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Mathematical Model with Shrinkage of an Eggplant Drying Process

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In this paper, the effect of a pretreatment on an eggplant drying process is investigated by using a suitable developed mathematical model with shrinkage. The objective is to assess the role of volume variation due to changes in pore structures in the dehydration processes. Parameters assessing eggplant quality are also taken into account and collected both with and without pretreatment. The built model is used to analyze evolutions of dehydration processes carried out at two temperatures to provide evidences of the advantages of using pretreatment to assure high quality of end products.

1. Introduction

Dehydration technologies found their main application in the field of vegetables conservation since vegetables are often marketed dehydrated. One of the most representative food products in which dehydration is suitable applied is eggplant. They found their main application as dehydrated ingredients in dehydrated food mixture used for example in dried soups preparation. Many efforts in this field are directed towards the investigation of the dehydration process to understand the best conditions assuring high food quality. The main objective to be reached theoretically is to keep almost constant the nutritional and sensorial properties of foods in a dehydration/re-hydration cycle. This is a serious issue as in practice these operations lead unavoidably to material deterioration due mainly to the dehydration process itself. Research interests are therefore addressed to understand the dehydration mechanism to improve end products quality. Several studies investigating dehydration processes of vegetables for industrial purpose are in fact available in literature (Hernando et al., 2008; Panchariya et al., 2002). Moreover, several studies are carried out using mathematical models, useful to highlight the processes as conditions change. Togrul and Pelhivan (2003), for example, analyze the drying behavior of apricots varying flow rate and temperature, testing several drying experimental models, while Akpinar et al. (2003) study the single layer drying behavior of potato slices using a pure Fickian equation.

In this paper we develop a mathematical model to analyze the role of volume variation due to changes in pore structures in a dehydration process of eggplants slices at constant

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temperatures and to establish how such changes are influenced by an innovative pretreatment under patenting. Pretreatment consists of a dipping in an aqueous solution. The theoretical mathematical model includes a dependence of the diffusion coefficient from the water content to take into account the change of porosity due to shrinkage. Model parameters are obtained by means of a suitable developed nonlinear regression procedure. Finally, a quality analysis is also reported. In particular, the effect of pretreatment on material structural changes are highlighted by means of SEM analysis and the global improvement achieved through the pretreatment is assessed through the analysis of color indexes.

2. Materials And Methods

2.1 Experimental design

Drying experiments are conducted on Eggplants (Solanum Melongena) cv. Longo. Vegetables are washed with distilled water and peeled. Cylindrical slices with diameters of 30 mm and thickness of 6 mm are prepared sampling randomly the material from the whole vegetable using a suitable steel mould and then cut using an electrical machine to obtain the desired thickness. The randomization allows neglecting the slight unavoidable differences in material structure which could invalidate the analysis.

Drying experiments are conducted at two temperature values 50, 60°C, as they are selected as those provided best results on the basis of visual quality assessment. During dehydration experiments eggplant slices are placed over a metal grating in a convective oven mod. Zanussi FCV/E6L3 operating at a fixed temperature. At suitable time intervals a slice is randomly removed from the oven and the weight loss was monitored by means of a digital balance mod. Gibertini E42, Italia. The procedure is repeated until the water content plateau was reached.

2.2 Mathematical model

A dehydration process is a complex process involving in general both mass and energy transfers. In our case, due to thickness value, it is allowed to assume that both the duration of thermal transient is far less than the duration of mass transport and the duration of mass transport along thickness is far less than the duration of mass transport along radius. This mean that the whole process may be regarded as taking place under isothermal conditions (as underlined in other works for example Di Matteo et al., 2002) and that the mass transport can be considered as evolving along slice thickness only (one-dimensional flow). Moreover, the material can be assumed to be homogeneous and isotropic due to randomization procedure adopted in sample preparation.

The equation describing mass balance, based on the Fick's law of mass diffusion, is the following:

$$\frac{\partial c}{\partial t}=\frac{\partial}{\partial x}\left[D\left(\alpha_1+\alpha_2\cdot c\right)\frac{\partial c}{\partial x}\right] \tag{1}$$

in which x is the space variable along slice thickness and t is the temporal variable. The variable c is the water content defined as: $c = \dfrac{\text{mass of removed water}}{\text{mass of removable water}}$.

The differential equation (Eq. 1) is solved using the following initial conditions (Eq. 2) and boundary conditions (Eq. 3):

$$c(x,0) = 1 \quad \forall x \in [-L, L] \tag{2}$$

$$\left.\frac{\partial c}{\partial x}\right|_{x=0} = 0 \quad t > 0$$
$$D(\alpha_1 + \alpha_2 \cdot c)\left.\frac{\partial c}{\partial x}\right|_{x=L} = K c|_{x=L} \quad t > 0 \tag{3}$$

In Eq. 3, the equilibrium condition linking the water content at both side of the interface between eggplant and environment is written in term of an overall mass transport coefficient depending on the c value at the interface.

The diffusion coefficient in Eq. 1 depends on the water content through a linear law (Wu et al., 2007) taking into account the changes in void fraction due to shrinkage, experimentally determined. Normalizing the experimental values respect to the initial void fraction value, the following relationship holds: $\alpha_1 = 1 - \alpha_2$. Thus the parameters to be determined are reduced to D, K, α_2 .

2.3 Quality analysis

The parameters taken into account to assess the effectiveness of the dehydration process are the surface color, chlorogenic acid content while microscope structure obtained by Scanning Electron Microscopy are here used to highlight the effect of pretreatment on material structural changes.

Surface color is obtained through a colorimeter Minolta Chroma Meter II Reflectance CR-300 (triple flash mode with aperture 10 mm). Hunter values L, a, b are collected and white index (WI) and the total color difference (ΔE) are determined through relations yet used in literature (Albanese et al., 2007).

3. Results And Discussions

3.1 Model's parameters calculation and discussion

The parameters values of the dehydration model with confidence intervals are reported in Table 1. They are calculated through a numerical procedure based on nonlinear regression methods. The procedure is based on the comparison between the diffusion equations solutions, obtained numerically by means of a finite difference method and the available experimental data for each temperature. The procedure is implemented in MatLab®. Although not reported, for parameters validation purpose, normalized residuals are also computed.

The developed mathematical model is able to describe with sufficient accuracy the isothermal dehydration processes with and without pretreatment. As an example, water content evolutions during time at 60°C are shown in Figure 1. In particular, both treated and untreated cases are reported.

Table 1: Calculated parameters of the dehydration model

		Dehydration			
T (°C)		Untreated		Treated	
		(Value$\cdot 10^5$)	(C. I. $\cdot 10^5$)	(Value$\cdot 10^5$)	(C. I. $\cdot 10^5$)
50	D (cm^2/s)	28.8	22.9 / 34.8	33.1	21.1 / 45.1
	K (cm/s)	47.8	44.6 / 51.0	34.4	29.7 / 39.0
	α_2	-62770	-65600 / -59900	-46980	-67900 / -26000
60	D (cm^2/s)	43.7	37.6 / 49.8	48.4	39.6 / 57.2
	K(cm/s)	78.7	67.1 / 90.3	54.3	50.3 / 58.2
	α_2	-60880	-64290 / -57470	-46740	-52110 / -41370

As can be easily observed, treated eggplants show a higher dehydration rate respect to untreated ones. This is essentially due to the yet underlined effect of the treatment of maintaining food structure during time. Further evidence is provided by the comparison of the α_2 values: at fixed water content higher values of the absolute value of α_2 imply higher void fractions. This represents one of the most important effect of the adopted pretreatment, from the industrial point of view, both because it reduces process operating time and because, limiting shrinkage, it lead to higher end product quality production. We underline that the model is able to determine such differences.

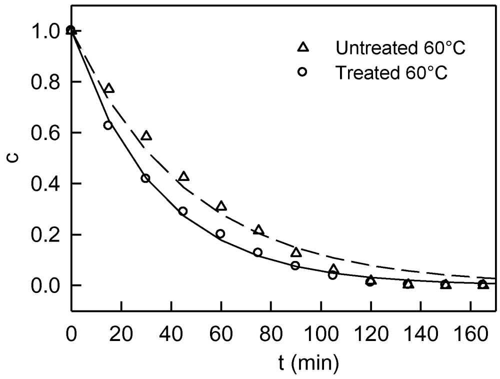

Figure 1: Experimental and theoretical water content evolution for untreated and treated eggplants at 60°C.

3.2 Experimental results

The developed mathematical model assesses differences in void fraction during evolution during dehydration process of untreated and treated samples. Such differences are confirmed by SEM images analysis. In Figure 2, SEM images (50x magnitude) of both untreated (left) and treated (right) dried tissues are reported. In particular, such figure refers to dehydration processes carried out at 60°C.

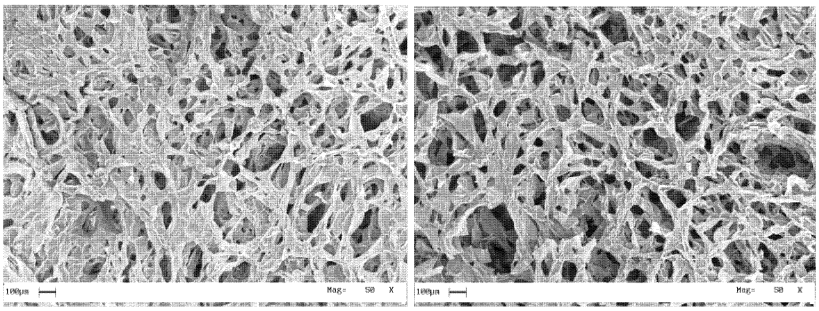

Figure 2: SEM of untreated (left) and pre-treated (right) eggplant tissue dried at 60°C.

Treated tissues exhibit larger pore size than untreated one. This means a reduced collapse of pores, which confirm the model prediction. The same effect is observed for eggplant samples dried at 50°C. The reduced structural changes have positive effect also on dehydration rate, as demonstrated by the diffusion coefficient values reported in Table 1. From a technological point of view, the adopted pretreatment, reducing shrinkage phenomena, in all the temperature conditions analyzed, contribute to improve end product quality.

The global improvement due to pretreatment can be briefly underlined in the following. Browning is one of the most important phenomena occurring during drying processes. The capability of slowing it down represents a key element for food industries to improve the overall quality of their products. In order to evaluate the magnitude of browning during drying tests at 50, 60 and 70°C and the effectiveness of pretreatment at the same temperatures, the WI and ΔE of fresh and dried eggplant samples are evaluated in Figure 3. In the case of untreated dried eggplant samples, data collected at the examined temperatures highlighted the significant chromatic changes occurring for both color parameters. In contrast no significant differences are observed for pretreated eggplant samples.

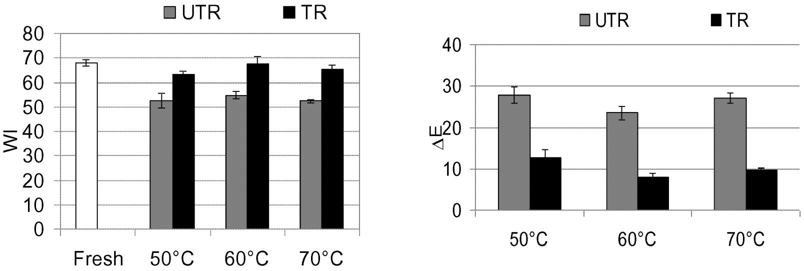

Figure 3: Color parameters whiteness index WI (a) and ΔE (b) of treated and untreated dried eggplant samples at 50, 60 and 70°C.

4. Conclusions

In this paper a mathematical model of an improved eggplants dehydration process has been developed. The innovative process consists in a suitable pretreatment applied to fresh eggplants. The diffusive mathematical model takes into account shrinkage phenomena through the introduction of a diffusion coefficient which depends on the water content. Model's parameters are calculated on the basis of a developed numerical algorithm based on nonlinear regression procedures. Through the model it is possible to quantify the contribution of the pretreatment in reducing shrinkage phenomena, which has also the secondary effect of accelerating dehydration. This is important from a technological point of view as food manufacturers are always interested to better products in less time. The result is confirmed through experimental SEM and color indexes analyses.

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