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ORIGINAL ARTICLE

Studies on moisture sorption isotherms for osmotically dehydrated papaya cubes and verification of selected models

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Abstract The water desorption properties of osmotically dehydrated papaya cubes at various temperatures were studied by fitting experimental isotherms in Henderson, Oswin, Chen and Clayton and Kuhn equations having 2 parameters and Henderson and Oswin equations were modified to describe the temperature dependence of isotherm data. Oswin equation was useful to predict the equilibrium moisture content values for use in determining the effective moisture diffusion coefficient during subsequent air drying process.

Keywords Papaya cubes · Desorption isotherms · Equilibrium moisture content · Diffusion coefficient · Osmotic dehydration · Air drying

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Introduction

One important property of a material related to drying is its moisture desorption isotherm, since this will determine the degree of drying required to obtain a stable product (Lerici et al. 1983, Sereno et al. 2001). Moisture sorption isotherms characteristics of food products and their constituents are important for understanding the moisture-related degradations like browning reactions and mould growth. A number of studies have described equations for predicting the water activity of intermediate moisture foods from their compositions (Chirife and Iglesias 1978, Saravacos 1986, Saravacos et al. 1986).

Mazza (1983) determined the equilibrium moisture contents (EMC) of sucrose treated carrots, and reported that at low water activities, it increased with increase in sucrose concentration. Because of penetration of sugar in to solids, osmotically dehydrated berries had higher moisture content at the same water activity (Kim and Toledo 1987). Jayaraman (1988) reported the moisture sorption isotherms at 25°C for untreated and 3% salt plus 6% sucrose treated and dehydrated cauliflower and found type II isotherm (sigmoid) in the untreated sample and type III in the treated one according to Brunauer, Emmett and Tetter (BET) classification (Rizvi 1986). Foods rich in soluble components like sugars have been reported to show type III behaviour (Sarvacos 1986).

Pokharkar and Prasad (1998) determined the water desorption isotherms for osmosed pineapple at 30, 40 and 50°C and observed that shapes of the isotherms fell under the category of type III according to BET classification. Goula et al. (2008) studied the adsorption isotherms of spray dried tomato pulp at 6 temperatures between 20 and 70°C using gravimetric techniques and isosteric heats of sorption were found to decrease exponentially with increasing moisture content. The EMC of carrot cubes osmotically pretreated with salt was highest among all pretreatments and was lowest for un-osmosed samples (Singh and Mehta 2008). Wesely et al. (2008) conducted experiments to determine EMC of groundnut at 25, 35, 43°C and 35 to 80% RH and Helsey, Harkins-Jura and Smith models gave good fit in the RH range of 35 to 55%. The water sorption/desorption properties of osmotically dehydrated papaya cubes are presented here.

Materials and methods

Ripen papaya (*Carica papaya*) of uniform size, colour and firm texture were sorted out, washed, peeled by vegetable peeler and cut into two halves. Seeds along with supporting fibres and the layer of flesh were scrapped off. The peeled and prepared segments were further cut into 1 cm × 1 cm × 1 cm pieces. Sugar syrup of 60°Brix was prepared by dissolving required amount of sugar in tap water.

In every experiment weighed papaya cubes of ~50 g were completely immersed in the syrup with initial fruit to syrup ratio of 1:4 in beaker. The beakers were placed inside the constant temperature water bath at 40°C. The syrup in the beakers was manually stirred at regular intervals to maintain uniform temperature. The samples were removed from the beakers after 4 h and immediately rinsed in flowing water and placed on tissue paper to remove surface moisture. Moisture content of fresh as well as osmotically dehydrated papaya pieces was determined by using AOAC (1995) method.

The water sorption isotherms of osmotically dehydrated papaya cubes of 79% moisture content (wb) were determined by gravimetric technique at 30, 40 and 50°C, in which the weight was monitored discontinuously within a standard static system of thermally stabilized desiccators. Ten salts were selected to get relative humidity (RH) in the range of 11 to 96% as reported by Palipane and Driscoll (1992). Standard solutions of lithium chloride (a_w=0.11), potassium acetate (a_w=0.24), magnesium chloride (a_w=0.34), potassium carbonate (a_w=0.43), calcium nitrate (a_w=0.56), sodium nitrite (a_w=0.65), sodium chloride (a_w=0.75), potassium chloride (a_w=0.88), potassium nitrate (a_w=0.96), potassium sulphate (a_w=0.98) were used to maintain the specified RH inside the desiccators at constant temperature. In order to prevent mould growth at high RH levels of 70% and above, small glass bottles containing toluene were placed besides the sample inside the sealed desiccators. The prepared desiccators were kept in temperature controlled cabinets at constant temperature of 30, 40 and 50 ± 0.5°C. The samples were weighed within interval of 24 h and were allowed to equilibrate until there was no discernible weight change, as evidence by constant weight values (±0.001 g). The total time required for removal, weighing and replacing samples in desiccators was ~25 sec. This minimized the degree of atmospheric moisture sorption during weighing. Each experiment was carried out in triplicate. The dry mass was determined gravimetrically.

Results and discussion

The EMC values varied from 4.0 to 78.2%, 3.7 to 81.8% and 3.1 to 80.2% as a_w increased from 0.121 to 0.834, 0.11 to 0.818 and 0.11 to 0.802 for 30, 40 and 50°C respectively (Fig. 1).

At a_w lower than 0.45 the EMC of papaya cubes decreased as the temperature was raised from 30 to 50°C. However, the reverse trend was observed at higher a_w and the papaya cubes absorbed more water at higher temperature which means that in the high humidity region, at constant water content, a_w would decrease as the temperature was raised. The change in sorption properties of the osmotically dehydrated papaya cubes at higher a_w is evidenced by crossing over of isotherms at a_w of 0.45 (Fig. 1).

The desorption isotherm data for osmotically dehydrated papaya cubes at 3 temperatures were fitted to following 4 equations

Henderson equation

$$M_e = (-)\left(\frac{\ln(1-a_w)}{b}\right)^{1/c} \quad (1)$$

Oswin equation

$$M_e = b \times \left(\frac{a_w)}{1-a_w}\right)^{c} \quad (2)$$

Chen and Clayton equation

$$a_w = e^{-ae^{-bM_e}} \quad (3)$$

and Kuhn equation

$$M_e = \left(\frac{a}{\ln a_w}\right) + b \quad (4)$$

where, M_e is the equilibrium moisture content (g water/g dry solids), a_w is water activity in fraction, *a, b* and *c* are the constants of particular equation at a given temperature. The data were statistically analyzed and coefficients of regres-

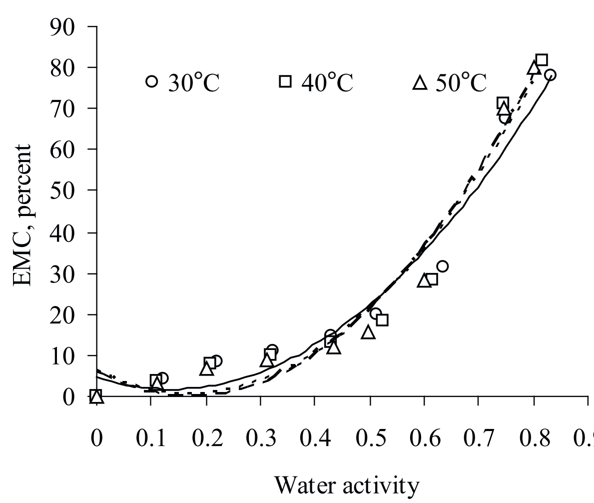

Fig. 1 Desorption isotherms of osmotically dehydrated papaya cubes at different temperature.

Table 1 Predicted parameters for various standard equation of EMC

Isotherm equation	Temperature, °C		
	30	40	50
Henderson's equation	b = 0.3532183	b = 0.349543	b = 0.346976
$M_e = (-)\left(\frac{\ln(1-a_w)}{b}\right)^{1/c}$	c = 1.1316	c = 1.1446	c = 1.2271
	R^2 = 0.97	R^2 = 0.97	R^2 = 0.98
Oswin equation	b = 0.221	b = 0.206	b = 0.196
$M_e = b \times \left(\frac{a_w)}{1-a_w}\right)^c$	c = 0.825	c = 0.961	c = 1.050
	R^2 = 0.98	R^2 = 0.98	R^2 = 0.99
Chen and Clayton equation	a = 1.663	a = 1.561	a = 1.506
$a_w = e^{-ae^{-bM_e}}$	b = 3.401	b = 3.123	b = 2.913
	R^2 = 0.94	R^2 = 0.93	R^2 = 0.94
Kuhn equation	a =(–) 0.160	a = (–) 0.189	a = (–) 0.205
$M_e = \left(\frac{a}{\ln a_w}\right) + b$	b = (–) 0.024	b = (–) 0.0665	b = (–) 0.090
	R^2 = 0.94	R^2 = 0.94	R^2 = 0.93

sion of Eqn 1 to 4 were predicted. It can be observed from Table 1 that the regression equations with Chen and Clayton and Kuhn model gave slightly less values of R^2 and are in the range of 0.93 to 0.94 while the Henderson and Oswin model predicted comparatively better values of EMC with R^2 values more than 0.97 in all 3 temperatures. The Henderson and Oswin equations would be more useful as they could include a built-in temperature effect. Such equations would make it possible to extend limited sorption data to other temperatures (Diamante and Mundro 1990). For Henderson and Oswin equations at 3 temperatures, the 2 constants were related to 3 temperatures by exponential and power regressions. The relationship with highest coefficient of determination was chosen as the temperature function for that constant, which showed little variation with temperature, without any definite correlation and therefore, the average value of the constant at 3 temperatures was used. The working forms of these equations are as follows:

Henderson's equation

$$M_e = (-)\left(\frac{\ln(1-a_w)}{0.3625e^{-0.0009T}}\right)^{1/1.1677} \quad (5)$$

Oswin equation

$$M_e = 0.2923T^{-0.0951} \times \left(\frac{a_w)}{1-a_w}\right)^{0.886667} \quad (6)$$

The predicted and observed values calculated by Henderson and Oswin model both were plotted as shown in Fig. 2 and 3, respectively and the coefficient of correlation values were analyzed.

The value of R^2 was 0.8427 for Henderson model and 0.9494 for Oswin model. The Oswin equation with temperature factor again gave higher regression coefficient (0.9494) than the Henderson's equation (0.8427) for the range of temperatures considered. Therefore, it may be concluded that Oswin equation with temperature factor gave best fit to the sorption isotherms of osmotically dehydrated papaya cubes for the range of 30 to 50°C and Oswin equation was found to be useful to predict the EMC values for use in determining the effective moisture diffusion coefficient during air drying process.

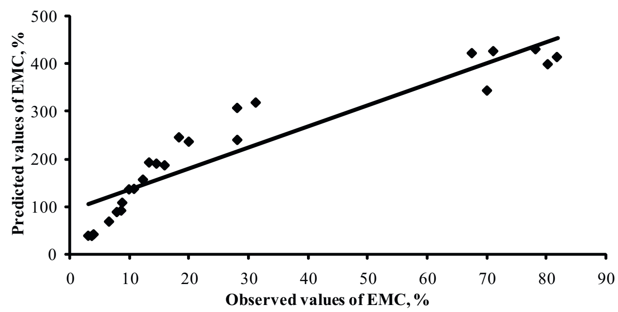

Fig. 2 Predicted and observed values of EMC by Henderson model.

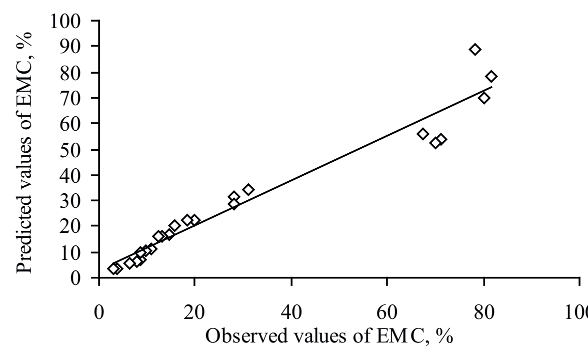

Fig. 3 Predicted and observed values of EMC by Oswin model.

It can be observed from Fig. 1 that osmotically dehydrated papaya cubes at 30°C and a_w of 0.45 gave moisture content of 13% (db) and the product was expected to be microbiologically shelf stable similar to raisin (Islam and Flink 1982, Kim and Toledo 1987).

Conclusion

Moisture sorption isotherms of osmotically dehydrated papaya cubes were obtained at 30, 40 and 50°C temperatures. The Henderson, Oswin, Chen and Clayton and Kuhn equilibrium moisture isotherm equations were used to assess the goodness of fit to experimental data. The Henderson and Oswin models were found to give the best fit. These models could therefore be used to plan and evaluate drying, storage conditions and moisture regime in papaya processing and handling. For drying, it is useful for predicting the level to which moisture would be removed during drying and for predicting the desired period for aeration during storage. This information is considered useful for processors.

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