adsorption kinetics. The baked product was crushed, and completely dried in a vacuum oven at 70 °C and 76 mm Hg for 48 h, and then in a desiccator over P_2O_5 for 2 weeks. The dried samples (in triplicate) were placed into desiccators with saturated salt solutions at 30 °C. The salt solutions included LiCl, $MgCl_2$, $Mg(NO_3)_2$, NaCl, and K_2NO_3 of known relative humidity (% *RH*): 11.3, 32.4, 51.4, 75.1, and 92.5% *RH*, respectively (Greenspan, 1977). Weights of samples as a function of time were measured; moisture content was then measured by drying in an oven at 105 °C for 3 h (Lane, 1998). Set of experiments was performed in two replications. This was expressed on a dry-weight basis as g H_2O/100 g dry sample. Water activity (a_w) was determined using a water activity instrument (Testo 650, Testo, Inc., Germany). Moisture adsorption curves of the samples were fitted to a mathematical model suggested by Peleg (1988):

$$M_t = M_0 + [t/(k_1 + k_2 t)], \tag{1}$$

where, M_t = moisture after time t; M_0 = initial moisture; and k_1 and k_2 = parameters.

A standard gravimetric methodology was used for determination of the adsorption isotherms. The baked product was prepared and conditioned, as described in Section 2.3. The dried samples in triplicate were equilibrated over saturated salt solutions inside desiccators at 30 °C for 4 weeks. The salt solutions included LiCl, CH_3COOK, $MgCl_2$, K_2CO_3, $Mg(NO_3)_2$, KI, NaCl, KCl and K_2NO_3 of known relative humidity (% *RH*): 11.3, 21.6, 32.4, 43.2, 51.4, 67.9, 75.1, 83.6 and 92.5, respectively (Greenspan, 1977). Moisture content was then measured by drying in an oven at 105 °C for 3 h (Lane, 1998). Set of experiments was performed in 4 replications. This was expressed on a dry-weight basis as g H_2O/100 g dry sample. Water activity was determined using a water activity instrument.