Influence of Process Parameters and Pre-treatments on Quality and Drying Kinetics of Apple Samples

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Abstract

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The aim of this research was to determine the influence of the process parameters and pre-treatment methods on the quality and drying kinetics of apple samples of the Florina variety using standard analytical methods: thermogravimetry, rehydration, colorimetry. The Apple samples were dried in a laboratory tray drier at different temperatures (50, 60, and 70°C), airflow velocities (1.5 m/s and 2.75 m/s), and pre-treatment methods (dipping in 0.5% ascorbic acid solution; 0.3% L-cysteine solution; 0.1% 4-hexyl resorcinol solution; 0.5% sodium metabisulfite solution; mixed solution of 0.05% 4-hexyl resorcinol and 0.5% sodium metabisulfite; blanching in hot water at 85°C). According to the drying time, rehydration and colour characteristics, the optimal drying parameters found were: temperature of 60°C and airflow velocity of 2.75 m/s. The drying kinetic equations were estimated using Page's mathematical model. The results of the estimation showed a good agreement with the experimental data. The best results were achieved when the samples were pre-treated with 4-hexyl resorcinol. Blanching in hot water resulted in a higher drying rate and higher rehydration ratio, but also in unacceptable changes in the colour appearance of the apple samples.

Keywords: drying kinetics; convection drying; apple; pre-treatment; rehydration; colour

The apple is an important raw material for many food products and apple plantations are cultivated in many countries of the world. Thus, it is very important to define the conditions under which the characteristics of fresh apples can be preserved and to define optimal parameters for their storage and reuse (Velić *et al.* 2004). Dried fruits have a long shelf life and therefore can provide a good alternative to fresh fruits, allowing out of season fruits to be available.

It is necessary to develop and expand the availability of high quality and consumer attractive dried products (Contreras *et al.* 2008) with acceptable colour, shape, and good rehydration characteristics. Drying is the oldest method of preserving food and also a widely used method of fruits and vegetables preservation that works by removing water from the food, thus preventing the growth of microorganisms and decay. Water is removed to the final concentration assuring microbial stability of the product and minimising chemical and physical changes of the material during storage. In most drying processes, water is removed by convective evaporation in which heat is supplied

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by hot air (Lewicki & Jakubczyk 2004). Drying behaviour is basically influenced by a number of internal (e.g., density, permeability, porosity, sorption-desorption characteristics, and thermo physical properties) and external parameters (e.g., temperature, velocity, and relative humidity of the drying medium) (Kaya *et al.* 2007). In order to improve the control of the drying process, it is important to dispose of accurate models to simulate the drying curves under different conditions. There are several empirical approaches for modelling the drying processes. Some widely used empirical models include Newton, Page, Modified Page, and Henderson and Pabis models, which have specific function forms (Lertworasirikul 2008). Empirical models are developed from experimental data without any assumption about the underlying phenomena.

Drying as a method of food preservation causes many physical, chemical and biochemical changes in the processed material. The advancement of these changes depends also on the pre-treatment. Pre-treatments quite often preceed drying of fruit and vegetable in order to minimise the adverse changes occurring during dehydration and subsequent storage. Pre-treatments stop the metabolism of cut tissue either by killing cells or by injuring enzymatic routes (Lewicki 2006). Many researchers have been looking for novel antibrowning agents to replace sulphites. One of them is 4-hexyl resorcinol, an effective agent for the enzymatic browning control in apple slices (Son *et al.* 2001).

The objective of the present study was to examine the effects of the drying temperatures and airflow velocities on the apple samples of the Florina variety and to find the most effective pre-treatment agent in relation to colour, rehydration ratio, and drying kinetics.

MATERIAL AND METHODS

Fresh material. Apples of the Florina variety were obtained from the local small family farm and stored at +4°C. After stabilisation at the ambient temperature, the apples were manually peeled and cut into disc shaped samples, diameter 20 mm and height 5 mm.

Drying equipment. Drying was performed in a pilot plant tray dryer (UOP 8 Tray Dryer, Armfield, UK). The dryer operates on the thermo gravimetric principle. The dryer (Figure 1) was equipped with the temperature and airflow velocity controllers. Air was drawn into the duct through a diffuser by a motor driven axial flow fan impeller. In the tunnel of the dryer were carriers for trays with samples, which were connected to a balance. The balance was placed outside the dryer, continuously determining and displaying the sample weight. A digital anemometer measured the airflow velocity at the end of the tunnel.

Drying procedure. The drying temperatures applied for the non-treated apple samples varied between 50°C, 60°C, and 70°C. The dryer was operated at the air velocities of 2.75 m/s and 1.5 m/s. Prior to drying at the temperature of 60°C and airflow velocity of 2.75 m/s, the apple samples were treated as follows: blanching in hot water at 85°C; dipping in 0.5% ascorbic acid solution; dipping in 0.3% L-cysteine solution; dipping in 0.1% 4-hexyl resorcinol solution; dipping in 0.5% sodium metabisulfite solution, and finally dipping in a mixed solution of 0.05% 4-hexyl resorcinol

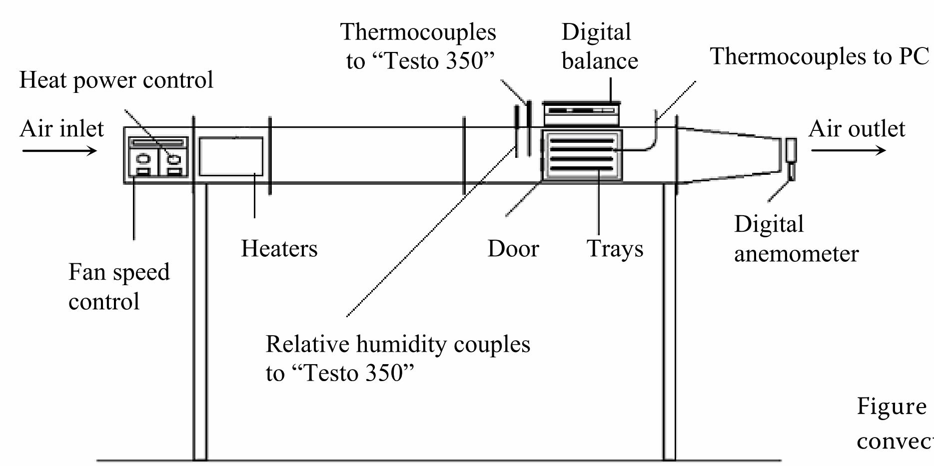

Figure 1. Schematic diagram of the convection drying equipment

and 0.5% sodium metabisulfite. The air streamed parallel to the horizontal drying surfaces of the samples. The drying process started when the drying conditions had been achieved. The apple samples were placed on the trays into the tunnel of the dryer and the measurement started from this point. "Testo 350" probes, placed into the drying chamber, were used to measure the relative humidity and drying air temperature. The 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 12% (wet base) was achieved. The airflow velocity was measured every five minutes with a digital anemometer (Armfield, UK) that was placed at the end of the tunnel. The dried samples were kept in airtight glass jars until the beginning of the rehydration experiments. The effects of temperatures and pre-treatments on the quality of the dried apple samples were determined on the basis of the colour and rehydration characteristics.

Determination of dry matter content. Dry matter content of the apple samples was determined by drying milled samples (~10 g) for 24 h at 105 ± 0.5°C to a constant mass. Analyses were done in triplicates for every category. The average dry matter content (w_{db}), expressed in percents, was calculated using the following equation:

$$w_{db}\ (\%) = (m_2/m_1) \times 100 \quad (1)$$

where:
m_1 – mass of the apple samples before drying (g)
m_2 – mass of the apple samples after drying (g)

Colour measurement. The colour of fresh and dried apple samples was measured using Chromameter CR-400 (Minolta). The analyses of the colour values were done twenty times with each fresh and dried apple sample. Three parameters, L^* (lightness), a^* (redness), and b^* (yellowness), were used to study the colour changes. L^* refers to the lightness of the samples and ranges from black = 0 to white = 100. The negative value of a^* indicates green, while *a* th*e* positive one indicates red-purple colour. Positive b^* indicates yellow and negative blue colours. The total colour difference (ΔE) was calculated as follows:

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

$$\Delta L^* = L^* - L_0^*, \quad \Delta a^* = a^* - a_0^*, \quad \Delta b^* = b^* - b_0^* \quad (3)$$

where: L_0^*, a_0^*, b_0^* – colour parameters of fresh apple samples. Fresh apple samples were used as the reference, a higher ΔE representing greater colour difference from the reference material

Rehydration. The rehydration characteristic was used as a quality index of a dried product. (Velić *et al.* 2004) expressed the rehydration rate (RR). Approximately 3 g (± 0.01 g) of dried samples were placed in a 250 ml laboratory glass (two analyses for each sample), 150 ml distilled water was added and the glass was covered and heated to boil within 3 minutes. The content of the laboratory glass was then gently boiled for another 10 min and then cooled. The cooled content was filtered for 5 min under vacuum and weighed. The rehydration ratio was calculated as:

$$\mathrm{RR} = W_r/W_d \quad (4)$$

where:
W_r – drained weight (g) of the rehydrated sample
W_d – weight of the dry sample used for rehydration

Drying rate curve determination. The exponential Page's model used successfully describes the drying kinetics of food materials (Doymaz 2004, 2007, 2008; Simal *et al.* 2005; Bozkir 2006; Margaris & Ghiaus 2007; Wang *et al.* 2007; Karaaslan & Tuncer 2008; Lertworasirikul 2008; Singh *et al.* 2008). The authors also used this model to describe the changes in the moisture content and drying rates. The time-dependent weight of samples was converted for the given time dependent on the moisture content. To avoid some ambiguity in the 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 vs. the drying time. For calculating the drying rate curves, a simplified model was used as follows:

$$X(t) = e^{(-kt^n)} \quad (5)$$

$$-\frac{dX'}{dt} = knt^{(n-1)}\, X'(t) \quad (6)$$

where:
k, n – parameters of Page's model
t – drying time

The correlation coefficient was used as the measure of the model adequacy.

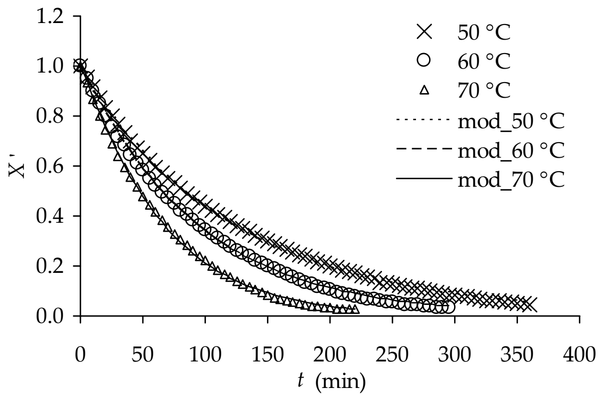

Figure 2. Experimental and approximated moisture content of non-treated apple samples at air velocity of 1.5 m/s

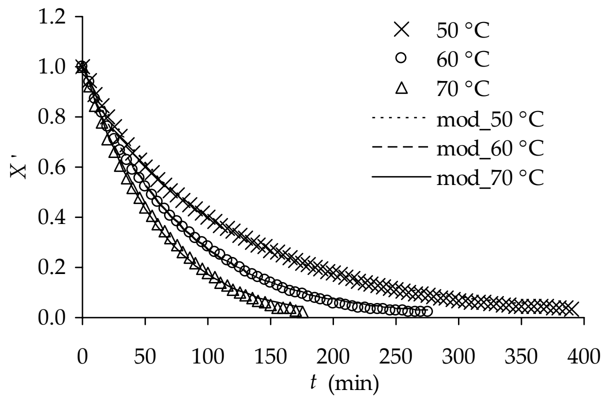

Figure 3. Experimental and approximated moisture content of non-treated apple samples at air velocity of 2.75 m/s

Statistic analysis. Statistica 7.0 (StatSoft Inc., USA) was used for the data analysis. Parameters k and n in Page's exponential model were calculated by non-linear regression method (Quasi-Newton). One-way analysis of variance (ANOVA) and multiple comparisons (*post-hoc* LSD) were used to evaluate significant differences of the data at $P < 0.05$ of colour and rehydration results. The data were expressed as means ± standard deviation. The experiments were replicated three times for statistical purposes.

RESULTS AND DISCUSION

The moisture contents (experimental and modelled data) vs. drying time at different temperatures and at different air velocities are shown in Figures 2 and 3. Obviously, a good agreement exists between the experimental data and the chosen mathematical model (Page's model), which is confirmed by the high values of the correlation coefficient (0.998–0.999) in all runs. The results show that the air temperature had a significant effect on the drying rate of apple. With the increase of the temperature, the time required to achieve a certain moisture content decreased.

Figures 4 and 5 show typical drying curves characterised by two falling rate periods with no apparent constant rate period.

Figure 6 shows the experimental moisture content versus drying time for different pre-treatments at the air velocity of 2.75 m/s and drying temperature 60°C.

Figure 7 shows the drying rate vs. drying time for different pre-treatments at the air velocity of 2.75 m/s and drying temperature 60 °C. While the drying process took 275 min with the non-treated apple samples, dipping the apple samples in different pre-treatment solutions had a statistically

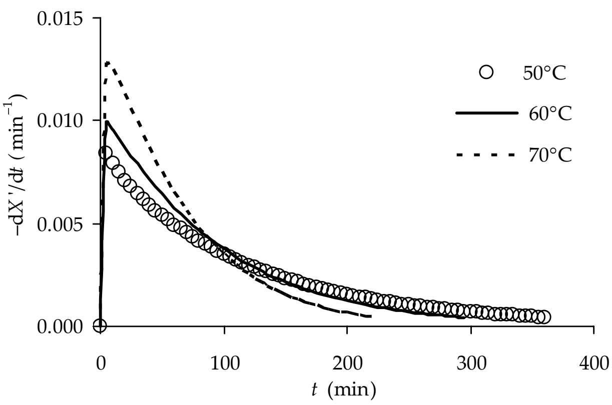

Figure 4. Drying rate dynamics of non-treated apple samples at air velocity of 1.5 m/s

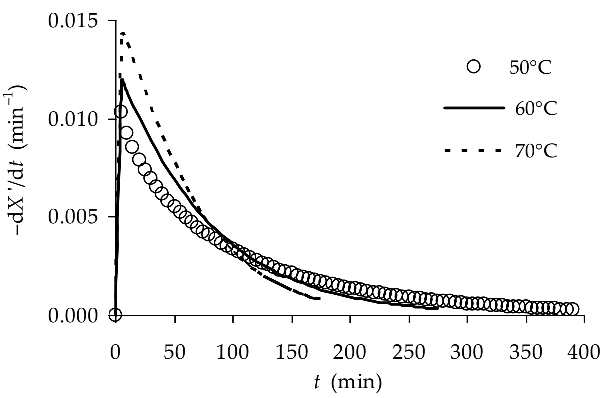

Figure 5. Drying rate dynamics of non-treated apple samples at air velocity of 2.75 m/s

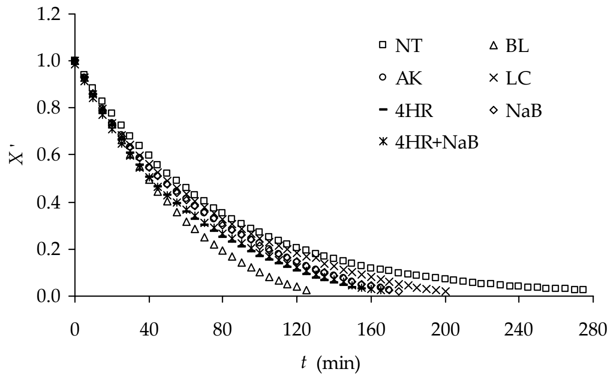

Figure 6. Experimental moisture content at 60°C drying temperature at air velocity of 2.75 m/s after different pre-treatments

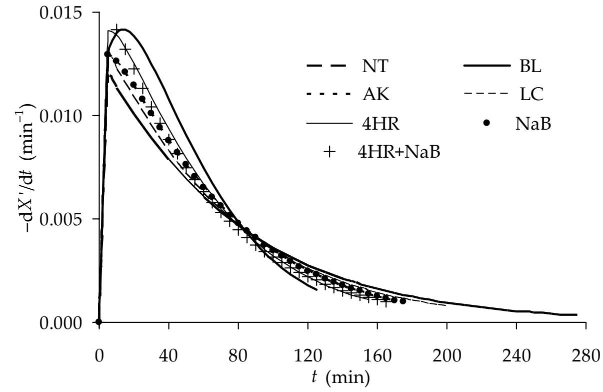

Figure 7. Drying rate dynamics of pre-treated apple samples at 60°C drying temperature and air velocity of 2.75 m/s

significant influence on the drying time decrease. Blanching in hot water reduced the drying time up to 54.55%, the pre-treatment with ascorbic acid reduced the drying time up to 38.18%, with L-cysteine 27.27%, with 4-hexyl resorcinol 43.64%, with sodium metabisulfite 38.18%, and with the mixed solution of 4-hexyl resorcinol and sodium metabisulfite as compared to the non-treated apple samples. The drying curves of the apple samples pre-treated with ascorbic acid exhibited a very similar trend as did those of the apple samples pre-treated with sodium metabisulfite.

Figure 8 shows total colour difference vs. different drying temperatures and different air velocities obtained with the non-treated apple samples. With the increase of the air temperature at the air flow velocity of 2.75 m/s, the total colour difference also increased, while at the air flow velocity of 1.5 m/s no clear dependence was observed of the total colour difference vs. different drying temperatures. Statistical analysis (ANOVA, *post-hoc* LSD, $P < 0.05$) showed that the drying temperature of 50°C for the chosen air velocities, and the drying temperature at 70°C for the airflow velocity of 1.5 m/s had no statistically significant influence on total colour change.

Total colour difference versus different pre-treatments at the air velocity of 2.75 m/s and drying temperature 60°C is shown in Figure 9. The pre-treatment with 0.1% 4-hexyl resorcinol resulted in

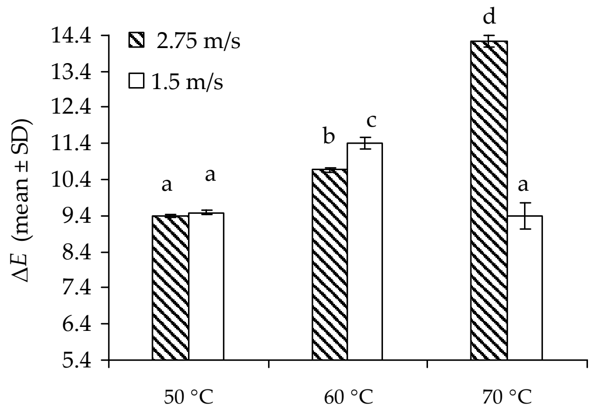

Figure 8. Total colour change (ΔE) of non-treated apple samples at different drying temperatures and different air velocities

a, b, c, d, e, f – groups which differed statistically significantly ($P < 0.05$) from one another according to different pre-treatments

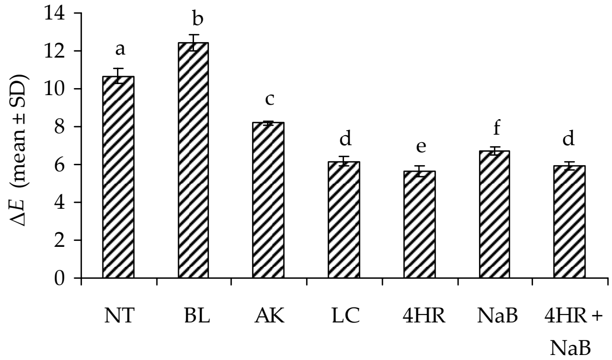

Figure 9. The total colour change (ΔE) of pre-treated apple samples at 60°C drying temperature and air velocity of 2.75 m/s

a, b, c, d, e – groups which differed statistically significantly ($P < 0.05$) from one another according to drying temperature and airflow velocities

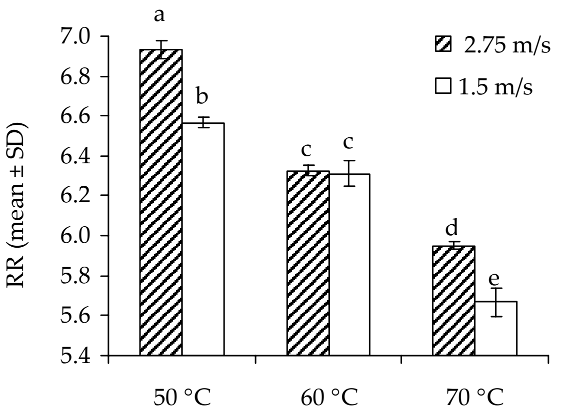

Figure 10. Rehydration ratio (RR) of non-treated apple samples at different drying temperature and air velocities

a, b, c, d – groups which differed statistically significantly $P < 0.05$) from one another according to different pre-treatments

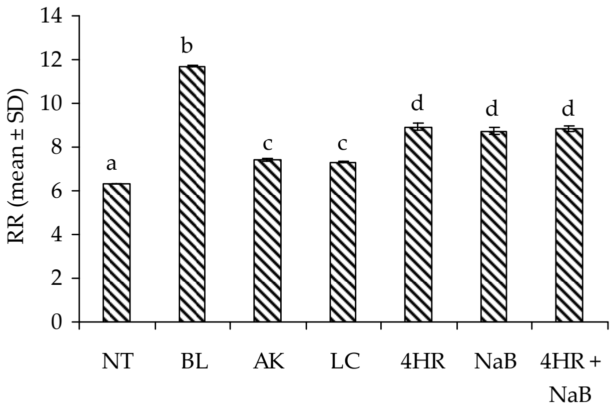

Figure 11. Rehydration ratio (RR) vs. different pre-treatments at air velocity of 2.75 m/s and drying temperature of 60°C

a, b, c, d – groups which differed statistically significantly $P < 0.05$) from one another according to different pre-treatments

the smallest change of colour while the blanching treatment gave the largest change of colour, compared to the non-treated samples. The ANOVA analysis showed the existence of six groups which differed significantly from one another ($P < 0.05$; *post-hoc* LSD) according to different pre-treatments. The results presented here show no statistically significant differences in the colour changes between the pre-treatment with L-cysteine and that with the mixed solution of 4-hexyl resorcinol and sodium metabisulfite.

Figure 10 shows the rehydration ratio vs. different drying temperatures and different air flow velocities for drying of the non-treated apple samples. With the increase of the drying temperature, the rehydration ratio of the non-treated apple samples decreased. At the air velocity of 2.75 m/s, the rehydration ratio vs. different drying temperatures was higher compared to that at the air velocity of 1.5 m/s. The results showed that with the apple samples exposed to a certain temperature for a long time, the degradative irreversible changes were higher. Statistical analysis showed that the drying temperature of 60°C for the selected air velocities had no statistically significant influence on the rehydration ratio.

It can be seen that blanching with hot water resulted in the highest rehydration as compared to other pre-treatments (Figure 11). The ANOVA analysis showed the existence of four groups which differed significantly from one another according to different pre-treatments. The presented results show no statistically significant differences in the rehydration ratio between the pre-treatment with ascorbic acid and that with L-cysteine. The results of the statistical analysis show no statistically significant differences in the rehydration ratio changes between the pre-treatments with 4-hexyl resorcinol, sodium metabisulfite, and the mixed solution of 4-hexyl resorcinol and sodium metabisulfite.

CONCLUSION

The kinetic equations were estimated using Page's mathematical model. The results of the estimation exhibited a relation to the experimental results. An increase of the drying temperature resulted in a decrease of the drying time. On the other hand, with the increase of the drying temperature the rehydration ability decreased and the overall colour changes (ΔE) of the non-treated samples increased, especially at the air velocity of 2.75 m/s. The results also show that the pre-treatments of the apple samples decreased the total colour changes (ΔE) up to 47% when compared to the non-treated samples. The only exception was the blanching treatment where the total colour change (ΔE) was by 16% higher when compared to that of the non-treated samples.

The best results (reduced drying time, high rehydration ratio, and minimum colour change) were achieved when the samples were pre-treated with 4-hexyl resorcinol. The apple samples pre-treatment with blanching in hot water at a temperature of 85°C resulted in a higher drying rate and a higher rehydration ratio, but also in an unacceptable change in the colour appearance.

Drying is a complex process which affects the food properties in many ways. The knowledge of the way in which the drying influences the food properties can be efficiently used to create new quality attributes and new functionality of the products.

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