Study of the Drying Kinetics of "Granny Smith" Apple in Tray Drier

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Summary

The drying characteristics of "Granny Smith" apples were analysed using a tunnel drier at different temperatures and different pre-treatments. „Granny Smith" apples were cut into rectangle-shaped samples 20x20x5 mm in size. The drying temperatures for non-treated samples varied from 50°C to 80°C at airflow velocity of 2.8 m s^{-1}. Prior to drying at 60°C, the samples were pre-treated either thermally or chemically, or both (blanching in hot water, steam blanching, blanching in hot 0.6% $CaCl_2$ solution, freezing to temperature of –18°C and dipping in 1% ascorbic acid solution). The aim of the study was to get dried apples with approximately 10% water content, with good texture, rehydration capability and colour quality. The effect of the temperatures and pre-treatments on the quality of dried apple samples was determined on the basis of colour and volume changes and reconstitution characteristics. The kinetic equations were estimated using exponential mathematical model. The results of the estimation exhibited correspondence to the experimental results. The best results for non-treated apple samples: shorter drying time, better rehydration properties and small colour changes were achieved at the drying temperature of 60°C and airflow velocity of 2.8 m s^{-1}. Blanching in hot water, steam blanching and blanching in hot 0.6% $CaCl_2$ solution resulted in higher values of rehydration ratio in comparison to other tested pre-drying methods. The given methods significantly improved rehydration properties and accelerated the drying kinetics in comparison to drying of non-treated apple samples. The values of rehydration ratio decreased with the increase of the drying temperature. The values of effective diffusion coefficient were higher in the case of drying of blanched samples in hot water at temperature of 85°C for three minutes in comparison to drying of non-treated apple samples.

Key words

tunnel dryer, apples, Granny Smith apple, pre-treatment, blanching, drying, rehydration, effective diffusion coefficient

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Introduction

The post-harvest losses of agricultural products can be reduced drastically by using proper drying techniques. The basic objective in drying of agricultural products is the removal of water in the solids up to certain level, at which microbial spoilage and deterioration 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). Fruit is generally characterized by high initial moisture content, high temperature sensitivity (i.e. colour, flavour, texture and nutritional value are subject to thermal deterioration) and shrinkage of materials during drying. The required amount of thermal energy needed to dry a particular product depends on many factors, such as, initial moisture content, desired final moisture content, temperature and relative humidity of drying air and air flow rate.

Apples are important raw material for many food products and apple plantations are cultivated all over the world in many countries. Apples are consumed either fresh or in the form of various processed products such as juice, jam, marmalade, dried apples, etc. Convection drying as well as other techniques for drying are used in order to preserve the original characteristics of apples (Velić et al., 2003).

During drying the material undergoes shrinkage. In the early stages of drying the surface layers do not differ much in properties from those in the centre. The material is viscoelastic, and is able to deform. The amount of evaporated water is reflected by change in volume (Lewicki et al., 1997). Total volume changes of the apple tissue with respect to the initial volume are dependent on the pre-treatment. Lapsley et al. (1992) reported that shrinkage of apples was approximately 23 % due to blanching. This value is similar to the reported porosity of the fruit where air spaces comprise 20-30 % of flesh tissue volume.

Blanching of the fruit tissue as a pre-drying treatment is usually carried out to prevent off flavours and color changes due to enzymatic reactions and to decrease of the initial microorganisms load. In the most cases blanching is a primary step in processing of fruits and vegetables. Despite its preserving advantage it leads to nutrient degradation, particularly of vitamins, and loss of colour. Duration and temperature of blanching inactivate particular enzymes; overblanching may result in an undesirable loss of colour, flavour, texture and nutrient quality in addition to excessive energy requirement and water disposal (Neuman, 1972; Seow et al., 1992).

Recently, the use of natural products and their derivatives was found to be effective in reducing browning and decay of many fresh-cut fruits and vegetables (Ahvenainen, 1996). These antibrowning agents and their derivatives such as 4-hexylresorcinol, N-acetylcysteine (AC), ascorbic acid (AA), isoascorbic acid (IAA), potassium sorbate, calcium chloride and propionate, alone or in combination at different concentrations, were found to be effective in retarding browning and reducing decay of fresh-cut products (González-Aguilar et al., 2001; Buta et al., 1999; Buta and Abbott, 2000).

As an attempt to preserve the quality of fresh-cut apples by reducing browning and decay, treatments with antibrowning compounds in conjunction with the convection drying was evaluated. Their effects on reduction of browning, modification of texture and other quality attributes as well as microbial decay were studied. The present study was, therefore, undertaken to investigate conditions under which the characteristics of fresh apples can be preserved and to define optimal parameters for their storage and reuse. This work also examined diffusion coefficients, which are the principle transport property for the moisture removal phenomena in the drying of apples.

Materials and methods

Apples (Granny Smith cultivar) were obtained from the local supermarket and stored at +4°C. After 2 h of stabilization at ambient temperature, homogenous samples were cut vertical to their axis into cylindrical slices of 5 mm thickness using a hand operated slicer and then were cut into the rectangle-shaped slices, dimensions 20x20x5 mm with standard model.

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

The drying temperatures for non-treated samples varied from 50°C to 80°C at airflow velocity of 2.8 $m.s^{-1}$. To speed up the dehydration kinetics and to eliminate the enzymatic browning activity, as well as non-enzymatic changes during dehydration process different physical and chemical procedures of samples pre-treatment were applied.

Prior to drying at the drying temperature of 60°C, the samples were pre-treated either thermally or chemically, or both: (*i*) blanching in hot water at 85°C for 3 min; (*ii*) steam blanching for 3 min; (*iii*) blanching in hot 0.6% $CaCl_2$ solution at 90°C for 1 min; (*iv*) freezing at temperature of –18°C for 24 hours; (*v*) dipping in 1% ascorbic acid solution for 3 min.

Drying equipment

The drying was performed in a pilot plant tray dryer. The dryer operates on the thermogravimetric principle. The dryer (Figure 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

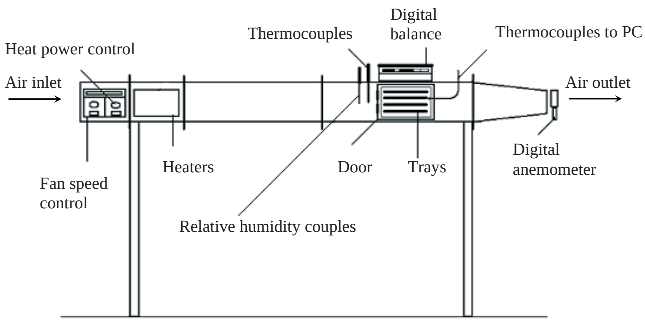

Figure 1. Pilot plant tray dryer

axial flow fan impeller. In the tunnel of the dryer 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.

Drying procedure

For the purposes of this study the dryer was operated at air velocity of 2.8 m s^{-1}. The air flowed parallel to the horizontal drying surfaces of the samples. The drying process started when drying conditions were achieved. The apple samples on trays were placed into the tunnel of the dryer and the measurement started from this point. During the drying process temperature changes of dried samples were continuously recorded by thermocouples connected to the PC. "Testo 350" probes, placed into the drying chamber, were used to measure relative humidity and drying air temperature. Sample weight loss was recorded every five minutes during the drying process using a digital balance (Ohaus, Explorer, USA). Dehydration lasted until a moisture content of about 10% (wet base) was achieved. Airflow velocity was measured every five minutes with a digital anemometer (Armfield, UK) that was placed at the end of the tunnel. Dried samples were kept in airtight glass jars until the beginning of rehydratation experiments.

Determination of the total solid/moisture content

Small quantities (~10g) of chopped sample were dried in a vacuum oven (8 h at 70°C and 30 mbar pressure). Time dependent moisture content of the samples was calculated from the sample weight and dry basis weight. Weight loss data allowed the moisture content to be calculated as follows:.$X(t) = m_w/m_{db}$

Colour measurement

The colour of the fresh and dried samples was measured using Chromameter CR-300 (Minolta). The three parameters L (*lightness*), a (*redness*) and b (*yellowness*) were used to study the colour changes. The total colour difference (ΔE) was calculated as follows (Hunter, 1975).

$$\Delta E = \sqrt{(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2} \quad (1)$$

$$\Delta L = L - L_0 \qquad \Delta a = a - a_0 \qquad \Delta b = b - b_0 \quad (2)$$

Samples were placed on the measure head of CR 400 and measurements of colour were performed on both sides of the largest surface (20 mm^2) for all prepared samples. A standard white colour was used as a reference.

Rehydration

Most of the dehydrated products usually rehydrate during their use, so the additional indicators of quality are the rate and extent of rehydration. The optimal reconstitution properties can be achieved through the control of the dehydration process and the rehydration conditions (Planinić et al., 2005). Rehydration ratio is widely used as a quality evaluation method after drying was performed. In fact, it is a complex process that indicates the chemical and physical changes caused by the drying procedures (Lewicki, 1998a; 1998b). Rehydration properties of the samples were expressed as rehydration ratio. Rehydration ratio (RR) was computed as follows:

$$RR = \frac{W_r}{W_d} \quad (3)$$

Where W_r is the drained weight (g) of rehydrated sample, and W_d is the weight of dry sample used for rehydration.

Shrinkage test

The shrinkage of foodstuff is a common physical phenomenon observed during different dehydration processes. These changes affect the quality of the dehydrated product and should be taken into consideration when predicting moisture and temperature profiles in the dried material (Mayor and Sereno, 2004; Krokida and Maroulis, 2001). For the shrinkage study the volume of fresh and dried samples was measured by immersing them in n-heptane. The percentage of shrinkage was calculated as follows:

$$\%\,\text{shrinkage} = \frac{V_0 - V}{V_0} \times 100 \quad (4)$$

Where V_0 and V are respectively the volume (ml) of apple at the beginning and at the end of the drying experiment.

Drying rate curve determination

The used Midilli-Kucuk model (a thin-layer model) successfully describes the drying kinetics of food materials (Midilli et al., 2002). The authors also used this model to describe the changes of moisture content and drying rates. The time dependent weight of samples was converted for the given time dependent to moisture content. To avoid some ambiguity in results because of the differences in the initial sample moisture, the sample moisture was expressed as dimensionless moisture ratio X' =.X(t)/X_0. The drying curve for each experiment was obtained by plotting the dimensionless moisture of the sample versus the drying time (Velić et al., 2004).

For the approximation of the experimental data and calculating drying curves and drying rate curves, the Midilli-Kucuk was used, as follows:

$$X'(t) = a \cdot e^{-k \cdot t^{n}} + b \cdot t \qquad (5)$$

$$-\frac{dX'(t)}{dt} = a \cdot k \cdot n \cdot t^{(n-1)} + b \qquad (6)$$

Midilli-Kucuk model parameters for drying kinetics *a*, *k*, *n* and *b* were calculated by non-linear regression method (Quasi-Newton) using Statistica 6.0 computer program. The correlation coefficient (r^2) was used as a measure of model adequation.

Determination of the effective diffusion coefficient

Fick's second law can be used to describe the drying behaviour of apple "Granny Smith". The simplified method (Zogozsa et al., 1994) 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):

$$\frac{X - X_e}{X_0 - X_e} = \sum_{n=0}^{n=1} \frac{8}{(2n+1)^2 \pi^2} \exp\left(\frac{-D_{eff} (2n+1)^2 \pi^2 t}{4\ell^2} \right) \qquad (7)$$

where X_e and X_0 represent equilibrium and initial moisture contents and ℓ 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 $X'=X/X_0$ (dimensionless moisture ratio) (Doymaz and Pala, 2002).

Where sample thickness is small (0.005 m) and drying time is relatively long, only the first term of Fickan's solution series is need, and equation (7) becomes:

$$X' = a \cdot \exp(-K \cdot t) \qquad (8)$$

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

Results and discussion

The drying characteristics of "Granny Smith" apple were analysed using tunnel drier at different temperatures and different pre-treatments. The drying temperatures of non-treated samples varied from 50°C to 80°C at airflow velocity of 2.8 m s^{-1}. Prior to drying at 60°C, the samples were pre-treated either thermally or chemically, or both (blanching in hot water, steam blanching, blanching in hot,6% $CaCl_2$ solution, freezing to temperature of – 18°C and dipping in 1% ascorbic acid solution). The apple slice

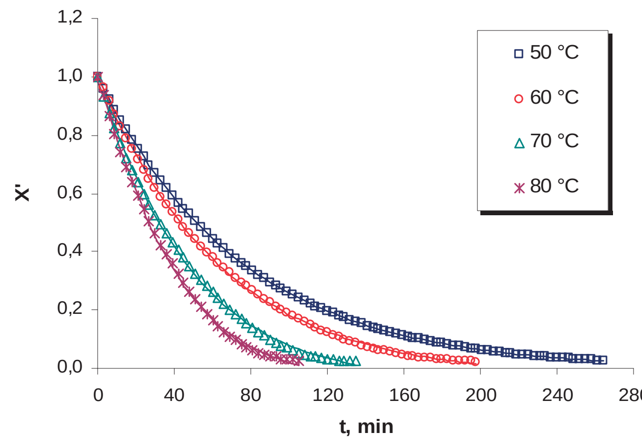

Figure 2. Experimental and approximated moisture content as a function of drying time at different drying temperatures and at air velocity of 2.8 m s^{-1} for convection drying of non-treated apple samples

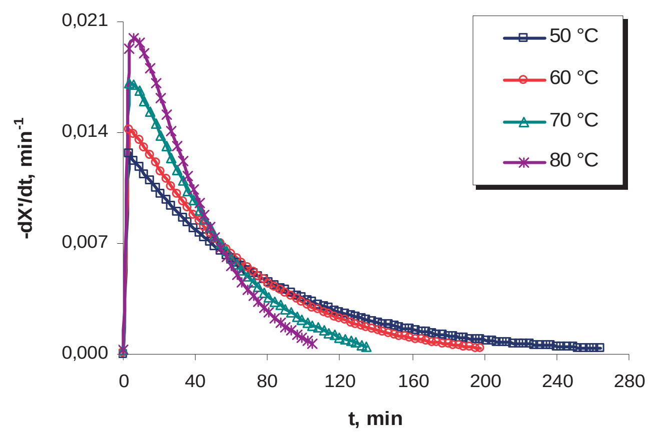

Figure 3. Drying rate vs. drying time for different drying temperatures for convection drying of non-treated apple samples

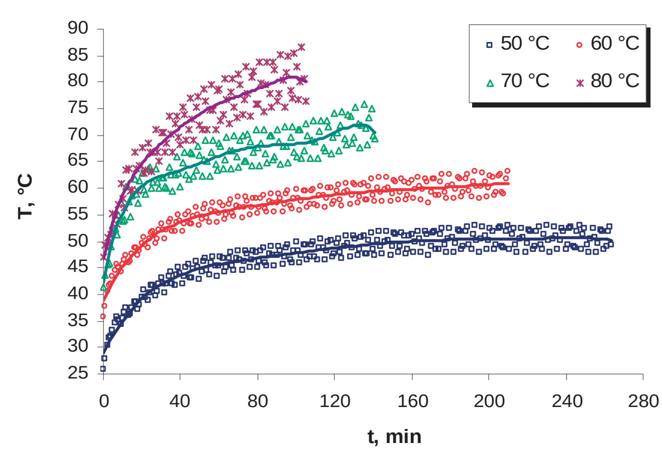

Figure 4. Temperature of non-treated apple samples vs. drying time at different drying temperatures

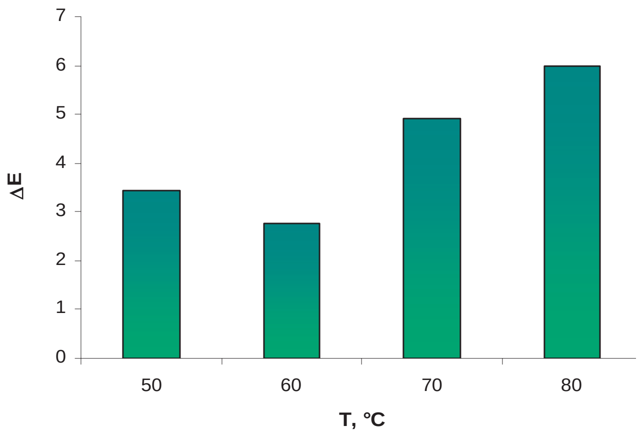

Figure 5. The total colour difference (ΔE) vs. different drying temperatures of non-treated apple samples

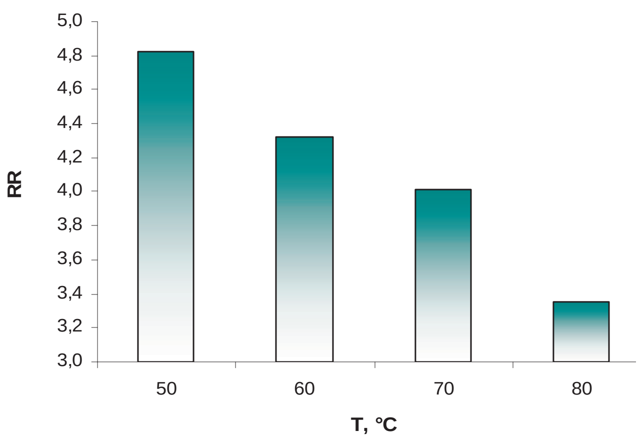

Figure 6. Rehydration ratio (RR) vs. different drying temperatures of non-treated apple samples

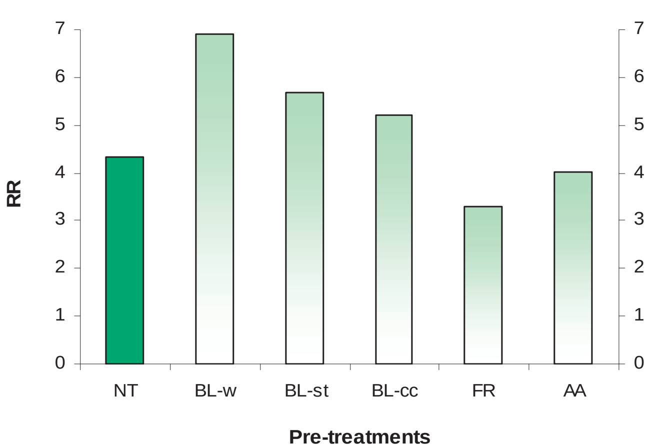

Figure 7. Rehydration ratio (RR) vs. different pre-treatments and drying temperature of 60°C

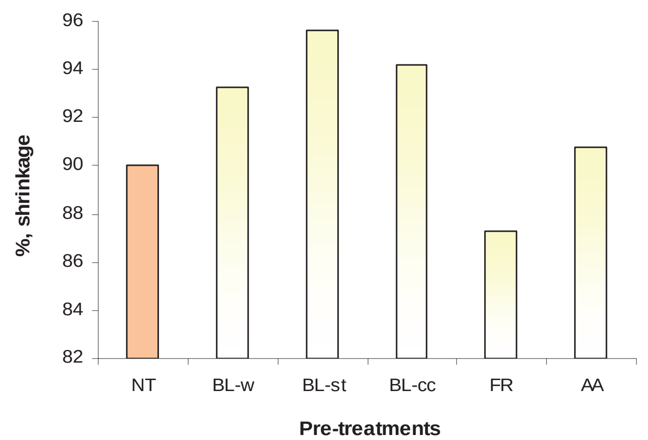

Figure 8. Percentage of shrinkage vs. different pre-treatments and drying temperature of 60°C
List of abbreviations: NT – non treated samples; BL-w – blanching in hot water; BL-st – steam blanching; BL-cc – blanching in $CaCl_2$ solution; FR – freezing; AA - ascorbic acid

of initial moisture content of approximately 6.94 kg water per kg of dry matter was dried to the final moisture content of approximately 0.12 kg water per kg of dry matter until no further changes in their mass were observed. The moisture contents (experimental and modelled data) versus drying time at different temperatures are shown in Figure 2. It can be seen that a good agreement between the experimental data and the chosen mathematical model (Midilli and Kucuk) exists, which is confirmed by high values of correlation coefficient (0.99) in all runs. Results show that the temperatures had a significant effect on drying rates of apple. With the increase of the temperature, the time required to achieve certain moisture content decreased.

Figure 3 show typical drying rate curve, which are characterised by two falling rate periods with no undoubtedly apparent constant rate period. If the slope of tangent to the drying curve (-dX/dt) was considered as the drying rate of the sample, the results suggest that in the second period drying was faster than in the first falling rate period.

Figure 4 shows temperature (temperature profile) in non-treated samples versus drying time at different drying temperatures. Figure 5 shows total colour difference versus different drying temperatures for non-treated apple samples. The lowest value of ΔE was found for untreated apple slices dried at a drying air temperature of 60°C.

Figure 6 shows rehydration ratio versus different drying temperatures for drying of non-treated apple samples. With the increase of the drying temperature, rehydration ratio for non-treated apple samples decreased. Figure 7 shows rehydration ratio versus different pre-treatments of apple samples. It can be seen that blanching with hot water resulted in the highest rehydration, compared to other pre-treatments. Comparison of the percentage of shrinkage of

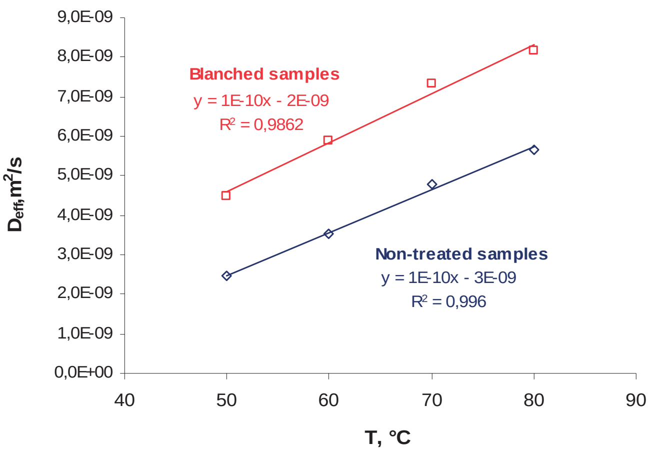

Figure 9. Effective diffusion coefficient vs. different drying temperatures of non-treated and blanched apple samples

pre-treated apple samples at the drying temperatures of 60°C is shown in Figure 8. It can be seen that shrinkage effect was intensive for pre-treated apple samples with the exception of freezing.

Figure 9 shows effective diffusion coefficient versus different drying temperatures of non-treated and blanched apple samples. The effective diffusivity increased with the increase of the drying air temperature in both cases. The values of effective diffusivity varied in the range of $2.46{\cdot}10^{-9}$ to $5.66{\cdot}10^{-9}$ $m^2\,s^{-1}$ for non-treated samples and in the range of $4.48{\cdot}10^{-9}$ – $8.15{\cdot}10^{-9}$ $m^2\,s^{-1}$ for blanched apple samples. Similar results were reported by Velić et al. (2004). The small differences between the results could be due to the differences in varieties, drying equipment and some uncontrolled parameters.

Conclusions

The kinetic equations were estimated using Midilli and Kucuk model. The results of the estimation exhibited correspondence to the experimental results. The best results for non-treated apple samples: shorter drying time, better rehydration properties and small colour changes were achieved at the drying temperature of 60°C and airflow velocity of 2.8 $m.s^{-1}$. Blanching in hot water, steam blanching and blanching in hot 0.6% $CaCl_2$ solution, have resulted in higher values of rehydration ratio in comparison to other tested pre-drying methods. The given methods significantly improved rehydration properties and accelerated the drying kinetics in comparison to drying of non-treated apple samples. The values of rehydration ratio of non-treated apple samples decreased with the increase of the drying temperature. The values of effective diffusion coefficient were higher in the case of drying of blanched samples in hot water at temperature of 85°C during three minutes in comparison to drying of non-treated apple samples. The values of effective diffusivity were found to vary in the range of $2.46{\cdot}10^{-9}$ to $5.66{\cdot}10^{-9}$ $m^2\,s^{-1}$ for non-treated samples and in the range of $4.48{\cdot}10^{-9}$ – $8.15{\cdot}10^{-9}$ $m^2\,s^{-1}$ for blanched apple samples.

References

Ahvenainen, R. (1996). New approaches in improving the shelf life of minimally processed fruit and vegetables. Trend Food Sci Technol 7 179–187

Baroni A. F., Hubinger M. D. (1998). Drying of onion: effects of pretretmant on moisture transport. Dry Technol 16 (9&10): 2083-2094.

Buta, G. J., Moline, H. E., Spaulding, D. W., & Wang, C. Y. (1999). Extending storage life of fresh-cut apples using natural products and their derivates. J Agri Food Chem 47: 1-6

Buta J. G., Abbott J. (2000). Browning inhibition of three cultivars of fresh-cut pears. Hort Sci 35: 1111–1113

Doymaz I., Pala M. (2002). The effects of dipping pretreatments on air-drying rates of the seedless grapes, J Food Eng 52 (4): 413-417

González-Aguilar G. A., Wang C. Y., Buta, J. G. (2001). Inhibition of browning and decay of fresh-cut radishes by natural compounds and their derivatives. Leben-Wissen Technol 34: 324–328

Hunter R. S. (1975). Scales for the measurements of color difference. In the Measurement of Appearance. John Willy & Sons, New York, 133–140

Krokida M. K., Maroulis Z. B. (2001). Structural properties of dehydrated products during rehydration. Int J Food Sci Technol 36 (5): 529-538

Lapsley K. G., Escher F. E., Hoehn E. (1992). The cellular structure of selected apple varieties. Food Struct 11: 339-349

Lewicki P. P., Witrowa-Rajchert D., Mariak J. (1997). Changes of structure during rehydration of dried apples. J Food Eng 63: 347-350

Lewicki P. P. (1998). Some remarks on rehydration of dried foods. J Food Eng 36: 81–87

Mayor L., Sereno A. M. (2004). Modelling shrinkage during convective drying of food materials: a review. J Food Eng 61 (3): 373-386

Midilli A, Kucuk H., Yapar Z. (2002). A new model for single layer drying. Dry Technol 20 (7): 1503-1513

Neuman H. J. (1972). Dehydrated celery: effects of pre-drying treatments and rehydration procedures on reconstitution. J Food Sci 37: 437-441

Planinić M., Velić D., Tomas S., Bilić M., Bucić A. (2005). Modelling of drying and rehydration of carrots using Peleg's model. Eur Food Res Technol 221: 446–451

Sabarez H. T., Price W. E., Back P. J., Woolf L. A. (1997). Modelling the kinetics of d'Agen plums (Prunus domestica). Food Chem 60 (1): 371–382

Seow C. C., Ng K. B., Bourne M. C. (1992). Effect of blanching treatments on physiochemical properties of dehydrated carrots, celery and green beans. ASEAN Food J 7 (4): 184-188

Velić D., Planinić M., Tomas S., Bilić M. (2004). Influence of airflow velocity on kinetics of convection apple drying. J Food Eng 64 (1): 97-102

Zogozsa N. P., Maroulis Z. B., Marinos-Kouris D. (1994). Moisture diffusivity methods of experimental determination a review. Dry Technol 12 (3): 483-515

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