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Kinetics of Moisture Uptake of Osmo-Foam-Mat Dried Mango Powders and Application of Sorption Isotherms to Shelf-Life Prediction

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Abstract: The kinetics of moisture uptake by foam-mat dried powder from mango pulp was evaluated at four temperatures (10, 20, 30 and 40°C) and two relative humidities (55 and 80%), while moisture sorption data for shelf life prediction was determined at the same temperatures and eight water activities ranging from 0.032-0.925. Result show that the rate of moisture uptake was highly in the first 2 to 4 h at any given storage temperature and relative humidity. Moisture uptake generally decreased with increase in storage temperature but did not show a defined trend after the first few hours. The rate of moisture uptake was higher at 55 than at 80% storage relative humidities. Effective diffusivities of samples incorporated with foam stabilizes were higher due to high porosity. Moisture uptake obeyed the penetration theory indicating that the process was Fickan. Predicted shelf-life of the powders generally decreased with increased storage relative humidity and temperature. The predicted shelf-life of the powders was generally above 365 days. The shelf life of powders incorporated with foam stabilizers was generally shorter as they had lower equilibrium moisture content. Predicted shelf life of the powders was longer in packaging materials of low permeability to thickness ratio.

Key words: Kinetics, moisture, osmo-foam-mat, sorption, shelf life

INTRODUCTION

Moisture absorption of material is a mass transfer mechanism. Water molecules diffuse into the material from the surrounding atmosphere due to concentration gradient. Moisture transfer with both time and location can be described by Ficks second law of diffusion Eq. 1 (Loong *et al*., 1995; Zhang *et al*., 1984; Alakali *et al*., 2006). The rate of moisture movement into a material (adsorption kinetics) is an important factor to be considered in the design of any process whose equilibrium characteristics and mass balances are required (Rizvi, 1995; Pezzutt and Crapiste, 1997). Water adsorption kinetics has been analyzed by mathematical models based on diffusion. One approach by Roman *et al*. (1982), involves the determination of effective diffusivity as a function of material properties of the food and its surrounding atmosphere. Another method involved numerical solutions of Ficks second law of diffusion to obtain values of effective diffusivity (Zhang *et al*., 1984; Bakshi and Snigh, 1980). The third method involved analytical solution of Ficks second law for moisture transfer in semi infinite slab (Crank, 1999). Ficks first law of diffusion to calculate the tolerable water vapour permeability of food materials written in Eq. 1:

$$\text{In}\ \frac{M-Me}{Mo-Me}=\frac{K}{X}\frac{ap}{Wb}t \tag{1}$$

Where:
K : Permeability of packaging materials

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b : Slope of the sorption isotherm
W : Weight of solid food
a : Packaging material surface area
X : Thickness of packaging material
p : Water vapour of packaging material at ambient temperature
t : Shelf life (storage time of food until it reaches critical moisture content)

Equation 1 permits the calculation of maximum possible storage time with a defined permeability of the film and vise versa, the allowable permeability for a defined storage time. Packaging is an important part of food processing which exhibit marketing and technical features. Proper packaging is expected among other things to protect the content against moisture uptake and loss that could result to deterioration of some kind (Labuza, 1984). Selection of appropriate packaging materials for defined storage conditions has tremendous economic consequences.

The objectives of this research are to study the moisture sorption kinetics of mango powders and to predict the shelf life of the products from sorption isotherms.

MATERIALS AND METHODS

About 8 kg of ripe and firm Peter variety of mango (*Magnifera indica* L.) fruits were purchased from a local market in Markudi the Benue state capital, Nigeria and the study conducted in the University of Agriculture Makurdi. The fruits were washed in tap water to remove adhering materials and peeled with stainless steel knives. The mesocarp was sliced into rectangular slivers of 20 mm thickness. The slices were divided into two parts A and B. Part A was osmosed in 70% shown syrup concentration at 80°C, part B was not osmosed. The materials in part A and part B were each divided into two lots A1, A2 and B1, B2. Each lot was blended into a puree. To A1 and B1 was added 1.0% glycerol monostearate (GMS) which acted as foam stabilizer. The remaining two lots (A2 and B2) were used as control. The samples were whipped using the gate impeller of Kenwood blender (Model KM 230, UK) to produce foams.

The resulting four foam-mat sample, (A1, A2, B1 and B2), were dried in an electric tray dryer (Model B35.355 EEE Milono Italy) at 72°C to produce foam-mat dried mango powders namely dry osmosed without foam stabilizers (DOM-FS), dry osmosed with foam stabilizer (DOM+FS), dry non-osmosed plus foam stabilizer (DNOM+FS) anddry non-osmosed without foam stabilizer, (DNOM-FS).

Moisture Adsorption Kinetic Data

Moisture sorption kinetics studies were performed as described by Loong *et al*. (1995). A 4×4×2 complete randomized factorial design comprising of four foam-mat dried mango powders four storage temperature (10, 20, 30 and 40°C) and two relative humidities (55 and 80%) were used to study the kinetics of moisture uptake. Triplicate sample, each 0.3 g, were weighed into crown corks and placed on wire gauze, supported above the sulphuric acid solution of 55 and 80% RH, respectively. The required environments were achieved inside air tight 500 mL capacity plastic containers and incubated at 10, 20, 30 and 40°C, respectively in a Gallenkamp Incubator, model INF 600.010R. At each temperature and relative humidity, sample were removed and weighed every 2 h for the first 12 h. Subsequently readings were taken at 12 h interval, until the difference between two successive readings was less than 0.5%.

Moisture Isotherm Data

Moisture absorption of the samples was evaluated gravimetrically as described by Mok and Hettiarrachchy (1990). A 4×4×8 factorial in complete randomized block design comprising of four temperatures, four sample and eight relative humidities were used. The experimental procedure was the same as described for kinetic studies above; except that in this case, sample were weight at the time interval of 48 h until constant weight was attained.

RESULTS AND DISCUSSION

Figure 1 and 2 indicate that the rate of moisture uptake was generally higher at the initial stages (first 2 to 4 h) and slowed as equilibrium condition was being approached. At the initial stages, samples were at low moisture content. This is due to more unsaturated sorption sites that were available for moisture adsorption. As the storage time increased, the sites became occupied, resulting to the reduction of the materials' capacity to absorb water. As the sites became fully occupied the moisture content approached equilibrium. Pilosof *et al*. (1985) and Elizalde *et al*. (1996) observed similar trends in the study of the kinetics of water uptake by food products.

At any given storage environment temperature, the rate of moisture uptake was higher at 80% than at 55% RH. At higher relative humidity, more water was available for absorption by the material.

The rate of moisture uptake decreased with increase in temperature at constant relative humidity. This implies that at low temperature the samples were more hygroscopic. From the kinetic theory, it could be argued that as the temperature increased, water molecules gained more kinetic energy and hence degree of freedom which promoted escape from the sorbent surfaces thereby causing the amount of sorbed water to decrease with increase in temperature.

The diffusivities of samples incorporated with foam stabilizers were higher than those without foam stabilizers. This was in agreement with Labuza (1984), who observed that the more porous a material, the higher it diffusion coefficient.

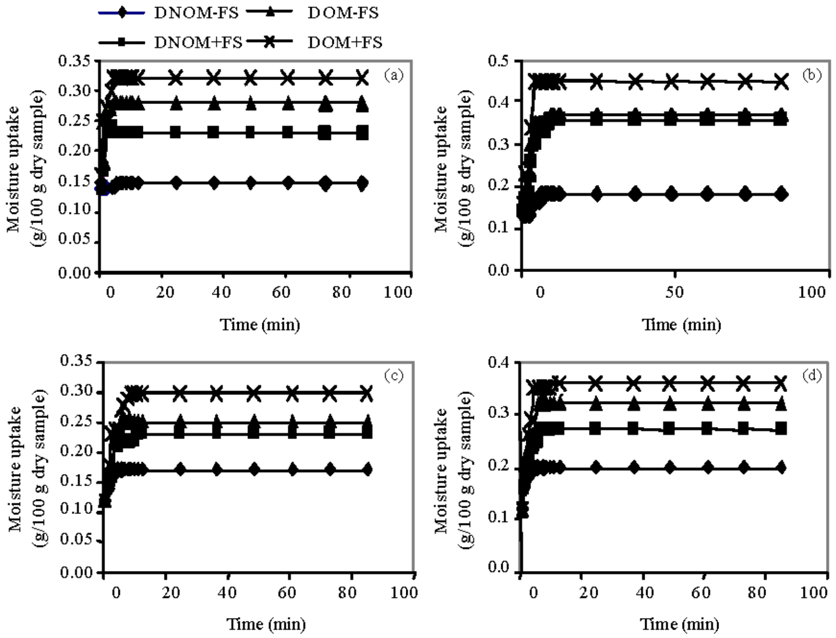

Fig. 1: Moisture uptake vs. time at (a) 10, (b) 20,(c) 30 and (d) 40°C and 55% RH

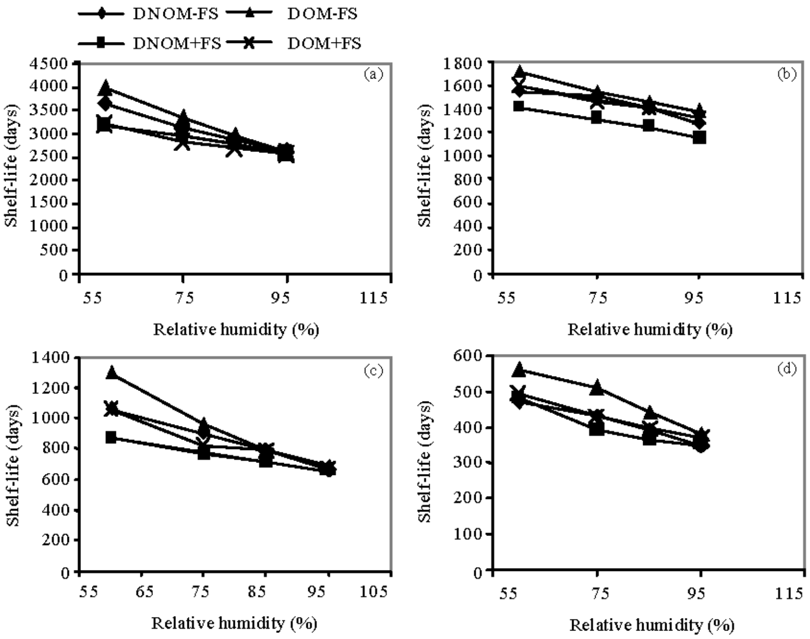

Fig. 2: Moisture uptake vs. time at (a) 10, (b) 20, © 30 and (d) 40°C and 80% RH

Table 1: Arrhenius parameters for the relationship between diffusivity (D_e) and absolute temperature for stored mango at 55 and 80% RH

	Relative humidity (%)							
	DNOM-FS		DNOM+FS		DON-FS		DOM+FS	
Regression parameters	55	80	55	80	55	80	55	80
R^2	0.845	0.917	0.985	0.984	0.806	0.986	0.953	0.956
Intercept	-0721.000	0.016	2.672	4.021	-7.110	-0.100	2.675	0.654
Gradient	-3968.840	-4167.140	-4922.520	-5031.460	-2190.490	-4084.260	4289.670	-4296.000
E_a (kJ mol^{-1})	33.000	34.600	40.900	41.800	40.900	34.000	48.600	36.000

R^2: Regression coefficient, E_a: Activation energy

Effective diffusivities of the powders ranged from 2.68×10^{-7} to 2.58×10^{-6} m^2 h^{-1}. The diffusivities of non-osmosed were generally higher than the osmosed samples at all temperatures and relative humidities studied. This can be explained to be due to solute uptake of the osmosed material, which may have reduced porosity and hence moisture adsorption.

The plot of Arrhenius type relationship between effective diffusivities (D_e) and absolute temperature (1/T) gave straight lines and the regression parameters (Table 1) also show good correlation with R^2, values ranging from 0.84 to 0.98.

The straight line curves and the high R^2 justify applicability of Arrhenius equation. The activation energy of samples was observed to increase with in storage relative humidity. The activation energy of osmosed samples without foam stabilizer was to lower than samples not incorporated with foam stabilizer was higher. This indicates that samples with high porosity were more sensitive to heat.

The applicability of Ficks unsteady state model Eq. 1 to the study of the kinetics of moisture uptake by mango powders was verified by a plot of the moisture ratio (M/M_e) versus time (t), in Fig. 3. Figure 3 shows linear relationships, indicating that moisture absorption obeyed the penetration

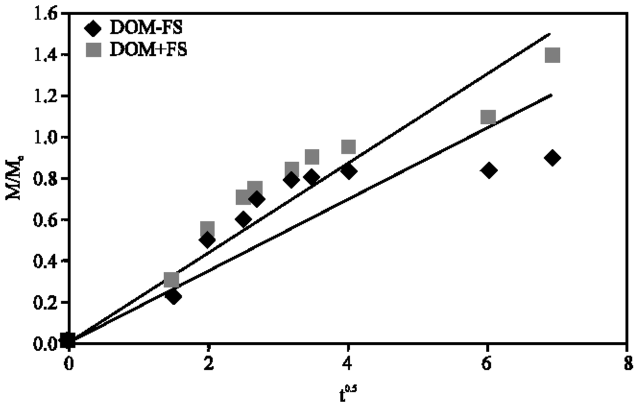

Fig. 3: Graph of M/M$_e$ vs. t$^{0.5}$ for water difussion during moisture sorption of mango purees

theory of mass transfer and is mainly Frickan (Silveira *et al*., 1996; Alakali *et al*., 2006). The activation energies of the samples ranged from 18.0 to 41.8 kJ mol^{-1}. According to Taoukis and Labuza (1989), activation energy for diffusion process range between 0-63 kJ mol^{-1}. The E$_a$ values were within this range, further justifying the applicability of Fick's unsteady state mass transfer equation to the data.

Shelf Life Prediction

Equation 1 was used to predict the shelf-life of DOM+FS, DOMFS, DNOM+FS, DNOM-FS in four packaging materials namely: poly-30, Dozek-49, Malinex-813 and proplin-C. Equilibrium moisture contents and critical moisture contents were derived from the moisture sorption isotherms at storage relative humidities of 60, 75, 85 and 95%. The vapour pressures of pure water at the storage temperature (10, 20, 30 and 40°C) were 9.21, 17.54, 31.83 and 55.32 mmHg, respectively. The ratio of permeability to thickness of the packaging materials are 1.94 and 0.99 g H_2O m^{-2} day-mmHg for poly-30 and Dozek-49, respectively 0.88 and 0.122 g H_2O m^{-2} day mmHg for malinex-813 and propelin-C, respectively.

Using the above storage conditions, the shelf life of samples was determined. Typical plots of predicted shelf life of samples versus relative humidity show that the shelf life decreased with increase in storage relative humidity and temperature (Fig. 4). This was in agreement with Labuza (1984) and Wang and Brennan (1991). Increase in storage relative humidity and temperature promote the activities of micro-organisms, enzymatic and chemical reaction and hence accelerate the rate of deterioration. Diosady *et al*. (1996) observed similar trends in other dehydrated food products.

The predicted shelf life of samples was generally above 365 days. Samples incorporated with foam stabilizer exhibited shorter shelf-life compared to those without foam stabilizer at all relative humidities and temperatures studied. This was consistent with the lower EMCs in the samples with foam stabilizers compared with the others. Materials with lower EMCs had lower critical water activities as well as critical moisture contents and attain equilibrium with the environment faster. Consequently such products exhibited shorter shelf-life.

The predicted shelf-life of osmosed mango powders without foam stabilizers were longer compared with the other samples at all storage relative humidities and temperatures studied. This was also expected since it was earlier observed that the EMCs of samples were generally higher than the other products, accounting for their higher shelf-life.

Packaging materials with low permeability to thickness ratios exhibited longer shelf life than the others. The predicted shelf life in propelin-C with the lowest permeability to thickness ratio of

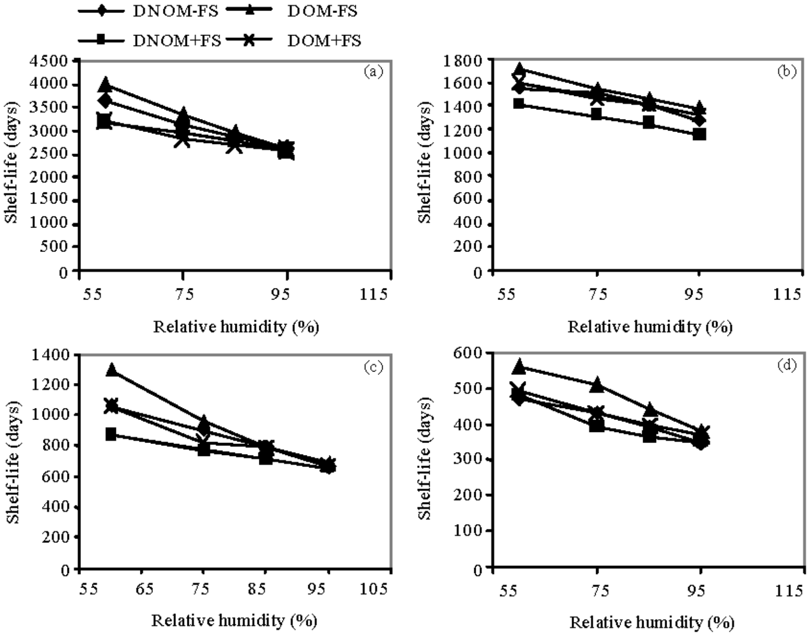

Fig. 4: Typical plot of predicted shelf life vs. relative humidity at (a) 10, (b) 20, (c) 30 and (d) 40°C

0.122 g H_2O m^{-2} day mmHg was generally longer while that of poly-30 with the highest permeability to thickness ratio of 1.94 g H_2O m^{-2} day-mmHg was shorter.

CONCLUSION

The ratio of moisture uptake was generally higher at the initial storage period and decreased as equilibrium was being approached. The rate of moisture uptake was higher at high storage relative humidities and decrease with increase in storage temperature of the environment.

Predicted shelf life of samples decreased with increase in both storage temperature and relative humidity. Samples incorporated with foam stabilizers exhibited longer shelf life.

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