

Research Article

Study and Application on Mathematical Model of Hot-air Drying for Red Jujubes

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Abstract: The Hot-Air drying characteristics of whole red jujube were investigated. Drying experiments were carried out at different levels of temperature (50, 60 and 70°C) and air velocity (0.5, 1.0 and 2.0 m/s). Six thin layer drying mathematical models were selected to fit the experimental data and the mathematical model of Hot-Air drying for red Jujube was established. The results showed that temperature affected the drying rate of whole red jujube: the higher the drying temperature, the shorter the drying time. Minimum influence of air velocity was observed on the processing time of red jujube. Also the results of the case introduced in the study showed that the model can be used in practice.

Keywords: Hot-Air drying, mathematical model, red jujubes, thin-layer drying

INTRODUCTION

Red jujube is a fruit mainly produced in and exported from China, whose cultivation area has reached more than 1.5 million hectares in China. Most of the red jujube were made of dried fruit and sold at home and abroad, except that a small proportion are reserved for fresh eating (Cao *et al.*, 2009). Red jujube containing abundant beneficial vitamins, protein, minerals and other trace elements (Lei *et al.*, 2006). It is not only a fruit, but also can be used for traditional Chinese Medicine. Post harvest fresh jujube, due to the higher moisture content, often result in 25-30% production. Drying is a widely used method for post harvest preservation of agricultural products. It can reduce the moisture and microbial activity in fresh fruit, increase product storage stability (Goyal *et al.*, 2007). Also can reduce the cost of products and transport (Doymaz, 2004).

Drying is a complicated process and the amount of energy required to dry a product depends on many factors, such as initial moisture, desired final moisture and drying air temperature and velocity (Karim and Hawlader, 2005). In recent years, based on the theory of thin layer drying, a lot of the grain, fruit and vegetables drying characteristics research were carried, the optimization of drying process had been done and the drying machine of high efficiency were designed (Hernandez *et al.*, 2000), also many research were carried on fruit drying, such as bananas, apples grapes, pistachios and so on. Some scholars studied drying of red jujube, however, these studies were conducted under the laboratory conditions and the results were not used in practice.

In this study, the Hot-Air drying characteristics of whole red jujube were investigated and the mathematical model of Hot-Air drying for red Jujube was established. Then we introduced a case and the results showed that the model can be used in practice.

MATERIALS AND METHODS

Materials and dryer: Shanbei red jujube is a very famous varieties of red jujubes, it is mainly produced in Yulin city of Shaanxi province. The material, fresh jujubes, used in this experiment was picked from Wubao County Yulin city Shaanxi Province at the end of September, 2013. The samples in the same species with full maturity and uniform size were stored in a refrigerator at 4°C before starting the experiments. The initial moisture content was about 68.79% wet basis and they will be swabbed with alcohol before the experiments.

The drying experiments were carried out by a laboratory dryer, it was provided by the Shaanxi province Wubao Everbright Jujube Industry Co., Ltd.. The Hot-Air drying machine mainly comprises a fan, an electric heater, a drying chamber, a temperature control unit etc. The fan's speed is adjustable and wind speed can be measured in real time through its wind speed measuring plate. A digital electronic balance is used to measure the weight of the samples.

Test of the hot-air temperature influence on drying rate of red jujubes: The dryer took 0.5 h to reach the desired value after starting up. And the drying experiments were carried out at different drying temperatures of 50, 60 and 70°C, the velocity was 1.0

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m/s. The red jujubes were taken out from the fridge and heated to the room temperature naturally. During the process of drying, moisture content was measured every hour, until it reaches the safe moisture content so far. Each determination was repeated three times and the average of the results was used for drawing the drying curves.

Test of the Hot-Air velocity influence on drying rate of red jujubes: The drying experiments were carried out at different drying velocity of 0.5, 1.0 and 2.0 m/s, the drying temperature was 60°C. The red jujubes were taken out from the fridge and heated to the room temperature naturally. During the process of drying, moisture content was measured every hour, until it reached the safe moisture content so far. Each determination was repeated three times and the average of the results was used for drawing the drying curves.

Determination of indicators and methods: The moisture content (dry basis) of jujubes was calculated by using following equation:

$$M_t = \frac{m_t - m_g}{m_t} \times 100t$$

where,

M_t = The moisture content (dry basis) at t

m_t = The mass at $t(g)$

m_g = The dry mass of sample (g)

Moisture contents of jujubes during Hot-Air drying experiments were expressed in dimensionless form as moisture ratios MR with the following equation (Midilli *et al.*, 1999; Midilli, 2001):

$$MR = \frac{M_t - M_e}{M_0 - M_e}$$

where,

MR = The moisture ratios of sample

M_t = The moisture content (dry basis) at t

M_e = The balance moisture content (dry basis)

M_0 = The initial moisture content (dry basis)

Mathematical model of Hot-Air drying: Drying is a complicated process relating to the physical properties of materials closely. Many theoretical, semi theoretical and empirical model, were summed up to be used to describe the drying process of moisture ratio variation with time. To select a suitable model for describing the Hot-Air drying process of jujubes, we selected 6 thin-layer drying moisture ratio models to fit with the drying curves, as was showed in Table 1

(Xanthopoulos *et al.*, 2007; Cihan *et al.*, 2007; Goyal *et al.*, 2007; Hayaloglu *et al.*, 2007).

Table 1: Commonly used mathematical models of thin-layer drying

Eq. no.	Model name	Model equation
1	Page	$MR = \exp(-kt^n)$
2	Newton	$MR = \exp(-kt)$
3	Modified Page	$MR = a \exp[-kt^n]$
4	Henderson and Pabis	$MR = a \exp(-kt)$
5	Logarithmic	$MR = a \exp(-kt) + c$
6	Wang and Singh	$MR = 1 + at + bt^2$

RESULTS AND ANALYSYS

Hot-Air temperature influence on drying process of red jujubes: The changes in moisture ratios with time for different drying air temperatures are shown in Fig. 1. As can be seen from the figure, the residual moisture of material was gradually reduced with the extension of the time. When the hot air velocity was 1.0 m/s, the drying time required to reduce the moisture from initial moisture content to final moisture content was 44, 27 and 18 h for red jujubes at drying air temperatures of 50, 60 and 70°C, respectively. Obviously the hot air temperature has an important effect on the drying process of jujubes and the higher the drying temperature, the shorter the drying time.

Hot-Air velocity influence on drying process of red jujubes: The changes in moisture ratios with time for different drying air velocity are shown in Fig. 2. As can be seen from the figure, the residual moisture of material was gradually reduced with the extension of

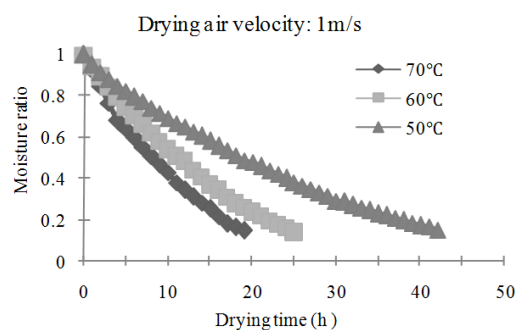


Fig. 1: Drying curves at different temperatures

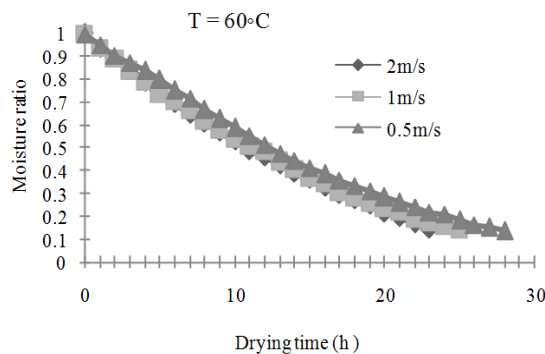


Fig. 2: Drying curves at different velocity

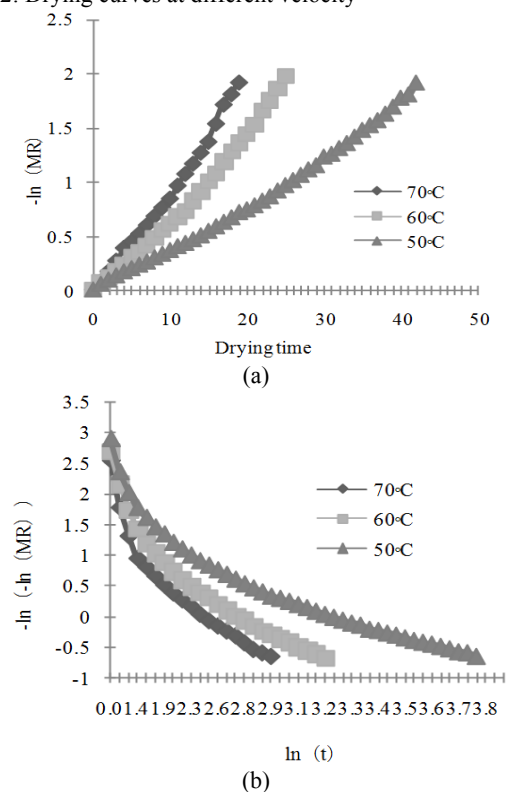


Fig. 3: Fitting curves at different temperature

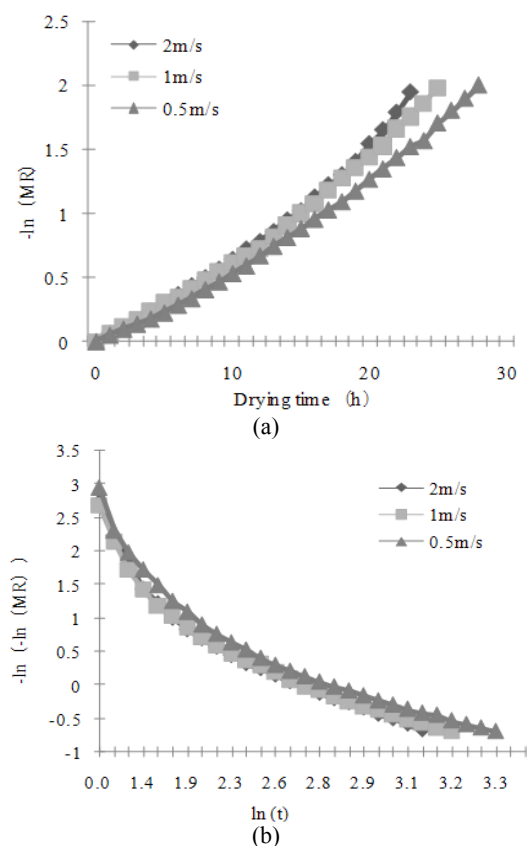


Fig. 4: Fitting curves at different velocity

Table 2: The schedule of field experiment for jujubes drying

No.	Drying air temperature (°C)	Drying air velocity (m/s)	Drying time (h)
1	50	1	44
2	60	1	27
3	70	1	18

Table 3: The results of field experiment for jujubes drying

No.	Predicted moisture ratio by the model	Experimental moisture ratio
1	0.1544	0.1522
2	0.1542	0.1502
3	0.1493	0.1563

the time. Minimum influence of air velocity was observed on the processing time of red jujubes. When the hot air temperature was 60°C, the drying time required to reduce the moisture from initial moisture content to final moisture content was 30, 27 and 24 h for red jujubes at drying air velocity of 0.5, 1.0 m/s and 2.0 m/s, respectively.

Mathematical models' establishment of hot-air drying for red jujubes: In order to establish the mathematical model of Hot-Air Drying for red jujubes, the experimental data was analyzed with statistical method and we got the following curves, as were shown in Fig. 3 and 4.

As can be seen in the figures, the variation of $-\ln(MR)$ with t (drying time) and the variation of $-\ln(-\ln(MR))$ with $\ln(t)$ at different temperature and velocity were shown. And it shows a nearly linear relation between the $-\ln(MR)$ and t (drying time) and the Hot-Air drying process of red jujubes can be described using the Page model.

As can be seen from the experimental datas, both of the drying constants, K and n , are the function of drying conditions (drying temperature T , hot air velocity v). By using the least squares method (using nonlinear regression analysis method in SAS), the values of parameters of thin-layer drying mathematical model can be obtained and then we got the relationship between K and T and v , so as the relationship between n and T and v . So we can get the mathematical model of hot air drying for red jujubes as below:

$$MR = \exp(-kt^n)$$

$$n = 0.8579 - 0.0201T + 0.0132v - 0.0025Tv + 0.00019v^2$$

$$K = \exp(-6.1474 - 0.146T - 0.0018T^2 + 0.0062Tv - 0.0855v)$$

Mathematical model's application of hot-air drying for red jujubes: In order to verify the model for actual production of Hot-air drying for red jujubes, we carried a field experiment in Shaanxi Yulin Everbright Jujube Industry Co., Ltd.. The schedule of field experiment for red jujube drying was shown in Table 2. And the field

experiments of hot-air drying were carried out at different drying temperatures of 50, 60 and 70°C, the velocity was 1.0 m/s. Each experiment was performed three times, at the end of each of the drying process, the MR of red jujubes was measured and then we got the average value of the three times.

The result was shown in Table 3. We compared the experimental values with the predicted value of our model and we found that the model can fully meet the needs to control the final product's moisture in the actual production conditions.

CONCLUSION

The hot-air drying characteristics of red jujubes were studied. The results showed that temperature affected the drying rate of whole red jujube: the higher the drying temperature, the shorter the drying time. Minimum influence of air velocity was observed on the processing time of red jujube. The hot-air drying process of red jujubes can be described by Page equation, in the equation K and n is determined by the drying temperature and wind velocity. The model equations are as follows:

$$MR = \exp(-kt^n)$$

$$n = 0.8579 - 0.0201T + 0.0132v - 0.0025Tv + 0.00019v^2$$

$$K = \exp(-6.1474 - 0.146T - 0.0018T^2 + 0.0062Tv - 0.0855v)$$

The results of a field experiment for red jujube drying show that the model can fully meet the needs to control the final product's moisture in the actual production conditions.

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