HIGH HYDROSTATIC PRESSURE AS A PRETREATMENT OF ALOE VER A GEL DEHYDRATION: ESTIMATION OF WATER DIFFUSION COEFFICIENT AND WEIBULL MODELLING

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Abstract: Impact of high hydrostatic pressure, blanching, enzymatic and microwaves on the drying kinetics of A. vera gel was investigated during convective hot-air drying at 70°C. Modeling of drying curves was studied by means of selected mathematical models such as Page, Modified Page and Weibull distribution. Among them, the Weibull model provided the best fit for the experimental data. All pretreatments increased the water diffusion coefficient compared to the control sample. Microwaves followed by high hydrostatic pressure presented the fastest drying rates. Based on these results, HHP prior to convective drying offers the chance of producing dried A. vera gel with required final water content optimizing process time.

Keywords: Weibull, Drying kinetics, High pressure, Aloe vera gel.

INTRODUCTION

A. vera (Aloe barbadensis Miller) belongs to the Liliaceae family. The gel of the plant has traditionally been employed by man for its content of substances having healing as well as therapeutic and functional properties. Dehydration is a classical method of food preservation, which involved removing of water in the solids up to certain level, in order to greatly minimized microbial spoilage and chemical reactions (Akpinar 2006). However, drying can cause undesirable changes in the quality of the dried product. Therefore, the combination of drying with different pretreatments has been suggested by many authors in order to not only reduce process time but also to enhance quality of dehydrated food (Corzo et al. 2008). During pretreatments, changes occur in the cell membranes which play a key role in the changes that occur within the tissue during further processing.

In addition, in order to control and optimize the drying process, it is necessary to use mathematical equations to simulate water transport phenomena, particularly diffusion and external resistance which are the fundamental mechanisms governing food dehydration. Although most of these models are empirical (Page, Modified Page and Weibull), they are mainly based on Fick’s second law of diffusion (Akpinar 2006). In particular, the standardized Weibull model can be applied in many biological systems, and it was found valuable in the modeling of dehydration-rehydration phenomena mainly for differentiating between diffusion and external resistance processes (Corzo et al. 2008).

The aim of this work was to study the effect of the application of several pretreatments such as enzymatic, blanching, microwaves and high hydrostatic pressure on the A. vera gel drying kinetics at 70°C. Moreover, simulation of experimental data was achieved by means of selected mathematical equations.
MATERIALS AND METHODS

Pretreatments and drying conditions

*A. vera* leaves were provided for Ini-Inihuasi, Coquimbo, Chile. The epidermis was separated from the gel. Then, fresh samples were subject to four different pretreatments prior to dehydration at 70°C: FRE samples were dehydrated without any pretreatment. ENZ samples were immersed in an enzymatic solution 0.8 g/100 g solution at 50°C for 30 min. BLA samples were blanched in hot water at 80°C in a water bath for 1 min. MIC samples were dried in a microwave oven at 1500 W for 30 s. HHP samples inside polyethylene bags were pressurized in an isostatic pressing system at 350 MPa for 30 s. Water was the pressurizing medium at room temperature.

Mathematical modeling

In order to study the mass transfer during drying of *A. vera* gel samples, Fick’s second law of diffusion was used. For sufficiently long drying times and one-dimensional slab geometry Eq. (1) was applied (Crank, 1975). From this equation, water diffusion coefficient ($D_{we}$, m$^2$/s) can be obtained for each working temperature.

$$\frac{X_{wt} - X_{wo}}{X_{we} - X_{wo}} = \frac{8}{\pi^2} \exp \left( -\frac{D_{we} \pi^2 t}{4L^2} \right)$$  

Where, $X_{wt}$ is the moisture content (g water/g dry matter), $X_{wo}$ is the initial moisture content (g water/g d.m.), $X_{we}$ is the equilibrium water content (g water/g d.m.), $t$ is the drying time (s) and $L$ is the product thickness (m).

Experimental drying curves were modeled using selected equations shown in Table 1 (Akpinar, 2006). The lowest value of statistical test (Eq. 5) was selected as optimal criterion to evaluate the fit quality of the proposed models.

![Graph showing drying curves](https://example.com/drying-curves.png)

Fig. 1. Experimental and Weibull-simulated drying curves (solid line) of Aloe gel at 70 ºC for each pretreatment: FRE (◊), ENZ (□), BLA (ŀ), MIC (○) and HHP (+).

<table>
<thead>
<tr>
<th>Model</th>
<th>Equation</th>
<th>$N^\circ$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Page</td>
<td>$MR = \exp \left( -kt^n \right)$</td>
<td>(2)</td>
</tr>
<tr>
<td>Modified Page</td>
<td>$MR = \exp \left( -\left( \frac{t}{n} \right)^k \right)$</td>
<td>(3)</td>
</tr>
<tr>
<td>Weibull</td>
<td>$MR = \exp \left( -\left( \frac{t}{n} \right)^{\frac{1}{k}} \right)$</td>
<td>(4)</td>
</tr>
<tr>
<td>Chi-square</td>
<td>$\chi^2 = \sum_{i=1}^{N} \left( \frac{MR_{exp,i} - MR_{calc,i}}{N} \right)^2$</td>
<td>(5)</td>
</tr>
</tbody>
</table>

Where, $MR_{exp,i}$ is the experimental moisture ratio, $MR_{calc,i}$ is the calculated moisture ratio, $N$ is the number of data values, $k$ is the kinetic parameters (min$^{-1}$), $n_i$ is the empirical parameters (dimensionless).

RESULTS AND DISCUSSION

Estimation of water diffusion coefficient

The initial water content of *A. vera* gel was 72.4±2.5 g/g d.m. Fig. 1 shows the drying curves obtained experimentally for the applied pretreatments. All pretreatments decreased considerably the drying time of control samples (300 min). HHP and MIC pretreatments presented the lower processing times compared to untreated samples. Similar behaviors were reported in dehydrated peach slices and bananas (Dandamrongrak et al., 2003; Kingsly et al., 2007). Fig. 1 also shows a clear exponential tendency of moisture ratio with drying time indicating that application of proposed models (Table 1) is highly recommended.

The $D_{we}$ reaches a maximum value of 11.15x10$^{-10}$ m$^2$/s for MIC pretreatment and a minimum value of 7.30x10$^{-10}$ m$^2$/s for FRE. The $D_{we}$ for the rest pretreatments were 7.35x10$^{-10}$ m$^2$/s for ENZ, 8.75x10$^{-10}$ m$^2$/s for BLA and 8.90x10$^{-10}$ m$^2$/s for HHP. Results show a clear influence of pretreatments on the $D_{we}$ in the *A. vera* gel samples. From the ANOVA, significant differences for each pretreatment were observed (p-value < 0.05).
Modeling of drying kinetics

Table 2 and 3 show the average values and standard deviation of the kinetic and empirical parameter $k_i$ ($i = 1, 2$ and $3$) and $n_i$ ($i = 1, 2$ and $3$), obtained for all the proposed drying models. Values of $k$ ranged from 0.0034 to 1.3070 min$^{-1}$ and values of $n$ ranged from 1.1782 to 87.92. In some models there was a clear positive increase of $k_i$ values with the pretreatment used in comparison to control sample, while the $n_i$ values remained relatively unchanged. A p-value>0.05 was obtained from the ANOVA on the averages of parameters $n_i= 1, 2$ and $3$ suggesting that there was no significant influence of the treatment used on these empirical parameters. The same statistical evaluation (ANOVA) was carried out on the averages of the kinetic parameters of Table 1, 2 and 3 ($k_i=1, 2$ and $3$), obtaining a p-value<0.05, which suggests a significant influence of the pretreatment used on these kinetics parameters.

Statistical test of models

Table 2, 3 and 4 show the values of the statistics test ($\chi^2$) performed to the proposed models. According to these results the model that best fitted the experimental data was the Weibull model ($\chi^2<0.0009$). Good modeling was also shown halfway through the drying process, which is a result not given by many models, since the middle stage of the drying process is the segment, where most of the water is removed from the food, requiring a good simulation prior to the beginning of the water vapor diffusion, which requires the greatest drying time (Corzo et al. 2008).

CONCLUSIONS

The results of this study demonstrate that all pretreatments significantly increased the drying rate of A. vera gel at 70ºC. Regarding to drying times, HHP and MIC pretreatments presented the lowest times (200 and 180 min) compared to control samples (300 min). The water diffusion coefficients of pretreated samples were higher than untreated samples. When simulating experimental drying curves with different mathematical models, the Weibull model showed the best fit ($\chi^2<0.0009$). Taking into account all these considerations, the use of HHP pretreatment is highly recommended before drying to obtain a final dried A. vera gel optimizing operation time.

REFERENCES