The paper presents the results of the research on the effects of osmotic dehydration, applied as a pre-treatment, on convective drying kinetics of pear cultivars “William”, in the form of ¼ of fruit, i.e. slices. Three-factor experiment of convective drying of pear slices was performed, while the experiment factors were pre-treatment, drying air temperature and velocity of drying air in front of the layer of materials. The following pre-treatment forms were applied: osmotic drying with solution temperature 40°C and solution concentration 50Bx, osmotic drying with temperature 60°C and solution concentration 65 Bx, and pear slices placed in a convective dryer with no pre-treatment. The statistical method of dispersion analysis in the three-factor experiment was used to evaluate the effects of the analysed factors on the kinetics of convective drying of slices. On the basis of the analysis it was determined that the selected pre-treatments and drying air temperature are important for kinetics of convective drying, while air velocity in front of the layer of material is less important, as well as the mutual interaction of the factors.

**Key words:** pear, drying kinetics, convective drying, osmotic dehydration.

**ABSTRACT**

The effects of osmotic pre-treatment on mechanical properties of dried quince were also examined (Babič, M. et al., 2007a; Babić, M. et al., 2007b; Singh, B. and Mehta, S., 2008). The mechanical properties of dried quince considerably improve by applying osmotic drying as a pre-treatment of convective drying. The dried material exhibits a slight change in elasticity modulus compared to the fresh material.

**INTRODUCTION**

Apart from plum and apple, pear is the most common fruit species in Serbia. Fresh pear processing in Serbia is restricted to the following productions: alcoholic drinks, soft drinks, stewed fruit, fruit yoghurt and jelly products. Production of dried pear is negligible (Statistical Yearbook, 2009). Dried pear can be found only in some health food stores. The quality indicators (colour, shape, texture, flavour and fragrance) of the fruit dried in classical way are unfavourable. The main disadvantage is application of inadequate drying technology.

A lot of research was carried out on the effects of osmotic dehydration, applied as a pre-treatment, on convective drying kinetics of pear cultivars “William”, in the form of ¼ of fruit, i.e. slices. Three-factor experiment of convective drying of pear slices was performed, while the experiment factors were pre-treatment, drying air temperature and velocity of drying air in front of the layer of materials. The following pre-treatment forms were applied: osmotic drying with solution temperature 40°C and solution concentration 50Bx, osmotic drying with temperature 60°C and solution concentration 65 Bx, and pear slices placed in a convective dryer with no pre-treatment. The statistical method of dispersion analysis in the three-factor experiment was used to evaluate the effects of the analysed factors on the kinetics of convective drying of slices. On the basis of the analysis it was determined that the selected pre-treatments and drying air temperature are important for kinetics of convective drying, while air velocity in front of the layer of material is less important, as well as the mutual interaction of the factors.

**Key words:** pear, drying kinetics, convective drying, osmotic dehydration.

**REZIME**

U radu su prikazani rezultati istraživanja uticaja osmotskog sušenja kao predrtetmana na kinetiku konvektivnog sušenja kraške sorte „william” u obliku ¼ ploda – kraški. Obavljen je trofaktorni eksperiment konvektivnog sušenja kraški kraške gde su faktori eksperimenta bili predrtetman, temperatura vazduha za sušenje i brzina vazduha za sušenje ispred sloja materijala. Oblici predrtetmana su bili: osmotsko sušenje sa temperaturom rastvora 40°C i koncentracijom rastvora 50Bx, osmotsko sušenje sa temperaturom rastvora 60°C i koncentracijom rastvora 65 Bx i kraške postavljene u konvektivnu susaru bez predrtetmana. Statističkom metodom dispersed analize trofaktornog eksperimenta ocenjen je uticaj analiziranih faktora na kinetiku konvektivnog sušenja kraški. Na osnovu analize ocenjeno je da izabrani predrtetmani i temperatura vazduha za sušenje su značajni na kinetiku konvektivnog sušenja dok je brzina vazduha ispred sloja materijala manje značajna kao i međusobna interakcija faktora.

**Ključne reči:** kraška, kinetika sušenja, konvektivno sušenje, osmotsko sušenje.

**ABSTRACT**

The effects of osmotic pre-treatment on retention of natural aroma was examined with melon. It was concluded that in the frozen quince flesh which was previously convectively dried, compared with the one with osmotic pre-treatment, the content of alcoholic components which produce negative aroma due to fermentation increased (Bignardi et al., 2000). Lately, there has been more and more research on the effects of the parameters of osmotic dehydration as a pre-treatment on convective drying kinetics (Kingsly, P., R., et al., 2007; Singh, B. and Mehta, S., 2008; Park, J., P. et al., 2002a).

The aim of this research is to analyse the influence of osmotic dehydration factors on kinetics of convective drying of “William” cultivar pear slices in a thin layer. Three-factor ex-
periment of convective drying was performed. The factors of convective drying were as follows: type of pre-treatment, drying air temperature, and velocity of drying air in front of the layer of material.

**Nomenclature:**

\[ a (\text{mm}) = \text{fruit length}, \]
\[ b (\text{mm}) = \text{fruit width}, \]
\[ c (\text{mm}) = \text{fruit thickness}, \]
\[ d (\text{mm}) = \text{diameter of measuring tube}, \]
\[ c_r \left( ^\circ \text{Bx} \right) = \text{solution concentration}, \]
\[ m (\text{kg}) = \text{fruit mass}, \]
\[ v (\text{m/s}) = \text{air velocity in front of drying layer}, \]
\[ p = \text{statistical significance}, \]
\[ p_d (\text{Pa}) = \text{dynamic air pressure}, \]
\[ x (\text{kg/kg}) = \text{absolute air humidity}, \]
\[ t (\text{°C}) = \text{temperature}, \]
\[ A (\text{m}^2) = \text{channel surface in front of drying layer}, \]
\[ V (\text{cm}^3) = \text{fruit volume}, \]
\[ W (\text{g}) = \text{moisture mass in a sample}, \]
\[ F = \text{calculated value of Fisher criterion}, \]
\[ F_{critic} = \text{tabulated value of Fisher criterion}, \]
\[ \Delta = \text{change of parameter value}, \]
\[ \sigma = \text{standard deviation}, \]
\[ \tau (\text{h}) = \text{drying time}, \]
\[ \rho (\text{kg/m}^3) = \text{air density}, \]
\[ \omega (\text{gw/gvm}) = \text{moisture content on wet basis}, \]
\[ \omega^i (\text{gw/gvm}) = \text{moisture content on dry basis}, \]

**Subscripts**

\[ o = \text{initial value}, \]
\[ cp = \text{whole fruit}, \]
\[ k = \text{slice}, \]
\[ i = \text{i moment}, \]
\[ r = \text{osmotic solution}, \]
\[ sm = \text{dry matter}, \]

**MATERIAL AND METHODS**

**Material preparation**

The material used in the experimental part of the research was fresh pear cultivar "William". Pears were taken from orchards in the District of Srem, around the village of Čerević, Serbia. Until the processing time, the fruit was stored in cold air chamber at the temperature 4°C and relative air humidity 75%.

The stage of fruit ripeness was the beginning of technological ripeness with the value pH = 3.4. The average values of the main physical properties of fresh fruits measured on a random sample of 20 fruits were: moisture content on wet basis 82.74% (\(\sigma = 0.76\)), whole fruit mass 179.45 g (\(\sigma = 23.23\)), dimensions \(a_{cp} = 88.52\) mm (\(\sigma = 5.6\)), \(b_{cp} = 67.18\) mm (\(\sigma = 2.72\)) and \(c_{cp} = 64.02\) mm (\(\sigma = 3.37\)).

Preparation of fresh fruit consisted of washing, removing seeds, cutting fruits into quarters – slices. This way of preparation provided usable flesh mass of 167.96 g (\(\sigma = 21.78\)), which is 93.6% (\(\sigma = 0.95\)) of the initial fruit weight. Thus prepared, the slices had the following values of physical properties (on the basis of the measured sample of 54 slices): \(m_k = 42.88\) g (\(\sigma = 1.84\)), \(a_k = 81.92\) mm (\(\sigma = 3.70\)), \(b_k = 32.95\) mm (\(\sigma = 1.19\)), \(c_k = 31.42\) mm (\(\sigma = 1.39\)), \(V_k = 40.18\) cm³ (\(\sigma = 3.57\)). Prevention from flesh discoloration was carried out by dry procedure of sulphuring, by burning 2 g of technical sulphur powder per 1 kg of prepared slices.

Convective drying experiment was performed as a three-factor experiment. The factors were the following: type of pre-treatment, drying air temperature and velocity of drying air in front of the layers of material. Three different preparations of sulphured slices for convective drying, i.e. pre-treatments, were performed (Table 1). After completion of the selected pre-treatment, the samples were placed in experimental convective dryer with trays “IVA – 2” (Pavkov et al., 2009). The principle of the experimental dryer is based on the heated air flowing horizontally over fruit samples arranged in thin layers on four trays. Dimensions of one tray are 440 mm x 290 mm, arranged 45 mm apart. There are 16 slices on each tray arranged with even space in the rows and between the rows. All the four trays have the same number of slices and the same arrangement of slices, and approximately the same weight. Specific weight on trays was 4.67 kg/ m² on average, i.e. averagely 2.385 kg of prepared slices were used and placed on four trays for one combination of factors.

Air temperature for convective drying varied at two levels: 40°C and 60°C. Air velocity in front of the layer of material varied at two levels: 1 m/s and 1.5 m/s. Duration of convective drying was 24 hours.

**Table 1. Pre-treatments**

<table>
<thead>
<tr>
<th>No.</th>
<th>Type of pre-treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Osmotic dehydration ((t_\text{r} = 40^\circ\text{C}, c_r = 50^\circ\text{Bx}, \tau = 3\text{ h}, \text{solute – sucrose, solvent – distilled water, weight ratio of solution and slices 8:1, experimental osmotic dryer of semi-industrial type})</td>
</tr>
<tr>
<td>2</td>
<td>Osmotic dehydration ((t_\text{r} = 60^\circ\text{C}, c_r = 65^\circ\text{Bx}, \tau = 3\text{ h}, \text{solute – sucrose, solvent – distilled water, weight ratio of solution and slices 8:1, experimental osmotic dryer of semi-industrial type})</td>
</tr>
<tr>
<td>3</td>
<td>Without osmotic dehydration</td>
</tr>
</tbody>
</table>

**Measurements**

During the experiment, measurements of important parameters for the kinetics of convective drying were performed. By measuring changes in the mass of samples during convective drying the basic data on drying kinetics were collected. This measurement was performed continually without interrupting the drying process. This was enabled by special tray carriers placed on the sensor for measuring mass. The sensor for measuring sample mass has the measuring range 0-20 kg, resolution 0.01 g, and accuracy ±2 g. It was manufactures by HBM, Germany, model PW6CC3MR. The sensor is connected to the measurement acquisition manufactured by National Instruments, USA, model NI 622225, which measured the mass change during drying every 60 seconds for 24 hours. Apart from the mass change, at the same time the acquisition also measured the following: temperatures of dry and wet thermometer of the ambient air, air temperature entering the layer of material, and slice temperature. The data on the measured values of temperature were obtained...
RESULTS AND DISCUSSION

The results of dispersion analysis of three-factor experiment are shown in Table 2. For the statistical probability of 99%, it was determined that there are statistically significant differences between a pre-treatment and the levels of the drying air temperature \((F>F_{crit})\) compared with the kinetics of convective drying. The selected levels of air drying velocity in front of the layer of material as well as the interaction of all factors are less important for the kinetics of convective drying.

Table 2. Results of dispersion analysis of three-factor experiment for statistical probability 99%

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>Sum of squares</th>
<th>Degree of freedom</th>
<th>Mean square</th>
<th>F</th>
<th>p-value</th>
<th>F_{crit}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-treatment</td>
<td>0.3257</td>
<td>2</td>
<td>0.1628</td>
<td>14.9778</td>
<td>0.000001</td>
<td>6.931</td>
</tr>
<tr>
<td>Drying air tempera-</td>
<td>0.0943</td>
<td>1</td>
<td>0.0943</td>
<td>8.679</td>
<td>0.003506</td>
<td>6.931</td>
</tr>
<tr>
<td>ture * Velocity of</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>drying air</td>
<td>0.0052</td>
<td>2</td>
<td>0.0026</td>
<td>0.2409</td>
<td>0.786118</td>
<td>6.931</td>
</tr>
<tr>
<td>Interaction: Pre-</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>treatment * Veloc-</td>
<td>0.0048</td>
<td>2</td>
<td>0.0024</td>
<td>0.221</td>
<td>0.801374</td>
<td>6.931</td>
</tr>
<tr>
<td>ity of drying air</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interaction: Dry-</td>
<td>0.00031</td>
<td>1</td>
<td>0.000005</td>
<td>0.002</td>
<td>0.957144</td>
<td>6.931</td>
</tr>
<tr>
<td>ing air temperature</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>* Velocity of drying</td>
<td>0.0003</td>
<td>2</td>
<td>0.0001</td>
<td>0.0178</td>
<td>0.982337</td>
<td>6.931</td>
</tr>
<tr>
<td>air</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Error</td>
<td>2.8707</td>
<td>264</td>
<td>0.0108</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figures 1 and 2 present summary diagrams of the kinetic curves of the changes of mean moisture content (\(\omega^t\)) depending on time \((t)\) during convective drying for air temperatures 40°C (Fig. 1) and 60°C (Fig. 2), pre-treatments 1, 2 and 3 and air velocity in front of the layer of material 1 m/s and 1.5 m/s. Analysis of the kinetic curves of the change of mean moisture content \((\omega^t)\), for 24 hours of convective drying proves that the reduction of the mean moisture content is a non-linear process. By comparing the curves in terms of the pre-treatment used, it is evident that the greatest reduction of the mean moisture content after 24 hours of drying is detected for the samples dried without the pre-treatment, then the samples dried with the pre-treatment 1 (cr = 50°Bx, \(t_p = 40^\circ\mathrm{C}\)), while the least reduction is detected with pre-treatment 2 (cr = 65°Bx, \(t_p = 60^\circ\mathrm{C}\)). At the drying air temperature of 60°C, the differences in the final moisture content are more prominent among all the three pre-treatments. At the lower drying air temperature of 40°C, the differences in the final moisture content are less prominent, especially between the applied pre-treatments 1 and 2. By comparing the curves in terms of drying air temperature within the same pre-treatment, it is evident that the greatest reduction of the mean moisture content after 24 hours of drying was observed with the samples dried without any previous pre-treatment at the temperature of 60°C and air velocity in front of the layer 1.5 m/s.
molecules from the material. This period lasts during the first 60 minutes of the process. Reaching the maximal rate of evaporation of water molecules in this period occurs as a result of increased concentration of the capillary surface-bound moisture, which mainly evaporates on the surface of the material, there is no dry zone of the material. By evaporation of the surface-bound moisture, the drying rate decreases and enters the second period. In this period the drying rate gradually decreases due to reeding of evaporation front inside the material, so a dry layer starts forming. After removing physically and mechanically bound moisture there is a phase change of various forms of physically and chemically bound moisture.

By comparing the curves of the mean drying rate from the first period of drying, in terms of the pre-treatment used, it can be observed that the greatest drying rate in the first period of drying is achieved by the samples dried without any pre-treatment, followed by the samples with the pre-treatment 1 (c_s = 50°Bx, t_r = 40°C), while the lowest drying rate is determined with the pre-treatment 2 (c_s = 65°Bx, t_r = 60°C). This tendency is due to different initial moisture content of slices, where the samples dried without a pre-treatment are the moistest, followed by the samples dried with the pre-treatment 1 and pre-treatment 2. Higher level of moisture content of slices results in higher content of surface-bound moisture and capillary-bound moisture with the moister samples.

The mean drying rates for different combinations of factors observed at the same point of time, as presented on diagrams (Fig. 3 and 4), are not mutually comparable due to different moisture content of slices at the observed point in time. However, analysing the calculated values of drying rates with the same mean moisture content, the highest values of mean drying rate is achieved with the samples dried without any pre-treatment, followed by the samples dried with the pre-treatment 1 and pre-treatment 2. This analysis confirms the results of dispersion analysis. The impact of the selected drying air temperature levels on the kinetics is evident on the presented figures. By dispersion analysis it was determined that there is no statistically significant difference of the impact of different levels of air velocity in front of the layers of material on the kinetics. However, this result should be carefully interpreted. By careful analysis of the presented diagrams slight influence of the selected levels of air velocity on kinetics can be observed, but it is less prominent than the selected pre-treatments and drying air temperatures. This result is caused by small difference in the selected levels of velocity of drying air in front of the layers of material as well as...
by the differences in dimensions and volume of slices used for the experiments. It is very difficult to provide a large number of slices in the natural form which are of the completely same dimensions and volume.

The effects of air temperature and air velocity in front of the layer of material on the kinetics of convective drying is prominent, which is in accordance with the results of other authors (Pérez and Schamáloko, 2009; Klingsly et al., 2007; Guine and Castro, 2002; 2003).

The influence of a pre-treatment on the mean drying rate decrease with pre-treatments 1 and 2 compared with the samples dried without any pre-treatment is caused by the transition of the solute from the solution into the material (increase of the dry matter) during osmotic drying. Higher osmotic solution temperatures and osmotic solution concentration cause more intense transition of solute into the pear flesh, i.e. increase of dry matter (Babić, Lišijana et. al., Pavkov et al., 2009; Guine, 2006b).

The samples prepared with the pre-treatment 2 (c0 = 65°Bx, t0 = 60°C) have a higher mass ratio of solute in slices flesh compared with the samples prepared with the pre-treatment 1 (c0 = 50°Bx, t0 = 40°C). The solute which was transferred into the flesh of the material in contact with moisture and dry matter of pear flesh make different forms of adsorption-bound moisture. This impedes the phase change of the moisture, that is, increases the overall heat required for water phase change.

Figure 5 presents dependence of material temperature on the moisture content for the pre-treatment 2 and no pre-treatment (pre-treatment 3) under the same conditions of convective drying. The diagrams show that with the same moisture content of material there is difference in material temperature with the sample prepared with the pre-treatment 2 compared with the sample prepared without any pre-treatment. The lower material temperature with the pre-treatment 2 results from using heat on tearing newly formed bonds between the dry matter, solute and moisture in slices flesh. The higher temperature of material with the pre-treatment 3 is due to the smaller amount of heat required for tearing the bonds between water and dry matter and using the heat residues on warming the dry matter of slices. The temperature of material, i.e. its surface and the air drying temperature tend to equalise, and in their equalising equilibrium moisture content of material is achieved. By analysing the slope of the curve with the pre-treatment 2, a larger slope is detected. Such tendency of the curve indicates that the material treated with the pre-treatment 2 has the tendency to achieve the equilibrium moisture content of material earlier.

Increasing of the share of adsorption-bound moisture in pear flesh increases the values of equilibrium moisture content of material, i.e. reduces the values of water activities, which was also noted by the authors Azoubel, Patricia et al., (2009). Higher values of equilibrium moisture content reduce the total time of convective drying for the materials previously prepared by osmotic dehydration. Consequently, the negative effects of osmotic pre-treatment on the kinetics of convective drying are minimised in terms of the total time of duration of the drying process.

CONCLUSION

On the basis of the results of convective drying measurements, the analysis on the effects of pre-treatment, drying air temperature and drying air velocity in front of the layer of material on convective drying kinetics of cultivar “William” pear slices was performed. According to the results of dispersion analysis it was determined that the applied pre-treatments and the selected drying air temperatures influence kinetics. The selected levels of air velocity in front of the layer of material within the examined range, as well as the mutual interaction of factors, have less influence on kinetics. Careful analysis of the presented diagrams show slight influence of the selected levels of drying rate on kinetics, but it is less prominent. With the increase of drying air temperature and air velocity in front of the layer of material, drying rate increases, as well. By applying osmotic dehydration as a pre-treatment, the rate of convective drying decreases due to forming of adsorption bonds of moisture, solute, and dry matter in pear flesh. Newly-formed bonds cause the increase of the values of equilibrium moisture content of the materials treated with osmosis, i.e. faster achieving of the equilibrium moisture content. Regarding the total drying time for obtaining the final product, the faster achieving of the equilibrium moisture content of the material eliminates the seemingly negative influence of osmotic pre-treatment on kinetics of convective drying on pear slices.

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