Study of the Drying Kinetics of "Granny Smith" Apple in Fluid Bed Dryer

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Summary

The drying characteristics of "Granny Smith" apple were investigated using a bench-scale fluidised bed drier at different temperatures and using blanching in hot water as pre-treatment. Temperatures of fluidisation for non-treated and treated samples were 50, 60, 70 and 80 °C and airflow velocity 3.50 m s^{-1}. The aim of the experiment was to get apples with approximately 9% water content, with good texture, rehydration capability and colour quality. The effect of temperatures and pre-treatment 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 logarithmic model. The results of the estimation have exhibited correspondence to experimental results. As a result of drying of non-treated apple at higher temperatures, drying time shortens, while rehydration properties improve. On the other hand, with the increase of the drying temperature, overall colour changes (ΔE) of non-treated samples increase. The best results, shorter drying time and better rehydration properties, were obtained when samples were pre-treated by blanching in hot water.

Key words

fluid bed dryer, Granny Smith apple, drying kinetics, pre-treatment, blanching, rehydration

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Introduction

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. 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 leads to increasing energy consumption and production (Mayor and Sereno, 2004; Bennamoun and Belhamri, 2003).

Fluidized bed drying among others has the advantage of high intensity of drying and high thermal efficiency with uniform and closely controllable temperature in the bed. It requires less drying time due to high rates of heat and mass transfer and provides for a wide choice in the drying time of the material (Topuz et al., 2004).

The practice of fresh-cut processing causes wounding, increases metabolic activities and decompartamentalizes enzymes and substrates. This may cause browning, softening, decay, and off-flavour development (Watada et al., 1990; Varoquax and Wiley, 1994). In 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).

Material and methods

The apples ("Granny Smith") were obtained from the local supermarket and were 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 cut into the rectangle-shaped slices, dimensions 20x20x5 mm with standard model. The apple samples were blanched in hot water at temperature of 85 °C for three minutes to prevent non-enzymatic browning and were drained for three minutes at room temperature; these samples were denoted as blanched samples. In order to determine drying kinetics, rehydration ratio, colour differences and shrinkage after drying, the apple slices were also dried in their natural form and denoted as non-treated samples.

Drying equipment

Fluidised bed dryer (FBD 2000 Endecotts) is a compact, portable dryer with a powerful air delivery system that allows very fast drying. The comprehensive set of controls makes it ideal for use in the laboratory on a wide selection of materials. Dryer is equipped with a detachable glass-loading vessel with outlet filter bag. The direction of airflow was perpendicular to the samples.


Figure 1.
Fluidised bed dryer

Temperatures of fluidisation for non-treated and blanched samples were 50, 60, 70 and 80 °C and airflow velocity 3.50 m s^{-1}. The samples were pre-treated with blanching in hot water (temperature of 85 °C) for three minutes. The mass of the samples was constantly monitored during the drying process. The sample weight loss was recorded every five minutes during the drying process. Dehydration lasted until a moisture content of about 10 % (wet basis) was achieved. Dried samples were kept in airtight glass jars until the beginning of rehydration experiments.

Determination of the total solid/moisture content

Small quantities (~10g) of chopped samples were dried in a vacuum oven (8 h at of 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).

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

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

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 the 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:

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

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 foodstuffs 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). For studying the shrinkage, the volume of fresh and dried samples was measured by immersing them in n-heptane.

The percentage of shrinkage was calculated as follows:

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

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 Logarithmic model (a thin-layer model) used successfully describes the drying kinetics of food materials (Sacilik and Elicin, 2006; Toğrul and Pehlivan, 2003). 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 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 the drying curves, the simplified model was used, as follows:

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

Logarithmic model parameters for drying kinetics a, k and c 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.

Results and discussion

The apple slices were dried in a bench-scale fluidised bed drier at different temperatures and by blanching in hot water as pre-treatment. The temperatures of fluidisation for non-treated and treated samples were 50, 60, 70 and 80°C and airflow velocity 3.50 m s^{-1}. The samples were pre-treated by blanching in hot water at temperature of 85 °C for three minutes. The apple slice of initial moisture content of 6.94 kg water per kg of dry matter was dried to the final moisture content of approximately 0.12 kg of water per kg of dry matter until no further changes in their mass were observed.

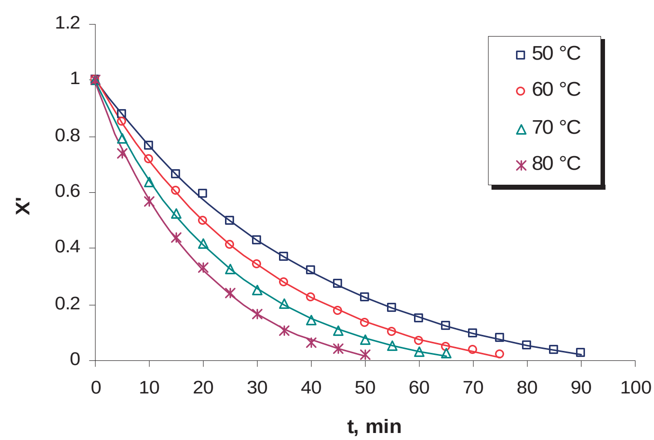

Figure 2. Experimental and approximating moisture content as a function of drying time at different drying temperatures and air velocities of 3.5 m s^{-1} for fluid bed drying (FBD) of non-treated apple samples

The moisture contents (experimental and modelled data) versus drying time at different temperatures are shown in Figures 2 and 5. It can be seen that a good agreement between experimental data and chosen mathematical model (logarithmic) exists, which is confirmed by high values of correlation coefficient (0.9995). The results show that the temperature had a significant effect on the drying rates of apple. With the increase of the temperature, the time required to achieve certain moisture content decreased. The drying curves are presented with Figures 3 and 6.

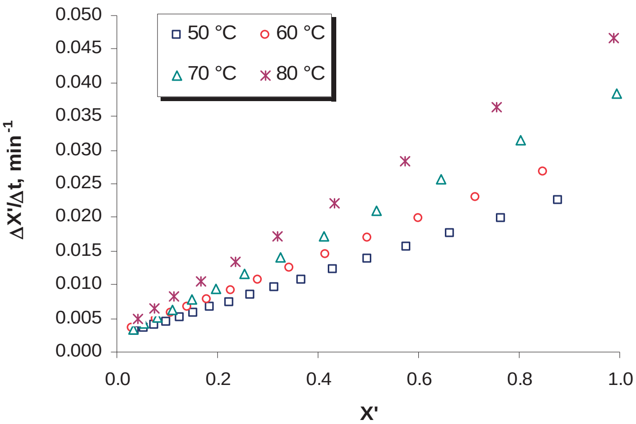

Figure 3. Drying rate vs. drying time at different drying temperatures for fluid bed drying (FBD) of non-treated apple samples

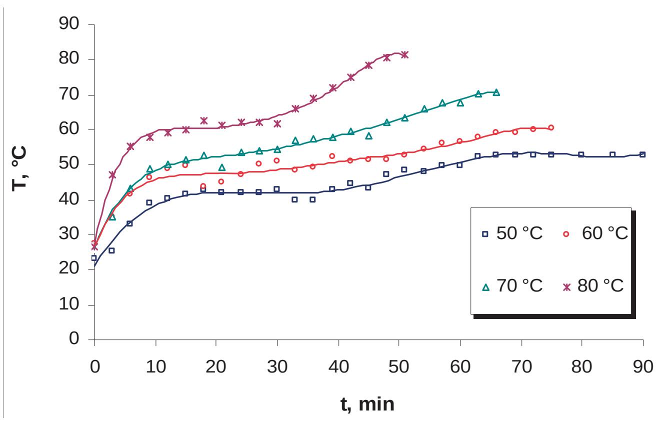

Figure 4. Temperature in non-treated apple samples vs. drying time for fluid bed drying (FBD) at different drying temperatures

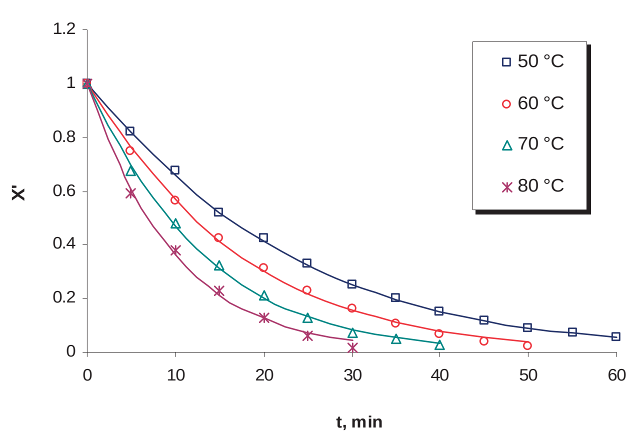

Figure 5. Experimental and approximating moisture content as a function of drying time at different drying temperatures and air velocities of 3.5 m s^{-1} for fluid bed drying (FBD) of blanched apple samples

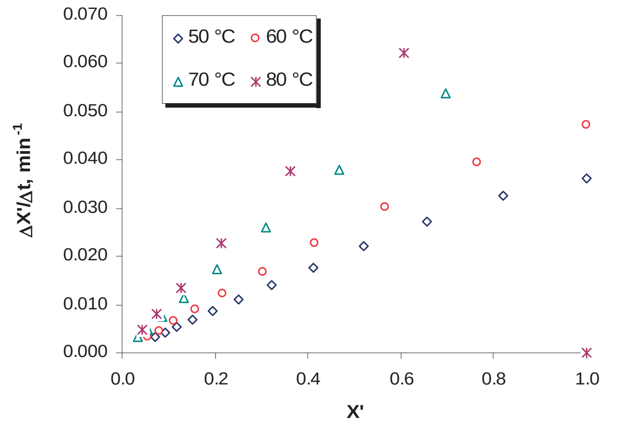

Figure 6. Drying rate vs. drying time for different drying temperatures for fluid bed drying (FBD) of blanched apple samples

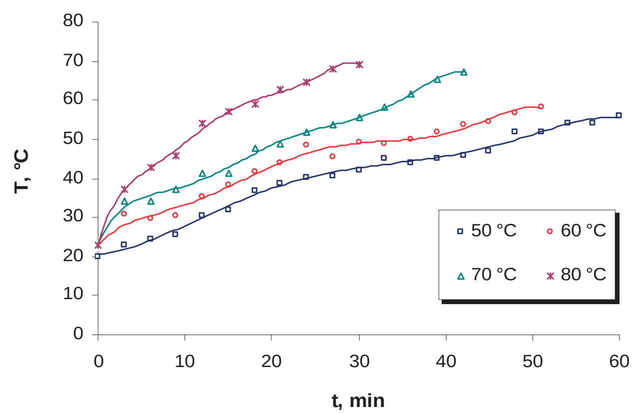

Figure 7. Temperature in blanched apple samples vs. drying time for fluid bed drying (FBD) at different drying temperatures

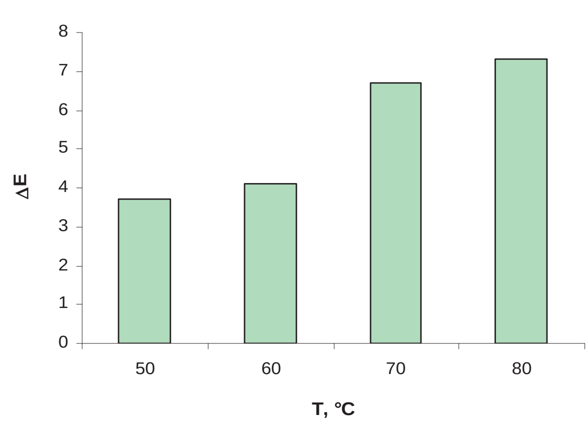

Figure 8. The total colour difference (ΔE) vs. different drying temperatures for non-treated apple samples

Figures 4 and 7 shows the temperatures in non-treated and blanched samples versus drying time for fluid bed drying at different drying temperatures. Figure 8 shows total colour difference versus different drying temperatures for fluid bed drying of non-treated apple samples. With the increase of the temperature the total colour dif-

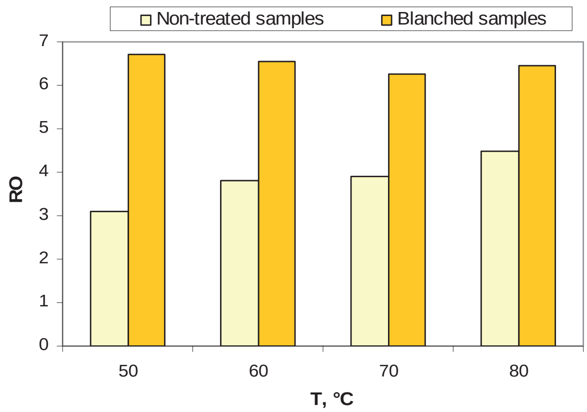

Figure 9. Rehydration ratio (RR) vs. different drying temperatures for non-treated and blanched apple samples

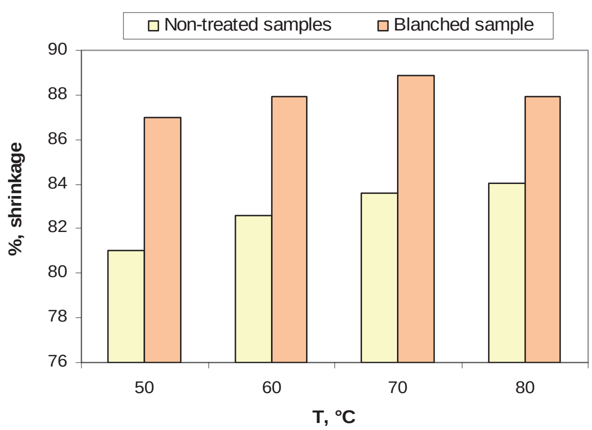

Figure 10. Percentage of shrinkage vs. different drying temperatures for non-treated and blanched apple samples

ference for the fluid bed drying increases. The lowest ΔE value was determined for the untreated apple slices dried at the drying air temperature of 50 °C. The increase of the drying air temperature resulted with a darker apple slice colour (high values of ΔE). The increase in browning of the apple slices with the increase of the drying air temperature was reported by Sapers and Douglas, 1987; Funebo and Ohlsson, 1998 and Wang and Chao, 2003. It was also observed that the original colour of fresh apple samples was more preserved when drying the non-treated samples at lower temperatures.

Figure 9 shows rehydration ratio versus different drying temperatures for drying of non-treated and blanched apple samples. With the increase of the drying temperature, rehydration ratio for non-treated apple samples increased, while with the increase of the drying temperature rehydration ratio for the blanched samples decreased in the most of the cases. The values of rehydration ratio for blanched apple were higher then those for non-treated apple samples.

The comparison between the percentage of shrinkage for non-treated and blanched apple samples at different drying temperatures are given in Figure 10. With the increase of the drying temperature, the percentage of shrinkage for non-treated apple samples increased, as well as for the blanched apple samples. It can be seen that the shrinkage effect was intensive for treated apple samples.

Conclusion

The kinetic equations were estimated using logarithmic model and the results of the estimation have exhibited correspondence to the experimental results. As a result of drying of non-treated apple at higher temperatures, drying time shortens, while rehydration properties improve. On the other hand, with the increase of the drying temperature, overall colour changes (ΔE) of non-treated samples increase. The lowest value for ΔE was determined for non-treated apple slices dried at the drying air temperature of 50 °C and air flow velocities of 3.5 m s^{-1}.

The best results, shorter drying time and better rehydration properties, were obtained when samples were pre-treated by blanching in hot water at temperature of 85 °C for three minutes. Shrinkage was intensive for blanched apple samples in all runs.

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