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Half-ripe Mangaba (*Hancornia speciosa* Gomes) Freezing Kinetics with Different Diameters

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The plant mangabeira (term referred for trees of mangaba fruit) is a tropical plant, native of Brazil, which has a great potential for economic exploration. In the state of Sergipe situated in the northeast region of Brazil, mangaba is one of the major fruit and very much sought in open markets, attaining even a price higher than that of grape and other noble fruits The freezing, in general, offer several advantages over other methods of food preservation, among them, the maintenance of color, flavor and nutritional qualities, when the freezing is done properly and the process storage follows strict criterious to keep product quality. Generally, the experimental determination of thermal properties of foods is the major difficulty of the large dependence of these properties and their large deviations of low temperature characteristics of the freezing process. Due to various complications encountered in the experimental evaluation of thermal properties during freezing, efforts are concentrated on building mathematical models based on the thermodynamic properties of an ideal solution. The mathematical correlations of the thermal properties of food as a function of its basic chemical composition and water content have been an alternative to experimental procedures. Models for estimation of thermo physical properties for systems with and without phase changes are easily found in the literature. The values of specific heat, density and thermal conductivity were estimated using Choi and Okos model from the composition of mangaba experimentally determined. The lack of tabulated values of thermal properties of mangaba has restricted the use of equations in mathematical models for the calculation of thermal properties. The heat transfer at steady state is normally used as a hypothesis. In this work we used the hypothesis of heat transfer dynamics to estimate the coefficient of heat transfer using the Biot number relating to food thermal conductivity and the heat transfer coefficient. Afterwards, it was estimated the coefficient of heat transfer. This study aimed to evaluate the kinetics of freezing mangaba in half-ripe maturation stage. The diameters were 27.96 ± 0,7 mm for small ones and 52.63 ± .,36 mm for the big ones. The freezing time for small mangabas was 40 min while for the larger fruit was 69 min. The Plank model predicted freezing time of 39 min and 65 min respectively. The model proposed by Pham was not more suitable for the prediction of freezing time with average deviations between 14.5 % - 27.5 % compared to the experimental data.

1. Introduction

The plant mangabeira (Hancornia speciosa) is a tropical and perennial plant, that occurs in areas of open vegetation, with an average temperature ideal between 24 and 26 ° C. The soils in which it develops are poor and sandy, predominantly in the region of the Cerrado and Tabuleiros Costeiros in

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the Brasil. The fruiting may occur at any time of year, but concentrated mainly from July to October or January to April (Soares et al., 2005). Its fruit, the mangaba, has detached due to the exotic flavor and tasty and is usually used as raw material for production of pulp, ice cream, candy, and others in the local market, where they were grown.

The main market of this fruit is restricted to North and Northeast regions of Brazil. Mangaba is most appreciated by consumers in open markets, supermarkets (Lederman et al, 2000). This is due to some factors that prevent the diffusion of mangaba to other regions of the country and the world.

Among the factors limiting the exploitation of culture mangaba, the high perishability causes a short-lived post-harvest (Pereira et al, 2006). It is necessary to use techniques that improve the conservation of these fruits for a prolonged period of time in order to facilitate the collection, transport, processing and marketing.

The freezing arises as technology for the preservation of food that combines quality with the reduction of losses and is used in food industries in several places in the world (Oetterer et al, 2006). The food preservation by freezing is derived from multiple mechanisms. When the temperature is below 0 ° C there is a reduction in the rate of microbial growth and the deterioration of the product corresponding to microbial activity, as well as preventing enzymatic and oxidative reactions that occur in food (Singh and Heldman, 2009).

The experimental freezing time determination is difficult because of differences in the initial temperature, the size and shape of the food, differences in the freezing point and the formation rate of ice crystals between several points of the food. Furthermore, changes occur in the thermophysical properties of foods, such as density, thermal conductivity, specific heat and thermal diffusivity of the reduction temperature of the food (Fellows, 2006).

There are various models for predicting freezing time been come previously analyzed by several authors with different resolutions forms (Cleland et al, 1982). The accuracy of the models varying in accordance with the considerations made by the model, practically the freezing time is predicted by equation Plank, however there are several adjustments broader this model, such as model Pham.

The Plank equation is the first and most popular for the prediction of freezing time. In this model, there are considerations to be made that affect the accuracy of results, these are heat transfer of the food is made by driving the physical properties of the food are independent of temperature and volume change is neglected. Moreover, the model is a modification of Pham Plank equation, which is actually derived from Rjutov (López-Leiva and Bengt, 2002). In this model, that the initial product temperature is constant, the final temperature is fixed and the heat transfer by convection at the surface of the object is described by Newton's law of cooling also considers the sensible heat removed during periods of before and after freezing, this makes the model Pham more acceptable than Plank (Singh and Heldman, 2009). In view of this, the paper had the objective to study the kinetics of freezing mangabas the mature stage of maturation medium with different diameters, to obtain the freezing time.

2. Materials and methods

The experiments were conducted at the Vegetables Products Processing Laboratory, Department of Food Technology, located at the Federal University of Sergipe. For the study, the fruits were purchased in Abaís beach, located in Estância, and transported to the laboratory under cooling.

2.1. Raw Material

The mangabas were manually selected, according to the degree of maturation, with the elimination of the fruits that had injuries such as physical damage, diseases caused by pests, green fruit or in a state of senescence, etc..It was chosen those that presented a half ripe stage, which was identified based on skin colour texture of the fruit. Subsequently, the fruits were sanitized in a solution of 200 ppm active chlorine for 10 minutes and then washed with water.

2.2. Determination of Physical and Chemical Properties

The selected mangabas had an average diameter of 27.96 ± 0.70 mm and 52.63 mm ± 3.36 for small and big one. It was used a pachymeter Mitutoyo with divisions of 0.01 mm to make these measurements. The fruits were analyzed for moisture, protein and ash according to methods described by the Adolfo Lutz Institute (1985) and fiber according to AOAC official methods. These were performed in triplicate.

2.3. Determination of Thermal Properties

The thermo properties depend of the composition and temperature of the food. For the present study we used Choi and Okos models for density, specific heat, thermal conductivity and diffusivity. The properties were weighted by the composition of mangaba. The generic formula of this model is given by Equation 1:

$$properties = e + bT + cT^2 \tag{1}$$

2.4. Kinetics of freezing

2.4.1. Experimental treatment

2.4.1.1. Equation of Plank

It was determined the theoretical time of freezing by Plank equation (Equation 2) for spherical geometry:

$$t_F = \frac{\rho_f L_f}{T_F - T_a}\left(\frac{P a}{h} + \frac{R a^2}{K_f}\right) \tag{2}$$

The latent heat of fusion of the food (L_f) was calculated by the relation moisture content of the product (U) and the latent heat of fusion of water, 333.2 KJ / kg as shown in Equation 3.

$$L_f = U.L \tag{3}$$

2.4.1.2. Equation of Pham

With the Pham's model it was calculated the time of freezing mangabas, Equation 4:

$$t = \frac{\rho d_c}{2h}\left[\frac{\Delta H_1}{\Delta T_1} + \frac{\Delta H_2}{\Delta T_2}\right]\left(1 + \frac{Bi}{4}\right) \tag{4}$$

This equation requires that several factors are calculated according to Table 1.

Table 1. Factors for the equation of Pham.

Factors	Equation
T_{fm}	$1.8 + 0.263T_c + 0.105T_a$
ΔH_1	$\rho_u c_u (T_i - T_{fm})$
ΔH_2	$\rho_f [L_f + c_f (T_{fm} - T_c)$
ΔT_1	$\left(\frac{T_i + T_{fm}}{2}\right) - T_a$
ΔT_2	$T_{fm} - T_a$

3. Results and Discussion

The characteristics data of the half-ripe mangaba is shown in Table 2. These parameters are important in the study of the kinetics of freezing, since these are essential to obtain thermo properties. Note that the half-ripe mangaba has a high moisture content, which leads to a freezing curve similar to water in pure state.

Table 2. Physical and chemical properties of half-ripe mangaba .

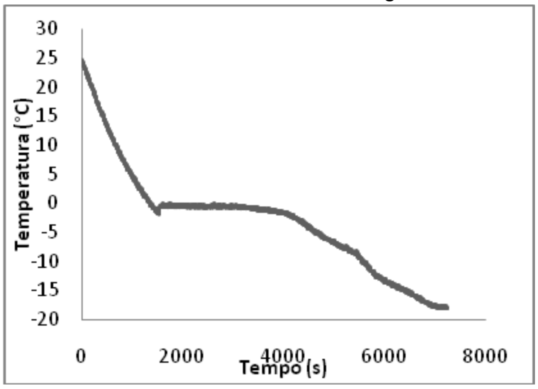
Properties	Half-ripe mangaba
Water (%)	79.49 ± 3.18
Fat (%)	2.8 ±1.40
Carbohydrate (%)	3.96 ± 0.63
Fiber (%)	6.19 ± 3.02
Ash (%)	4.98 ± 0.47
Protein (%)	2.50 ± 0.43

The thermo properties are essential for determining the freezing time. They are dependent on the composition and temperature of the food. Due to the great difficulty in determining the thermo physical properties of the foods, because of their wide variety, use is made of theoretical models as a function of temperature and composition of the food, a model is largely known and Choi Okos. The results relating to these properties are shown in Table 3.

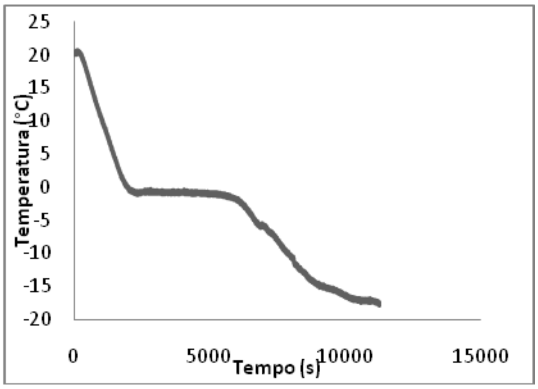
Table 3. Thermal Properties of half-ripe mangada

Properties	Small mangaba	Big mangaba
Density (kg/m³)	1061.161	1061.973
Specific heat (kJ/[kg^{0}C])	3.666	3.664
Thermal diffusivity (m²/s)	1.38×10^{-7}	1.361×10^{-7}
Thermal conductivity (W/[m^{0}C])	0.555	0.549

The Figure 1 represents the kinetics of freezing half-ripe mangaba small (left) and half-ripe mangaba large (right). It is observed in both graphs the regions of pre-freezing, freezing plateau and pos-freezing. During the pre-freezing mangaba is cooled to the point of sub-cooling, this is below zero with the exception of pure water, because of the existence of soluble solids in food. Small mangaba showed a point of subcooling freezing characteristic curve whose value is from -1.9 °C, however, to this point was not as great half-ripe big mangaba visible, the value was found to be -1.2 °C. Then, suddenly increases to the point of freezing to the extent that the ice crystals begin to form and the latent heat of crystallization is released, the freezing point was -0.6 °C and -0.2 °C to mangabas the small and big respectively. At this stage, the temperature remains almost constant, by the fact that the latent heat is removed and ice is formed, is formed at this stage most of the ice. It occurs continuously crystallization water and solutes at the plateau of freezing, the freezing time which is determined by the rate at which latent heat is removed. The temperature of the food drops to a temperature corresponding to the freezer at -17.9 °C case for both mangabas with different diameters.



Freezing curve for small half-ripe mangaba



Freezing curve for big half-ripe mangaba

Figure 1. Freezing curves for mangabas with different diameters

The coefficient of heat transfer values was 61.072 W/(m².°C) and 208.266 W/(m².°C) to small half-ripe mangaba and the big one. The theoretical freezing time with different diameters are presented in Table 4.

Table 4. Freezing time predicted and experimental

Model	Small mangaba		Big mangaba	
	Freezing time (min)	Relative error (%)	Freezing time (min)	Relative error (%)
Experimental	40	-	69	-
Model of Plank	39	5,8	65	2,5
Model of Pahm	51	14,5	79	27,5

It appears that the model better fit the time of freezing experiment was Plank, which was not expected due to the limitations provided by the model. Lopez-Leiva and Hallstrom (2003) compared different experimental and theoretical times for freezing various foods, it was noted that for all foods analyzed the model of Pham showed the smallest errors when compared with the model of Plank. Furthermore, the model best fit Plank the data of mangabas with different diameters. The enthalpy change of the Pham model overestimated the time of freezing mangabas.

4. Conclusion

Freezing time is of obvious economic importance and a analysis of the factors that affect freezing time is, therefore, of interest. It can be concluded that the Planck Model fitted well to the experimental data of the kinetics of freezing mangaba for different diameters. The Pham's method Pham can be used to rough surfaces, but was not suitable for mangabas that present near a sphericity almost equal one. Despite the limitations, the ease of using Planck's equations associated with a simple method for predicting freezing time makes this model popular and suitable for regular surfaces with high water contents.

Nomenclature

a	Diameter of the object(m)	T_c	Final center temperature (°C)
ρ_f	Density of the frozen food (kg/m³)	T_{fm}	Mean freezing temperature
L_f	Latent heat of the food (kJ/kg)	d_c	Characteristic dimension (m)
T_F	Freezing temperature (°C)	E_f	Shape factor, an equivalent heat transfer dimension
T_a	Freezing air temperature (°C)	ΔH_1	Change in volumetric enthalpy for the precoolong period (J/m³)
h	Convective heat transfer coefficient at the superface of the material(W/[m²°C])	ΔH_2	Change in volumetric enthalpy for the postcooling period (J/m³)
k	Thermal conductivity of the frozen material (W/[m°C])	ΔT_1	Temperature gradient 1 (°C)
P', R'	Constants definig the geometry of the food	ΔT_2	Temperature gradient 2 (°C)
t	Freezing time according to Plank (s)	ρ_c	Density of the unfrozen food (kg/m³)
t_F	Freezing time according to Pham (s)	c_u	Specific heat for the unfrozen food (J/[kgK])
N_{Bi}	Biot number	c_f	Specific heat for the frozen food (J/[kgK])

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