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IMPROVED EGGPLANT DRYING: MATHEMATICAL MODELLING AND QUALITY ASSESSMENT

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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 analyze 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 varying temperature 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 mixtureused 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 theoretically reached is to keep almost constant the nutritional and sensorial properties of foodsin a dehydration/re-hydration cycle. This is a serious issue as in practice these operations lead unavoidably to material deteriorationdue 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 (e.g. Hernando et al., 2008; Panchariya et al., 2002). Moreover, many among them 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 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 and chlorogenic acid content.

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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 three temperature values 50, 60 and 70°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:

$$\frac{\partial c}{\partial t} = \frac{\partial}{\partial x}\left[D_{eff}\frac{\partial c}{\partial x}\right] \tag{1}$$

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: $c = \frac{\text{mass of removed water}}{\text{mass of removable water}}$.

To take into account the changes in void fraction due to shrinkage, experimentally determined, a dependence of the effective diffusion coefficient D_{eff}in Eq. 1 on the water content through a linear law (Wu et al., 2007) is introduced. Thus, Eq. 1 becomes:

$$\frac{\partial c}{\partial t} = \frac{\partial}{\partial x}\left[D\left(\alpha_1 + \alpha_2 \cdot c\right)\frac{\partial c}{\partial x}\right] \tag{2}$$

Normalizing the experimental values respect to the initial void fraction value, the following relationship holds: $\alpha_1=1-\alpha_2$.

The differential equation (Eq. 2) should be solved using the following initial conditions (Eq. 3) and boundary conditions (Eq. 4):

$$c\left(x,0\right) = 1 \quad \forall x \in \left[-L, L\right] \tag{3}$$

$$\begin{aligned} &\left.\frac{\partial c}{\partial x}\right|_{x=0} = 0 \quad t > 0 \\ &D\left(\alpha_1 + \alpha_2 \cdot c\right)\left.\frac{\partial c}{\partial x}\right|_{x=L} = h\left(\frac{c|_{x=L}}{G} - c_\infty\right) \quad t > 0 \end{aligned} \tag{4}$$

The equilibrium distribution curve relating water content at eggplant/outer environment interface is assumed to be linear and characterized by an equilibrium constant *G*. Moreover, the water diffusion in the gaseous film around the slice is described through a convective mass transfer coefficient *h*. Assuming that $c_\infty$is negligible respect to *c*, the boundary conditions can be rewritten as follows:

$$\left.\frac{\partial c}{\partial x}\right|_{x=0} = 0 \quad t > 0$$
$$D\left(\alpha_1 + \alpha_2 \cdot c\right)\left.\frac{\partial c}{\partial x}\right|_{x=L} = K\left. c\right|_{x=L} \quad t > 0 \qquad (5)$$

In Eq. 5, 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 term depending on the *c* value at the interface through the coefficient *K*.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 andthe chlorogenic acid content while the microscopic structure obtained by Scanning Electron Microscopy are here usedto 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).

Chlorogenic acid content is determined by HPLC method using an *Agilent* model *1100* series coupled with a refraction index detector and a *Phenomenex LunaC18 25μm* column (*250*4.6 mm)*. Homogenized eggplant material (*1 g*)is dissolved into *20 ml* of pure methanol. Tubes are centrifuged (*3000 r.p.m* for *15 min*), and the clear supernatant was collected. The mobile phase used is a solution of acetic acid (*6%*) and pure acetonitrile. A suitable gradient is adopted, according to a literature procedure (Luthria et al. 2006). Chlorogenic acid is detected by reading the absorbance at*280 nm*.

The microstructure of eggplant samples are evaluated by visual inspection through a *Scanning Electron Microscope LEO 420 2.04* model. Before scanning, samples are coated with gold by means of a metallization process lasting *150s* using an *Agar Auto Putter Coater 108A* model (England).

3. RESULTS AND DISCUSSIONS

3.1 Model's parameters calculation and discussions

The parameters values of the dehydration model are reported in Table 1together with confidence intervals.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 and it is implemented in MatLab®.

Table 1: Calculated parameters of the dehydration model

T (°C)	Untreated (Value·10^5)	C. I. (Value·10^5)	Treated (Value·10^5)	C. I. (Value·10^5)
50	*D*(cm^2/s)	28.8	22.9 /34.8	33.1
	K (cm/s)	47.8	44.6/51.0	34.4
	α_2	-62770	-65600 / -59900	-46980
60	*D*(cm^2/s)	43.7	37.6 / 49.8	48.4
	K(cm/s)	78.7	67.1 / 90.3	54.3
	α_2	-60880	-64290 / -57470	-46740

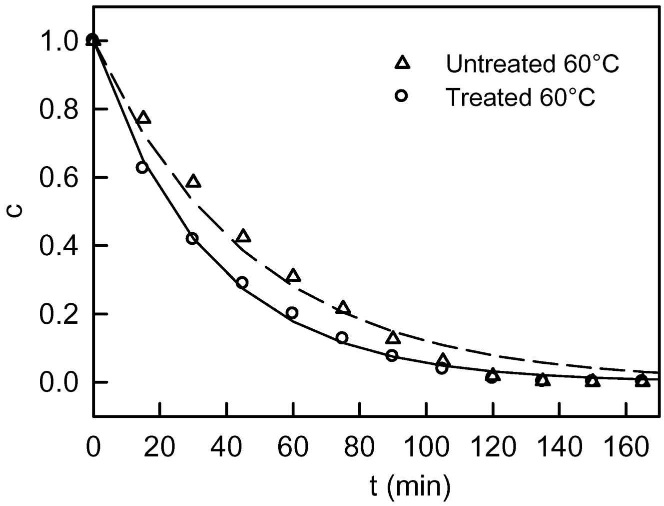

Fig. 1: Experimental and theoretical water content evolution for untreated and treated eggplants at 60°C.

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 Fig. 1. In particular, both treated and untreated cases are reported.

As can be easily observed, treated eggplants show a higher dehydration rate respect to untreated ones. This is, in our opinion, essentially due to the effect of the treatment of maintaining food structure during time. Further evidence is provided by the comparison of the α2 values: at fixed water content higher values of the absolute value of α2 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.

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.

Treated tissues exhibit larger pore size than untreated ones. 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.

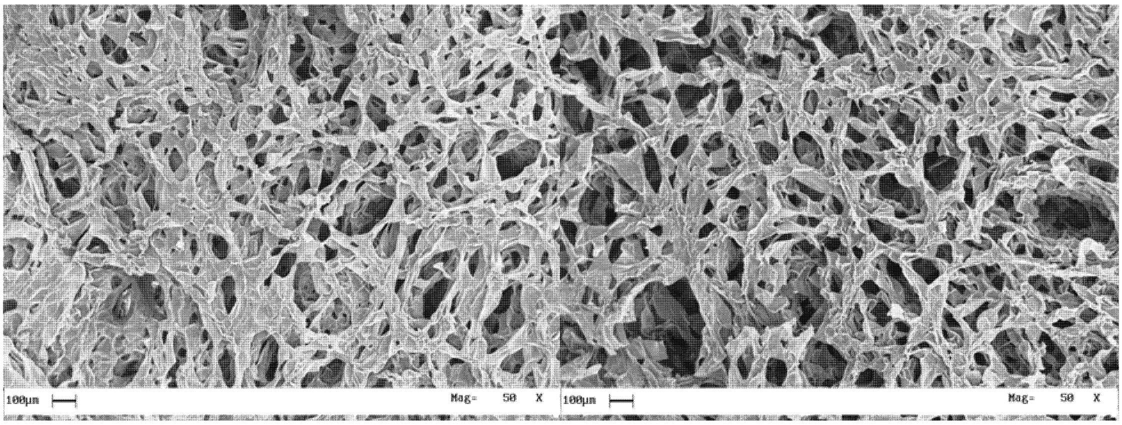

Fig. 2: SEM of untreated (left) and pre-treated (right) eggplant tissue dried at 60°C.

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 Fig. 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.
Similar trends are observed for chlorogenic acid content (Fig. 4) at *50* and *60 °C*. Compared to fresh samples, untreated ones show a decrease of about *33%* in chlorogenic acid content. Hence, the pretreatment is able to preserve phenols content only in the temperature range of *50-60°C*. On the other hand, no differences in chlorogenic acid content between untreated and treated eggplants are observed at *70°C*, showing in both cases a decrease respect to fresh samples of about *42%*.

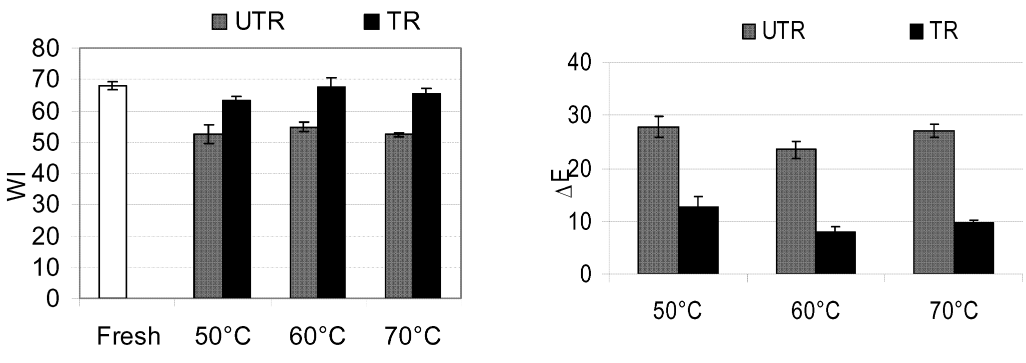

Fig. 3: Color parameters whiteness index WI (a) and ΔE (b) of treated and untreated dried eggplant samples at 50, 60 and 70°C.

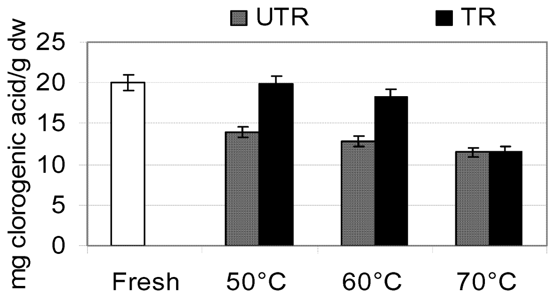

Fig. 4: Chlorogenic acid content in treated and untreated dried eggplant samples at 50, 60 and 70°C.

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 have been calculated on the basis of a developed numerical algorithm based on nonlinear regression procedures. Through the model it has been possible to quantify the contribution of the pretreatment in reducing shrinkage phenomena, which has been also the secondary effect of accelerating dehydration.This is important from a technological point of view as food manufacturers are always interested to obtain better products in less time. The result is supported by SEM analysis. The global improvement of end-product quality due to the pretreatment has been also confirmed through the experimental analysis, which has been shown both the reduction of browning phenomena and the preservation of chlorogenic acid content.

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