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Densidad del puré de mandioca rehidratada en función de la concentración y la temperatura

Density of Rehydrated Mashed Cassava as a Function of Concentration and Temperature

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Resumen

El puré de mandioca deshidratada es un nuevo alimento en el mundo desarrollado por nuestro grupo de investigación. La densidad del puré de mandioca rehidratada para las variedades Concepción y Pomberí se determinó en un rango de concentración de 125 a 200 g/L y temperaturas entre 30 y 80º C. Los valores de densidad aumentan cuando la concentración aumenta y la temperatura disminuye. Los valores de densidad de ambas variedades se ajustaron a una ecuación de regresión múltiple en función de la temperatura y la concentración, con un nivel de confianza del 95%. El efecto de la concentración sobre la densidad puede describirse mediante ecuaciones lineales, potenciales y exponenciales, y todas las ecuaciones fueron estadísticamente significativas con un nivel de confianza del 95%. Se utilizó una ecuación de Arrhenius para determinar el efecto de la temperatura sobre la densidad y así se calcularon los valores de Ea. Dependiendo de la concentración, las energías de activación varían de 0,82 a 1,19 kJ/mol y de 0,56 a 0,81 kJ/mol para la variedad Concepción y Pomberí, respectivamente.

Palabras clave: Densidad; mandioca triturada; concentración; temperatura; Concepción; Pomberí.

Abstract

Dehydrated mashed cassava is a new food in the world developed by our research group. Density of rehydrated mashed cassava for Conception and Pomberí varieties was determined in a concentration range from 125 to 200 g/L and temperatures between 30 and 80º C. Density values increase when the concentration increase and temperature decrease. Density values of both varieties were fitted to a multiple regression equation as a function of temperature and concentration, at a confidence level of 95%. The effect of concentration on density can be described by linear, potential and exponential equations and all equations were statistically significant at a confidence level of 95%. An Arrhenius equation was used to determine the effect of temperature on density and thus Ea values were calculated. Depending on the concentration, the activation energies vary from 0.82 to 1.19 kJ/mol and 0.56 to 0.81 kJ/mol for Conception and Pomberí variety, respectively.

Keywords: Density; mashed cassava; concentration; temperature; Conception; Pomberí.

Introduction

Dehydrated mashed cassava is a product developed by a research group of Faculty of Exact, Chemical and Natural Sciences at Misiones University, and it is nowadays an alternative industrial production of the Agricultural and Industrial Cooperative San Alberto Ltd. in Province of Misiones, Argentina. It is a gelatinized product that will arrive to the market as a dehydrated food, which when it is reconstituted with water, will give a final product similar to cooked fresh root mashed cassava.

Starch is the reserve carbohydrate synthesized by superior plants and it constitutes the main source of energy of most living organisms (1). Its presence in roots and tubers such as cassava (Manihot esculenta), potato (Solanum tuberosum), Peruvian carrot (Arracacia xanthorrhiza), as well as in seeds and cereal grains mainly contribute to the texture properties of some foods and as raw material in some industrial applications as thickener, colloidal stabilizer, gelling agent, adhesive and water holding agent (2) (3) (4). Cassava starch obtained from cassava roots is widely used in the food industry because of its high viscosity, clear appearance, and low production cost (5).

Although the physical properties of some roots and cassava starch solutions have been reported (6) (7) (8), no report is available in the literature for cassava mashed.

The engineering property data with efficient applications in food systems are scarce so far. Information such as the variation of density with concentration and temperature is very important for the food industry and it is essential for the design and the optimization of several processing operations including heat transfer and fluid transport (9).

The objective of this study was to determine the density of rehydrated cassava mashed of Conception and Pomberí varieties, at different concentrations as a function of temperature, and to model the relationship between the density and the combined effect of temperature and concentration.

Materials and methods

Raw material

Dehydrated mashed cassava of Conception and Pomberí varieties were obtained from San Alberto Ltd., Misiones, Argentina. The chemical characteristics of raw material are given in Table 1.

Table 1: Characteristics of the dehydrated mashed cassava

	Dehydrated mashed cassava	
	Concepción	Pomberí
Moisture content (%)	9.3 ± 0.3	13.5 ± 0.3
Protein (%)	2.3 ± 0.1	0.7 ± 0.1
Ash (%)	1.9 ± 0.1	0.6 ± 0.1
Carbohydrates (such as) starch)	83 ± 1	82 ± 1
Fats (%)	0.4 ± 0.1	0.6 ± 0.1
Crude fiber (%)	2.1 ± 0.3	2.9 ± 0.3

2.2 Preparation of rehydrated mashed

Dehydrated mashed cassava was rehydrated by adding 500, 600, 700 and 800 mL of water at 80º C to 100 g of dried product, in order to obtain different mashed concentrations (200, 167, 143 and 125 g mashed / L water). It was cooked for two minutes and was kept in a thermostatic bath at different test temperatures.

Determination of the density

The density was determined by pycnometry (10) and the temperature was controlled by a thermostatic water bath (Schott Gerate, model CT1150 (SCHOTT Instruments GmbH, Germany). The determinations were done in triplicate.

The density of the rehydrated mashed was calculated by Eq. 1.

$$\rho = \frac{M_{pm} - M_{pv}}{V} \qquad \text{Eq. (1)}$$

where ρ is the density (kg/m^3), Mpm is the mass of the pycnometer with sample (kg), Mpv is empty pycnometer mass (kg) and V is the volume (m^3).

Models

Several different models (11) (12), can describe the variation of density with concentration.

The density values were fitted to lineal, power and exponential models (Eq. (2), (3), (4)).

$$\rho = a + bC \qquad \text{Eq. (2)}$$

$$\rho = aC^b \qquad \text{Eq. (3)}$$

$$\rho = ae^{bC} \qquad \text{Eq. (4)}$$

where ρ is the density (kg/m^3), C is the concentration (g/L), a and b are constants of the models.

To study the variation of density with temperature and concentration and give a simple equation within the ranges studied, the experimental data have been fitted to a transformed polynomial equation Eq. (5), expressed by (7).

$$\rho = a + bT + cC \qquad \text{Eq. (5)}$$

where ρ is the density (kg/m^3), C is the concentration (g/L), T is the temperature (C), a, b, and c are constants of the models.

The effect of temperature on the density was described by the Arrhenius relationship, Eq. (6) (13).

$$\rho = \rho_0 \exp(-Ea/RT) \qquad \text{Eq. (6)}$$

where ρ is the density (kg/m^3), ro is a parameter that is considered as the density at infinite temperature (kg/m^3), Ea is the activation energy (kJ/mol), R is the molar gas constant (kJ/mol K), and T is temperature (K).

The Ea values were correlated with the concentration (g/L) for the power law Eq. (7) and exponential type Eq. (8) models.

$$E_a = aC^b \qquad \text{Eq. (7)}$$

$$E_a = ae^{bC} \qquad \text{Eq. (8)}$$

where Ea is the activation energy (kJ/mol), C is the concentration (g/L), a and b are constants of the models.

The goodness of fit of derived models was evaluated by the root mean square error (RMSE) Eq. (9), the mean bias error (MBE) Eq. (10), the mean percentage error (E %) Eq. (11), in addition to R2. These statistics allow for the detection of the differences between experimental data and the model estimates. These parameters can be calculated as following:

$$\mathrm{RMSE} = \left[\frac{\sum_{i=1}^{n} (c_{cal} - c_{\exp})_n^2}{n} \right]^{0,5} \qquad \text{Eq. (10)}$$

$$\mathrm{RMB} = \frac{\sum_{i=1}^{n} (\mathrm{c}_{\mathrm{cal}} - \mathrm{c}_{\mathrm{exp}})_n}{n} \qquad \text{Eq. (11)}$$

$$\mathrm{E}\,\% = \frac{\sum_{i=1}^{n} \frac{(c_{cal} - c_{\exp})_n}{\mathrm{c}_{\exp n}}}{n} *100 \qquad \text{Eq. (12)}$$

where ccal is the predicted value, cexp is the experimental value and n is the number of data points

A good fit is indicated by small values of RMSE and MBE, R2> 0.85 and E % <10% (14) (15). GraphPad Prism Software 4.0 and Statgraphics Plus for DOS version 7.0 were used in the statistical analysis. All correlations and statistical analyzes were done for a 95% confidence interval.

Results and Discussion

The experimental data of density of rehydrated mashed cassava for different concentrations and temperatures are shown in Table 2 for Conception and Pomberí varieties according to the methods of (16).

Multifactorial ANOVA indicated that the concentration and temperature significantly influence the density of rehydrated mashed cassava ($p < 0.05$) of the Conception and Pomberí variety.

As was expected, it shows a decrease in density with an increase in temperature and with a decrease in concentration.

Values of density that have been obtained for rehydrated cassava mashed are comparable with other mashed food or paste with the same trend, such as results obtained by (10) for apple and quince purees, by (13) for banana puree, (6) for pastes of cassava (Manihot esculenta Grantz), sweet potato (Ipomoea batatas L. Lam) and white yam (Dioscorea rotundata Poir) tubers.

Influence of concentration on the density of rehydrated mashed cassava

The parameters obtained for the linear (Eq. 2) , potential (Eq. 3) and exponential (Eq. 4) models for Conception and Pomberí varieties and the goodness of fit are summarized in table 3.

Table 2: Experimental values for density (kg/m³) at different concentration and temperature for the rehydrated mashed cassava, Conception and Pomberí varieties

Concentration (g/L)	Temperature (°C)							
	30		40		50		60	
	Conception	Pomberí	Conception	Pomberí	Conception	Pomberí	Conception	Pomberí
200	1112.7±0.7^a	1117.3±0.6^a	1107,3±0,3^a	1108.0±0.7^a	1095,3±0,3^a	1098.3±0.3^a	1080,7± 0,9^a	1096.0±0.6^a
167	1092.7±0.7^b	1098.3±0.6^b	1083,3±0,9^b	1090.7±0.3^b	1066,3± 0,7^b	1082.3±0.3^b	1059,0±0,6^b	1072.0±0.6^b
143	1070.7 0.7^c	1081.0±0.6^c	1062±1^c	1074.3±0.7^c	1044,7±0,9^c	1063.0±0.6^c	1032,0±0,9^c	1054.0±0.6^c
125	1055.3±0.9^d	1062.7±0.9^d	1044,7±0,7^d	1050.7±0.3^d	1026,3±0,7^d	1042.7±0.8^d	1012,3±0,9^d	1031.7±0.9^d

Values are average of three replicates ± standard error.
* Within a column with different letters are significantly different ($p < 0.05$)

Table 3: Constants of the linear, potential and exponential models and the goodness of fit for the rehydrated mashed cassava, Conception and Pomberí varieties

Temperature (°C)	a	b	R^2	Goodness of fit		
				RMSE	MBE	E %
Model Eq. [2]						
60	901±7^a	0.92±0.04^a	0.98	3.56	-0.15	0.29
50	913±2^a	0.92±0.01^a	0.99	0.88	0.03	0.08
40	942±4^b	0.83±0.02^a	0.99	1.69	0.03	0.15
30	961±5^b	0.77±0.03^a	0.99	2.23	-0.09	0.17
Model Eq. [3]						
60	513±11^a	0.141±0.004^a	0.99	2.21	0.03	0.18
50	526±5^a	0.138±0.002^a	1.00	0.71	0.07	0.06
40	574±6^b	0.124±0.002^a	1.00	0.30	0.004	0.02
30	608±8^b	0.114±0.002^a	0.99	1.23	0.22	0.10
Model Eq. [4]						
60	911±6^a	0.0009±0.00004^a	0.98	3.79	-0.05	0.31
50	923±2^a	0.0009±0.00001^{ab}	1.00	1.12	0.01	0.10
40	951±4^b	0.0008±0.00002^{ab}	0.99	1.89	-0.01	0.17
30	968±4^b	0.0007±0.00003^b	0.99	2.39	0.05	0.18

* Within a column with different letters are significantly different ($p < 0.05$)

The coefficients and the goodness of fit of the three models indicated that all of them adequately describe the variability of density with the concentration. However, statistical analysis showed that potential model seems to describe better the effect of the concentration on the density in comparison with linear and exponential model. The higher is the values of R2 average for all temperatures and the lower is the values of E %, MBE and RMSE, the better will be the goodness of fit. A multiple regression analysis on the density–concentration data showed that the three models statistically fitted, and they could be proposed to evaluate the density of rehydrated mashed cassava for the interval of concentrations studied.

For all models and both varieties, the parameter "a" decreased with increasing temperature for all studied concentrations. Parameter "b" decreased with decreasing temperatures, but the associated changes were very small.

Influence of combined effect of temperature and concentration on the density of rehydrated mashed cassava

Different models were proposed by various authors to represent the combined effect of temperature and concentration on the density. The model that fitted most appropriately to the experimental values was a polynomial equation, where the density varies linearly with temperature and with concentration for both varieties. Table 4 shows the values of the obtained constants and summary of the statistical analysis.

The density decreases with temperature with a coefficient of -1.27 and -0.89 and increased with concentration with a coefficient of 0.85 and 0.75 for Conception and Pomberí varieties, respectively.

Table 4: The combined effect of temperature and concentration on the density of rehydrated mashed cassava

Model Eq. [5]	a	b	c	R^2	Goodness of fit		
					RMSE	MBE	E %
Conception	986±4	-1.27±0.04	0.85±0.02	0.99	3.41	-0.05	0.24
Pomberí	996±4	-0.89±0.05	0.75±0.02	0.97	3.89	0.0005	0.33

The density of cassava starch powder decreased with increasing temperature with a coefficient of -0.462, but increased with increasing concentration with a coefficient of 2.116, in the temperature range (30-50° C) and concentration (20-50% w/w) (7).

Influence of temperature on the density of rehydrated mashed cassava

Density of rehydrated mashed cassava of both varieties, Conception and Pomberí, at different concentrations has also found to be a function of temperature. It decreases considerably with increasing temperature. The effect of temperature on the density follows an Arrhenius-type relationship with R2 values greater than 0.95 (Table 5).

Table 5: Parameters of the Arrhenius-type model for Conception and Pomberí varieties

Concentration (g/L)	jo	Ea(kJ.mol-1)	R2	Goodness of fit		
				RMSE	MBE	E %
	Conception variety					
200	806±19^{a}	0.82±0.04^{a}	0.95	2.7	-0.05	0.25
167	763±14^{b}	0.91±0.03^{b}	0.97	2.03	-0.08	0.17
143	704±16^{c}	1.06±0.05^{c}	0.97	2.27	0.08	0.18
125	660±13^{d}	1.19±0.03^{d}	0.98	1.96	0.2	0.17
	Pomberí variety					
200	893±14^{a}	0.56±0.02^{a}	0.95	1.73	-0.04	0.14
167	844±9^{ab}	0.66±0.02^{b}	0.98	1.06	0.04	0.1
143	807±9^{bc}	0.74±0.03^{c}	0.99	1.04	0.03	0.08
125	771±9^{b}	0.81±0.02^{c}	0.99	0.78	0.01	0.07

Within a column with different letters are significantly different ($p < 0.05$)

Activation energy values (Ea) ranged from 0.56 to 0.81 for Conception variety and 0.82 to 1.19 kJ/mol for Pomberí variety. Mashed cassava of Conception variety showed the highest activation energy values. Density was most affected by the temperature with decreasing concentration. The effect of concentration on activation energy is displayed in Fig. 1 for both, Conception and Pomberí varieties. Results showed that the activation energy decreased when concentration increased.

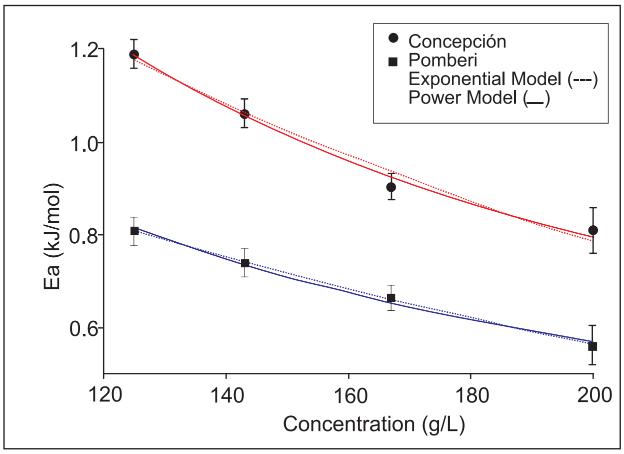

Figure 1: Activation energy-concentration plot for the rehydrated mashed cassava for Conception and Pomberí varieties.

Therefore, the density variation is more sensitive to temperature at low concentration, i.e., the less the concentration, the more the temperature sensitivity was. The variation of activation energy with concentration was modeled by using both exponential and power models. The linearized forms of these two equations were used to determine the model constants (Table 6). Power model was found to be a better fit for Conception variety and exponential model was found to be a better fit for Pomberí variety.

All models had a good fit to the experimental data as shown by the values of R2, RMSE, MBE and the percentage error of the table6. Results in this study indicated that the density of the rehydrated mashed cassava followed an Arrhenius type variation with temperature, and the change of experimental activation energy data with the concentration could be fitted to a power model for Conception variety and exponential model for Pomberí variety. The values of activation energy of other tubers were not found in literature.

Table 6: Influence of concentration on activation energy

Model	a	b	R^2	Goodness of fit		
				RMSE	MBE	E %
	Conception variety					
Eq. [7]	73±22	0.85±0.06	0.95	0.02	-0.001	1.51
Eq. [8]	2.3±0.2	0.0051±0.0004	0.94	0.03	-0.001	2.43
	Pomberí variety					
Eq. [7]	31±11	0.76±0.07	0.92	0.01	0.0004	0.96
Eq. [8]	1.5±0.1	0.0051±0.0004	0.92	0.002	0.0003	0.28

The values of a and b are averages of three replications ± standard error

Conclusion

Density of rehydrated mashed cassava for Conception and Pomberí varieties prepared in concentrations of 200, 167, 143 and 125 g/L were measured at 30, 40, 50 and 60º C. Statistical analysis indicated that temperatures and concentrations significantly ($p < 0.05$) affected density. The concentration influences in 74 and 82% on the variation of the density, for variety Concepcion and Pomberí, respectively, and the temperature influences to a lesser degree on the total variation, in a value of 26% and 16% for variety Concepcion and Pomberí, respectively.

Density -concentration relationship was expressed by lineal, power and exponential models with excellent fit, and density- concentration and temperature combined effect relationship could be related by a polynomial equation. The variation of density with temperature at constant concentration followed an Arrhenius-type model, and the obtained activation energy has been related to concentration by power and exponential models for both varieties.

The effect of temperature and concentration on density can be described by equations that could be useful for preliminary equipment design, and process design and have direct applications fluid flow and heat transfer.

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