INFLUENCE OF PRE-TREATMENTS ON THE DESORPTION ISOTHERM CHARACTERISTICS OF PLANTAIN

P-N. T. JOHNSON
Food Research Institute, Council for Scientific and Industrial Research, P. O. Box M20, Accra, Ghana

Abstract

The desorption isotherms of fresh and pre-treated plantain, at 50 and 60 °C, for relative humidity (RH) range 10-80 per cent were constructed. The sorption data were fitted to three known models and the monolayer moisture contents determined. Three pre-treatments used were: blanching at 90 °C for 5 min, and two moist-infusing treatments with 40 °B sucrose and a combined solution of 15 °B sucrose in 0.06 kg/kg NaC1, at 4 °C for 16 h. The last two pre-treatments reduced the monolayer moisture contents of plantain. The equilibrium moisture contents (e.m.c) of the pre-treated plantain were lower, at RH < 45 per cent but higher, at RH > 45 per cent, than those of the fresh plantain. At 50 °C and RH < 45 per cent, the e.m.c range for pre-treated plaintain was 2-5 per cent (d.s), compared to 4-8 per cent (d.s) for fresh plantain . At RH > 45 per cent, howerver, the e.m.c ranges were 10-48 and 10-28 per cent (d.s), respectively. Thus, at the same drying temperature, a much lower humidity condition will be required for the proper drying of pre-treated than for fresh plantain.

Introduction

Plantain (*Musa paradisiaca*) is rated as one of the cheapest staple food to produce per kilogram per hectare per calorie in the humid tropics (Stover & Simmonds, 1987). However, it is not only a seasonal crop but also highly perishable, making it scarce and, therefore, very costly during the off seasons. Dehydration has been identified as one of the cost-effective ways of preserving plantain. Unfortunately, ordinary dehydration of most food-crops results in products with poor colour, adverse texture and poor rehydration ability (Okos *et al.*, 1992). Johnson (1996) found that most of these adverse effects can be minimized significantly if plantain is pre-treated by a number of known techniques before drying. For the efficient dehydration of plantain a knowledge of the desorption isotherm characteristics of fresh and pre-treated plantain is required. This is because desorption isotherms give information of maximum permissible humidities that can be used to obtain desired moisture contents and, therefore, the design of drying equipment. The equilibrium moisture content is used in determining properly the end-point of drying (King, 1968). The objectives of this study were, therefore, to construct and compare the moisture desorption isotherms of fresh and pre-treated plantain, and discuss the implications of the results to the dehydration of plantain.

Experimental

Fresh plantain fingers (*Musa paradisiaca*, var. French Horn), at ripening stage 3 (Medlicott, 1992), were transversely sliced into 1 mm disc and pre-treated using three known methods. Pre-treatments used were blanching at 90 °C for 5 min and two moist-infusing pre-treatments (i) using 40 °B sucrose, and (ii) 15 °B in 0.06 kg/kg NaC1, both at 4 °C for 16 h (Jayaraman, 1988). The fresh plantain samples were used as control.

The desorption isotherms were determined at relative humidities (RH) 10-80 per cent at 50 ° and 60 °C. In each experiment, 3 ± 0.005 g sample was comminuted and weighed in a small polypropylene bowl 44 mm × 44 mm in size (Fisher Scientific, UK). The weighed samples in the polypropylene bowls were suspended over different concentrations of aqueous solutions of H_2SO_4 contained in vacuum

TABLE 1
Relative humidities of sulphuric acid solutions at the temperatures used

Temperature (°C)	Per cent (w/w) sulphuric acid								
	20	30	40	50	55	60	65	70	80
50	88.2	76.2	58.5	38.3	28.5	19.0	11.8	5.4	1.2
60	88.3	76.6	59.3	39.4	29.6	20.0	12.7	6.2	1.8

Source: Wang & Brennan (1991) and Young (1967)

(0.1 mm Hg) dessicators. Table 1 gives the different aqueous H_2SO_4 concentrations used to achieve the different RHs (Young, 1967; Wang & Brennan, 1991). Triplicate determinations were made at each RH. The samples were comminuted to help provide as much surface area as possible to facilitate the exchange of water vapour between the interior of the samples and the surrounding atmosphere. The samples were removed from the dessicators weekly and weighed. When two successive weighings showed no further change, the sample was considered to have reached equilibrium. The duration of equilibration averaged between 4 and 5 weeks. The equilibrium moisture content (M_e) was determined by vacuum method at 70 °C for 24 h (AOAC, 1984). The means were used in constructing the isotherms.

Results and discussion

The moisture sorption isotherms

The shapes of the desorption isotherms of fresh and blanched plantain samples were found to be different from the other two plantain samples pre-treated by moist-infusion (Fig. 1). The difference in the shapes of the isotherms is an indication that the sorptive properties of plantain become modified when pre-treated by moist-infusion. Isotherms of the two moist-infused plantain are similar to those of freeze-dried pineapple (Vega-Mercado & Barbosa-Canovas, 1993). Those of fresh and blanched plantain samples belong to the S-shaped isotherms usually referred to as type II isotherms, according to the BET classification (Labuza, 1984). The S-shaped isotherm was first found by Emmett (1942) in his study of nitrogen adsorption on the surface of inorganic materials.

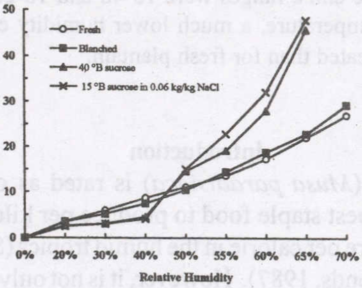

Fig. 1. Desorption isotherms at 50 °C of fresh and pre-treated plantain samples

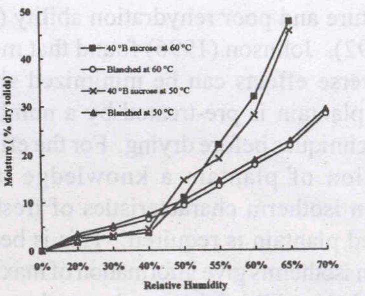

Fig. 2. Desorption isotherms at 50 °C and 60 °C of two pre-treated plantain samples (blanched only at 90 °C for 5 min and moist-infused with 40 °B sucrose)

The S-shaped isotherms are characterized by an inflection point which is thought to represent the approximate limits of ordinary surface adsorption occurring at low humidities and the beginning of multi-layer adsorption occurring at high humidities (Rizvi, 1995).

Results of plantain samples exposed to 80 per cent RH were discarded because they became mouldy. From Fig. 1 and 2, the equilibrium moisture contents (M_e) show two trends. The M_e of the moist-infused plantain samples were lower, at RH < 0.45, and higher, at RH > 0.45, than the M_e of the fresh and blanched plantain. Kapsalis (1987) explained that, at lower RH, the sorption process in pre-treated foods was mainly due to the bio-polymers present in the food. In the case of plantain, the main bio-polymers are starch and sugar molecules (Marriott, Robinson & Karikari, 1981). The decrease in equilibrium moisture contents, at RH < 45 per cent, can be attributed to the colligative effects of the sucrose and NaC1. The colligative effect reduced the vapour pressure and this affected the amount of water molecules that was adsorbed at the active sorptive sites of the pre-treated plantain (Kapsalis, 1987). At RH > 45 per cent, the increased equilibrium moisture content could be attributed to the fact that the sugar molecules in the plantain, which at low RH are in amorphous state (Iglesias, Chirife & Lombardi, 1975), become increasingly transformed into cystalline and more stable states (Labuza, 1984). The pre-treatment using the 40 °B sucrose moist -infusion technique increased the mean total sugar content from 11.8 per cent dry solids (for the fresh plantain) to 28.6 per cent dry solids (for plantain pre-treated using 40 °B sucrose). Thus, from the point of laws of mass action, the presence of extra sugar meant an increased re-crystallization. As a result, more water is adsorbed from its immediate environment than normally the case (Labuza, 1984). This is reflected in the upward swinging of the isotherms of the moist-infused plantain samples (Fig.1).

When the temperature was increased from 50 to 60 °C, Fig. 2 shows that, at RH < 50 per cent, the equilibrium moisture contents (M_e) decreased for both blanched and most-infused plantain. This reduction in M_e is because the sorption process occurs spontaneously and, therefore, the change in free energy, ΔG, must be a negative value (Rizvi, 1995). The sorption process is accompanied by a decrease in entropy since the adsorbate becomes ordered upon adsorption and loses its degree of freedom. Thus, from the well-known thermodynamic relation, $\Delta G = \Delta H - T\,\Delta S$, the change in enthalpy of sorption, ΔH, decreases slightly with increase in temperature and, therefore, an increased temperature will cause a corresponding decrease in ΔS. As a result, the ΔG becomes less negative causing a reduction in the number of adsorbed water molecules. At RH > 50 per cent, corresponding to the capillary condensation and multi-layer adsorption stages (Labuza, 1984), the increased M_e for the most-infused plantain can be attributed to the prominence of the dissolution of extra sugar absorbed during the pre-treatment of the plantain. At this sorption stage, the process of sugar dissolution, which is an endothermic process, is facilitated by an increased temperature (Rizvi, 1995).

Fitting models

Chirife & Iglesias (1978) have reviewed most of the mathematical models currently used to describe the moisture sorption data of foods. Table 2 lists three of these models which were fitted to the moisture sorption data obtained. Fitting was by non-linear regression programs (SAS, 1985). The quality of the fittings were evaluated by calculating the mean relative percentage deviation modulus, E per cent, (Boquet, Chirife & Iglesias, 1978). In Tables 3-5, only those fits with E per cent < 10 have been reported because these values are considered very good for practical purposes (Boquet, Chirife & Iglesias, 1978). The monolayer moisture contents of the sample were estimated from the GAB model (Table 1). The Iglesias & Chirife (1978) model was particularly developed to solve the diffculty of theoretical prediction, caused by dissolving sugar, of the isotherms of fruits and other foods high in sugar.

TABLE 2
List of models fitted to the desorption data of plantain

Name of model	*Model*	*Comments*
1. Henderson (1952)	$1-a_w = \exp[AM^B]$	M = moisture content
		M_o = monolayer moisture content
2. Iglesias & Chirife (1978)	$Ln\,(M+\sqrt{M^2+M_{0.5}}) = Ba_w+A$	$M_{0.5}$ = moisture content at $a_w = 0.5$
		a_w = water activity
*3. Guggenheim-Anderson-de Boer (GAB) (1981)	$M=CKM_oa_w / [(1-Ka_w)(1-Ka_w + Ka_w)]$	A, B, C and K are constants in the various equations

* The GAB model is a combination of three models from Anderson (1946), Guggenheim (1966) and de-Boer (1953) put together by van den Berg & Bruin (1981).

The estimated parameter values obtained for the models are given in Tables 2-4. The values obtained are comparable to those for other fruits (Boquet, Chirife & Iglesias, 1978). Fig. 3 shows that the sorption data of plantain pre-treated by 40 °B sucrose fit all three models adequately.

Implications of the results for the dehydration of pre-treated plantain

The main aim of dehydrating any food is to prolong its shelf-life beyond that of its fresh material. This is achieved through a reduction in its moisture content to a level that will ensure that

TABLE 3
Estimated parameters and monolayer moisture content (M_o) of fresh and pre-treated plantain obtained from the GAB (1981)

Plantain sample	*Temperature (°C)*	*Estimated parameters*		*Monolayer moisture content*	*E per cent*
		C	*K*	M_o	
Fresh	50	10.1	0.93	7.2	4.7
	60	11.6	0.87	7.3	3.6
Pre-treated: Blanched only	50	2.95	1.21	5.4	3.7
	60	2.51	1.22	4.9	1.7
Pre-treated: 40 °B sucrose solution	50	8.84	0.81	2.5	9.1
	60	n.c	n.c	2.1	n.c
Pre-treated: 15 °B sucrose in 0.06 kg/kg NaCl	50	n.c	n.c	1.1	n.c
	60	n.c	n.c	1.9	n.c

n.c = not calculated because E per cent > 10.

TABLE 4
Estimated parameters of fresh and pre-treated plantain obtained from the Henderson (1952) model

Plantain sample	Temperature (°C)	Estimated parameters A	B	E per cent
Fresh	50	4.59	0.71	5.6
	60	2.45	0.5	7.1
Pre-trerated: Blanched only	50	0.54	0.54	4.3
	60	3.67	0.68	9.8
Pre-treated: 40 °B sucrose solution	50	3.21	0.92	7.1
	60	n.c	n.c	n.c
Pre-treated: 15 °B sucrose in 0.06 kg/kg NaCl	50	0.36	0.67	8.8
	60	0.64	0.17	8.9

n.c = not calculated because E per cent > 10.

TABLE 5
Estimated parameters of fresh and pre-treated plantain obtained from the Iglesias & Chirife (1978) model

Plantain sample	Temperature (°C)	Estimated Parameters A	B	E per cent
Fresh	50	1.37	3.67	7.3
	60	1.33	3.93	8.6
Pre-trerated: Blanched only	50	1.24	3.93	6.1
	60	1.03	4.17	7.7
Pre-treated: 40 °B sucrose solution	50	1.26	3.62	3.5
	60	1.38	3.11	5.9

NB: Results of plantain pre-treated by 15 °B sucrose in 0.06 kg/kg NaCl not calculated because the E per cent > 10.

the product does not undergo any adverse biochemical and/or microbiological changes. From Table 2, the monolayer moisture contents (M_o) obtained give the upper limits of permissible moisture contents that will help achieve this aim (Labuza, 1984). Table 2 also indicates that a much lower moisture content and, therefore, a much lower water activity is achievable in pre-treated than fresh plantain during their dehydration. This means a more stable product is assured from the pre-treated than the fresh plantain. However, from the nature of the isotherms and equilibrium moisture contents, a well-dried pre-treated plantain can be obtained if the relative humidity of the drying air used is much lower than that of the fresh plantain (Makower & Dehority, 1943).

Conclusion

This study has established that the equilibrium and the monolayer moisture contents of plantain are affected when the fruit is pre-treated before dehydration. An air-dried product from plantain

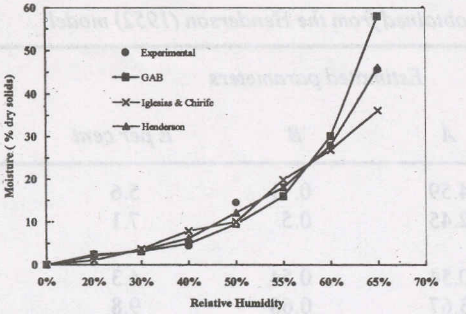

Fig. 3 Fitting the GAB, Iglesias & Chirife and Henderson models to the desorption isotherm of pre-treated plantain (moist-infused with 40 °B sucrose) at 50 °C

Fig. 3. Fitting the GAB, Iglesias & Chirife and Henderson models to the desorption isotherm at 50 °C of pre-treated plantain (moist-infused with 40 °B sucrose)

has less residual moisture and, therefore, more stable, if obtained from the pre-treated fruit than from the fresh material.

Acknowledgement

The financial support of the National Agricultural Research Project (CSIR) is gratefully acknowledged.

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Received 10 Jun 98; revised 12 Jan 99.