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Heat and mass transfer modeling of the osmo-convective drying of yacon roots (*Smallanthus sonchifolius*)

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HIGHLIGHTS

- Osmo-convective drying technology on yacon roots has been investigated.
- A mathematical model for the conjugated heat and mass transfer involved in the process has been developed.
- Moisture dependent thermophysical properties have been considered.
- Proposed model was solved by the Finite Element Method using COMSOL Multiphysics®.
- Moisture content, osmotic agent uptake and temperature were satisfactorily predicted by the model.

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ABSTRACT

Osmotic treatments are often applied prior to convective drying of foods to impart sensory appeal aspects. During this process a multicomponent mass flow, composed mainly of water and osmotic agent, takes place. In this work, a heat and mass transfer model for the osmo-convective drying of yacon was developed and solved by the Finite Element Method using COMSOL Multiphysics®, considering a 2-D axisymmetric geometry and moisture dependent thermophysical properties. Yacon slices were osmotically dehydrated for 2 h in a solution of sucralose and then dried in a tray dryer for 3 h. The model was validated by experimental data of temperature, moisture content and sucralose uptake ($R^2 > 0.90$).

1. Introduction

Fruit and vegetable processing demands special attention, as these are considered important sources of vitamins and minerals which are essential for mankind [1]. Drying has been extensively used as a food preservation procedure. Yacon is a root originated from South America, grown in many parts of the world. It has around 90% of moisture content (w.b.) and is known for its prebiotic property, ascribed to the high content of fructooligosacharides (FOS). Besides improving the bifidogenic activity in the digestive system, FOS has been related to the reduction on the glucose and triglycerides level in the blood, blood pressure normalization and diabetic metabolism improvement [2,3]. Yacon is mostly consumed in natural or in dried form, but it can also be added in a powdered form in a wide variety of foods such as bakery products, yogurts and juices. Considering that prebiotic concentration of yacon decrease along the post-harvest period due to the depolymerization of FOS, and that its shelf-life is lower than 7 days in ambient conditions, it is critical to process it in order to preserve its nutritional and sensorial attributes.

Drying of food is a very energy intensive process and accounts for up to 15% of industrial energy usage. Although drying operations are widely applied as a method of conservation in the food industry, improper drying process can damage the quality of dried food and consume huge amount of excess energy. It is important to understand the fundamental process in order to overcome these problems [4]. For example, the use of relatively high temperatures accounts for damages such as enzymatic browning, shrinkage and alterations on flavor, color and aroma. An alternative to minimize the product thermo degradation is to reduce its initial water content by an osmotic dehydration process. In the osmotic treatment, fruits and vegetables are immersed in a saturated solution of

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osmotic agent at low temperatures, which results in the water loss and/or uptake of sugar [5,6]. This process can improve color, flavor and texture for processed food and enhance color pigment and nutrient stability during storage [7,8]. The enhancement of some quality attributes of convective dried yacon after the application of an osmotic treatment was demonstrated in the study of Perussello et al. [9].

The mathematical models have the potential to predict the drying behavior of a food product, determine the influence of process parameters and thus minimize the costs of drying process and degradation of nutritional and sensorial attributes of the product [10]. Drying is a complicated process involving simultaneous heat and mass transfer. Fruits and vegetables have certain morphological features quite distinct from other natural materials that greatly influence their behavior during drying and preservation [11]. Complex nature of food structure and change in properties during the drying process complicate the modeling of drying of fruits and vegetables. The majority of the models developed in food drying are based on the equations of Fick and Fourier, which can represent the transient phenomena of mass and heat transfer, respectively [12–15]. However, modeling the osmotic dehydration represents some additional challenge as two opposite and concomitant flows of water and sugar needs to be considered in the model. Although some theoretical models have been developed for osmotic dehydration of different foods [16,17], no model on yacon is found in the literature. As yacon has some specific thermophysical properties different from others, it is necessary to develop a mathematical model for osmotic dehydration of yacon. Therefore, the goals of this work were: (i) to develop a theoretical model for simulating the osmo-convective drying process of yacon slices, and (ii) to validate the model using the experimental data. The model developed herein can be applied to other foodstuffs, even when using another osmotic agent for the osmotic dehydration and also other process conditions for the osmo-convective drying, since it uses a phenomenological approach. In this case, the researcher would only need to use specific thermophysical properties for the products being worked with, and coefficients of heat and mass transfer adequate to the process conditions.

2. Mathematical modeling

A finite cylinder, as shown in Fig. 1, represents the computational domain. The radius of the cylinder is r and the thickness is z. For the purpose of model development, the following simplifying assumptions have been made:

1. Heat and mass transfer are two dimensional;
2. Materials are homogenous;
3. Material properties are considered as moisture dependent;

The heat and mass transports were considered in two dimensions, radius (r) and width (z). The thermal and mass balances were written based on the Fourier Equation and the Fick's second law, respectively [18]:

$$\rho \mathrm{Cp}\frac{\partial T}{\partial t} + \rho \mathrm{Cp}\cdot u\cdot \nabla T = \nabla(k\nabla T) + Q \tag{1}$$

and

$$\frac{\partial C_i}{\partial t} + \nabla(-D_i\nabla C_i) + u\cdot\nabla C_i = R \tag{2}$$

where T is temperature [K], t is process time [s], ρ is density [kg/m^3], Cp is specific heat [J/kg K], k is thermal conductivity [W/m K], u is the velocity field [m/s], Q is heat generation [W/m^3], C_i is the moisture concentration of the diffusive species i [mol/m^3], D is the diffusion coefficient [m^2/s], and R is the consumption or production of species [mol/m^3 s]. Considering that the yacon slice is not in movement and there is no heat generation or chemical reaction involved in this study, the variables u, Q and R are neglected.

The initial and boundary conditions for the heat transfer process were defined as: homogeneous temperature at the beginning of the process, convection on the surface of the material and null heat flux in the symmetry region as shown in Eqs. (3)–(5) respectively.

$$T = T_0 \text{ at } t = t_0 \quad \text{for } 0 < r < R \text{ and } 0 < z < \varepsilon \tag{3}$$

$$k\nabla T = h(T_\infty - T) \text{ for } \begin{cases} \text{if } z = \varepsilon, 0 < r < R, \text{ and} \\ \text{if } r = R, 0 < z < \varepsilon \end{cases} \tag{4}$$

$$\frac{\partial T}{\partial r} = 0 \quad \text{for } 0 < z < \varepsilon \text{ if } r = 0 \tag{5}$$

where T_0 is the initial temperature [K], t_0 is the initial process time, T_∞ is the drying air temperature [K], r is the slice radius [m] and ε is the slice width [m].

Similarly the initial and boundary conditions for the mass transfer process were defined as: homogeneous moisture content in the beginning of the process, convective condition on the surface of the material and null mass flux in the symmetry region as shown in Eqs. (6)–(8) respectively.

$$C_i = C_{i0} \text{ at } t = t_0 \text{ for } 0 < r < R \text{ and } 0 < z < \varepsilon \tag{6}$$

$$D_i\frac{\partial C_i}{\partial r} = h_\mathrm{m}(C_{i\mathrm{eq}} - C_i) \text{ for } \begin{cases} \text{if } z = 0, \ 0 < r < R \\ \text{if } z = \varepsilon, \ 0 < r < R, \text{ and} \\ \text{if } r = R, \ 0 < z < \varepsilon \end{cases} \tag{7}$$

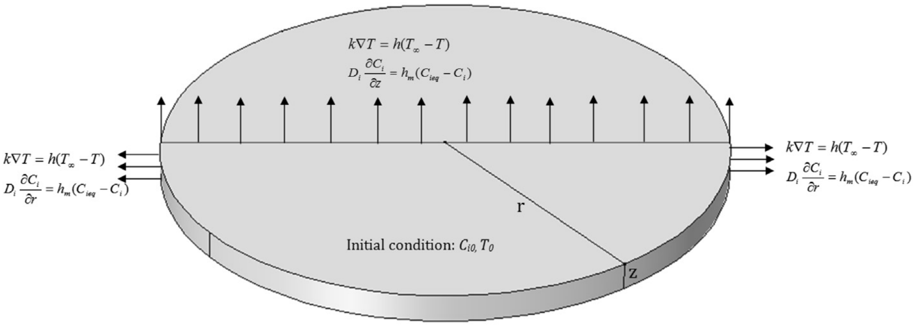

Fig. 1. Computational domain.

$$\frac{\partial C_i}{\partial r} = 0 \quad \text{for } 0 < z < \varepsilon \quad \text{if } r = 0 \tag{8}$$

where C_{i0} is the moisture concentration in the beginning of the process [mol/m^3] and C_{ieq} is the equilibrium moisture concentration [mol/m^3].

2.1. Heat and mass transfer coefficients

The convective heat transfer coefficient, h [W/m^{2}K], was calculated by using Eq. (9) [19]:

$$h = \frac{Nu k_\infty}{d} \tag{9}$$

where Nu is Nusselt number, k_∞ is the drying air thermal conductivity [W/m K] and d is the yacon slice diameter [m].

Nu was calculated by using Eq. (10) [20] a correlation between Reynolds number (Re) and Prandtl number (Pr), which is applied to the fluid flow through cylinders.

$$Nu = 0.683 Re^{0.466} Pr^{0.33} \qquad Pr \geq 0.7 \text{ and } 0.4 \leq Re \leq 4 \times 10^5 \tag{10}$$

Re and Pr were calculated according to Incropera and Dewitt [21] by

$$Re = \frac{\rho_\infty v_\infty d}{\mu_\infty} \tag{11}$$

and

$$Pr = \frac{\mathrm{Cp}_\infty \mu_\infty d}{k_\infty} \tag{12}$$

where μ_∞ is the drying air viscosity [Pa s], v_∞ is the velocity [m/s] and k_∞ is the thermal conductivity [W/m K].

The convective mass transfer coefficient, h_m [m/s], was calculated according to Bejan [19] by

$$h_\mathrm{m} = \frac{h}{\rho_\infty \mathrm{Cp}_\infty \left(\frac{\alpha_\infty}{D_\infty}\right)^{2/3}} \tag{13}$$

where α_∞ is the air thermal diffusivity [m^2/s] and D_∞ is the water diffusivity on air [m^2/s], available in Ref. [21].

Nu was calculated differently for the osmotic dehydration conducted without solution agitation, in which only natural convection took place. Eq. (14) [22] is applied to natural convection for vertical cylinders.

$$Nu = 0.6 \left(Ra \frac{d}{L}\right)^{1/4} \tag{14}$$

where Ra is Rayleigh number, calculated according to Incropera and Dewitt [21] as

$$Ra = Gr \cdot \mathrm{Pr} \tag{15}$$

The Grashof number, Gr, is determined as [21]

$$Gr = \frac{L^3 g \beta (T - T_\infty)}{\mu_\infty^2} \tag{16}$$

where g is gravity [m/s^2] and β is thermal expansion coefficient of the osmotic solution [K^{-1}].

The diffusion coefficient (D) was obtained by an inverse method, called Differential Evolution Optimization [23] by using a computation code in Matlab (The Mathworks, MA, USA). This numerical simulation was carried out within an estimated interval for D between 10^{-9} and 10^{-12} m^2/s, typical for food products [1,12,14,15].

2.2. Simulation procedure

The heat and mass transfer phenomena are conjugated by the thermophysical properties, which are dependent on moisture content. The governing equations were solved by the Finite Element Method using the software COMSOL Multiphysics® 4.3. The mesh, composed by 612 triangular elements, was created automatically by the software. Grid dependence tests revealed that the results are not dependent on the number and format of elements. The model was solved according to the flow chart illustrated in Fig. 2.

3. Experiments

3.1. Materials

Yacon roots (*Smallanthus sonchifolius*), sourced from a local market in the city of Curitiba, Brazil, and kept under refrigeration

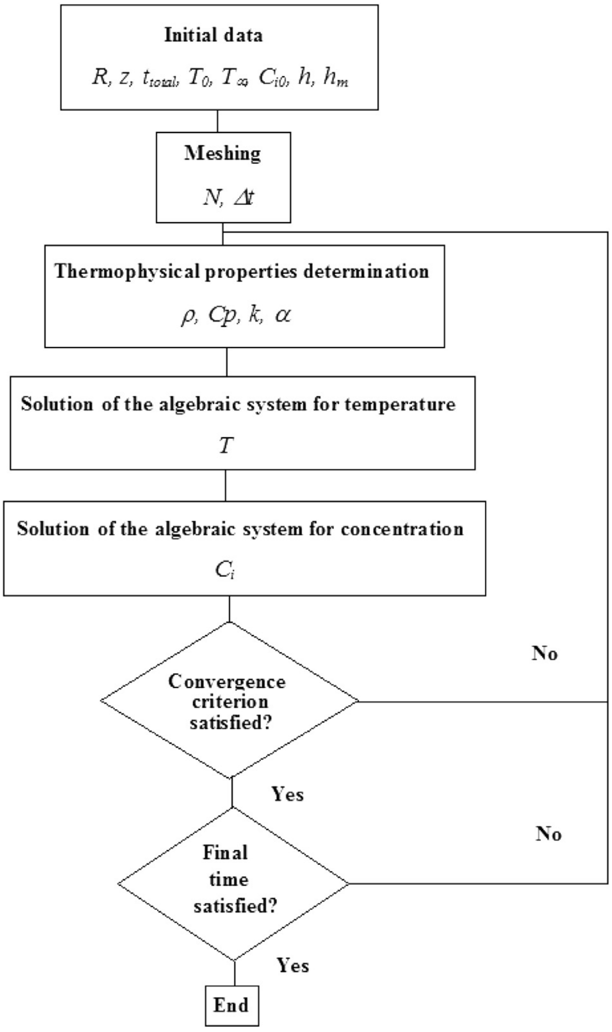

Fig. 2. Numerical algorithm.

Table 1
Experimental design.

Variable	Variable code	Level	
		−1	+1
Solution temperature (°C)	*x1*	30	50
Solution stirring rate (cm s^{-1})	*x2*	0	4
Drying temperature (°C)	*x3*	60	80

up to 7 days, were peeled and shaped into radial slices of thickness 2 mm. Sucralose (Linea®), a sugar cane derivate with caloric value near to zero, was used as the osmotic agent. Sucralose has high temperature and pH stability and high water solubility [24].

3.2. Osmotic treatment and convective drying

During an osmo-dehydration process, i.e., a convective drying preceded by an osmotic pre treatment, the product loses water and gains sugar. The osmotic treatment was carried out in a thermostatic bath (Quimis, model Dubnoff Q-226M2) with temperature and stirring control using a sucralose solution. The convective drying was carried out in a convective tray dryer with forced ventilation.

Four beakers containing 140.0 ± 0.5 g of 20% (w/w) concentration sucralose solution and 28.6 ± 1.2 g of yacon slices were conditioned in the thermostatic bath for 2 h. Previous tests conducted by these authors revealed that a process time longer than 2 h leads to uptake of sugar, without significant water loss. The proportion between yacon and solution was 1:5 (w/w). Temperature and stirring rate were set according to the experimental design (Table 1), being 30 °C and 50 °C to the osmotic solution temperature and 0 cm/s and 4 cm/s to the solution stirring rate. The main objective of osmotic treatment was to improve some quality attributes, such as color, texture and structural integrity of the yacon slices during the convective drying. For the measurements of mass and moisture content, each beaker was removed from the thermostatic bath at a predefined time interval (30 min, 60 min, 90 min and 120 min) and the slices were wiped with absorbent paper. After the osmotic treatment, the slices were dried for 3 h in the convective tray dryer using temperatures of 60 °C and 80 °C, according to the experimental design (Table 1).

All the experiments, carried out in triplicate, followed a full 2^3 factorial design, where 2 is related to the number of levels to be studied and 3 is related to the number of variables being evaluated, which are the osmotic solution temperature, the osmotic solution stirring rate and the drying temperature. The experimental design is presented in Table 1, resulting in 4 osmotic treatments and 8 osmo-convective drying processes.

3.3. Thermo physical properties analyses

The moisture content of the slices was determined by the gravimetric method [25]. The temperature profile was obtained using T type thermocouples connected to a data acquisition system (Field Logger, brand Novus). The sensors were placed at the center and edge of the slices. The yacon thermophysical properties, namely density, specific heat, thermal conductivity and thermal diffusivity, were determined at every 30 min by direct methods. Density was measured by the liquid displacement method, using a pycnometer of 25 mL and distilled water [26]. Specific heat and thermal conductivity were determined by a thermal property analyzer (Decagon KD2 Pro), using the TR1 sensor, which is suitable for solid materials. The KD2 Pro is a portable device that uses the

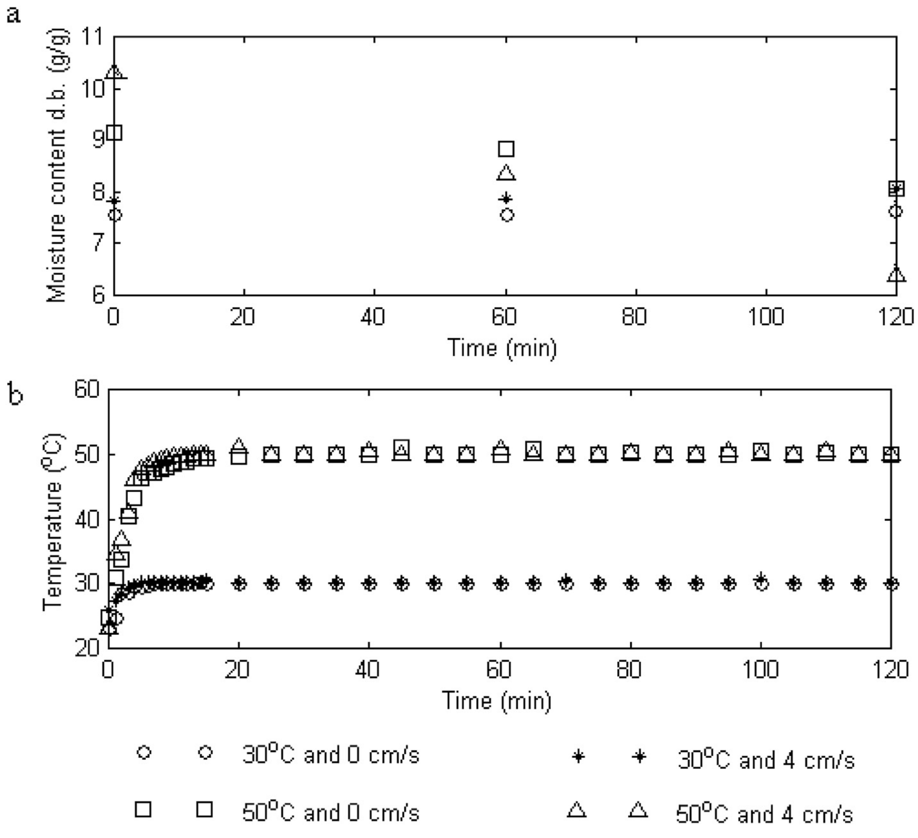

Fig. 3. (a) Moisture content; and (b) temperature during the osmotic treatment of yacon.

Table 2
Sucralose uptake after the osmotic treatment of yacon.

Process conditions	Sucralose (mg/g yacon)
In natura	0
30 °C and 0 cm/s	20.26 ± 1.81
50 °C and 0 cm/s	16.82 ± 0.09
30 °C and 4 cm/s	22.86 ± 0.28
50 °C and 4 cm/s	22.23 ± 1.25

Table 3
Fitted equations to calculate the yacon thermophysical properties as a function of moisture content.

Property	Equation	R^2
Density (kg/m^3)	$\rho(X) = 1525.18 - 466.07 \times (1 - \exp(-X/0.9325))$	0.9896
Specific heat (J/kg °C)	$\mathrm{Cp}(X) = 433\ln(X) + 2959$	0.9660
Thermal conductivity (W/m °C)	$k(X) = 0.25 + 0.2594 \times (1 - \exp(-X/1.0034))$	0.9883
Thermal diffusivity (m^2/s)	$\alpha(X) = -1\text{e-}7 + 2.8\text{e-}8 \times (1 - \exp(-X))$	0.9023

transient line heat source method, developed by Sweat [27] to measure thermal conductivity, resistivity, diffusivity and specific heat. In this method, a known heat flow is generated from the product center to its periphery, resulting in the establishment of a continuous current. After a brief time interval, the relation between temperature - in a point close to the probe – and time becomes linear in a mono-log scale. Solving the Fourier equation using these results, thermal conductivity value can be obtained [28]. The line heat source probe is recommended for a wide range of food products because of its simplicity, fastness, convenience and low cost [29]. Thermal diffusivity was calculated by:

$$\alpha = \frac{k}{\rho \mathrm{Cp}}, \tag{17}$$

where ρ is density [kg/m^3], Cp is specific heat [J/kg K] and k is thermal conductivity [W/m K].

A nonlinear regression procedure was used to relate the values of the experimental properties with moisture content by the minimization of the least squares function.

The sucralose uptake was determined after completion of osmotic treatment by High Performance Liquid Chromatography (HPLC) using the chromatographic system Agilent HP 1110, column Rezex RSO (200 × 10 mm) and pre column Rezex RSO (60 × 10 mm). The operating conditions were 80 °C for the column temperature, 0.5 mL/min solution flow rate, injection volume of 100 μl and running time of 30 min. The sample preparation for the chromatographic analysis was carried out according to the method described in Oliveira and Nishimoto [30].

4. Results and discussion

A large number of osmo-convective drying tests were conducted, however only the results of the tests conducted at 50 °C, 0 cm/s and 60 °C, as per experimental design, are presented here. The moisture profile of yacon during the osmotic treatment in different conditions is presented in Fig. 3a. The moisture content of the yacon slices varied only subtly, from around 90.0%–88.5% w.b. In fact, as mentioned previously, the osmotic pre-treatment has been commonly used in several studies to enhance some quality attributes, such as flavor, color, texture and stability of nutrients during storage [8,31], not to provide significant water loss. Fig. 3b presents the temperature variation at different temperature setting (i.e. 30 °C and 50 °C) during osmotic treatment. It can be seen that there is no temperature variation in each setting, which indicates that the use of agitation does not increase the heat transfer. The sucralose uptake was different for each experimental condition, assuming values between 16.82 and 22.86 mg of sucralose per g of yacon (Table 2).

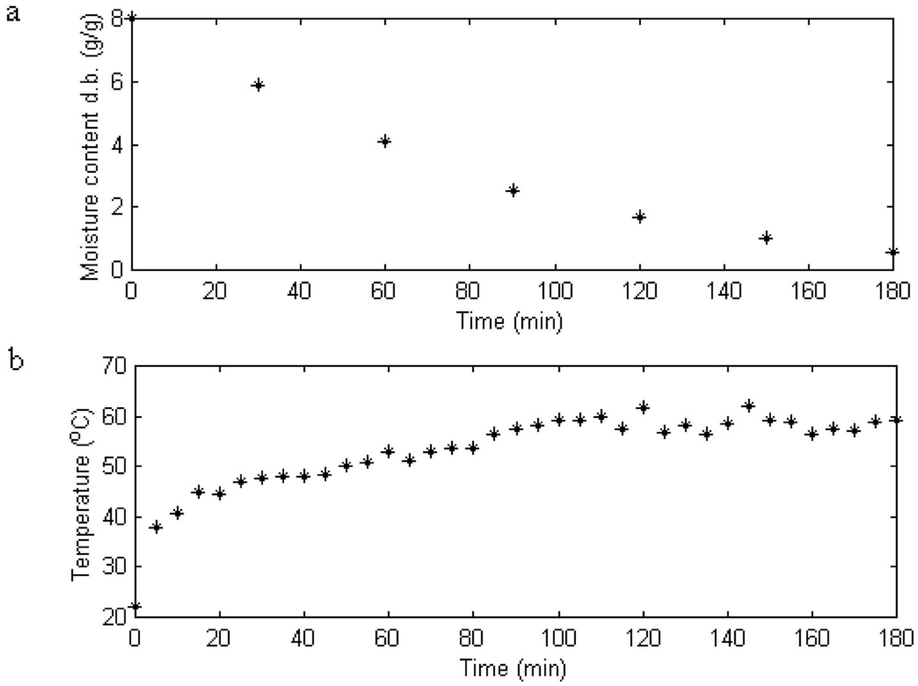

Fig. 4. (a) Moisture content; (b) temperature during the convective drying conducted at 60 °C after the osmotic treatment carried out with a temperature solution of 50 °C without agitation.

Table 4
Heat and mass transfer coefficients.

Process	Conditions	h (W/m °C)	h_mw (m/s)	h_ms (m/s)	$D_{ef}w$ (m²/s)	$D_{ef}s$ (m²/s)
Osmotic treatment	30 °C, 0 cm/s	8.78	$4.23 \cdot 10^{-3}$	$5.37 \cdot 10^{-4}$	$8.22 \cdot 10^{-9}$	$1.81 \cdot 10^{-9}$
Osmotic treatment	30 °C, 4 cm/s	11.01	$5.54 \cdot 10^{-3}$	$7.03 \cdot 10^{-4}$	$4.16 \cdot 10^{-9}$	$9.41 \cdot 10^{-10}$
Osmotic treatment	50 °C, 0 cm/s	541.33	$2.18 \cdot 10^{-1}$	$2.76 \cdot 10^{-2}$	$4.37 \cdot 10^{-9}$	$3.38 \cdot 10^{-9}$
Osmotic treatment	50 °C, 4 cm/s	503.47	$2.53 \cdot 10^{-1}$	$3.21 \cdot 10^{-2}$	$2.03 \cdot 10^{-9}$	$1.99 \cdot 10^{-9}$
Osmo-convective drying	50 °C, 0 cm/s, 60 °C	6.0	$2.40 \cdot 10^{-2}$	–	$9.27 \cdot 10^{-11}$	–

During the convective drying, the moisture content was decreased from 7.99 to 0.56 g/g (Fig. 4a) and the sample temperature reached 60 °C after 100 min (Fig. 4b).

The thermophysical properties of yacon used in the computational simulation are described by the equations presented in Table 3, which were fitted to the experimental values obtained according to the methodology described in Section 3.3. The heat and mass transfer coefficients for the osmotic treatments and the complete osmo-convective drying process, obtained as described in Section 2.1, are presented in Table 4.

Comparison of experimental and simulation results are presented in the following sections. It can be seen that the numerical results obtained from COMSOL are in concordance with the experimental values for temperature (Fig. 5), moisture content (Fig. 6) and sucralose uptake (Fig. 7) for the osmotic treatment of yacon. The values illustrated in Fig. 5 correspond to the temperature on the edge of the slices and the results for moisture content (Fig. 6) and sucralose (Fig. 7) are the average for a whole slice. It is worth noting here that due to some limitations such as high cost and longer time requirement of the HPLC method, the content of sucralose was determined only at the beginning and the end of osmotic dehydration. Therefore, only two experimental values of sucralose uptake are presented in Fig. 7 for each process condition. Although the trend of the absorption process was not determined, the initial and final values are the same for numerical and experimental results. Fig. 7 also shows that, according to the simulation results, in about 30 min of osmotic treatment, there is a decrease in the rate of absorption of the osmotic agent, which is physically coherent, due to the decreasing concentration gradient over time and a possible tissue surface sealing resulting from the impregnation of osmotic agent in this region.

Fig. 8 presents the temperature and moisture content variation of the yacon slices during the convective drying. It can be seen that simulation results closely agree with experimental results. High correlation coefficients (R^2 of 0.9804 for moisture content and 0.9512 for temperature) further demonstrate the validity of the models. Slight differences between experimental and numerical results during drying can be attributed to the on-off temperature

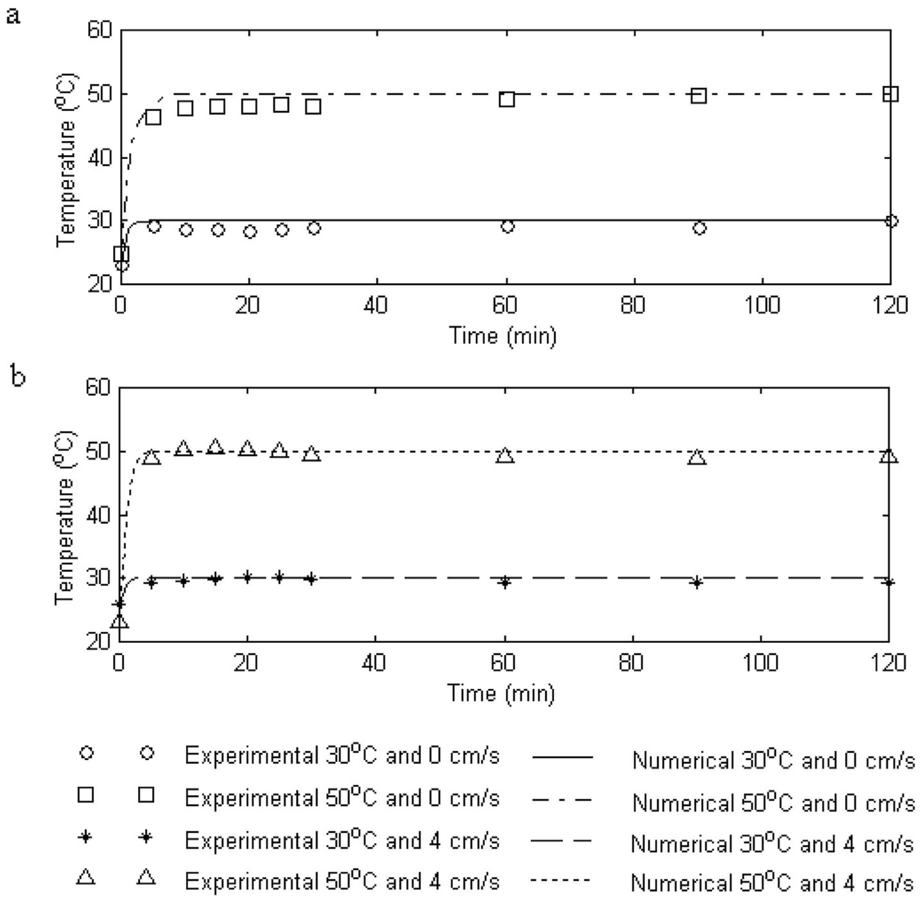

Fig. 5. Temperature of the yacon slices during the osmotic treatment conducted (a) without agitation, and (b) with an agitation rate of 4 cm/s.

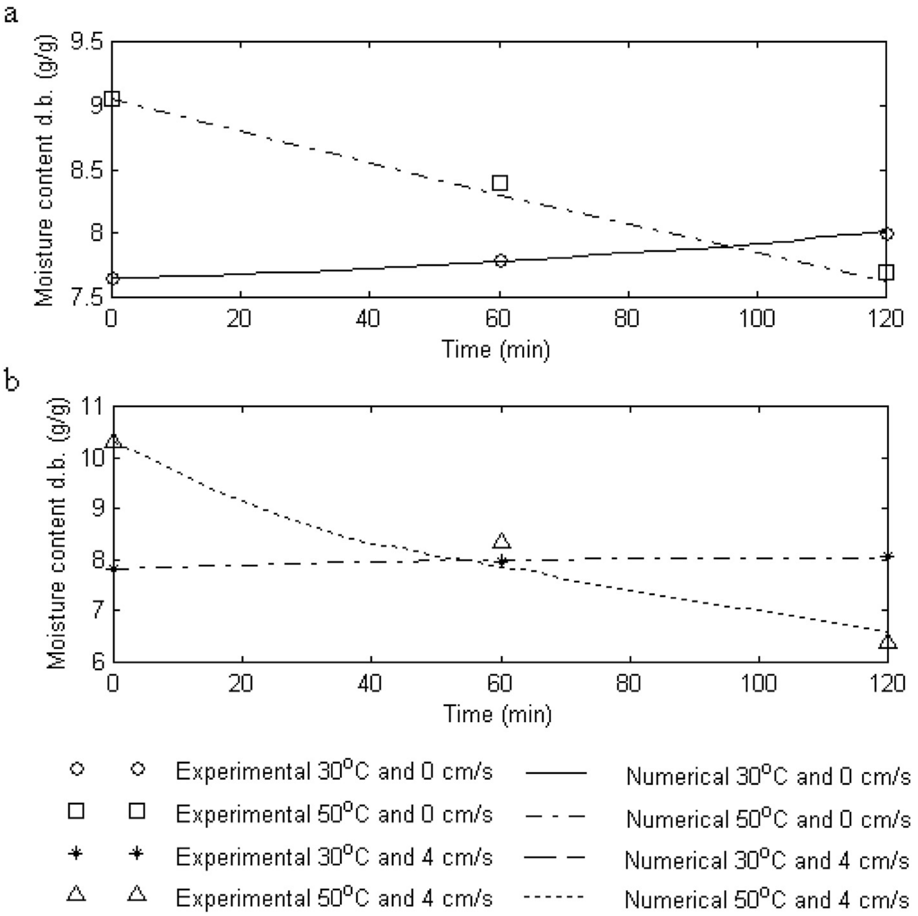

Fig. 6. Moisture content of the yacon slices during the osmotic treatment conducted (a) without agitation, and (b) with an agitation rate of 4 cm/s.

controller of the tray dryer. Because of this kind of control, there is a variation in the drying air temperature along the process, resulting in a heating profile of slices which is different than that obtained in an ideal condition, as predicted numerically.

The 2D numerical results for the osmo-convective drying process conducted at 50 °C, 0 cm/s (osmotic treatment) and 60 °C (convective drying) are presented in Figs. 9 and 10 respectively. It can be seen that after 2 h of osmotic treatment, the sample has not reached the equilibrium, i.e., the sample did not have a homogeneous moisture content (Fig. 9a) and sucralose concentration (Fig. 9b). In fact most part of the slice has substantially the same moisture content, between 8 and 7.5 g/g, and a very thin layer close to the surface had its moisture content reduced to various levels. Indeed, as indicated by Fig. 9a, overall reduction of moisture content during the osmotic dehydration was low. Fig. 9b indicates that the sucralose absorption occurred mainly on the product surface, which was sufficient to confer sweeter taste to dry yacon. The results are in concordance with the experimental values presented in Table 2, for which the average sucralose uptake for the whole slice is 16.82 ± 0.09 mg/g.

It can be seen that after 3 h of convective drying, there is still a moisture gradient between center and edge of the slice (Fig. 10), although he slice had reached to average moisture content of 0.56 g/g. The sample still did not reach the equilibrium moisture content (0.0129 g/g) but achieved the desired value of water activity (0.4) within this period. It demonstrates that there remains a substantial moisture gradient inside the sample until the end of drying period.

The numerical results were validated by the experimental data, therefore the computational simulation of the model developed can be used to test new experimental conditions, assisting in the design and optimization of the process studied, targeting to decrease time and costs with laboratory tests. Considering that the centesimal composition of yacon assumes similar values between roots from different regions and kinds of cultivars (Table 5), and that two drying techniques were used in this work (osmotic treatment and convective drying) the model developed, which uses specific thermophysical properties, can benefit other researches on thermal processing of this product.

5. Conclusions

By applying the process of osmo-convective drying, it is possible to reduce the moisture content of yacon and provide it a sweeter flavor. Heat and mass transfer model for the osmo-convective drying of yacon developed in this study provides a good prediction of temperature and moisture distribution and sucralose contend in the material. As predicted values from the model agree closely with experimental values, mathematical formulation and the related assumptions are considered reasonable to describe osmo-convective drying. High correlation coefficients (R^2 of 0.9804 for moisture content and 0.9512 for temperature) further demonstrate the validity of the models. This model represents an important tool in the design and optimization of the processes as it can be used to test new experimental conditions, targeting to decrease time and costs involved in laboratory tests. Experimentally determining profiles of moisture content and specially of osmotic agent are expensive and time consuming, however they are needed in the design and optimization of a convective-drying process since they

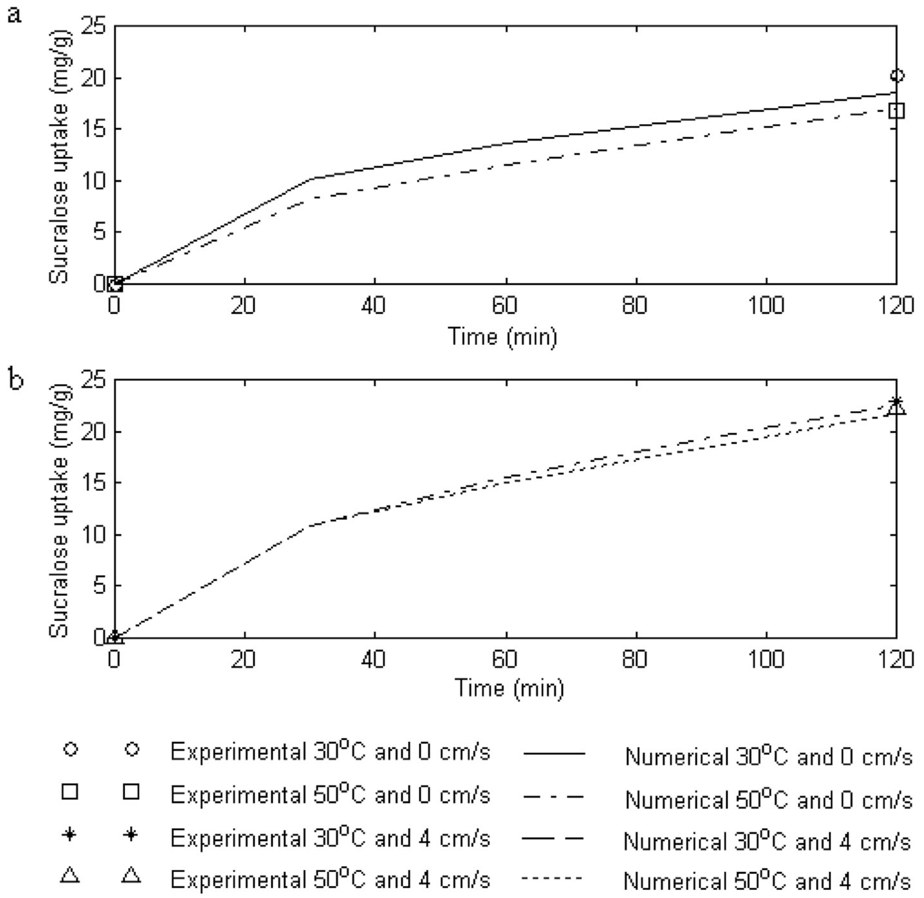

Fig. 7. Sucralose uptake of the yacon slices during the osmotic treatment conducted (a) without agitation, and (b) with an agitation rate of 4 cm/s.

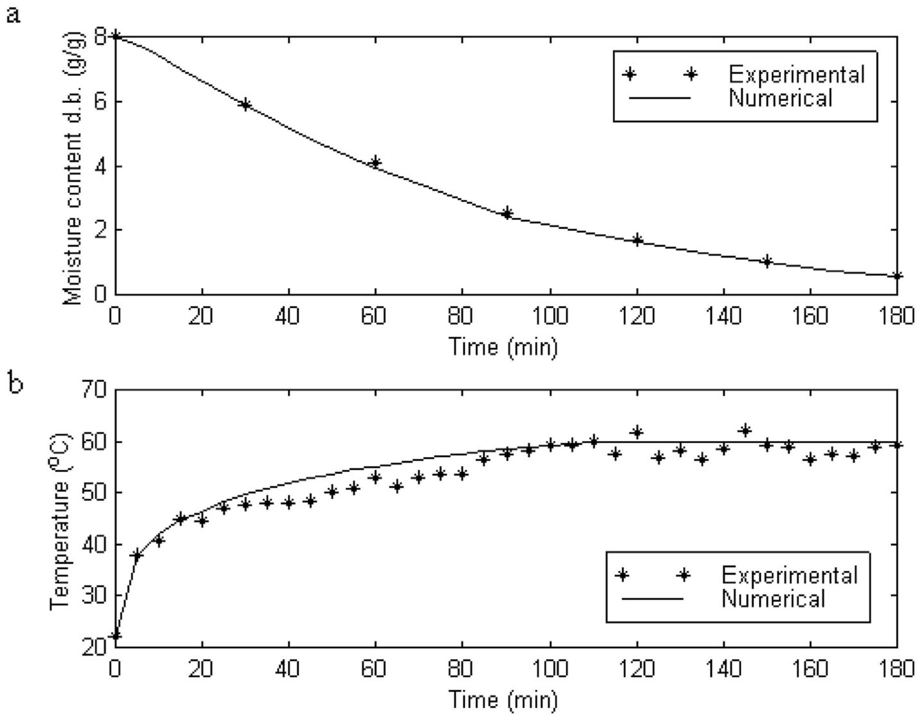

Fig. 8. (a) Moisture content; (b) temperature during the convective drying conducted at 60 °C after the osmotic treatment carried out with a temperature solution of 50 °C without agitation.

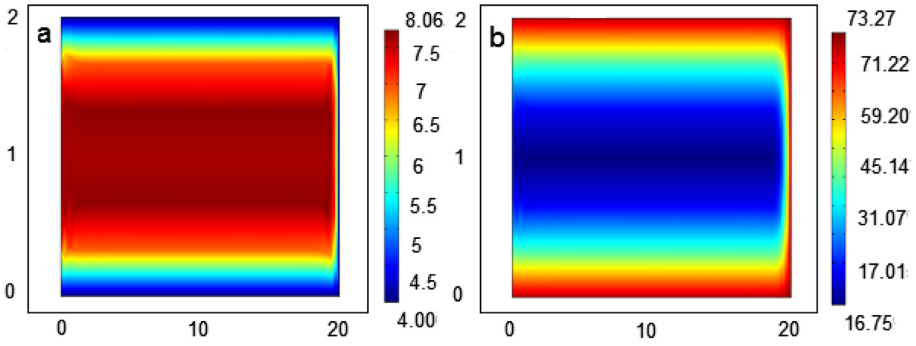

Fig. 9. Profiles of (a) moisture content (g/g) profile and (b) sucralose uptake (mg/g yacon) at the end of the osmotic treatment conducted at 30 °C and 0 cm/s.

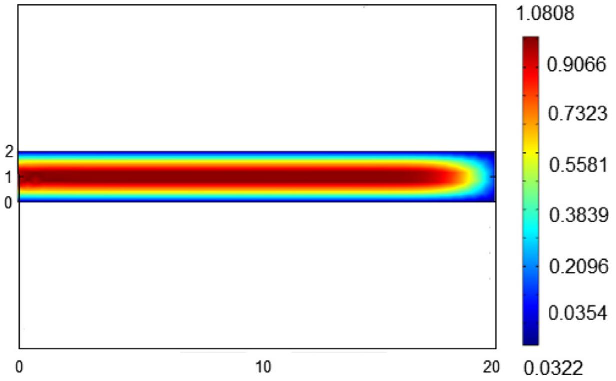

Fig. 10. Profile of moisture content after the convective drying conducted at 60 °C.

Table 5
Centesimal composition of yacon *in natura*.

Component	Perussello et al. [9]	Kotovicz [32]	Michels [33]	Moura [34]	Hermann and Freire [35]
Moisture content w.b. (%)	89.85 ± 4.18	88.68 ± 1.02	89.8 ± 1.92	90.63	86.4–90.2
Proteins (%)	0.53 ± 0.06	0.26 ± 0.12	0.45 ± 0.03	0.33	0.3–0.5
Fats (%)	0.57 ± 0.30	0.07 ± 0.04	0.06 ± 0.01	<0.10	0.1–0.5
Minerals (%)	0.31 ± 0.05	0.34 ± 0.00	0.34 ± 0.02	0.39	ND
Total carbohydrates (%)	8.88 ± 4.33	ND	ND	ND	ND
SSC (°Brix)	10.01 ± 1.62	12.16 ± 2.38	9.31 ± 0.93	9.5	ND

Note: SSC = soluble solids concentration, ND = not determined.

influence the sensorial and microbiological attributes of the dried product. Considering that the model is based on a theoretical approach, it can be used for simulating osmotic dehydration and convective drying of other foodstuff with the adequate adaptations, i.e. specific thermophysical properties and coefficients of heat and mass transfer. The osmotic dehydration models applied both to water and osmotic agent transfer existent in the literature are empirical, consisting of equations fitted to experimental data, therefore only valid for identical process conditions. Present study overcomes this limitation.

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