The dehydration and rehydration characteristics of the seeded breadfruit or breadnut seed

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Harrynanan, L. and Sankat, C. K. 2008. **The dehydration and rehydration characteristics of the seeded breadfruit or breadnut seed**. Canadian Biosystems Engineering/Le génie des biosystèms au Canada **50**: 3.37–3.45. Experiments were carried out to determine the effects of dehydration and rehydration of in-shell mature breadnut seeds. Pretreated (cooked in salted water) and untreated in-shell mature breadnut seeds were dried in a forced convective, horizontal, air-flow cabinet oven at 35°C, 50°C, 65°C and 80°C and at a relative humidity range of 15-25% at a fixed air-flow rate of 1.2 ms^{-1}. A two-term solution of the diffusion equation described the thin-layer drying behavior of the in-shell seeds reasonably well. This model improved the fit as compared with a single term exponential model. In addition, the drying of the in-shell seeds took place exclusively in the falling rate period. Water absorption during soaking of the pretreated and untreated dried in-shell seeds at 28 (ambient), 70 and 100°C showed that the pretreated seeds absorbed more water. Peleg's equation was used to model rehydration and water absorption of the untreated and pretreated in-shell seeds that were previously dried at 50 and 65°C. The two constants, K_1 and K_2 from Peleg's equation, were obtained. The reciprocal of K_1 equates to the hydration rate, and the pretreated dried seed material showed a higher absorption rate as compared with the untreated. The temperature dependence of the drying rate constants and Peleg's constants from the dehydration and rehydration models, respectively, was further demonstrated by an Arrhenius-type relationship. **Keywords:** Breadnut, in-shell seeds, dehydration, rehydration, diffusion equation, Peleg's equation.

Des expériences ont été réalisées dans le but de déterminer les effets de la déshydratation et de la réhydratation de fruits de l'arbre à pain matures dans leurs écales. Des fruits de l'arbre à pain matures dans leurs écales traités (cuits dans de l'eau salée) et non traités ont été séchés dans un four à convection à débit d'air forcé horizontal constant de 1,2 m/s, à des températures de 35°C, 50°C, 65°C et 80°C et à une humidité relative variant de 15% à 25%. Une solution à deux paramètres de l'équation de diffusion décrivait de manière adéquate le comportement de séchage en couche mince de ces fruits dans leur écale. Ce modèle décrivait le comportement de façon plus exacte comparativement à un modèle exponentiel à un seul paramètre. De plus, le séchage des fruits dans leur écale a été complété uniquement durant la phase de ralentissement de la vitesse de séchage. L'absorption d'eau durant le trempage des fruits dans leur écale traités et non traités à 28°C (température ambiante), 70°C et 100°C a démontré que les fruits non traités ont absorbé une plus grande quantité d'eau. L'équation de Peleg a été utilisée pour prédire la réhydratation et l'absorption d'eau des fruits dans leur écale non traités et traités qui avaient été séchés au préalable à 50°C et 65°C. Les deux constantes, K_1 et K_2, de l'équation de Peleg ont ainsi été obtenus. La réciproque de K_1 égale le taux d'hydratation et les fruits prétraités séchés ont montré un taux d'absorption plus élevé comparativement aux fruits non traités. La dépendance en température des constantes de taux de séchage et les constantes de Peleg des modèles de déshydratation et de réhydratation, respectivement, a été confirmée par une relation de type Arrhenius. **Mots clés:** fruit de l'arbre à pain, fruits dans leur écale, déshydratation, réhydratation, équation de diffusion, équation de Peleg.

INTRODUCTION

In the Caribbean countries, the breadfruit (*Artocarpus altilis*), a traditional carbohydrate comprises both the seeded and seedless clones. The seeded form, which is quite distinct from the breadfruit, is commonly known as breadnut in the English-speaking world. In the Caribbean, and especially in Trinidad and Tobago and Guyana, both the seeds and pulp of the seeded breadfruit are consumed in the green, partially immature stage as a vegetable. In the ripened stage, the seeds are roasted, steamed or boiled and consumed as a snack. They are chestnut-like in size, composition and flavor (Winton and Winton 1935; Bennett and Nozzolillo 1987). It is reported that the seeds contain many minerals and a high source of protein 5.25–13.3 and 13.8–19.9 g per 100 g of edible portion in the fresh and dried states, respectively (Morton 1987).

The fruit's high perishability is a major problem; however, preservation through reduced temperature storage and drying may prolong the usefulness of the fruit or parts of the fruit in a utilizable form for future use. Each fruit contains from 50 to 100 seeds and these comprise less than 50% of the fruit. Each seed contains an outer fairly rigid membrane (the aril) and an inner fragile paper-like membrane, which envelopes the fleshy white edible portion of the seed (De Bravo et al. 1983). A limited shelf-life of 2–3 days is expected of these seeds in its fresh state due to rapid deterioration when the fruit falls to the ground. Breadfruit is a climacteric fruit and the peak carbon dioxide production coincides with softening and peak ethylene production (Worrell and Carrington 1994). However, breadnut seeds are traditionally gathered from the softened fruits after they fall to the ground. Predicting the drying and rehydration rate of these seeds are necessary to understand the biological behavior and the mechanism governing moisture transfer and for the design of drying and quality control systems in the development of value-added products. Although some information on the drying of agricultural crops with a protective shell has been reported, much less information is available with regards to the soaking or rehydration of such materials.

In this study, the drying behavior of materials with protective shells such as nutmeg, almond and macadamia nuts was used as a basis for studying the drying behavior of the breadnut. The behavior of soybean, peanut, brown rice and corn was used as a basis for rehydration. Agricultural products such as grains and nuts with a hull or shell intact should not be treated as a homogeneous material during drying as the hygroscopic nature of the shell or the hull and the kernel is different in most cases (Farinati and Suarez 1984; Palipane and Driscoll 1994). As a result of such previously reported work, two drying models were evaluated for in-shell breadnut seed drying and these are based on Crank's (1975) solution of the moisture diffusion equation.

A simple one-term model, Eq. 1, analogous to Newton's law of cooling and a two-term solution of the diffusion equation, Eq. 2, were used to model the drying in-shell breadnut seed data. The two-term model might better take into consideration the different drying characteristics of the seed components as has been demonstrated by many other researchers working on similar materials (Sharma et al. 1982; Noomhorm and Verma 1986; Palipane and Driscoll 1994).

$$MR = \frac{M - M_e}{M_o - M_e} = A\exp(-kt) \qquad (1)$$

$$MR = \frac{M - M_e}{M_o - M_e} = A_1\exp(-k_1 t) + A_2\exp(-k_2 t) \qquad (2)$$

In the above equations, MR = moisture ratio; k, k_1, k_2 = drying constant (h^{-1}); M = average moisture content at time t (% dry basis); M_e = equilibrium moisture content (% dry basis); M_o = initial moisture content (% dry basis); t = drying time (h); and A, A_1, A_2 = empirical constants.

The mechanism governing water absorption can also be described as diffusion driven (Crank 1975). A model developed by Peleg (1988), was reported to adequately describe the sorption behavior of commodities such as soybean and dehulled and undehulled peanuts (Sopade and Obekpa 1990). As a result, Peleg's model (Eq. 3) was used to model the rehydration data for dried in-shell breadnut seeds.

$$M_t = M_o + \frac{t}{(K_1 + K_2 t)} \qquad (3)$$

In the above equations, M_o = initial moisture content (% dry basis); M_t = moisture content (% dry basis) at time t; t = soaking time (h); K_1 = constant (h% weight); and K_2 = constant (reciprocal of percent on dry weight basis).

Mathematical models may be used to describe the drying and rehydration processes and show the importance of the various factors governing moisture transfer. Furthermore, the models can provide a means for the optimization of the various factors influencing the dehydration and rehydration behavior of the in-shell seeds and assist in the effective design of dryers and ultimately the development of good quality value-added products. Therefore, the objectives of this study were to investigate the drying and rehydration characteristics of the breadnut in-shell seeds under a range of temperatures and treatments, and to evaluate suitable models that describe the dehydration and rehydration behavior.

MATERIALS and METHODS

Sample preparation

Freshly harvested seeds from the ripe (very mature) breadnut fruit were either bought from the market or obtained from ripe, fallen fruits. The initial moisture content of seeds ranged from 100 to 150% dry basis (50–60% wet basis). Collected seeds were washed and one-half was pretreated by boiling in salted water for 35–40 minutes and the other half was left untreated (control). The experimental layout for the drying studies consisted of 2 replicates and 2 treatments at 4 drying air temperatures (35, 50, 65 and 80°C) and at a fixed air-flow rate of 1.2 m/s.

In-shell seeds previously dried at 50 and 65°C were subjected to rehydration studies. A total of 24 rehydration runs were conducted. The experimental layout consisted of 2 replicates and 2 treatments (pretreated and untreated) of seeds previously dried either at 50 or 65°C followed by rehydration at 3 temperatures (100, 70 and 28°C).

Drying system

The experimental drying system was achieved using a forced convection oven (Blue M Stabil-Therm Mechanical Convective Horizontal Air-Flow, Blue M Electric Company, Blue Island, IL), which produced air at a rate of 1.2 ms^{-1}. Air-flow rate was measured using a Turbo Meter Windspeed Indicator (Davis Instruments, Seattle, WA). The relative humidity of the drying air varied from 25% at 35°C to approximately 15% at 80°C. The oven was run for at least 2 h to obtain steady-state conditions prior to placing the samples for drying. The seeds were spread out in a single layer, over flat-bottomed, wire mesh drying trays. The empty trays and the trays containing the samples were weighed on an Ohaus Electronic Balance (Ohaus Scale, Cambridge, England) and immediately placed in the drying chamber. To determine weight loss and the development of the drying curves, the trays containing the material being dried were removed from the oven at predetermined times, weighed, and immediately returned to the oven. The weights were recorded initially at 0.25 h intervals, followed by 0.5 h and hourly intervals. Thereafter, depending on the reduced drying temperature used, time intervals were increased as the drying rate decreased. The drying test was terminated when the weight of the sample remained constant over a 24 h period.

Rehydrating system

For the rehydration studies approximately 20 seeds from each of the 2 dehydration temperatures and treatments were placed in 700-ml beakers containing excess distilled water at boiling point (100°C). Before placing the seed material for rehydration, the temperature of the water in the beakers was equilibrated to boiling point and maintained at that temperature in 2 thermostatically controlled water baths [Polytherm Type PY5 (L), Science/Electronic Inc., Dayton, OH]. Four seeds were removed at predetermined times after 1.0, 2.0, 3.5, 6.0 and 9.0 h of immersion. Seeds were manually separated into kernels and shells for final moisture content determination. The experiment was repeated at rehydration temperatures of 70 and 28°C (ambient temperature). Rehydration at ambient temperature was continued for up to 28 h.

Determination of moisture content

Moisture content (dry basis) was determined by placing samples for 24 h in a natural convection oven (Blue M Stabil-Therm Gravity; Blue M Electric Company, Blue Island, IL) at 80°C or until constant weight was achieved. The initial and final moisture contents prior to and after each drying run were determined. Moisture contents of the fractions (shells and kernels) from the rehydrated samples were determined separately.

Analysis of data

A non-linear least-squares estimation program from Genstat 5 Statistical Software (Lawes Agricultural Trust 1996) was used to fit the experimental drying data to two models (Eqs. 1 and 2). Analysis of variance tables were also produced from the statistical analysis. The statistical program Minitab, Release 8.21 (Minitab Ltd., Coventry, England) was used to analyze the rehydration data fitted to the linear form of Peleg's equation. The goodness of fit between the experimental and predicted data was further determined by the root mean square deviation (RMSD) as defined by Sopade et al. (1991) and was calculated from Eq. 4.

$$RMSD = \frac{1}{n}\sqrt{\sum_{i=1}^{n}(M_{ti} - M_{pi})^2} \quad (4)$$

In the above equation, n is the experimental data; M_{ti} the experimental moisture content (dry basis); and M_{pi} the predicted moisture content (dry basis).

RESULTS and DISCUSSIONS

Drying behavior of in-shell seeds

The initial moisture content averaged 121% dry basis (54.4% wet basis) and 145% dry basis (59% wet basis) for pretreated and untreated in-shell seeds, respectively. Typical drying curves of moisture content versus elapsed drying time for both pretreated and untreated in-shell breadnut seeds were obtained. Figs. 1 and 2 show typical drying curves for pretreated and untreated in-shell seeds, respectively, which indicate that the rate of moisture loss decreases as the elapsed time increases until finally the seeds approach the equilibrium moisture contents.

The drying rate curves show the absence of a constant-rate period of drying for both pretreated and untreated in-shell seeds with all the drying occurring in the falling rate period (Figs. 3 and 4). As the surfaces of the in-shell seeds were heated up, all the surface moisture was quickly removed as evident from the initial high drying rates. The water and/or vapor from within the kernel then moved to the inner surface of the in-shell seeds before diffusing through the shell and into the air.

Modeling water desorption

Two thin-layer drying models expressed by Eqs. 1 and 2 were fitted to the experimental drying data by non-linear regression. The drying parameters k, k_1, and k_2 and the constants A, A_1 and A_2 were determined for each drying run. The coefficients of determination, R^2, which determine goodness of fit and the drying constant, k for the one-term model are shown in Table 1. As expected, the average drying constant, k, from the one-term model for each temperature and treatment decreased as the temperature decreased. The variances within each treatment were very small and consistent (p value <0.001) for all k values when the one-term equation was used indicating that the drying process had good repeatability from one run to another.

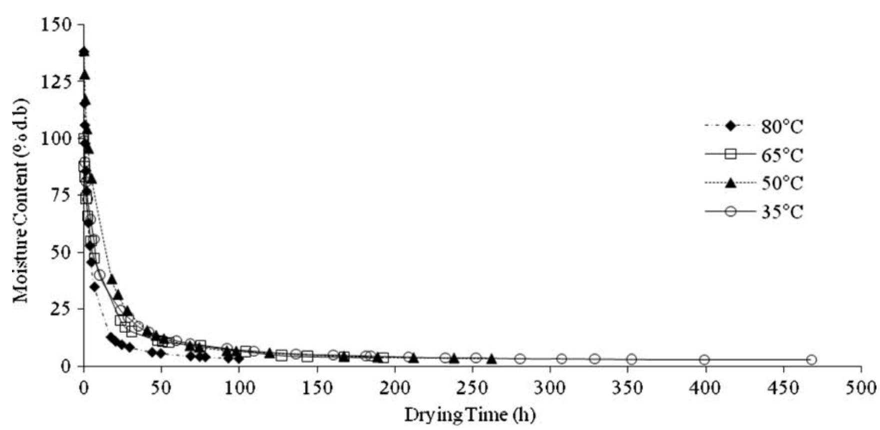

Fig. 1. The effect of temperature on moisture changes for pretreated in-shell breadnut seeds.

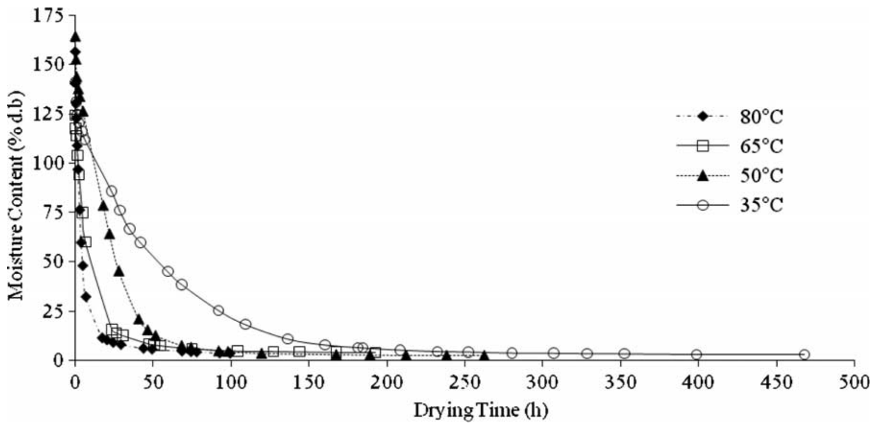

Fig. 2. The effect of temperature on moisture changes for untreated in-shell breadnut seeds.

The best predictions of the experimental data covering all the drying runs were obtained from the two-term model. All corresponding R^2 values were consistently higher than those for the one-term model for both pretreated and untreated in-shell seeds (Table 2). The level of significance for the drying constant, k_1 for both pretreated and untreated in-shell seeds were high (p value <0.001) whereas those for k_2 varied from a p value <0.01 to being non-significant. As for the one-term model, average k values for the two-term model decreased as the temperature decreased.

Plots of the experimental data versus the best fit of the assumed equations showed that the one-term, simple exponential equation did not adequately represent the experimental results as compared with the two-term model. These results are illustrated in Figs. 5 and 6 for pretreated and untreated in-shell seeds at the drying-air temperatures of 80 and 65°C, respectively. Similar results were obtained for the other temperatures of 50 and 35°C. These results further demonstrated the adequacy of the two-term model. Nellist (1976) in the study of ryegrass seeds concluded that the curve fitting procedure varied k_1 and k_2 in the two-term exponential model independently of each other and the equation is also better able to follow fluctuations in the drying curve caused by any experimental errors. Similar arguments can be put forward in the use of the two-term model for this study.

The drying constants from the two models were related to the absolute temperature of the drying air by the Arrhenius-type relationship given by Eq. 5.

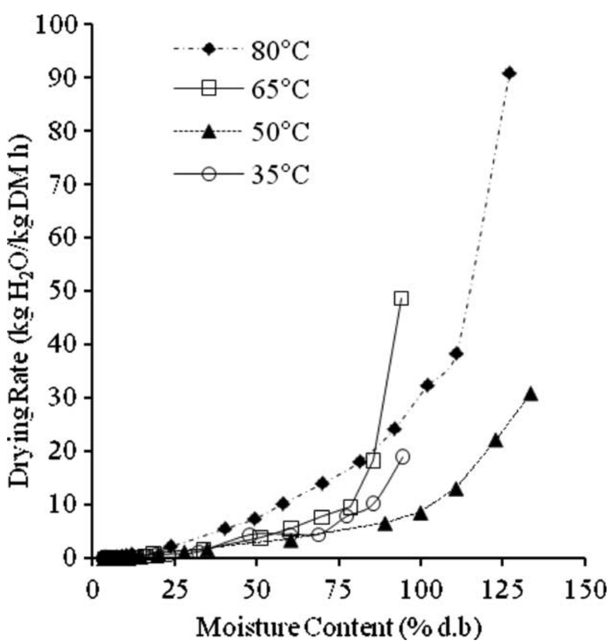

Fig. 3. Drying rate as a function of moisture content at four different drying temperatures for pretreated in-shell breadnut seeds.

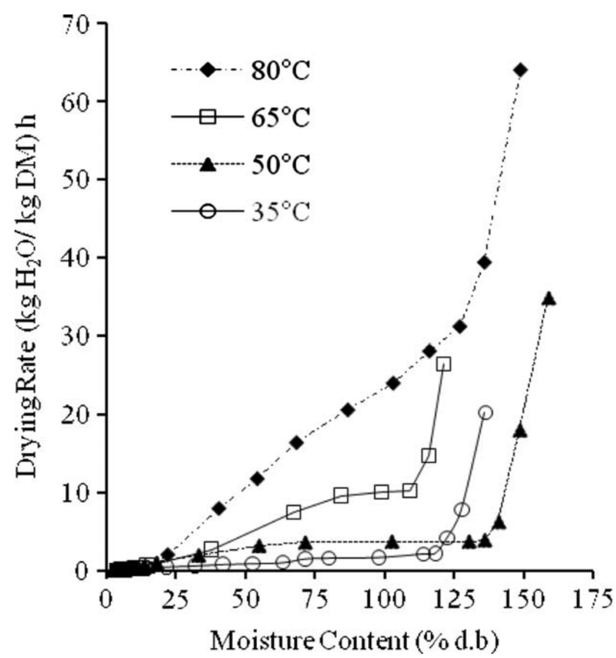

Fig. 4. Drying rate as a function of moisture content at four different drying temperatures for untreated in-shell seeds.

Table 1. One-term model fitted by non-linear regression to the experimental data.

$MR = Ae^{-kt}$						
	Pretreated in-shell seeds			Untreated in-shell seeds		
Drying temp. (°C)	A	k (h^{-1})	R^2	A	k (h^{-1})	R^2
80	0.8992	0.2320	0.9860	0.9669	0.2456	0.9975
65	0.8816	0.1012	0.9785	0.9732	0.1169	0.9980
50	0.8886	0.0804	0.9810	0.9645	0.0488	0.9965
35	0.9159	0.0534	0.9815	0.9322	0.0178	0.9960

R^2 denotes coefficient of determination.

$$k = a\exp(-E/RT_a) \quad (5)$$

In the above equation, k is the drying rate constant, h^{-1}; E is activation energy, kJ mol^{-1}; a is a constant; R is the universal gas constant, 8.318 kJ mol^{-1} K^{-1}; and T_a is the absolute drying air temperature, °K. Plots of ln k, k_1 *or* k_2 against $1/T$ for pretreated and untreated in-shell seeds demonstrated the dependence of the drying constants to temperature. A better correlation coefficient ($r = 0.9653$) was obtained for the first drying constant k_1 of the two-term model for pretreated in-shell seeds as compared with k ($r = 0.9257$) from the one-term model (Table 3). The Arrhenius relationship also held for untreated in-shell seeds, with $r = 0.9851$ and 0.9965 for k_1 and k of the two-term and one-term models, respectively. The drying constant, k_2, represents the more rapidly decaying term of the double exponential of Eq. 2. Work completed in the measurement of drying rates in ryegrass seeds by Nellist and O'Callaghan (1971) showed that the k_2 values of the double exponential were not related to either drying air temperature or initial moisture content.

The activation energy for drying of pretreated in-shell seeds was also determined from the slopes of the plot (ln k vs. $1/T$) and corresponds to 28 kJ mol^{-1} and 37 kJ mol^{-1}, respectively for the one-term and two-term models. Higher activation energies of 52 and 53 kJ mol^{-1} for the one-term and two-term models, respectively, were also obtained for untreated in-shell seeds. The magnitude of the activation energy of the untreated material was considerably higher than that of the pretreated material indicating that there were greater intermolecular interactions in the case of the untreated material. Precooking may affect the diffusivity of water by causing changes in physical properties of tissue and gelatinization of starch through the heating process thereby lowering the initial energy requirement.

Rehydration of in-shell seeds

The in-shell seeds to be rehydrated were separated into their fractions of shells and seeds so as to investigate the rehydration behavior of the kernels only at the rehydrating temperatures of 100, 70 and 28°C. This separation was necessary because, on rehydration of the intact seeds, the kernels did not fully return to their original shape and size. The porous nature of the shell and the trapped water in the void caused the shells to reach equilibrium levels much faster than the kernels. Fig. 7 illustrates the faster uptake of water by the shells as compared with the kernels when in-shell seeds previously dried at 65°C were rehydrated at 100°C.

An initial high rate of water absorption followed by slower absorption in the latter stages was observed at all rehydration temperatures for kernels. Generally, there was rapid absorption in the first 2 h for moisture uptake at 100 and 70°C (Fig. 8). The water uptake by the kernels from in-shells seeds soaked in water at ambient (28°C) temperature required a considerably longer time ($\approx$28 h) as compared with the higher temperatures. Kernels absorbed more water at higher rehydration temperatures, and this finding is in agreement with other studies (Sopade and Obekpa 1990; Sopade et al. 1992). As explained by Sopade et al. (1992), the higher the temperature, the greater the water absorption due to increased water diffusion rate.

The different dehydration temperatures used in the prior drying process did not significantly influence the moisture uptake as the final moisture contents only

Table 2. Two-term model fitted by non-linear regression to the experimental data for pretreated and untreated in-shell seeds.

$MR = A_1e^{-k_1t} + A_2e^{-k_2t}$						
	Pretreated in-shell seeds			Untreated in-shell seeds		
Drying temp. (°C)	k_1 (h^{-1})	k_2 (h^{-1})	R^2	k_1 (h^{-1})	k_2 (h^{-1})	R^2
80	0.1420	1.5560	0.9990	0.1369	2.8189	0.9995
65	0.0585	0.4390	0.9979	0.0749	3.4146	0.9994
50	0.0455	0.4223	0.9989	0.0552	2.8039	0.9987
35	0.0192	0.1533	0.9992	0.0170	1.7175	0.9993

R^2 denotes coefficient of determination.

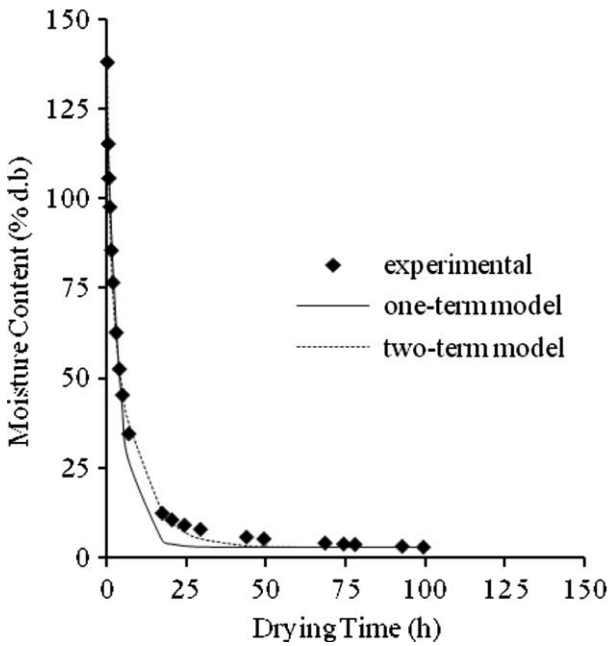

Fig. 5. Experimental and predicted drying curves for the one and two-term drying models at 80°C for pretreated in-shell seeds.

differed by small amounts. However, pretreated seed material generally showed higher moisture uptake than the untreated (control) material. The literature has reported that blanching causes an increase in water uptake during hydration (Haas et al. 1974). Cooking in salted

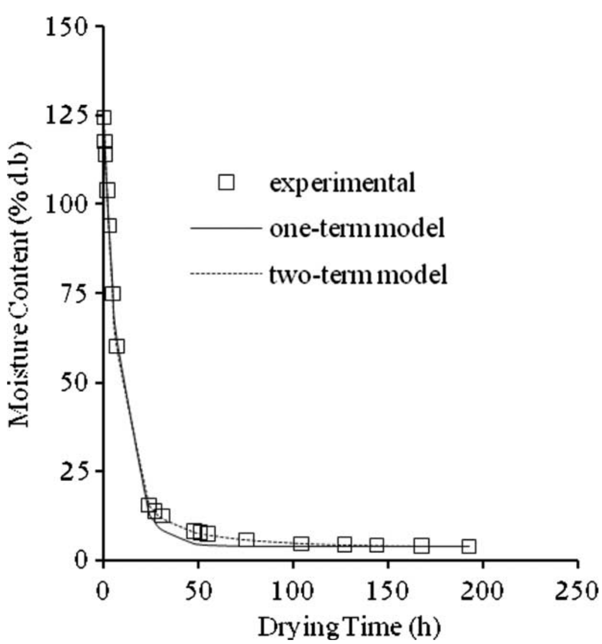

Fig. 6. Experimental and predicted drying curves for the one and two-term drying models at 65°C for untreated in-shell seeds.

Table 3. Correlation coefficient, *r*, produced when the drying rate constants were related to temperature by the Arrhenius-type equation.

	Correlation coefficient, *r*	
	in-shell seeds	
Source of *k*	Pretreated	Untreated
one-term, k	0.9257	0.9965
two-term, k_1	0.9653	0.9851
k_2	0.9447	0.0539

water prior to dehydration greatly improved the rehydration properties of the breadnut seeds.

Modeling water absorption

Fitting Peleg's equation (Peleg 1988) to the experimental data by linear regression analysis resulted in correlation coefficients, *r* of between 0.984 to 0.993 and 0.904 to 0.995 for kernels from pretreated and untreated in-shell breadnut seeds, respectively (Tables 4 and 5). These results indicate that Peleg's equation better described the sorption behavior for kernels from pretreated in-shell breadnut seeds compared with those for untreated in-shell seeds. The errors between experimental and predicted moisture content as measured by the root mean square deviation (RMSD) ranged from 7.7×10^{-4} to 2.07×10^{-2} for kernels from pretreated and untreated in-shell seeds, respectively. These small errors coupled with high *r* values showed close agreement between experimental and predicted results.

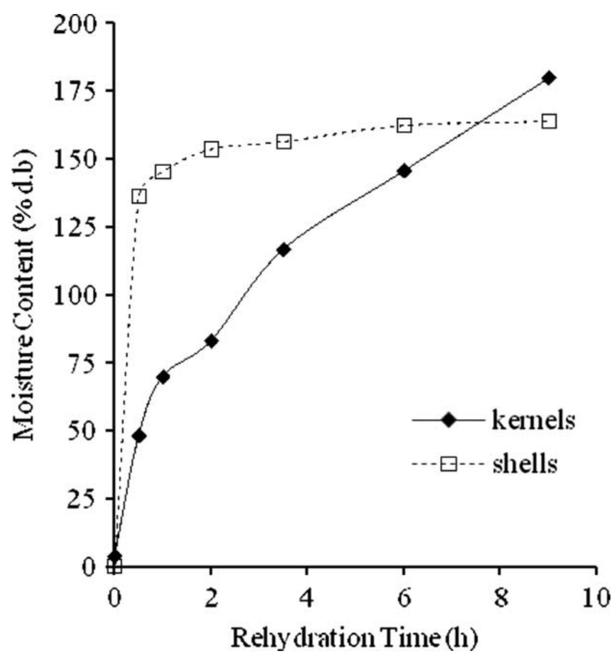

Fig. 7. Hydration curves showing faster water uptake by the shell as compared with the kernels during hydration at 100 for 65°C dried in-shell breadnut seeds.

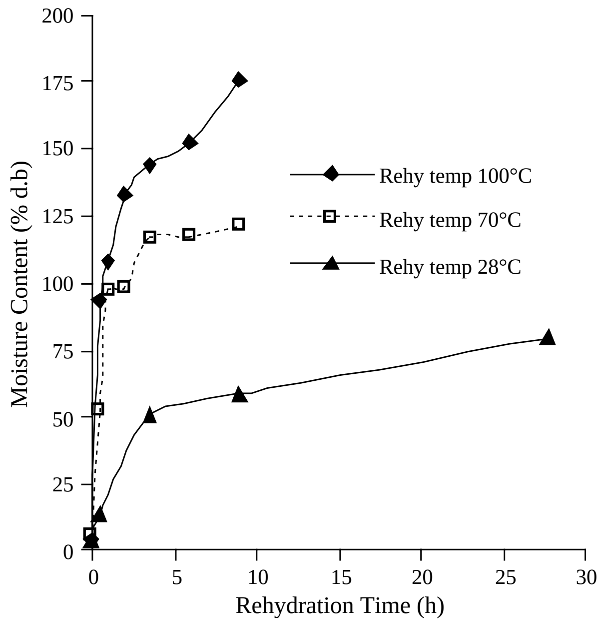

Fig. 8. Water absorption of pretreated 65°C dried kernels during rehydration at 100, 70 and 28°C.

The rehydration constant, K_1 (h per% d.b.) for both pretreated and untreated kernels, generally increased with a decrease in the rehydration temperature, illustrating the temperature-dependency factor. Similarly, K_2 appeared to be temperature-dependent. The K_2 values between the pretreated and untreated in-shell seeds for the corresponding temperatures, in the main were relatively constant and did not indicate any great difference in water absorption between the different pre-rehydration (drying) conditions.

Peleg (1988) noted that the unit of K_1 is hour per percent dry basis (h per% d.b.) and the unit of the reciprocal represents% d.b per hour, which also equates to the hydration rate. Sopade et al. (1992) further indicated that the sensitivity of the reciprocal of K_1 to temperature gives an indication of the temperature effect on the rate of water absorbed. These results show that the hydration rate increased as the rehydration temperature increased for the pre-rehydration conditions (Table 6).

The lowest hydration rates were obtained for seed material rehydrated at ambient temperature (28°C) and this coincided with the highest K_2 values. The results therefore suggest that the lower the K_2, for both pretreated and untreated seed material, the greater the amount of water absorbed, and the results are in agreement with those of Sopade and Obekpa (1990), Sopade et al. (1992), and Sopade et al. (1994).

Table 4. Values of the constants in Peleg's equation for rehydrated kernels from pretreated breadnut seeds and for a range of rehydration temperatures.

Parameter	Rehydation temp.	Pretreated 65°C	Pretreated 50°C
K_1	100°C	3.90×10^{-3}	4.60×10^{-3}
	70°C	4.70×10^{-3}	5.40×10^{-3}
	28°C	3.35×10^{-2}	2.52×10^{-2}
K_2	100°C	6.15×10^{-3}	5.75×10^{-3}
	70°C	7.70×10^{-3}	6.80×10^{-3}
	28°C	1.37×10^{-2}	1.30×10^{-2}
RMSD	100°C	7.70×10^{-4}	9.20×10^{-4}
	70°C	1.02×10^{-3}	1.08×10^{-3}
	28°C	1.01×10^{-2}	3.75×10^{-3}
r*	100°C	0.993	0.988
	70°C	0.991	0.989
	28°C	0.984	0.984

*Correlation coefficient.

Table 5. Values of the constants in Peleg's equation for rehydrated kernels from untreated breadnut seeds and for a range of rehydration temperatures.

Parameter	Rehydation temp.	Untreated 65°C	Untreated 50°C
K_1	100°C	8.45×10^{-3}	2.60×10^{-3}
	70°C	1.02×10^{-2}	8.90×10^{-3}
	28°C	6.54×10^{-2}	6.03×10^{-2}
K_2	100°C	5.75×10^{-3}	6.00×10^{-3}
	70°C	1.02×10^{-2}	8.70×10^{-3}
	28°C	1.18×10^{-2}	$1.10 \text{ x } 10^{-2}$
RMSD	100°C	1.69×10^{-3}	6.80×10^{-4}
	70°C	2.25×10^{-3}	1.82×10^{-3}
	28°C	2.07×10^{-2}	1.97×10^{-2}
r*	100°C	0.995	0.990
	70°C	0.976	0.981
	28°C	0.904	0.908

*Correlation coefficient.

Table 6. Reciprocal of K_1 (hydration rates) for pretreated and untreated kernels.

Pre-rehydration conditions	Rehydration temperature (°C) 100	70	28
	Peleg's constant, K_1 (h per% d.b)		
Pretreated 65°C	0.0039	0.0047	0.0335
Pretreated 50°C	0.0046	0.0054	0.0252
Untreated 65°C	0.0085	0.0102	0.0654
Untreated 50°C	0.0026	0.0089	0.0603
	Reciprocal of K_1 (% d.b h^{-1})		
Pretreated 65°C	256.40	212.80	29.80
Pretreated 50°C	217.40	185.20	39.70
Untreated 65°C	118.30	98.00	13.30
Untreated 50°C	384.60	112.40	16.60

The relationship between the reciprocal of K_1 and temperature was studied using an Arrhenius-type equation similar to (Eq. 5). The reciprocal of K_1 is related to the reciprocal of the absolute temperature as measured by the correlation coefficient, r from plots of $\ln(1/K_1)$ versus $1/T$. Correlation coefficients ranged from 0.965 and 1.000 for kernels from pretreated and untreated in-shell seeds that were dried at 65 and 50°C. These high r values showed that there were reasonably good dependence between $1/K_1$ and $1/T$. High r values suggest a linear decrease in water absorption as the rehydration temperature decreases.

Effects of drying and rehydration on product quality

This study has shown that the much underutilized breadnut seeds can be dried and rehydrated successfully. However, the dehydration and rehydration temperatures are the major factors affecting final quality. Preliminary observations indicate that at the higher drying temperatures, darkening and some shattering of the seeds occurred and were more pronounced with untreated seeds (no data shown). More acceptable overall visual quality was obtained at the lower drying temperatures (50 and 65°C) of the pretreated seeds and hence, a more desirable rehydrated product. Prolonged dehydration and rehydration times decrease the nutritional and sensorial value of the final product and may lead to the development of off-odors and flavors including some safety concerns in the latter process. However, preliminary results indicate that pretreated in-shell seeds dehydrated at 65°C and subsequently rehydrated in boiling water may offer a ready-to-eat product of comparable flavor, odor and nutritional content to the fresh product.

CONCLUSIONS

Thin-layer drying investigations indicated that all of the drying of breadnut seeds occurred in the falling rate period which implied that the rate of drying was internally controlled by the mechanism of diffusion. This drying behavior of the in-shell seeds was adequately described by a two-term exponential model based on the general form of the solution of the diffusion equation. This model improved the fit to the experimental data as compared with a single-term exponential model, which assumed the in-shell seeds to be of a uniform material. For rehydration studies Peleg's equation adequately described the rehydration characteristics of dried, pretreated and untreated in-shell breadnut seeds. Consequently, from an examination of the rehydration behavior of in-shell seeds, a linear relationship was used to describe the relationship between Peleg's K_1 constant and temperature. Peleg's K_1 could be likened to a diffusion coefficient; as the rehydration temperature increased, the constant K_1 decreased, and was therefore influenced by the rehydration temperature. Additionally, the rehydration rate $1/K_2$ (% d.b h^{-1}) increased as the rehydration temperature increased. The temperature dependence of the drying and rehydration rate constants was also demonstrated by an Arrhenius-type relationship. Preliminary results indicate that through prior dehydration, and then rehydration, a previously underutilized, seasonal vegetable may have much wider shelf-life and marketability. However, prolonged dehydration and rehydration may decrease the nutritional and sensorial value of the final product, which will have to be investigated further. Preliminary results suggest that pretreated in-shell seeds dehydrated at 65°C offer a ready-to-eat product when rehydrated.

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