Influence of Drying Temperature on Drying Kinetics and Physico-Chemical Properties of Two Chestnut Varieties (*Castanea sativa* Mill.)

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**Abstract**

The convective air-drying of two chestnut varieties was evaluated in a laboratory drying oven, at different drying air temperatures (40, 50, 60 and 70°C) and airflow velocities of 2.80 m s⁻¹. The drying kinetics were compared and the effect of different air-drying temperatures on colour stability, effective diffusivity and starch digestibility was analysed. The two varieties of chestnut used in this study were of the type *Castanea sativa* (Istrian marron and Italian chestnut).

The kinetic equations were estimated using an exponential mathematical model (Page). The results of the estimation have exhibited correspondence to the experimental results. The rate constants, $k$ and $n$, of the exponential and Page’s model for thin-layer drying were established by regression analysis of the experimental data which were found to be affected by drying air temperature. It can be seen that a good agreement between the experimental data and the chosen mathematical model (Page’s) exists, which is confirmed by high values of correlation coefficient (0.99) in all run.

The influence of temperature on the drying process is an important aspect and should be taken into consideration when choosing the optimal operation conditions. Results show that certain temperatures had a significant effect on the drying rates of chestnut. The drying air temperature significantly influenced the total drying time, which is strongly related to the total energy requirement for drying.

The values of effective diffusivity were found to vary in the range of $1.64 \times 10^{-9}$ to $7.88 \times 10^{-9}$ m² s⁻¹ for Istrian marron samples and in the range of $8.65 \times 10^{-10}$ to $4.40 \times 10^{-9}$ m² s⁻¹ for Italian chestnut samples.

Colour change of both varieties was generally increased with the increase of the drying temperature, with the exception of Istrian marron, where colour change was larger after drying at 50°C than after drying at 60°C (probably due to longer exposure to elevated temperature).

Digestibility of starch, determined by AOAC 2002.02 method, was increased by drying for both chestnut varieties (Istrian marron and Italian chestnut).

**INTRODUCTION**

The agriculture producer is constantly confronted with the challenge of improving the product quality and quantity. Indeed, this cannot be done without investment in more and more complicated methods and tools that lead to increasing energy consumption and production (Bennamoun and Belhamri, 2003; Mayor and Sereno, 2004).

The post-harvest losses of agricultural products can be reduced drastically by using proper drying techniques. The basic objective in drying agricultural products is the removal of water in the solids up to a certain level, at which microbial spoilage and deteriorating chemical reactions are greatly minimised. The other advantages of dried product are minimized packaging requirements and lower shipping costs as a result of reduced weight (Sabarez et al., 1997; Velic et al., 2007). Food dehydration is still one of the most relevant and challenging unit operations in food processing although the art of food preservation through the partial removal of water content dates from several...
centuries ago. Chestnuts are, unlike other nuts, rich in starch, and low in fat and protein (Künsch et al., 2001). This characteristic is making chestnuts growingly important in the Mediterranean diet. Starch is a main energy source in the human diet. Recent studies show that, although humans have enzymes for digesting starch, not all starch is digested in the small intestine. Part of starch, called resistant starch (RS) passes through to the large intestine, where it acts as prebiotic and diet fiber (Haralampu, 2000; Topping et al., 2003; Sajilata et al., 2006). Therefore, RS is being recognized as a very important nutritive component.

Due to the large proportion of moisture and sugar content, enzyme activity and pericarp characteristics, the shelf-life of chestnuts is very limited (Correia et al., 2009). Therefore, chestnuts are frozen, cold stored or dried in order to extend their storage period.

During drying, many changes in food materials occur. Moisture exudates from food, properties of starch and other components are changing, non-browning reactions cause change in colour, etc. Most of the references on chestnut drying focus mainly on the drying process itself and only few on the effect of the drying temperature on fruit’s composition and properties.

The aim of this study was to examine kinetics of chestnut drying at different temperatures and to determine the influence of the different drying temperatures on starch digestibility and colour change of two chestnut varieties.

MATERIALS AND METHODS

Istrian marron was grown in Lovran, Croatia and Italian chestnut in Cazin, Bosnia and Herzegovina. Both chestnut varieties were harvested in 2006. Before drying, chestnut pericarp was peeled, chestnut with epicarp was treated with water vapour (100°C, 60 s), and then the epicarp was peeled off. The chestnut was cut in halves.

Dry matter content was determined by drying at 70°C/20 mbar until constant mass. The drying experiments were performed in a pilot plant tray dryer. The dryer was operated on the thermogravimetric principle. The dryer (Fig. 1) was equipped with controllers for controlling the temperature and airflow velocity. Air was drawn into the duct through a diffuser by a motor driven axial flow fan impeller. In the dryer tunnel there were carriers for trays with samples, which were connected to a balance. The balance was placed outside the dryer and continuously determined and displayed the sample weight. A digital anemometer at the end of the tunnel measured airflow velocity.

The dehydration kinetics of samples was determined by continuous recording of mass changes, temperature profile of material and drying media, as well as moisture profile using computer process control.

The drying temperatures for chestnut halves varied between 40, 50, 60 and 70°C at airflow velocity of 2.80 m s⁻¹.

Page’s exponential model successfully describes the drying kinetics of food materials (Simal et al., 2005; Wang et al., 2007; Singh et al., 2008). The authors also used this model to describe the changes of moisture content and drying rates. To avoid some ambiguity in results due to differences in initial sample moisture, the sample moisture was expressed as dimensionless moisture ratio (X' = X(t)/X₀). The drying curve for each experiment was obtained by plotting the dimensionless moisture of the sample vs. the drying time. For approximation of the experimental data and calculating drying curves (Eq. 1) the simplified model was used, as follows:

\[ X'(t) = e^{(kt^n)} \]  

(1)

The parameters k and n were calculated by non-linear regression method (Quasi-Newton) using Statistica 6.0 computer program. The correlation coefficient (r²) was used
as a measure of model adequacy.

Fick’s second law can be used to describe the drying behaviour of chestnut samples. The simplified method (Velic et al., 2004) was used to determine the effective diffusion coefficient. For a thin plate the solution of Fick’s law of diffusion, with assumptions of moisture migrating only by diffusion, negligible shrinking, constant temperature and diffusion coefficients and long drying times, are given below (Baroni and Hubinger, 1998):

\[
\frac{X - X_e}{X_0 - X_e} = \sum_{n=0}^{\infty} \frac{8}{(2n + 1)^2 \pi^2} \exp \left( -\frac{D_{\text{eff}}(2n + 1)^2 \pi^2 t}{4\ell^2} \right)
\]

where \(X_e\) and \(X_0\) represent equilibrium and initial moisture contents, and \(\ell\) is the slab thickness. The value of the equilibrium moisture content is relatively small (low air relative humidity) compared to \(X\) or \(X_0\). Thus \((X - X_e)/(X_0 - X_e)\) is simplified to \(X'/X_0\) (dimensionless moisture ratio). Where sample thickness is small (halves samples) and drying time is relatively large, only the first term of Fickan’s solution series is needed, and equation (2) becomes:

\[
X' = a \cdot \exp(-K \cdot t)
\]

where \(K = \left(\frac{D_{\text{eff}} \pi^2}{4\ell^2}\right)\) is represent the slope of \(X'\) vs. \(t\) plotting on the semi-logarithmic diagram.

Resistant starch assay kit (Megazyme, Ireland) was used for analyses of RS content in chestnut. Before each analysis chestnut halves were grinded and sieved through a household sieve. Resistant starch content was determined by AOAC Method (2002.02). Briefly, the sample was incubated with pancreatic \(\alpha\)-amylase and amyloglucosidase (AMG) (37°C, 16h). Incubation was followed by multiple washing with ethanol, after which RS residue was melted in 2M KOH and incubated with AMG (50°C, 30 min). Resulting glucose was determined spectrophotometrically, after reaction with GOPOD (glucose oxidase - peroxidase - 4-aminoantipyrine) reagent (50°C, 20 min).

Colour was measured on cut surface of each nut before and after drying using Chromameter Konica Minolta CR-300, in CIELAB system.

RESULTS AND DISCUSSION

Moisture Content Determination

Dry matter content of fresh Italian chestnut was approximately 44%, and in Istrian marron approximately 53% (Fig. 2). These values are similar to those obtained by Correia et al. (2009) and De La Miguelez et al. (2004). As with Correia et al. (2009), increasing drying temperature increased the amount of water released from the product. The total moisture loss was somewhat more significant for IC variety, since it had higher starting moisture.

Drying Kinetics and Effective Diffusivity Study

In this study, the drying kinetics is greatly affected by the air temperature and material characteristic dimension, while all other process factors exert practically negligible influence. The influence of temperature on the drying process is an important aspect and should be taken into consideration when choosing the optimal operation conditions.

The kinetic equations were estimated using exponential mathematical model (Page). As seen in Figures 3 and 5, the Page’s equation adequately described the convective drying of chestnut samples over a selected range of drying air temperatures.
The results of the estimation have exhibited correspondence to the experimental results. The rate constants, \( k \) and \( n \), of the exponential and Page’s model for thin-layer drying were established by regression analysis of the experimental data which were found to be affected by drying air temperature. It can be seen that a good agreement between the experimental data and the chosen mathematical model (Page’s) exists, which is confirmed by high values of correlation coefficient (0.99) in all run. These results are in accordance with Simal et al. (2005) and Wang et al. (2008). It was observed that the total time of drying reduced significantly with the increase in the temperature of hot air.

The drying rate curves are presented with Figures 4 and 6. The results show that the temperature had a significant effect on the drying rates of chestnut samples. The drying rate constant \( (k) \) increased, in the range of 0.0136 to 0.0228 min\(^{-1} \) with the drying air temperature for Istrian marron samples and in the range of 0.0257 to 0.0563 for Italian chestnut samples. The results suggested that the Arrhenius law might be applicable to relate the dependence of the drying rate constant on drying air temperature.

As seen in Figure 7, with an increase of the airflow velocity an increase of heat transfer coefficient and effective diffusion coefficient was found. Similar results were obtained for the experimental conditions examined and are in accordance with results obtained for the same as well as other biological materials (Simal et al., 2005; Velić et al., 2007; Wang et al., 2008).

**Digestibility of Chestnut Starch**

Digestibility of starch in fresh and dried chestnut is shown in Figure 8. Total starch content of fresh Italian chestnut, determined by AOAC 2002.02 method, was 62.57% d.m. and of Istrian marron 66.13% d. m. These values are higher than total starch content determined by Ačkar et al. (2006) who reported an average content of 54.53% d.m. for *Castanea sativa* cultivars grown in western Bosnia and Pereira-Lorenzo et al. (2006) reported an average content of 57% for different chestnut varieties grown in different regions of Spain. However, De La Montana Miguelez et al. (2004) determined that starch content in chestnut varieties grown in Galicia, Spain varied between 56.74 and 81.7%. Drying temperatures generally caused decrease in total starch content. These results are in accordance with those of Attanasio et al. (2004) and Correia et al. (2009). According to these authors, thermal treatments cause formation of modified starch which is not detectable by the enzymatic test.

Digestibility of both chestnut varieties increased at all drying temperatures, with highest reduction of RS/total starch ratio at 50°C. According to Attanasio et al. (2004), \( \beta \)-amylase is highly active in chestnut. This enzyme hydrolyses \( \alpha-1,4 \)-bonds, but \( \alpha-1,4 \)-bonds located 2 or 3 units from the branch remain intact. Residue molecules, known as “limits dextrins” are formed, which are more easily digested by enzymes. However, treatment of chestnut with water vapour (100°C, 60 s) should inhibit activity of enzymes. It is possible that, since \( \beta \)-amylases are thermo stable enzymes, they keep residue activity due to short period of heat treatment.

**Colour Evaluation**

Colour of chestnut was measured in CIELAB system. Results, presented in table 1, showed high degree of lightness of both varieties (\( L^* \) values 89.22-90.28 for untreated IM and 87.82-88.56 for untreated IC). All drying temperatures reduced lightness of both varieties. Reduction of lightness was proportional to temperature increase for IC, while IM showed highest reduction of lightness at 50°C. Both varieties had predominant yellow color (positive \( b^* \) values as opposed to negative values, which indicate blue). Drying caused no change in yellow for IM, while yellowness of IC increased with drying.

Total color difference (\( \Delta E \)) for IC was proportional to increase of drying temperature and ranged between 5.75 at 40°C and 7.49 at 70°C. Generally, IM followed a similar trend (\( \Delta E \) 5.88 at 40°C to 8.87 at 70°C), with the exception of slightly higher \( \Delta E \) at 50°C (7.81) in comparison to \( \Delta E \) at 60°C (7.18).

Correia et al. (2009) measured colour of freshly milled chestnut flour after
chestnut drying. They observed that drying at 50 and 60°C resulted in similar ΔE values, which were higher than those observed after drying at 40 and 70°C. They also observed that darkness of flours increased with increase of drying temperature. Due to increase in a* values, which shifted closer to red area, as is case in this research, they concluded that this colour change was due to larger extension of caramelisation and Maillard reactions. Since a* values in this research still remain in negative domain, it can be stated that non-enzymatic browning is not significantly pronounced at either drying temperature.

CONCLUSIONS

With the increase of drying temperature the amount of excluded water from chestnut increases in both varieties.

The kinetic equations were estimated using an exponential mathematical model (Page). The results of the estimation have exhibited correspondence to the experimental results. It can be seen that a good agreement between the experimental data and the chosen mathematical model (Page’s) exists, which is confirmed by high values of correlation coefficient (0.99) in all run.

The influence of temperature on the drying process is an important aspect and should be taken into consideration when choosing the optimal operation conditions. Results show that certain temperatures had a significant effect on the drying rates of chestnut. The drying air temperature significantly influenced the total drying time, which is strongly related to the total energy requirement for drying.

The values of effective diffusivity were found to vary in the range of 1.64·10⁻⁹ to 7.88·10⁻⁹ m² s⁻¹ for Istrian marron samples and in the range of 8.65·10⁻¹⁰ to 4.40·10⁻⁹ m² s⁻¹ for Italian chestnut samples.

Digestibility of starch increases by drying, which is shown by reduction of RS/total starch ratio. While drying at 70°C causes least changes in RS/total starch ratio, drying at 50°C results in highest digestibility of starch at both varieties.

Change of colour of both varieties is generally increased with the increase of drying temperature. Exception is Istrian marron, where colour change is slightly larger after drying at 50°C than after drying at 60°C (probably due to longer exposure to elevated temperature).

Browning is not pronounced at neither temperature, since a* values remain in negative and b* values in positive domain, while L* values indicate lightness of nut surfaces both before and after drying. Considering time of drying, changes in colour and starch digestibility, 70°C is the most suitable temperature among investigated temperatures for chestnut drying.

ACKNOWLEDGEMENTS

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Literature Cited


### Tables

#### Table 1. Influence of drying temperature on colour change of chestnut.

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Istrian marron</th>
<th>Italian chestnut</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>40°C</td>
<td>50°C</td>
</tr>
<tr>
<td></td>
<td>before</td>
<td>after</td>
</tr>
<tr>
<td>L*</td>
<td>89.22</td>
<td>84.60</td>
</tr>
<tr>
<td>a*</td>
<td>-3.12</td>
<td>-1.32</td>
</tr>
<tr>
<td>b*</td>
<td>23.45</td>
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<tr>
<td>∆E</td>
<td>5.8759</td>
<td>7.8139</td>
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</table>
Figures

Fig. 1. Pilot plant tray dryer.

Fig. 2. Influence of drying temperature on dry matter content of chestnut. IM = Istrian marron; IC = Italian chestnut.
Fig. 3. Experimental and approximating moisture content as a function of drying time at different drying temperatures and air velocities of 2.8 m/s for convection drying of Istrian marron (IM) samples.

Fig. 4. Drying rate vs. drying time at different drying temperatures for convection drying of Istrian marron (IM) samples.
Fig. 5. Experimental and approximating moisture content as a function of drying time at different drying temperatures and air velocities of 2.8 m/s for convection drying of Italian chestnut (IC) samples.

Fig. 6. Drying rate vs. drying time at different drying temperatures for convection drying of Italian chestnut (IC) samples.
Fig. 7. Effective diffusion coefficient vs. different drying temperatures of Istrian marron (IM) and Italian chestnut (IC) samples.
Fig. 8. Influence of drying temperature on digestibility of chestnut. IM = Istrian marron; IC = Italian chestnut; RS = resistant starch; TS = total starch.