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Case studies on the effect of the air drying conditions on the convective drying of quinces

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ABSTRACT

The objective of the current study is to examine experimentally the thin-layer drying behavior of quince slices as a function of drying conditions. In a laboratory thermal convective dryer, experiments were conducted at air temperatures of 40, 50 and 60 °C and average air velocities of 1, 2 and 3 ms^{-1}. Increasing temperature and velocity resulted to a decrease of the total time of drying. The experimental data in terms of moisture ratio were fitted with three state-of-the-art thin-layer drying models. In the ranges measured, the values of the effective moisture diffusivity (D_{eff}) were obtained between 2.67×10^{-10} and 8.17×10^{-10} $m^2\,s^{-1}$. The activation energy (E_α) varied between 36.99 and 42.59 kJ mol^{-1}.

1. Introduction

The drying is used for the removal of moisture content of different fruits and vegetables, aiming to the efficient preservation and storage for long periods of time. It is a complex process where a simultaneous heat and mass transfer in transient conditions occurs. Knowledge of the heat and mass transfer mechanisms related to the process and the role of the drying parameters has a direct impact on the improvement of the quality of the dehydrated product. The main parameters affecting the drying process are temperature, velocity and relative humidity of the drying air.

There are many published studies dealing with the effect of the drying parameters during the drying process of vegetables and fruits. Drying kinetics of vegetables such as potato, carrot, pepper, garlic, mushroom etc. were studied by Krokida et al. [1]. The authors studied the effect of air drying conditions i.e. air temperature, humidity and velocity, and characteristic sample size on drying kinetics and they concluded that the drying constant and the equilibrium moisture content of the dehydrated product increases with temperature. For the examined cases, the temperature of the drying air was the most important factor affecting the drying rate. Sacilik et al. [2] studied the thin layer characteristics of organic apples slices in a convective hot air dryer as a single layer with thickness of 5 and 9 mm. Temperatures ranged from 40 to 60 °C while a single air velocity of 0.8 ms^{-1} was utilized. They noticed that both moisture content and drying rate were affected by the drying air temperature and slice thickness and they observed a decrease in the drying time, with the increase of the air drying temperature and an increase in the drying rate, with the decrease of the slice thickness. Babalis et al. [3]

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Nomenclature

a, n	coefficients in thin layer drying models
D_0	pre-exponential factor of the Arrhenius equation ($m^2\ s^{-1}$)
D_{eff}	effective moisture diffusivity ($m^2\ s^{-1}$)
DR	drying rate (g water/h)
E_α	activation energy (kJ mol^{-1})
k	constants in thin layer drying models (h^{-1})
L	half-thickness of samples (m)
N	integer number of terms in Fick's equation
M_0	initial moisture content (g water/g dry matter)
M_{eq}	equilibrium moisture content (g water/g dry matter)
MR	moisture ratio (dimensionless)
M_t	moisture content at any time t (g water/g dry matter)
R^2	coefficient of determination
R_g	gas constant (8.3143 kJ $mol^{-1}\ K^{-1}$)
RMSE	root mean square error
T	drying temperature (°C)
t	drying time (h)
T_{abs}	absolute temperature (K)
w	weight loss (g)
w_d	dry matter (g)
w_t	dry matter at any time t (g)
w_{t+dt}	dry matter at time $t+dt$ (g)

Greek symbols

χ^2	reduced chi-square

studied the influence of the drying conditions on the drying constants and moisture diffusivity during the thin-layer drying of figs. The authors stated that air velocities greater than 2 ms^{-1} has no significant effect on the drying rate and they concluded that the drying kinetics is most significantly affected by the air temperature, with the airflow velocity having a limited influence on the drying process.

Focusing on the drying of quince slices, Kaya et al. [4] and Barroca et al. [5] studied the effect of the temperature and velocity of the air stream. The former also conducted measurements by altering the humidity of the drying air. In the study of Kaya et al. [4], the values of the imposed temperatures varied from 35 °C to 55 °C, the relative humidity values from 40% to 70% while air velocities from 0.2 ms^{-1} to 0.6 ms^{-1}. The authors concluded that increasing the temperature or the velocity of the drying air, the total drying time is decreased, while the relative humidity and the total drying time are related in vice-versa manner. Barroca et al. [5] carried out experiments in temperatures ranging from 40 °C to 60 °C and velocities from 0.7 ms^{-1} to 1.2 ms^{-1}. The authors stated that the moisture curves followed sigmoidal shape characteristic of the drying processes and gave evidence of a reduction in drying time with the increase in temperature. They also concluded that an increase in air velocities resulted to a higher drying rate; however, the effect of the drying velocity on the drying rate was nearly negligible for lower moisture ratios.

The purpose of the present study is the experimental investigation of the drying kinetics of quinces for air drying conditions (temperature 40, 50 and 60 °C, velocity of 1, 2 and 3 ms^{-1}, humidity 10%) that have not been studied in the earlier literature and the determination of the effective moisture diffusivity as well as the activation energy for the above conditions.

2. Experimental methods

Fresh quinces were stored in a refrigerator at about 6 °C. Before drying, the quinces were cleaned and sliced manually to a thickness of 12 mm. The initial net weight of the quince slices was about 700 g and the initial moisture content (M_0) was measured to be 81.04% in wet basis (w.b.) or 4.27 g water/g dry matter in dry basis (d.b.) and was determined by the oven-drying method, for the fresh and for the final dehydrated products at 70 °C for 24 h [6] with repetition in order to assure accurate moisture content average values.

The laboratory thermal convective dryer (LTCD) unit was starting 2 h before each experiment in order to achieve the desired steady state conditions of the drying air flow. Experiments were performed at air drying conditions of 40, 50 and 60 °C, air velocities 1, 2 and 3 ms^{-1}, while the relative humidity remained constant at 10%. Product weight, air drying temperature, probe-surface temperature and relative humidity were acquired every 10 min. All experiments were twice repeated and the means of measurements were averaged and used to express the data of the moisture content.

Fig. 1 shows the LTCD unit which is equipped with an integrated measurement and control instrumentation. The overall dimensions of the facility are 4.7 m (length), 2.5 m (width) and 2.5 m (height). The air ducts are made from steel of 0.8 mm thickness. All the ducts were insulated with 10 mm of Alveolen (Frelen). The square section drying chamber (0.5 m × 0.5 m) is of tower (vertical) type and contains a metal tray which is supported on four, side wall mounted, load cells. A set of four refractory glasses of 10 mm thickness are available to replace the side steel walls when optical clarity and precise visual observations are required. A detailed description of the components and the operational characteristics has been presented in a previous publication [7].

The air and drying product temperatures were measured using calibrated PT100 with class A tolerance and accuracy ±0.15 °C. A 3-wire transmitter used to connect the probes to the card interface with accuracy ±0.2 °C was used.