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Desorption Isotherms for plantain at several temperatures

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Abstract

Moisture equilibrum data for desorption of water from ripe and unripe plantain were obtained at 40°, 50°, 60° and 70°C over a range of relative humidities from 10 to 90 percent, using a static gravimetric method. Ribe plantain exhibited higher equilibrum moisture content (EMC) than unripe plantain under the same conditions. A non-linear least squares regression programme was used to fit 5 desorption isotherm models to the experimental data and the parameters of the models evaluated. Using the modified Halsey model, the minimum standard error of estimates of the EMC was 1.9% for ripe and 1.4% for unripe plantain.

Introduction

Plantain *(Musa paradiasca)* is an important source of carbohydrate in the humid tropics. It is a seasonal crop being plentiful during the rainy season and scarce during the dry season. Traditionally, the fruit is allowed to ripen at ambient temperature before being processed for consumption, or dried and milled into flour in the unripe stage. There are no cheap, practical storage techniques for the fruit. Thus, they ripen at about the same time leading to high post-harvest losses which could be from 35 – 100% (NAS, 1978). Several methods of processing plantain to extend the storage life are presently being investigated. These methods include drying, transformation into chips, powder and flour (Ogazi and Jones, 1981). These processes invariably involve the drying and storage of the crop. A fundamental characteristic of food materials which influences every aspect of the drying process and the storage stability of the dried product is its water sorption characteristics. The equilibrium relationship tying moisture content of an agricultural product with temperature and relative humidity of the surrounding air is of primary interest in the modelling and design of crop drying and storage facilities. This information is useful in studying drying characteristics of products and in developing relationships to predict drying rates of the product under various drying conditions. It can also be used to predict what moisture levels would be necessary for long-term safe storage of the product. Hence, there have been many scholarly contributions which deal with the experimental means to obtain sorption isotherms for several agricultural products. Gal (1981) pointed out that there are three basic methods of determining sorption data namely manometric gravimetric and special methods. He concluded that the gravimetric method has been preferred for obtaining complete sorption isotherms. These data are available for a wide variety of products (ASAE, 1981) but none is available for plantain. It is known that the chemical composition of an agricultural product has a substantical effect on its sorption isotherms (Labuza, 1968). Thus, it is expected that ripening of plantain will alter its sorption isotherms.

Many other researchers have developed and tested models of the forms.

$$MC = MC\ (RH, T)$$

and

$$RH = RH\ (MC, T)$$

where T = temperature

MC = moisture content at equilibrum

RH = relative humidity at equilibrum

A recent review of the models was done by Bruin and Luyben (1980).

The objective of this study was to obtain data on desorption isotherm of ripe and unripe plantain at 40°, 50°, 60° and 70°C and to interprete the data in terms of established sorption models. These could be used in the design of crop drying and storage facilities to obviate the losses attendant on a seasonal crop like plantain.

Materials and Methods

The plantain used for this study was obtained from the University of Ife Teaching and Research Farm. Ripe and unripe fingers were investigated, the latter being obtained from bunches that were stored in a warm environment in order to ripen. The samples were peeled, cut into pieces of about 1.5cm thick and dried in an oven at 90°C until the weight was reduced by about one third. This drying technique was found necessary to reduce the length of time required for equilibrum to be reached and also lessen the amount of excess salt needed in the saturated salt solutions.

A static gravimetric technique was used for the equilibrum moisture content determination. Samples of about 20g were placed in wire baskets which were then placed in dessicators. Each dessicator contained a saturated salt solution, the set of solutions being selected to provide adequate screening of ambient relative humidities from 10 to 90% at the different temperatures (Young, 1967). The dessicators were placed in ovens set at 40°, 50°, 60° and 70°C (± 1.0°C). The samples were weighed daily and equilibrum condition was considered to have been reached when three consecutive measurements gave identical readings. The dry matter of the samples was obtained by drying in an oven at about 90°C to constant weight. At this temperature, the samples dried without caking. Each experiment was replicated once.

Results and Discussion

The equilibrum moisture data, expressed as percent dry basis, at different temperatures and relative humidities are presented in Table 1 for ripe plantain, and Table 2 for unripe plantain. The data indicate that the equilibrum moisture content of ripe plantain is higher than that of unripe plantain at all temperatures and for all relative humidity values investigated. This is clearly illustrated in Figure 1. It has been shown that during ripening of plantain, complex carbohydrates especially starch are hydrolysed to reducing sugars and sucrose and that there is an increase in the moisture of the fruit (Ketiku, 1973). Crapiste and Rotstein (1982) in a study of the sorption equilibrum data of starch-containing foodstuff, concluded that a product with a large amount of solute and less insoluble materials has less equilibrum water at low relative humidities but rather more at high relative humidities. This was demonstrated in comparisons of equilibrum moisture data for beans with potatoes and peas with corn. Mazza (1982) has also shown that the addition of glucose and sucrose to potato caused the equilibrum moisture to decrease in the low and intermediate relative humidity ranges while increasing it significantly at the high relative humidity range. The higher equilibrum moisture values of ripe plantain at low and high relative humidities are therefore unexpected. This however could be due to the effect of other changes that occur during ripening. These changes include decreases in acidity, starch and ascorbic acid contents, as well as increases in pH, ash and fibre content (Ketiku, 1973).

TABLE 1: OBSERVED DESORPTION EQUILIBRIUM MOISTURE OF RIPE PLANTAIN.

Temperature °C	Relative Humidity (%)	Equilibrium Moisture Content (% dry basis)		
		Rep 1	Rep 2	Mean
40	11.8	9.73	10.22	9.98
40	22.0	11.26	11.21	11.24
40	31.8	11.76	13.59	12.68
40	48.0	14.42	14.29	14.34
40	61.0	26.89	26.98	26.94
40	71.0	35.37	37.09	36.23
50	11.4	6.70	7.74	7.22
50	21.0	8.92	8.99	8.96
50	31.4	10.90	10.97	10.94
50	47.0	12.85	12.35	12.60
50	60.0	19.53	21.27	20.40
50	71.0	28.85	27.69	28.27
60	11.2	5.91	6.59	6.25
60	21.0	7.62	7.89	7.76
60	30.8	8.87	9.09	8.98
60	50.0	10.63	11.71	11.17
60	60.0	22. 0	20.87	21.44
60	69.0	22.62	24.14	23.38
70	11.1	5.37	4.91	5.14
70	20.0	6.85	7.37	7.10
70	29.8	9.54	9.36	9.45
70	50.0	10.19	9.24	9.72
70	60.0	15.04	16.51	15.78
70	69.0	16.07	16.71	16.39

TABLE 2: OBSERVED DESORPTION EQUILIBRUM MOISTURE CONTENT OF UNRIPE PLANTAIN

Temperature °C	Relative Humidity (%)	Equilibrium Moisture Content (% dry basis)		
		Rep 1	**Rep 2**	**Mean**
40	11.8	4.56	4.58	4.57
40	22.0	8.10	8.02	8.06
40	31.8	9.95	9.75	9.85
40	51.0	10.31	10.28	10.30
40	61.0	11.79	11.66	11.73
40	71.0	17.15	17.46	17.31
40	89.0	26.76	27.78	28.77
50	7.0	1.18	1.17	1.18
50	21.0	6.57	7.66	7.12
50	31.4	9.62	9.55	9.59
50	47.0	10.02	9.64.	9.83
50	60.0	11.24	11.00	11.12
50	74.0	15.71	14.29	15.00
50	99.0	25.52	27.14	26.33
60	7.0	0.96	0.97	0.97
60	21.0	4.42	4.74	4.58
60	30.8	6.72	6.72	6.72
60	50.0	8.62	8.69	8.61
60	60.0	10.61	11.14	10.88
60	69.0	14.16	12.25	13.43
60	88.0	22.40	22.27	22.34
70	7.0	0.96	0.85	0.91
70	20.0	3.58	4.30	3.94
70	29.8	5.88	5.87	5.88
70	50.0	7.37	6.89	7.13
70	60.0	9.25	9.45	9.35
70	69.0	11.47	10.83	11.15
70	78.0	13.35	1370	13.53

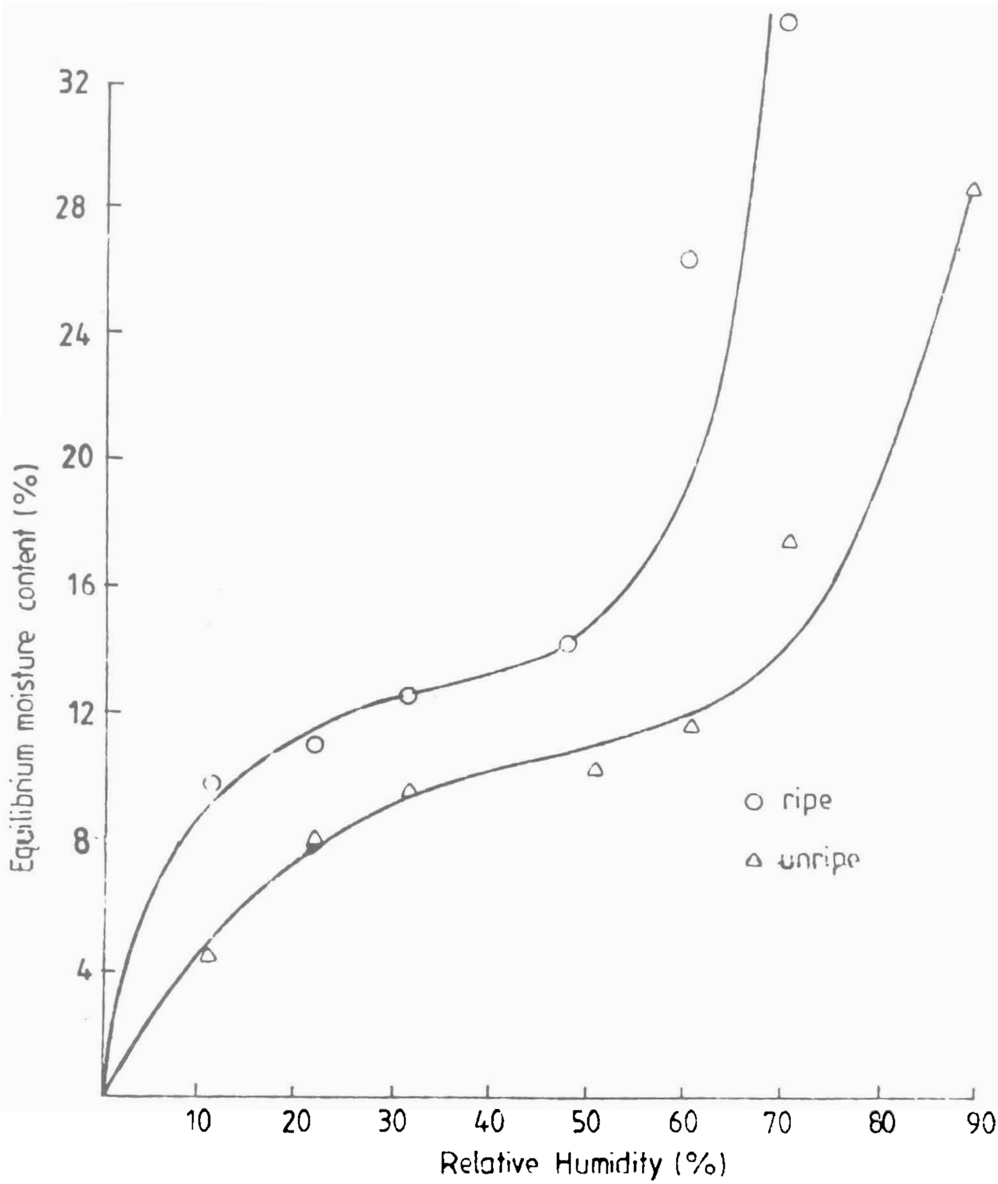

Fig. 1 Effect of ripeness on equilibrium moisture content of plantain at 40°C

A non-linear, least squares regression program GENSTAT OPTIMIZATION (NAG, 1981) was used to fit five desorption models (Table 3) to the experimental data. Parameters were estimated for the model first by taking the equilibrum relative humidity (ERH) to be the dependent variable and secondly, by taking the equilibrum moisture content (EMC) as the dependent variable.

TABLE 3: EQUILIBRIUM MOISTURE CONTENT AND EQUILIBRIUM RELATIVE HUMIDITY MODELS.

Name of Model	Equilibrium moisture content models	Equilibrium relative humidity model
Henderson (Henderson, 1952)	$M = \text{Ln}\left[\frac{(1-RH)}{-aT}\right]^{-(1/b)}$	$1 - RH = \text{EXP}(aTM^{b})$
Chung–Pfost (Chung and Pfost, 1967)	$M = \frac{-b}{}\text{Ln}\left[\frac{T\ \text{Ln}\ RH}{-a}\right]$	$RH = \text{EXP}\left[\frac{-a}{T} - \text{EXP}(-bM)\right]$
Modified Halsey (Iglesias and Chirife, 1967)	$M = \left[\frac{\text{EXP}(a - bT)}{-\text{Ln}\ RH}\right]^{\frac{1}{c}}$	$RH = \text{EXP}\left[-\text{EXP}(a + bT)M^{-c}\right]$
Chan–Clayton (Chen and Clayton, 1971)	$M = \frac{-1}{CT^{d}}\ \text{Ln}\left[\frac{\text{Ln}\ RH}{-aT^{b}}\right]$	$RH = \text{EXP}\left[-T^{b}\ \text{EXP}(-cT^{d}M)\right]$
Henderson–Thompson (Thompson, 1972)	$M = \left[\frac{\text{Ln}(1-RH)}{a(t+b)}\right]^{\frac{1.0}{c}}$	$1 - RH = \text{EXP}\left[-a(t+b)M^{c}\right]$

a, b, c, d = Parameters of the models
M = Moisture content, % dry basis
RH = relative humidity, decimal fraction
T = temperature, k
t = temperature, ^{o}C

The estimated parameters for the ERH models and the standard errors of estimate for relative humidity are shown in Tables 4 and 5 for ripe and unripe plantain respectively. The estimated parameters for the EMC models and the standard errors of estimate of the moisture content are also shown on Tables 6 and 7 for ripe and unripe plantain respectively. Comparisons of the estimated parameters in Tables 4 and

6, and Tables 5 and 7, show that the parameters obtained with the EMC models are not the same as the corresponding parameters in the ERH models.

TABLE 4: COMPARISON OF EQUILIBRIUM RELATIVE HUMIDITY MODELS FOR RIPE PLANTAIN.

	a	b	c	d	Standard Error of Estimate (%)
Henderson	7.075×10^{-5}	1.210			9.6
Chung–	8.84×10^{2}	8.10×10^{-2}			10.1
Modified Halsey	9.83	-2.019×10^{-2}	1.321		5.9
Chen–Clayton	4.797×10^{1}	–4.457	5.037×10^{-4}	8.900×10^{-1}	8.7
Modifed Henderson	-3.5×10^{-4}	1.361	9.410		7.5

TABLE 5: COMPARISON OF EQUILIBRIUM RELATIVE HUMIDITY MODELS FOR UNRIPE PLANTAIN

	a	b	c	d	Standard Error of Estimate (%)
Henderson	7.553×10^{-5}	1.450			8.5
Chung–Pfost	1.098×10^{3}	1.574×10^{-1}			8.3
Modified Halsey	1.030×10^{1}	-2.161×10^{-2}	1.612		8.0
Chen–Clayton	5.371×10^{6}	–2.453	9.378×10^{-5}	1.286	7.3
Modified Henderson	-3.9×10^{-4}	1.562	–4.61	–	6.4

TABLE 6: COMPARISON OF EQUILIBRIUM MOISTURE CONTENT MODELS FOR RIPE PLANTAIN.

	a	b	c	d	Standard Error of Estimate (%)
Henderson	5.2×10^{5}	1.319		--	3.9
Chung–Pfost	1.123×10^{3}	9.407×10^{2}			4.1
Modified Halsey	1.048×10^{1}	2.272×10^{-2}	1.252	–	1.9
Chen–Clayton	9.953×10^{5}	–2.173	1.593×10^{-5}	1.496	3.4
Modified Henderson	3.6×10^{-4}	1.370	-1.172×10^{1}	–	2.6

TABLE 7: COMPARISON OF EQUILIBRIUM MOISTURE CONTENT MODELS FOR UNRIPE PLANTAIN.

	a	b	c	d	Standard Error of Estimate (%)
Henderson	1.157×10^{-4}	1.278	–	–	2.1
Chung–Pfost	1.042×10^{3}	1.446×10^{-1}	–		2.2
Modified Halsey	1.012×10	1.998×10^{-2}	1.777		1.4
Chen–Clayton	1.718×10^{7}	–2.67	2.761×10^{-5}	1.481	1.8
Modified Henderson	5.2×10^{-4}	1.359	6.275		1.6

Equilibrium moisture content (%)

32 28 24 20 16 12 O O O O O ripe Δ Δ Δ Δ unripe

10 20 30 40 50 60 70 80 80

Relative Humidity (%)

For ripe plantain, the lowest standard error of estimate for ERH (5.9%), and EMC (1.9%) were obtained using the modified Halsey model (Tables 4 and 6). For the unripe plantain, the lowest standard error of estimate of 6.4% for ERH was obtained using the modified Henderson model while the lowest standard error of estimate of EMC (1.4%) was obtained using the modified Halsey model.

Conclusions

Desorption equilibrum moisture data are presented for ripe and unripe plantain for temperatures from 40°C to 70°C over a range of relative humidities from 10 to 90 percent. The EMC of ripe plantain were higher than that of unripe plantain at all conditions tested.

Parameters for five EMC and five ERH models have been estimated for the desorption of water from ripe and unripe plantain. This information may be useful to processors involved in the drying and storage of plantain.

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