

Original article

Effect of osmotic dehydration on the drying kinetics and quality of cashew apple

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Summary The effect of different osmotic pretreatments on cashew apple drying kinetics and product quality were investigated. The osmotic pretreatment was carried out in an incubator at constant temperature and agitation. The drying process was conducted in a fixed bed dryer at different temperatures and constant air velocity. Experimental data were fitted successfully using the Page and the two-term exponential models for dried fresh and pretreated fruit, respectively. It was found that drying rates of osmotic fruits decreased owing to the presence of infused solutes. Evaluation of the final product was performed by means of ascorbic acid content, water activity and sensorial test. The osmotic pretreated samples showed the highest vitamin C losses and the lowest water activity. The samples pretreated in sucrose solution had the highest acceptance.

Keywords Cashews, drying, kinetics, osmotic dehydration, quality.

Introduction

The seasonal nature of the production of the perishable cashew apple, the poor storeability and the lack of information on an appropriate processing technology are the reasons hindering the full utilisation of the fruit (Bidaisee & Badrie, 2001).

Air drying is an ancient process used to preserve foods in which the solid to be dried is exposed to a continuously flowing hot stream of air where moisture evaporates. Although air drying offers dehydrated products that can have an extended life of a year, the quality of a conventionally dried product is usually drastically reduced from that of the original foodstuff (Ratti, 2001).

Several predrying treatments are commonly used in order to minimise adverse changes occurring during drying. Osmotic dehydration is a viable process for partial removal of water from cellular materials, such as fruits and vegetables, without a phase change that reduces the physical, chemical and biological changes during drying at higher temperatures (Kowalska & Lenart, 2001). It is based on placing foods in a

hypertonic solution. As this solution has a higher osmotic pressure, and hence, lower water activity, a driving force for water removal arises between solution and food, while the natural cell acts as a 'semi-permeable' membrane. As this membrane is only partially selective, there is always some leakage of solute from the solution into the food and from the fruit into the solution (Lerici *et al.*, 1985). However, the effectiveness of the osmotic behaviour is highly dependent on the osmotic agents utilised (McMinn & Magee, 1999). Various osmotic agents, such as sucrose, glucose, fructose, corn syrup and sodium chloride, have been used for osmotic dehydration. Generally, sugar solutions are used for fruits (Vijayanand *et al.*, 1995).

Many researchers have investigated the influence of osmotic dehydration prior to conventional drying on the moisture transport characteristics (Islam & Flink, 1982; Mazza, 1983; Sankat *et al.*, 1996; Nieto *et al.*, 1998). However, in recent years, there has been an increased interest in the investigation of the physical characteristics of fruits after osmotic pretreatment and drying (Mandala *et al.*, 2005).

The objective of this work was to study osmotic dehydration in combination with drying of cashew apple and to evaluate the influence of pretreatment in relation

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to the solution type on the drying kinetics, physico-chemical characteristics and sensorial properties of the dried cashew apple.

Material and methods

Raw material

Fresh cashew apples (*Anacardium occidentale* L.) were obtained from a local market (Campinas, Brazil). The fruits were sorted visually for size and maturity level (soluble solids content from 10 to 12°Brix). The nuts were separated manually and the cashew apple was cut into 0.5-cm thick slices using a cutter designed for this purpose. The average slice diameter was 5 cm.

Osmotic pretreatment

The osmotic dehydration was based in a previous work (Azoubel & Murr, 2003), in which two different 52% (w/w) solutions were used: one containing sucrose and the other corn syrup solids (MOR-REX® 1940; Corn Products, Brazil). The slices of cashew apple, previously weighed and identified, were placed in 600 mL beakers containing the osmotic solutions. A fruit/solution ratio of 1:10 was used. The samples were placed in an incubator (Tecnal, TE 421; Tecnal, Piracicaba, SP, Brazil), maintained at 34 °C and agitation at 80 r.p.m. After 165 min of experiment, samples were taken out from the osmotic medium, lightly rinsed to remove any excess of sugar solution, drained and then placed on a preweighed drying tray in order to proceed to the drying process.

Drying

Drying experiments were carried out in a continuous flow fixed bed dryer at constant air velocity of 2.1 m s⁻¹ and at three air temperatures (50, 60 and 70 °C). The dryer system consisted of vertical air flow through trays and was arranged as a closed circuit. To maintain constant air condition, only one tray was used with a single layer of sample on it (approximately 60 g). For the air heating, three electric resistances were used (two of 1600 W and one of 800 W), which could work independently, controlled by a digital thermostat. A thermal-hygrometer (TESTO, model 635; Testo, Lenzkirch, Germany) was used to measure the dry bulb temperature and the drying air humidity. The air velocity was monitored by an anemometer (AIRFLOW, model LCS 6000; TSI, Buckinghamshire, UK).

Samples had average initial moisture content (wet basis) of 85.7% for fresh, 69.7% for sucrose pretreated and 79.7% for corn syrup pretreated, which was gravimetrically measured using a vacuum oven at 70 °C for 24 h. Sample moisture content during the air-drying process was gravimetrically determined from the sample

initial moisture content (before air-drying process). Sample weight was measured using a semi-analytical balance. Weighing intervals of 15 min were used during the first hour of processing, 30 min for the next 2 h and then 1 h until the dynamic equilibrium between the sample moisture content and drying air humidity was reached, when the sample weight became constant.

The drying data were fitted with six semi-theoretical thin-layer drying models (Table 1), where a , b , c , k , k_0 , k_1 and n are the empirical constants in drying models; t is the drying time, s; MR is the moisture ratio, defined as:

$$\frac{\bar{X} - X_e}{X_0 - X_e} \quad (1)$$

where \bar{X} is the average moisture content at time t , kg H₂O per kg dry matter; X_e is the equilibrium moisture content, kg H₂O per kg dry matter; X_0 is the initial moisture content, kg H₂O per kg dry matter.

The modelling was characterised by the mean relative deviation module E (eqn 2) and the determination coefficient R^2 .

$$E(\%) = \frac{1}{N} \sum_{i=1}^N \left| \frac{V_e - V_p}{V_e} \right| \times 100 \quad (2)$$

where N is the number of experimental data, V_e is the experimental value and V_p is the calculated value (Lomauro *et al.*, 1985).

Determination of water activity

The water activity (a_w) of fresh and dried cashew apple was evaluated at 25 °C using a water activity meter (Decagon, model 3TE; Decagon, Pullman, WA, USA). Determinations were made on triplicate and the results were reported as an average (error less than 0.5%).

Determination of ascorbic acid (AA) content

The AA content was determined by the method described by Ranganna (1977), which is based on the

Table 1 Thin-layer models used for mathematical determination of drying of cashew apple

Model	Equation	Reference
Single exponential	MR = exp(-kt)	Abe & Afzal (1997)
Page	MR = exp(-kt ⁿ)	Page (1949)
Henderson and Pabis	MR = a exp(-kt)	Henderson & Pabis (1961)
Logarithmic	MR = a exp(-kt) + c	Yaldiz <i>et al.</i> (2001)
Two-term exponential	MR = a exp(-k ₀ t) + b exp(-k ₁ t)	Ozdemir & Devres (1999)
Wang and Singh	MR = 1 + at + bt ²	Wang & Singh (1978)

reduction of 2,6-dichlorophenol indophenol by AA. Determinations were made on triplicate and the results were reported as an average (error less than 2%).

Sensorial analysis

Cashew apple with and without osmotic pretreatment, dried at 60 °C, was evaluated by 30 non-trained panelists for appearance, colour, taste and aroma on a nine-point hedonic scale (1 = 'disliked extremely'; 9 = 'liked extremely'). Samples were randomly coded with three-digit numbers and their order of presentation was completely randomised for each panelist. Partitioned booths with fluorescent lighting were used for evaluation and these were located in Sensory Evaluation Laboratory of the Faculty of Food Engineering, State University of Campinas (Campinas, Brazil).

A two-way analysis of variance (ANOVA) was used to test the effects of processing pretreatments on the sensory attributes of dried cashew apple. Tukey's test

was used to separate the means of the quality attributes by treatments at $P \leq 0.05$.

Results and discussions

Drying kinetics

For comparison reasons, the dimensionless moisture content was calculated (up to the dynamic equilibrium point) and its change during drying is presented in Fig. 1. As expected, air temperature affected drying curves, decreasing the drying time of samples.

The statistical analysis values of the models with E around 10% are summarised in Table 2. The two-term exponential gave good R^2 values (> 0.99) and calculated mean relative deviation ranging from 0.24 to 9.28, except for the condition of drying the fresh cashew apple at 70 °C, where the Page equation gave the best fit. Similar result was obtained by Doymaz (2004), in which the empirical two-term exponential model gave the best

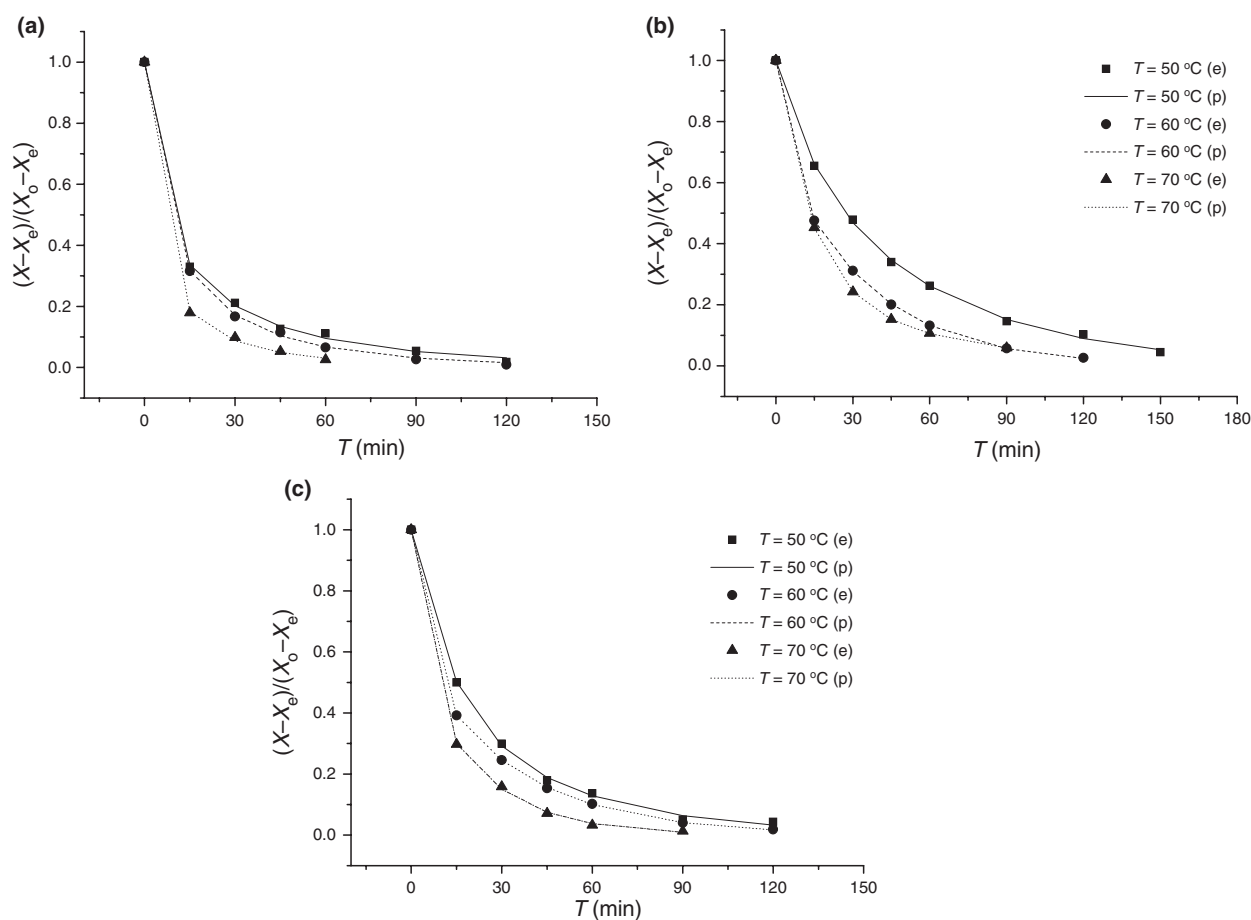


Figure 1 Experimental (e) and predicted (p) drying curves for: (a) fresh (Page model); (b) sucrose osmosed (two-term exponential model); and (c) corn syrup osmosed (two-term exponential model) cashew apple.

Table 2 Statistical results for thin-layer models with E close to 10%

$T = 50\text{ }^{\circ}\text{C}$			
Sample	Model	Model parameters	E (%)
Fresh	Two-term exponential	$a = 0.60$ $k_o = 0.17$ $b = 0.40$ $k_1 = 0.02$	10.27
Sucrose osmosed	Page	$k = 0.04$ $v = 0.84$	5.15
	Logarithmic	$a = 0.94$ $k = 0.03$ $c = 0.05$	10.13
	Two-term exponential	$a = 0.25$ $k_o = 0.07$ $b = 0.74$ $k_1 = 0.18$	4.82
Corn syrup osmosed	Page	$k = 0.08$ $v = 0.78$	9.27
	Two-term exponential	$a = 0.54$ $k_o = 0.08$ $b = 0.46$ $k_1 = 0.02$	9.28
$T = 60\text{ }^{\circ}\text{C}$			
Sample	Model	Model parameters	E (%)
Fresh	Two-term exponential	$a = 0.41$ $k_o = 0.03$ $b = 0.59$ $k_1 = 0.16$	5.76
Sucrose osmosed	Page	$k = 0.10$ $v = 0.74$	7.56
	Two-term exponential	$a = 0.73$ $k_o = 0.03$ $b = 0.27$ $k_1 = 0.38$	1.67
Corn syrup osmosed	Two-term exponential	$a = 0.60$ $k_o = 0.03$ $b = 0.40$ $k_1 = 0.24$	2.34
$T = 70\text{ }^{\circ}\text{C}$			
Sample	Model	Model parameters	E (%)
Fresh	Page	$k = 0.40$ $v = 1.60$	7.85
Sucrose osmosed	Page	$k = 0.11$ $v = 0.75$	6.46
	Logarithmic	$a = 0.93$ $k = 0.06$ $c = 0.07$	7.76
	Two-term exponential	$a = 0.27$ $k_o = 0.02$ $b = 0.73$ $k_1 = 0.07$	0.25

Table 2 (Continued)

$T = 70\text{ }^{\circ}\text{C}$			
Sample	Model	Model parameters	E (%)
Corn syrup osmosed	Page	$k = 0.18$ $v = 0.70$	10.92
	Two-term exponential	$a = 0.60$ $k_o = 0.05$ $b = 0.40$ $k_1 = 1.82$	9.17

fit to the untreated plums. Plots of the experimental and predicted moisture ratios with drying time are represented in Fig. 1.

Figures 2 and 3 show the drying rates as a function of moisture content, where these rates were obtained from experimental values of the moisture with drying time. The physical and chemical changes in the fruit slices during osmosis caused differences in these rates. The sucrose pretreated samples showed the lower rates. Moisture is bound within the solid matrix in many ways (capillaries, physico-chemical bonding to the solid constituents). Hence, the observed differences in drying rates may be related to the solute uptake that occurs in the osmotic process (solids gain was around 6% for sucrose and 2% for corn syrup osmosed cashew apple), which resulted in an increased internal resistance to mass transfer, as observed by Rahman & Lamb (1991) for pineapple and by Karathanos *et al.* (1995) and Mandala *et al.* (2005) for apple.

Water activity and AA content

As it is well known, the stability and safety of foods does improve if water activity (a_w) of the product decreases. The a_w of foods influences the multiplication, metabolic activity, resistance and survival of the organisms present (Leistner *et al.*, 1981).

The reduction of a_w to about 0.93 would be enough to suppress the growth of most pathogenic bacteria (Chirife & Favetto, 1992) with the exception of *Staphylococcus aureus*, which may grow aerobically at a_w values down to 0.86. Most mould and yeast strains are inhibited between 0.88 and 0.80, although some osmophilic yeast strains can still grow down to 0.6 (Iglesias & Chirife, 1982).

The osmotic pretreatment was more efficient in reducing a_w (Table 3) as a considerable amount of water was removed during osmosis and an incorporation of sugars occurred. The sample without pretreatment and dried at lower temperature (50°C) did not lower a_w to a safe value.

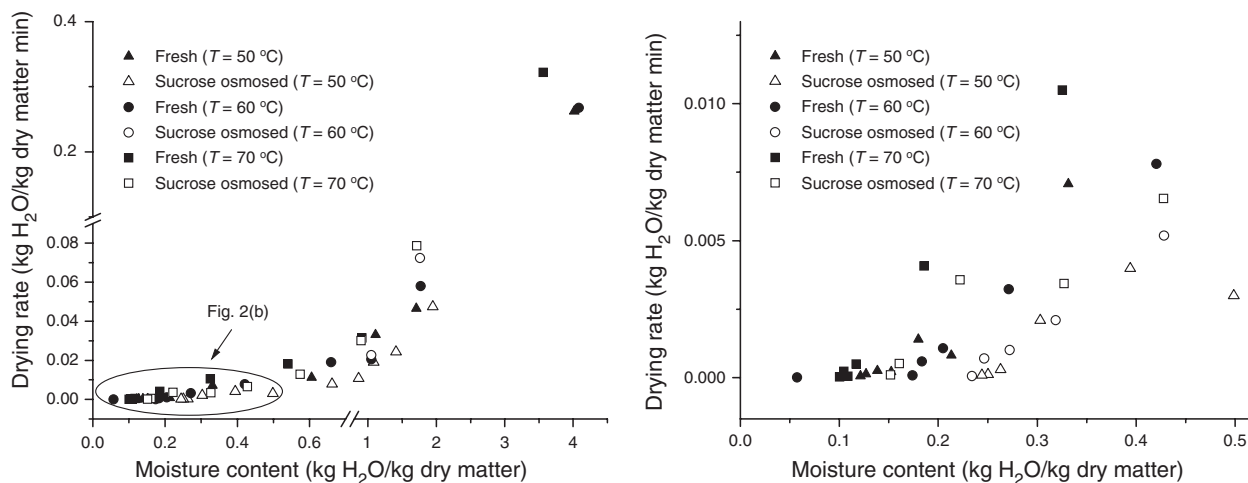


Figure 2 Drying rate curves for fresh and sucrose osmosed cashew apple.

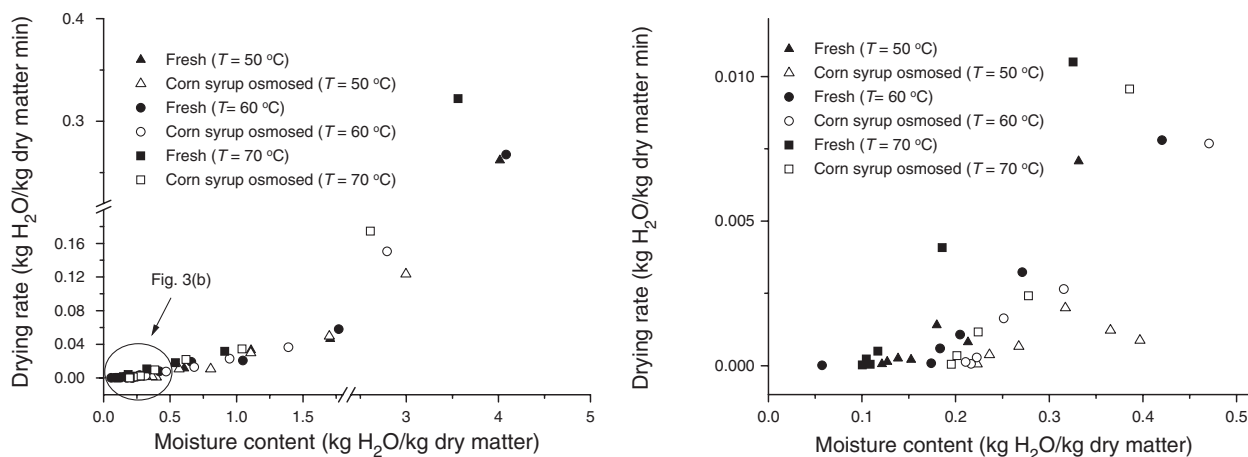


Figure 3 Drying rate curves for fresh and corn syrup osmosed cashew apple.

Ascorbic acid was determined in dried cashew apple (Table 3). All processes resulted in vitamin C (AA) losses. Higher temperatures gave higher losses and the pretreatment was not efficient to protect the samples from oxidations during drying, as the samples submitted to osmotic dehydration presented the lowest AA content. This behaviour may be attributed to the leaching of vitamin C from the product to the osmotic solution and the chemical degradation during subsequent drying. A similar result was found by Islam & Flink (1982), Jayaraman *et al.* (1990) and Azoubel & Murr (1999), in the drying of potato, cauliflower and cherry tomato, respectively, with and without osmotic dehydration. Islam & Flink (1982) also reported that, although any dehydration process resulted in vitamin C losses, the

losses appear to be less than that which could occur during warehouse storage of fresh potato over 5 months. Thus, dried or osmosed dried products represent potential improvements in vitamin C levels for stored potato product.

Sensory evaluation

The sensory evaluation was performed with the samples dried at 60 °C, as at 50 °C, the untreated sample did not present a safe a_w value, and at 70 °C, the vitamin C losses were higher, as discussed earlier.

The score attributes of the cashew apple dried at 60 °C are shown in Table 4. Products pretreated in sucrose solution had the highest test scores, except for

Table 3 Water activity (a_w) and ascorbic acid (AA) content of dried cashew apple

Sample	T (°C)	a_w	AA (mg per 100 g)
Fresh	50	0.718 ± 0.001 ^{aA}	72.67 ± 0.49 ^{aA}
	60	0.545 ± <0.000 ^{bA}	57.77 ± 1.35 ^{bA}
	70	0.442 ± 0.002 ^{cA}	49.92 ± 1.35 ^{cA}
Sucrose osmosed	50	0.474 ± 0.002 ^{aB}	59.05 ± 1.01 ^{aB}
	60	0.440 ± 0.001 ^{bB}	51.52 ± 0.42 ^{bB}
	70	0.370 ± 0.010 ^{cB}	39.98 ± 1.06 ^{cB}
Corn syrup osmosed	50	0.476 ± 0.001 ^{aB}	59.11 ± 0.55 ^{aB}
	60	0.482 ± <0.000 ^{bC}	48.45 ± 1.36 ^{bC}
	70	0.434 ± <0.000 ^{cA}	34.77 ± 2.09 ^{cC}

Natural cashew apple: a_w = 0.989 and AA = 204.78 mg per 100 g. Values represent means of three determinations ± standard deviations. Mean separation by the Tukey test ($n = 3$). Different letters are considered significantly different at the 5% level ($P < 0.05$). Lowercase letters represent the response variation with drying temperature. Capital letters represent the response variation with osmotic agent.

Table 4 Sensory scores for quality attributes of dried cashew apple

Sample	Appearance	Aroma	Taste	Texture
Fresh	6.81 ^a	6.54 ^a	6.04 ^a	5.92 ^{ab}
Sucrose osmosed	7.42 ^a	6.00 ^a	7.38 ^b	6.38 ^a
Corn syrup osmosed	7.00 ^a	5.88 ^a	6.62 ^{ab}	5.42 ^b

Any means in the same columns with the same letters are not significantly different ($P > 0.05$).

aroma. The samples pretreated in corn syrup had test scores closer to the untreated samples. As observed by Azoubel & Murr (2003), samples immersed in sucrose solution had a solid gain around 6%, while those immersed in corn syrup had a solid gain around 2%, what explained the similar behaviour to the untreated samples.

There were no significant differences (95% level) between samples for appearance and aroma. However, although Torreggiani (1993) reported that osmotic dehydration is effective in minimising heat damage to aroma, the samples with no pretreatment step had the highest score for this attribute. The samples osmotically pretreated had the highest scores for appearance, in which the sugar uptake, owing to the protective action of the saccharides, increases the stability of pigments during processing, as observed by Kim (1990).

Regarding taste, there was no significant difference (95% level) among pretreated samples. However, there was a significant difference between the samples osmotically pretreated in sucrose solution and those not pretreated. Nassu *et al.* (2001) observed that differences in the acceptance of fresh and sucrose osmosed cashew apple may be attributed to a reduction of typical astringency caused by tannins in fresh fruit, when a

complex with tannins and added sugar is formed and by degradation of tannins caused during heat treatment. In addition, some of the acids are removed from the fruit during osmotic dehydration; hence a blender and sweeter product than ordinary dried fruits is obtained (Ponting *et al.*, 1966).

For texture, there was a significant difference (95% level) only between the samples osmotically pretreated. Islam & Flink (1982) reported that differences in texture may arise from differences in rate and extent of drying, together with the effect of infused solute. Lenart (1996) also reported that osmotic dehydration before drying has a protective effect on the structure of the dried material, which is characterised by a flexible and fluffy structure.

Conclusions

Osmosed samples had lower drying rates owing to the initial solid content, requiring more time to reach the same final moisture content as fresh cashew apple. Sucrose pretreated samples had the lowest values owing to the higher solute uptake during osmotic dehydration.

Page's model showed a good fit to the experimental data of dried fresh fruit, and the calculated average relative errors were up to 15%. For the pretreated samples, the two-term exponential model had the best fit, with calculated average relative errors lower than 10%.

The osmotic pretreatment was more efficient in reducing a_w ; however, it was not efficient to protect samples from AA losses. The sucrose osmosed samples had the highest acceptance.

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