Journal of Food Technology 5 (1): 18-22, 2007

Water Sorption Characteristics of Plantain and Sweet Potato

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Abstract: This investigation was conducted to study the behaviour of dehydrated products of Plantain and Sweet Potato in stimulated storage environment at temperature range of 25 (298k) and 40°C (313k). Salt solutions were used to achieve water activity in the range of 0.075 to 0.97. Equilibrium moisture content obtained was used to produce sorption isotherm at these temperatures. Sorption models of Halsey, Henderson, Chung Pfost and Caurie were evaluated on the experimental data as well as modified versions of Halsey and Henderson. Coefficient of determination range from 0.798 to 0.964 in all the models. Most equilibrium moisture content obtained during the experiment reflects adsorption except for very low water activity. Chung Pfost equation gave the best fit for the adsorption characteristics of these crop having the least residual mean square. Least moisture content was derived for storage stability of these crops and the region of local isotherm II was identified as the region of optimum storage.

Key words: Equilibrium moisture content, relative humidity, sorption isotherm and storage stability

INTRODUCTION

Agricultural crops and their products are hygroscopic in nature and when exposed to the environment, their moisture content will either increase or decrease until it equilibrate with the environment. During storage the moisture content of stored products is altered by prevailing temperature and relative humility of the environment. Water activity has been of great importance in influencing biological activities which results in bio-degradation (Rockland and Nishi, 1980). The effects of dynamic process of water movement during the storage of crops or crop products require considerable attention for optimum storage qualities. The high moisture content exhibited by most agricultural crops compounds the problem of their storage in the natural state.

Plantain, (*Musa paradisiaca*), a tropical fruit crop has high starch content when harvested. Matured fruits ripen within a short time afterwards and thereby renders long period of storage in natural state difficult. However, unripe Plantain are peeled, sun dried and processed into flour for stable storage.

Sweet Potato (*Impomoea batatas*) is a crop of considerable potential widely grown in Nigeria and known to be rich in carbohydrates, Vitamin A and C as well as significant amount of calcium and iron. It is perishable in it's natural state, hence not suitable for durable storage except when transformed to chips which are sun dried and milled into flour.

Water has been a major constituent of agricultural crops and it ranges between 60-70% for the crops under investigation (F.A.O., 1981; Okunola, 1991; Rockland and Nishi, 1980) identified three major ways in which water exist in biological materials. Firstly, it could exist as a mono-molecular layers of water molecules bound to the surface of the cells; secondly, there can be multi-molecular layer of molecules stacked on top of the first layer and thirdly, there are free moisture within the cells. The high moisture content of Plantain and Sweet Potato coupled with the hygroscopic nature of biological materials when exposed to humid environment establishes the influence of moisture as an important factor in the maintenance of storage stability.

The inherent high moisture content of plantain and sweet potato make biological deterioration by microbial activities inevitable in their natural state. Reduction in moisture content to a safe level results in decrease in metabolic activities of micro-organism and inherent temperature during storage (Labuza, 1980 and Okunola, 1991).

Water activity has been generally accepted to be more closely related to the physical, chemical and biological properties of food than it's total moisture content. According to Labuza (1980), specific changes in colour, aroma, flavour, texture, stability and acceptability of raw and processed food products have been associated with relatively narrow water activity range. Water activity is the related analogous term which is the

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fraction of Equilibrium Relative Humidity (ERH). Independent and inter dependent chemical moieties that affect the properties of biological products have been identified to be influenced by affinity for water molecules of it's environment and the competing influences of neighboring hydrophilic or hydrophobic chemical groups (Labuza, 1980). Water sorption characteristics influences inherent shelf life qualities and determine duration for good storage. Crop losses during storage that are enhanced by moisture includes biological, bio-chemical enzyme activated reaction, microbiological and physiological types (F.A.O., 1981).

Ambient temperature and relative humidity also have great influence on crop products during storage. Sharp increase in the inherent temperature of crops in storage is an indicator of the extent of micro-organism activities and most chemical reaction taking place. Ambient temperature of the environment is recognized as the determinant of moisture content of crops during storage. Likewise, high Equilibrium Relative Humidity (ERH) of the environment has significant influence on stored products determination because of the moisture exchange between the product and the environment. The ERH increase with increase in temperature and vice-versa.

The water sorption characteristics is usually described by sorption isotherm which has been used to understand behaviuors of agricultural products during storage or storage simulation. (Ajisegiri, 1987; Labuza 1975; Igbeka *et al*., 1975 Okunola and Igbeka). Adsorption isotherm is obtained by rehydrating a completely dried material in varying conditions of relative humidity while monitoring weight gained. Many authors have determined experimentally sorption isotherms for food materials and other biological products. They have found that equilibrium moisture content and relative humidity is temperature dependent and sorption curves must be found over a wide range of temperatures especially when accuracy is desired. (Henderson, 1952; Labuza, 1968; Pixton and Warbuton, 1971).

Labuza (1968) described this behaviour as a loss of hygroscopicity in agricultural products at high temperature. However, (Verma and Maharaji, 1990) in their study of moisture content and equilibrium relative humidity of Jaggery (a concentrated sugar products) observed that it's hygroscopicity increases with increase in temperature which is in conformity to earlier observations of (Iglesia and Chirife, 1978) on sugar and high sugar containing food. The hygroscopic behaviour of Plantain and Sweet Potato at high temperatures are of interest being crops of high sugar content. Desorption isotherms for plantain at several temperatures have been reported (Ajibola, 1986).

Table 1: Sorption Models and their linear forms

Author	Model	Linear Form
Hasely (1984)	$M_T\left[\mathrm{In}\,\frac{A}{Aw}\right]^{1/n}$,	$\mathrm{In}\,M=\frac{1}{B}\,\mathrm{in}\,\frac{A}{T}+\frac{1}{B}\,\mathrm{in}\,(-\mathrm{in}\,Aw)$
Henderson (1952)	$M=\frac{-\mathrm{In}(1-Aw)^{1/B}}{AT}$	$\mathrm{In}\,M=\frac{1}{B}(-\mathrm{in}(1-Aw)+\frac{1}{B}\mathrm{In}\frac{1}{AT}$
Chung Pfost, (1967)	$M=-\frac{1}{B}\left[\mathrm{In}\,\frac{A}{RT}-\mathrm{In}(-\mathrm{In}\,Aw\right.$,	$\left.\right]M=\frac{1}{B}\,\mathrm{In}\,\frac{A-1}{RTB}\,\mathrm{In}\,(\mathrm{In}\,Aw)$
Modified Henderson	$M=\mathrm{In}\frac{(1-Aw)1}{-\mathrm{In}\,AW}/c$,	$\mathrm{In}\,\underline{M}=\frac{1}{C}\mathrm{In}(-\mathrm{In}\frac{(1-Aw)}{T}-\mathrm{In}A\frac{(T+B)}{B}$
Modified Halsey	$M=\mathrm{Exp}\frac{(A-BT)}{-\mathrm{In}\,Aw}1/c$,	$\mathrm{In}M=\frac{1}{C}(A+BT)\,\mathrm{In}(-\mathrm{In}\,Aw)$

Note: EMC (decimal, dry basis), Aw = Water activity (decimal) A, B, C are parameters pertinent to each model/equation T = Absolute temperaqture (Kelvin) R = Universal gas constant (J/molk)

A number of equations have been published by various researchers to describe the water sorption isotherms of foods (Ajisegiri and Sopade, 1990; Chung and Pfost, 1967; Iglesias and Chirife, 1981). Six sorption equations which have shown suitability for predicting EMC for high carbohydrates food over a wide range of water activity are selected to analyse the experimental data in this report. The sorption models and their linearised forms are shown in Table 1.

MATERIALS AND METHODS

The static gravimetric method was used to determine equilibrium moisture content of the samples at various water activity as enumerated by Henderson and Pixton (1981). Ten solutions were selected to produce varying water activities between 0.075 to 0.97 at reasonable interval. The relative humidity value of these salts were reliable to 0.05 water activity and experience minimum changes within temperatures of 25 to 40°C which was used for the experiment. (Rockland, 1960; Rockland and Nishi, 1980). The temperatures of the experiment was chosen to stimulate variation in ambient temperature prevalent during storage in South Western part of Nigeria. The saturated salt solutions were placed at the base of glass desiccators and wire mesh screen was used to hold the samples. The desiccators lid was sealed with silca gel and then placed at desired temperatures in Gallen Kamp 300 oven.

Thin slices (2 mm) of sun dried samples were placed in three replicates in the desiccators in all the experiments. Moisture content of plantain and sweet potato at commencement of sample preparation was found to average 60.65 and 67.32%, respectively. Oven method was used for moisture content determination at 105°C with sample being weighed at six hours intervals until constants weight of three consecutive reading was achieved.

Table 2: Equilibrium moisture content of plantain and sweet potato at 25°C (298k)

Aw	0.082	0.23	0.43	0.66	0.75	0.80	0.93	0.97
EMC(P)	6.08	11.38	19.57	14.79	20.81	28.25	31.47	38.67
EMC(SP)	8.95	8.24	19.34	13.88	25.03	31.91	42.13	46.72

Table 3: Equilibrium moisture content of plantain and sweet potato at 40°C (313k)

Aw	0.075	0.23	0.40	0.65	0.75	0.79	0.89	0.96
EMC(P)	3.13	6.67	11.25	12.03	19.78	20.00	30.61	33.99
EMC(SP)	3.90	5.55	9.88	10.54	18.88	23.42	37.11	48.78

RESULTS AND DISCUSSION

Table 2 and 3 shows the average of three replicates of EMC of plantain and sweet potato at temperatures of 25 and 40°C, respectively. The equilibration time was earliest reached for sweet potato in all the experiments. The experimental data (Observed EMC) and their respective water activity were imputed into a linear regression programme to predict EMC in all the two parameter models using (Genstart, 1984) statistical procedure. A non linear least square grid search was used for the three parameter models using Gauss-Newton method having the two temperature levels incorporated for it's applicability over the varying temperature. Table 4 to 7 summarise the usefulness of the sorption equation in predicting adsorptive EMC at temperatures of 25 and 40°C.

From Table 4 and 5 showing Plantain isotherm characteristics, modified Hasley has the highest Coefficient of Determination (COD) of 0.9228 though Chung Pfost gave the best fit with Residual Mean Square (RMS) of 0.11 at the temperature of 25°C. At 40°C, Caurie has the highest COD of 0.95 while Chung Pfost gave the best fit at RMS of 0.06%. For Tables 6 and 7 having sweet potato isotherm characteristics, Chung Pfost gave the best fit having COD of 0.901 and RMS of 0.21% at 25°C. At the higher temperature of 40°C, Halsey equation has the highest COD of 0.95 though Chung Pfost with a COD of 0.905 and RMS of 0.24 has the best fit for the experimental data.

Table 4: Water adsorption characteristics of plantain at 25°C (298k) with predicted values of sorption models

Aw	Observed EMC%	Halsey	Predicted henderson	EMC% chung pfost	Caurie	M.Hal	M.Hen
0.082	6.08	8.87	6.40	7.38	7.32	5.13	7.36
0.23	11.38	10.81	10.74	11.11	9.74	9.59	9.43
0.43	19.57	13.28	15.32	15.01	14.12	14.72	12.20
0.66	14.79	17.28	20.73	19.99	21.08	21.20	16.97
0.75	20.81	19.81	23.29	22.57	24.41	24.40	20.13
0.80	28.25	21.78	24.96	24.36	26.41	26.52	22.65
0.93	31.47	33.05	31.50	32.07	32.07	35.14	38.19
0.97	38.67	45.64	35.81	33.94	33.94	41.02	51.18
R2		0.808	0.902	0.846	0.846	0.923	0.849
RMS (%)		6.99	0.11	8.38	8.38	4.31	8.98

Note: Aw = water activity, M. Hal = Modified Halsey M. Hen = Modified Henderson. R.M.S. = Residual mean square R^2 = Co-efficiency of determination/percentage variance

Table 5: Water adsorption characteristics of plantain at 40°C (313k) with predicted values of sorption models

Aw	Observed EMC%	Halsey	Predicted henderson	EMC% chung pfost	Caurie	M.Hal	M.Hen
0.075	3.13	4.45	2.88	1.81	3.48	3.61	5.49
0.23	5.67	6.16	6.38	6.35	5.35	7.11	7.14
0.40	11.25	8.09	9.91	10.13	8.47	10.36	8.90
0.65	12.03	12.49	15.92	16.16	16.03	15.50	12.64
0.75	19.78	15.75	19.11	19.39	20.32	18.11	15.25
0.79	20.00	17.67	20.66	20.99	22.26	19.36	16.73
0.89	30.61	26.50	25.95	26.62	27.67	23.50	23.22
0.96	33.99	48.48	33.26	35.01	31.91	29.03	37.81
R^2		0.889	0.964	0.948	0.95	0.923	0.849
RMS		7.57	2.4	0.06	4.58	4.31	8.98

Table 6: Water adsorption characteristics of sweet potato at 25°C (298k) with predicted values of sorption models

Aw	Observed EMC%	Halsey	Predicted henderson	EMC% chung pfost	Caurie	M.Hal	M.Hen
0.082	8.95	8.91	6.69	50.68	7.12	5.32	7.27
0.23	8.24	11.13	11.52	10.71	9.91	10.24	9.59
0.43	19.34	14.03	16.72	15.95	15.22	16.04	12.80
0.66	13.88	18.87	22.97	22.66	23.96	23.51	18.49
0.75	25.03	22.00	25.95	26.13	28.19	27.22	22.39
0.80	31.91	24.47	27.90	28.54	30.73	29.71	25.55
0.93	42.13	39.13	35.63	39.16	37.88	39.88	45.81
0.97	46.72	56.26	40.76	47.37	40.24	46.89	71.93
R^2		0.844	0.798	0.901	0.829	0.861	0.89
RMS(%)		6.91	8.96	0.21	12.79	9.77	7.58

Table 7: Water Adsorption characteristics of sweet potato at 25°C (298k) with predicted values of sorption models

Aw	Observed EMC%	Halsey	Predicted henderson	EMC% chung pfost	Caurie	M.Hal	M.Hen
0.075	3.90	4.24	2.9	1.71	3.29	3.69	5.33
0.23	5.55	6.09	6.66	4.67	5.32	7.45	7.16
0.43	9.88	8.24	10.55	9.99	8.89	11.04	9.15
0.65	10.54	13.36	17.30	18.50	18.00	16.83	13.55
0.75	18.88	17.31	20.94	23.05	2329	19.81	16.71
0.79	23.42	19.66	22.92	25.92	25.69	24.23	18.63
0.89	37.11	30.88	28.82	33.23	32.35	26.02	26.73
0.96	48.78	60.46	37.35	44.05	37.50	32.45	46.10
R^2		0.953	0.89	0.905	0.892	0.861	0.892
RMS(%)		3.7	8.62	0.24	12.96	9.77	7.58

Table 8 and 9 shows the parameters obtained in sorption models used to predict the EMC at various water activity and temperature. Moisture sorption isotherm curves were produced from the experimental data for the equilibration temperature. Fig. 1 and 2 shows the effect of temperature of moisture sorption characteristic of Plantain and Sweet Potato, respectively. From Fig. 1 having the sorption isotherm for Plantian, at 25° the EMC increases steadily with increse in Relative Humidity (RH) up to 43% and a decrease in gradient to 65% before a steep increase as the RH approaches saturation. A remarkable increase of temperature at 40° causes a decrease in it's moisture content, there is gradual increase in the EMC with an

Table 8: Estimate of model parameters for plantain

Model	Temperature	A	B	C
Halsey	25^0C	7.998968x104	-2.69137	-
Henderson	"	0.10882	2.15641	-
Chung Pfost	"	2.107847x103	14.23114	-
Caurie	"	15.05971	2.10918	-
M. Halsey	25-40^0C	0.6722036	-269.37958	1.786198
M. Henderson	"	5.090651	0.0331668	2.1508724
Halsey	40^0C	2.69656x104	-1.73700	-
Henderson	"	0.05485	1.52069	-
Chung Pfost	"	1.01727x103	12.5027	-
Caurie	"	34.4422	2.89709	-

Table 9: Estimate of model parameters for sweet potato

Model	Temperature	A	B	C
Halsey	25^0C	3.8347x10^4	-2.39218	-
Henderson	"	0.07518	2.0550	-
Chung Pfost	"	1.3445x10^3	10.5715	-
Caurie	"	15.94961	2.44609	-
M. Halsey	25-40^0C	0.5113163	-270.02557	1.7067766
M. Henderson	"	5.1019579	0.0312781	1.923807
Halsey	40^0C	1.6821x10^4	-1.56116	-
Henderson	"	0.04314	1.45586	-
Chung Pfost	"	6.9633x10^2	8.87569	-
Caurie	"	37.52611	3.24415	-

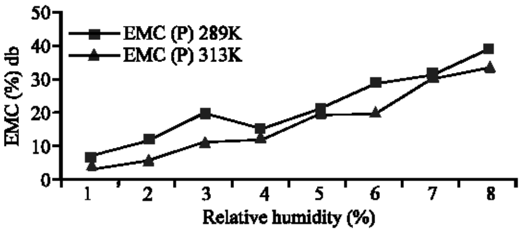

Fig. 1: Moisture sorption isotherm of plantian

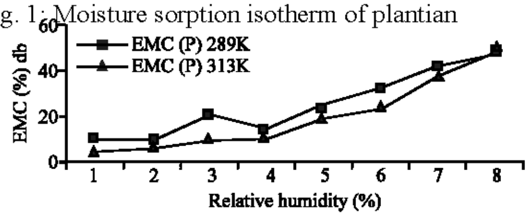

Fig. 2: Moisture sorption isotherm of sweet potato

inflection at 35% RH up to 65% where there is sharp increase as the relative humidity increases. For Fig. 2 which shows the sorption isotherm for Sweet Potato. At 25°C, the EMC increases with increase in the RH to about 43% where a sharp fall occurs till about 65% then a sharp increase on EMC till 100% RH was reached.

At higher temperature of 40°C EMC increases gradually as the relative humidity increase up to 66% RH; beyond this, there is a sharp increase in EMC as the RH approaches unity. At very high RH (beyond 90%) EMC value of Sweet Potato at 40°C was found to be higher than that obtained at 25°C which was not observed in plantain. This behaviour is attributed to increase in hygroscopicity at high temperatures which is in agreement with the behaviours reported for sugar and high sugar containing food (Verma and Maharaji, 1990; Iglesias and Chirife, 1978; Okunola and Igbeka). This implies that a sudden change to high temperature during storage will cause an increase in the EMC of high sugar food. As unripe Plantain with high sugar content was used for this experiment, hygroscopic behaviour for ripe Plantain having high sugar content should be investigated. The determination of least moisture content is necessary for stable storage of dehydrated food. (Caurie, 1970), Model was utilized.

$$\mathrm{In\,C} = \frac{1}{0.045\mathrm{Mn}} \quad \mathrm{Aw\,In\,r} \qquad (1)$$

Where

$$C = \frac{100 - \%H_2O}{\%H_2O}$$

In linear regression analysis, the intercept is equivalent to In A which implies

$$\mathrm{In}\ \frac{A = 1}{0.45\mathrm{Mn}} \qquad (2)$$

Where Mn is the least moisture content.

The least moisture content was determined to be 8.19% and 6.28% for Plantain at 25°C and 40°C, respectively; Sweet Potato least moisture content reflects the monolayer moisture of these crops. At high temperatures, capacity of stored products to accommodate moisture reduces. This differs from ability to enhance rapid biological and physio-chemical reaction at increased temperature. (Ajisegiri, 1987). Storage of these crop below the above value will cause anti oxidation and rancidity development as earlier reported. (Rock land and Nishi, 1980). Optimum storage stability zone therefore exist above this point up to the inflection point of the in isotherm curve. That is the local isotherm II region.

CONCLUSION

Moisture sorption isotherm at two ambient temperatures were obtained for stored products of Plantain and Sweet Potato. The stability of dehydrated food products during storage is affected by environmental conditions apart from inherent chemical and biological factors. The Halsey, Henderson, Chung

Pfost, Caurie, modified Halsey and modified Henderson sorption equations were used to evaluate goodness of fit to experimental data. All the models shows a high coefficient of determination ranging from 0.798 to 0.964. Chung Pfost gave the best fit for the adsorption characteristic of the crops of concern with the least RMS and it can be used to predict their EMC with high accuracy.

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