Study of Drying Kinetics of Quince

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Abstract

The present work aimed at studying the influence of temperature (40, 50 and 60 ºC) and air velocity (0.7, 0.9 and 1.2 m/s) on drying of quince. From the results obtained it was possible to conclude that the quince drying had a similar kinetic behaviour, regardless of the operating conditions. As to the influence of the drying temperature on the process, it was observed that increasing the drying temperature from 40 ºC to 60 ºC leads to a diminishing of 30 % in the drying time. On the other hand the increase in air velocity does not have a proportional effect on the reduction of dimensionless moisture, particularly at higher quince moisture contents.

The rate of quince drying is characterised by the absence of the constant drying-rate period followed by falling-rate period, regardless of the conditions.

The data for the moisture ratio over time was fitted to different empirical models with the best performances coming from the Modified Page, Henderson & Page and Logarithmic models.

Key words: quince, drying, drying kinetics, moisture content

1. Introduction

Quince fruit (*Cydonia oblonga*), a member of the *Rosaceae* family, is known for its characteristic and pleasant odor and distinctive taste. However, like other fruits, they are perishable; therefore drying is fairly advantageous, reducing water activity of the material, thus diminishing the microbiological activity to a level preventing deterioration.

Even though the drying is one of the most common methods used to improve food stability, it is a complex process involving simultaneous coupled heat and mass transfer phenomena. However, the theoretical application of these phenomena to food products becomes difficult due to the complex structure and to the physical and chemical changes that occur during drying. For such purposes, many attempts have been made by several researchers to analyse physical properties during drying for different fruits and vegetables such as apple, banana, carrot, potato and garlic (Baysal et al., 2003; Mayor & Sereno, 2004; Khraished et al., 1997; Krokida & Maroulis, 1997). Koç et al. (2008) studied the effect of different drying methods (conventional drying in fluid bed and tray driers, infrared assisted air drying, osmotic dehydration combined with conventional air drying and freeze drying) on bulk density, substance density, porosity and shrinkage of quince and concluded that all the properties, except substance density, were affected by drying method.

Due to the complexity involved, the most common models to describe the mechanism of heat and mass transport are empirical and correlate the influence that certain process variables exert on the moisture removal process. The variables that influence drying behaviour include internal and external parameters (e.g. physic and thermophysical properties of the material being dried, temperature, humidity, and velocity of the drying gas). However, the research on the effects of these parameters on the quince drying process is still very scarce. Kaya et al. (2007) studied the effect of air temperature of 35 ºC, 45 ºC and 55 ºC on quince drying but with low air velocities, 0.2, 0.4 and 0.6 m/s. Hence, the experiments conducted aimed to study the air drying of quince in terms of kinetics evaluated at different temperatures (40, 50 and 60 ºC) and air velocities of 0.7, 0.9 and 1.2 m/s.

2. Materials and methods

2.1. Drying procedure

Quince slices weighting about 120 g with a thickness of 0.3 mm were placed in a wire-mesh tray (25 cm x 20 cm) in a drying unit, which has a square cross section of (30 cm x 30) and a length of 2.5 meters, being the tray placed in the middle of the drying unit. Air flowed parallel to the horizontal drying surfaces of the samples. The mass flow rate of the drying air was regulated by a fun driven via a variable speed motor and the temperature was regulated using a rheostat. Both instruments are located on the top of the drying unit.

The initial moisture content of slices was determined by weight loss in a drying chamber at atmospheric pressure and 105 ºC until constant weight. Each drying experiment was independent, and the quinces used for all trials were from the same farm and had the same average initial moisture content. During the experiments, the sample weight and temperature (ambient, before and after the tray) were recorded at every 40 seconds, using, respectively, a balance and thermocouples coupled to humidity/temperature meter connected to a PC. Furthermore, the velocity of the air was measured by an anemometer at the end of the unit dryer.

2.2. Drying rate curve determination

Due to differences in initial mass of fresh quince, the sample moisture content (W) was expressed in a dry basis. The drying curve for each experiment was obtained by plotting the moisture (W) of the sample as a function of the drying time, t, measured in minutes.

The drying rate ($-d(W_{t+\Delta t}-W_t)/dt$) was used to characterize the drying kinetics of quince and the results were plotted against t, in minutes, and with respect to average moisture (W_m) between the interval t and $t+\Delta t$. Apart from the drying rate, the data obtained experimentally for the different temperatures and air velocity studied were plotted in the form of moisture ratio (MR) versus time, being MR defined as:

$$MR = (W-W_e)/(W_0-W_e)$$

where W, W_e and W_0 are, respectively, the moisture content at time t, the equilibrium moisture content and the initial moisture content, all expressed in dry basis (g water/ g dry solids).

The experimental sets of (MR, t) were fitted using the software Sigma Plot (Version 8.0, SPSS, Inc.) to different empirical models well-known in the literature, namely Newton, Modified Page, Henderson & Pabis, Wang & Singh, Vega-Lemus and Logarithmic. The correlation coefficient, R^2, was used to access the quality of each models estimate.

3. Results and discussion

The average of initial moisture content in fresh quince samples was 0,805 g water/g wet basis which corresponds to 4.12 g water/g dry basis. Before the drying experiments of quince, the equipment was run for about one hour to achieve the steady sate conditions of temperature and air velocity. Each drying experiment was continued until the equilibrium moisture content was reached.

Figure 1 illustrates the moisture of quince samples during the air drying at the different temperatures studied. The drying curves obtained for the air velocity of 0.9 m/s and temperatures of 40 ºC, 50 ºC and 60 ºC reveal a similar kinetic behaviour. As expected, there is an acceleration of the drying process due to the increase in the temperature of the drying from 40 ºC to 60 ºC. However, in the early stages of drying the temperature of 60 ºC shows a much faster decrease of moisture ratio as compared to the temperature of 40 ºC and 50 ºC. In fact, the reduction of water in relation of the initial moisture content took values of 85.8 %, 72.4 % and 66.6 %, respectively, for 60 ºC, 50 ºC and 40 ºC for the second hour of drying. With the increase of drying time those differences diminish and after 5 hours the moisture ratio is similar for all temperatures.

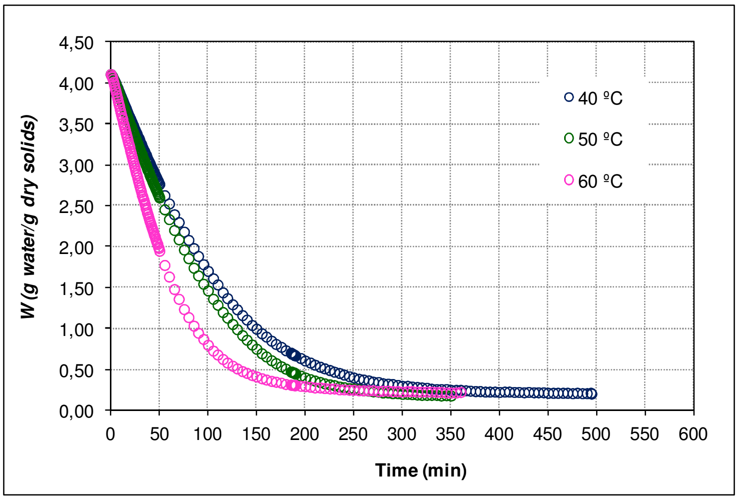

FIGURE 1: Profiles of moisture for temperatures of 40, 50 and 60 ºC and air velocity of 0.9m/s.

Figure 2 shows that the air velocity had a significant influence on the moisture ratio at the temperature of 60 ºC, particularly in the early stages of drying. However, as the airflow velocity has increased, the lost of moisture was not proportional. In fact, the lost of moisture from the quince was much slower at air velocity of 0.7 m/s than at higher values of air velocity. After a drying time of approximately 2 hours the increase in air velocity from 0.7 m/s to 0.9 m/s allowed reductions of moisture content, respectively, of 70.2 % and 85.8 % in relation to the initial moisture content of quince. A further augment in air velocity to 1.2 m/s lead to a slighter reduction of moisture content, 90.7 %, for the same drying time. As the drying time increased the difference in moisture of the samples dried at the different air velocities was much less pronounced. Moreover, an increase in air velocity results in decreasing of drying time due to the increase of heat and mass transfer between the air and the quince. The drying time declined from 390 minutes to 345 minutes when the air velocity increased from 0.7 m/s to 1.2 m/s.

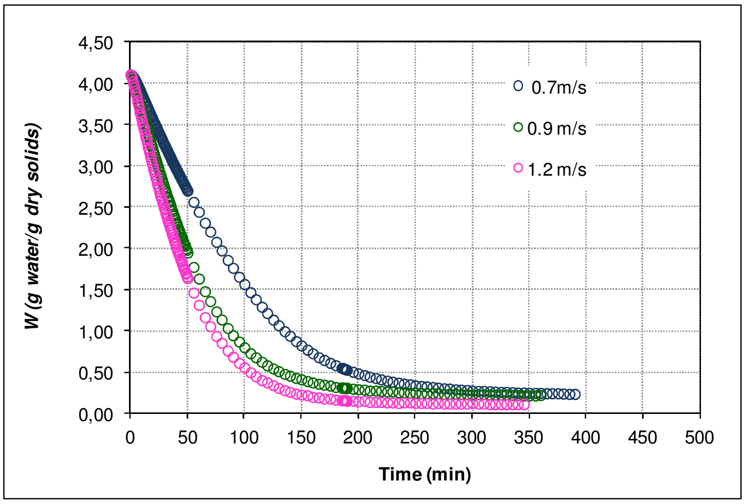

FIGURE 2: Variation of moisture along drying time for different air velocities at 60 ºC.

The curves of the drying rate with moisture content for different temperatures and air velocities are illustrated, respectively, in Figures 3 and 4. The results in Figure 3 show that the period of constant drying rate, that sometimes is observed in fruits, is very small or does not exist for the three temperatures studied. In addition, the rise in temperature allowed an increase in the drying rate. However, the increase in temperature from 40 to 50 ºC had a smaller effect on drying than the increase from 50 to 60 ºC. In fact, for a moisture content of 3 g water/g dry solids the drying rate was 0.027 g water/(g dry solids.min), 0.030 g water/(g dry solids.min) and 0.045 g water/(g dry solids.min) for the temperatures of 40, 50 and 60ºC, respectively. At moisture contents lower than 1 g water/ g dry solids, the effect of the temperature on the drying rate was much less pronounced. At these values of moisture content the quantity of water to evaporate is small and consequently the increase in the air temperature has no significant effect on the drying rate.

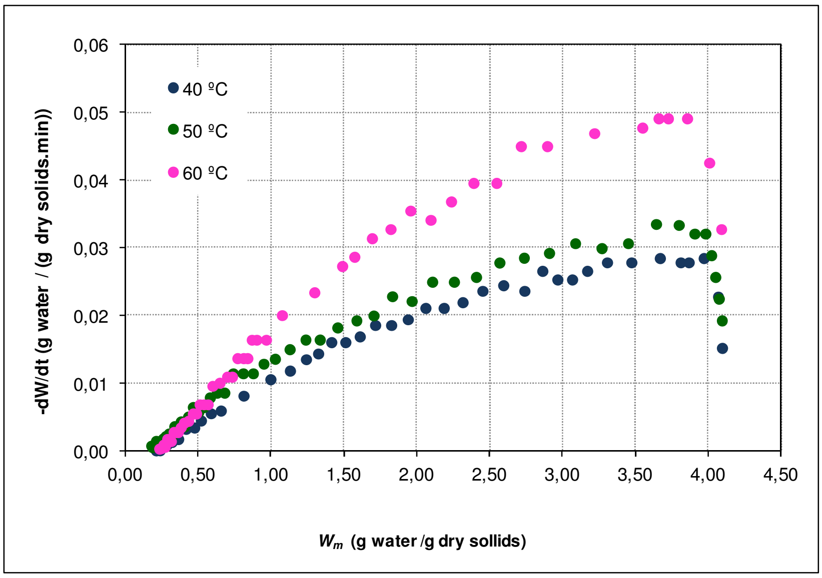

FIGURE 3: Drying rate curve versus moisture content for temperatures of 40 ºC, 50 ºC and 60 ºC and air velocity of 0.9 m/s.

Figure 4 reveals that in the early stages of drying the rise in air velocity from 0.7 m/s to 0.9 m/s increased the drying rate in approximately 40 % but the increase in air velocity to 1.2 m/s only allowed an increase of 15 % on drying rate as compared with the value to 0.9 m/s. However, for values of moisture content lower than 1 g water/g dry solids the increase in air velocity from 0.7 m/s to 1.2 m/s had a smaller effect on the drying rate.

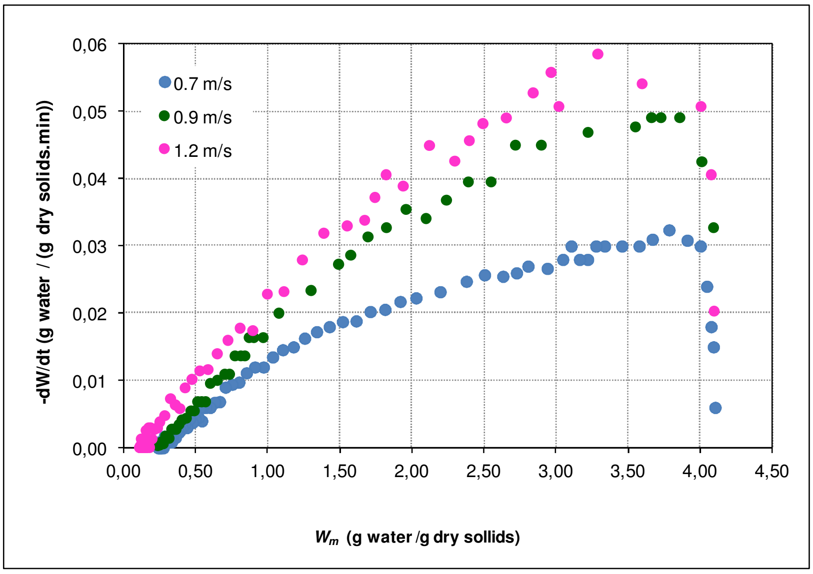

FIGURE 4: Drying rate curve versus moisture content at 60 ºC and air velocity of 0.7 m/s, 0.9 m/s and 1.2 m/s.

The drying kinetics data obtained for the different temperatures and air velocities studied, in the form of moisture ratio versus time, was fitted to six different kinetic models commonly

cited in literature: Newton, Modified Page, Henderson & Pabis, Wang & Singh, Vega-Lemus and Logarithmic (Yaldýz & Ertekýn, 2001; Togrul & Pehlivan, 2003; Lahsasni et al., 2004).
From the results obtained to the estimated parameters with the corresponding standard deviation, as well as the determination coefficient which characterizes each fitting, it was possible to conclude that the best models for the case under study are the Modified Page, Henderson & Pabis and Logarithmic with R^2 ranging between 0.9913 and 0.9999. On the other hand, the worst model is the Wang & Singh, with R^2 varying from 0.7946 to 0.9782. In fact, the polynomial function proved to be less adequate to describe the kinetic data obtained for the drying of quince. Although the three models, Modified Page, Henderson & Pabis and Logarithmic, show a good agreement between the experimental and fitted data, the Henderson & Pabis and Logarithmic tend to give predictions of moisture ratio higher than one for the initial time. Thus, considering that the Modified Page is the best model applicable to the drying of quince, the experimental values of the moisture ratio for the different temperatures and air velocities as well as the predictions obtained for each case using this model are illustrated, respectively, in Figures 5 and 6.

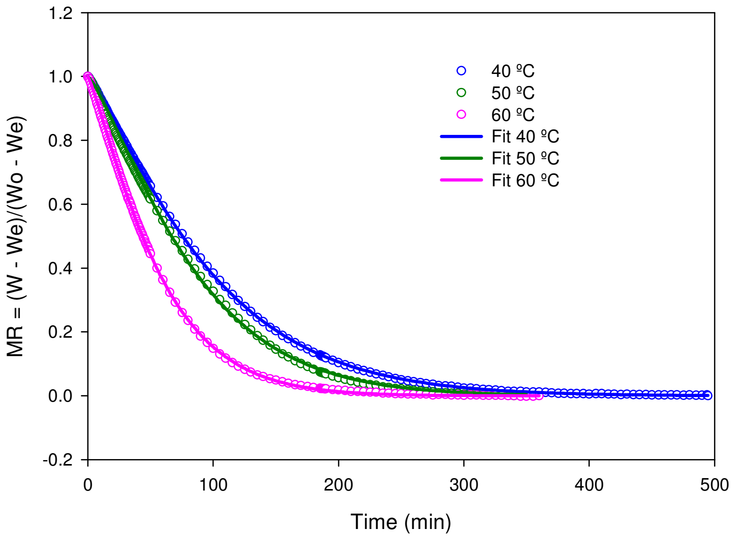

FIGURE 5: Fitting the moisture ratio with de Modified Page model at different temperatures and air velocity of 0.7 m/s.

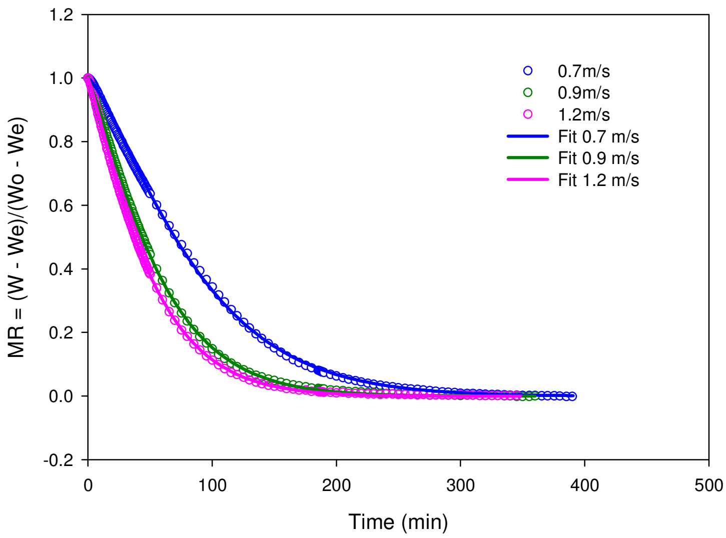

FIGURE 6: Fitting the moisture ratio with de Modified Page model at different air velocities and temperature of 60 ºC.

As it can be seen, the Modified Page model proved to give good fits for the different drying temperatures and air velocities, along the entire drying periods.

4. Conclusions

The results showed that moisture curves for the drying of quince at the three temperatures followed a sigmoidal shape, characteristic of the drying processes, and gave evidence of a reduction in drying time with the increase in temperature, from 8.2 h at 40 ºC to 6.0 h at 60ºC. The increase in air velocities from 0.7 to 1.2 m/s, at a constant temperature of 60 ºC, originated a higher drying rate. However, the effect of the drying air velocity on the drying rate was nearly negligible for lower moisture ratios.

The drying kinetics data obtained for the different conditions studied in the different trials, expressed in the form of moisture ratio versus time, was fitted to different models (namely Newton, Modified Page, Herdersen and Pabis, Wang and Singh, Vega-Lemus and Logarithmic) available in the literature and a good agreement was observed. However, based on the standard deviation results, as well as on the additional statistical information, the Modified Page model was one of the best models to describe this drying kinetics.

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