MATHEMATICAL MODELING OF THIN LAYER PLUM FRUITS IN SOLAR TUNNEL DRIER

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Abstract

Drying of thin layer plum fruits was studied using a solar tunnel dryer under the ecological conditions of Isparta, Turkey. An experimental solar dryer with a flat plate solar collector has been constructed at the Department of Agricultural Machinery and Technologies Engineering at Suleyman Demirel University. During the drying process, solar irradiation, drying air temperature, relative humidity, and air velocity were measured constantly in different parts of the dryer. The change of plum fruits mass was measured daily. In this study, the fresh plum fruit samples were selected, sorted, washed in water. The drying characteristic curves were evaluated against ten mathematical models and the Two Term model was found to be the best descriptive model for solar tunnel drying of thin layer plum fruit samples.

Key words: drying characteristics, plum fruits, tunnel dryer, mathematical modeling

Drying is one of the most widely used processing methods in the food industry. Traditionally fruits and vegetables are dried in open sunlight, which is weather dependable and also prone to microbial and other contamination (Goyal *et al*., 2007). Solar drying is one of the most common drying methods utilizing solar energy (Bala et al., 2003). Conventional solar drying, which has been applied on the ground in open air, is the most commonly used method of drying in developing countries because it is the simplest and the most inexpensive method of conserving foodstuffs (Stiling *et al*., 2012). though conventional solar drying offers inexpensive way of drying operation, agricultural products are exposed to uncontrolled weather conditions and to the attack of insect, pests, microorganisms, and dust (Bala et al., 2003) and harmful effects of UV radiation (Stiling et al., 2012). Plum (*Prunus domestica*) is an important temperate zone fruit crop. Plums are rich in sugars and carotenes. Plums can be used as fresh dessert fruit, dried or cooked. Dried plums are rich in minerals and vitamins and are mildly laxative. Plums are highly perishable and hence drying and storage are considered important.

The main objective of this study to use the solar tunnel dryer for thin layer drying of plum fruits. This study specifically focused on evaluation of the effects of plums on the drying process using a solar tunnel dryer in Isparta conditions and to determine the best describing mathematical model to experimental data.

MATERIAL AND METHOD

Plum samples (*Prunus domestica*) were purchased from the supermarket in same brand name to provide the consistency of results for the experiment. A solar tunnel dryer constructed at Department of Agricultural Machinery and Technologies Engineering at Suleyman Demirel University was used in this study (*Figure 1*).

Figure 1 **The experimental solar tunnel dryer**

It comprised of a flat plate solar collector, a drying tunnel, a solar cell module, and a small axial fan. All units are mounted on metal frame. The bottoms of solar collector have hexagonal channels and are directly connected to drying tunnel. The bottom of solar tunnel dryer is painted black to absorb radiation. The collector is coated with a transparent polycarbonate material. The dryer is equipped with a 150 W solar cell module. A fan delivers air to the drying tunnel. Solar energy absorption area of the collector is 2 m

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length and 1.9 m width. The drying tunnel area is twice the area of collector. The dryer is oriented in east-west direction and its drying tunnel is not shaded by trees or buildings between 9:00 am and 5:00 pm.

The plum samples were sorted, graded, washed in water before drying. Plum samples weighted on a balance reading to 0.01 g (Sartorius GP3202, Germany). The plum samples to be dried were placed in pre-weighed trays in one layer in the drying tunnel. About 500 g samples of plum samples were placed into trays for drying experiments. Drying experiment started after completion of the loading at 9:00 am and was paused at 5:00 pm. Weight loss of the plum samples in the solar tunnel drier was measured during the drying period at one-hour interval with a digital balance. In the afternoon after 5:00 pm, the samples of plum in the solar tunnel drier were kept in the drier in the environmental conditions. Then, samples were exposed to the same weather conditions. The drying process was terminated until no mass change was detected. Experiments were carried out on July 25-27, 2014. Solar irradiance was measured hourly (09:00 am- 17:00 pm) on a horizontal surface by pyranometer. Relative humidity and temperature of drying air were measured using K type thermocouples and DT-3 hygrometer at the drying tunnel of dryer. Air velocity at the outlet of drying tunnel was measured by a hotwire anemometer.

Plum samples were subjected to the moisture analysis at the oven at the temperature of 105 °C for 24 hours. The moisture ratio (MR) was calculated based on moisture content as a function of time (t) (M(t)), initial moisture content of samples (M_0), and equilibrium moisture content of samples (M_e).

$$MR = \frac{M(t) - M_e}{M_0 - M_e} \quad (1)$$

All moisture contents were reported as wet basis (%, w.b). Simplification of MR in Eq. (1) as M/Mo was suggested by Diamente and Munro, 1993; Elicin and Sacılık, 2005 due to the continuous fluctuation of relative humidity of drying air under solar tunnel dryer conditions. Therefore, the drying rate as g_{water}/h (DR) of the plum samples was determined by Eq. (2):

$$DR = \frac{M_{t+dt} - M_t}{dt} \quad (2)$$

Where M_{t+dt} is the moisture content at *t*+d*t* (g water/g dry matter). A non-linear regression analysis (Sigma Plot 12.00) was applied to experimentally obtained MR as a function of time using drying models given in Table 1. The constants (a, n, b, c, m, k, and g) of models tested in Table 1 were determined based on the non-linear regression analysis. The performance of models was evaluated by coefficient of determination (R^2), the standard error of estimate (SEE), and residual sum of square (RSS).

RESULTS AND DISCUSSIONS

Solar drying of plum samples was conducted on July in 2014. During the experiment, the weather was sunny and no rain was recorded. The experiment lasted for 3 days.

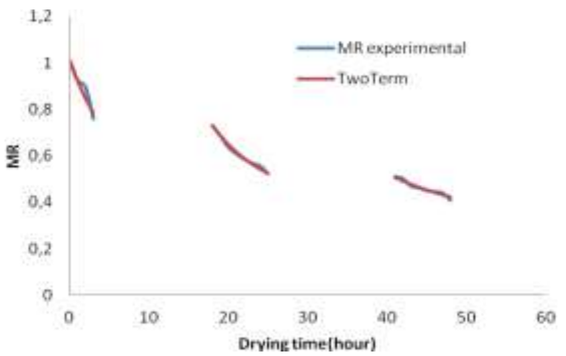

Figure 2 **Variation of moisture ratio with drying time for solar tunnel drying of plum**

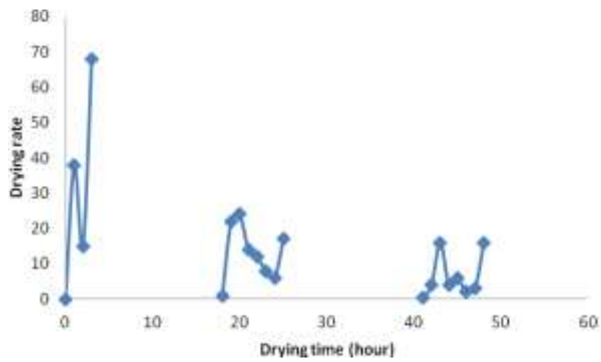

Figure 3 **Variation of drying rate as a function of drying time for solar tunnel drying of plum**

The influence of thin layer plum samples on moisture ratio, drying rate values were also investigated. The drying time necessary for reduction of initial moisture content from (75% w.b.) to the desired final moisture content up to (22% w.b.) was found to be 2880 min. As shown in Figure 2, moisture ratio decreased continuously with decreasing moisture content. The absence of lines in drying cycle in each day in *figure 2* indicates the night periods (Elicin and Sacılık, 2005).

The change of drying rate as a function of time is depicted in *Figure 3* in solar tunnel drier. The results showed that the drying rate was 68 g/h within three hours and at the final stage of drying rate decreased to 2-3 g/h for plum samples. The drying rate sharply increased within three hours and then decreased. This behavior was periodic and gradually diminishing in magnitude on each day of drying

Table 1 shows the outcomes of nonlinear regression analysis applied to the ten drying models to the experimental data for plum samples with R^2, SEE, and RSS. The best model describing drying of plums in given conditions was determined based on R^2 with the lower value of SEE and RSS, which are evaluation criteria used to compare the statistical validity of the fit. The results showed that the R^2, SEE, and RSS values of nonlinear regression analysis ranged from 0.9119 to 0.9930, from 0.0158 to 0.0544, and from 0.0040 to 0.0504, respectively (*table 2*). Furthermore, two term model yielded the highest R^2 (0.9930) for plum samples, with the lowest SEE and RSS values (*table 2*).

Table 1

Mathematical models tested for the moisture ratio values of the plum samples

No	Model name	Model Equation	References
1	Diffusion approach	MR=a exp(-k t)+(1-a) exp(-k b t)	Artnaseaw *et al*. 2010
2	Henderson and pabis	MR=a exp(-k t)	Doymaz, 2014
3	Logarithmic	MR=a exp(-k t)+c	Akpinar 2008
4	Midilli *et al*.	MR=a exp($-kt^m$)+b t	Midilli *et al*. 2002
5	Newton	MR=exp(-kt)	Toğrul and Pehlivan 2002
6	Page	MR=exp($-kt^n$)	Akpinar 2008
7	Two term	MR=a exp($-k_0t$)+b exp($-k_1t$)	Yaldiz *et al*.2001
8	Two term exponential	MR=a exp(-kt)+(1-a)*exp(-m*k*x)	Sharaf-Elden *et al*. 1980
9	Verma *et al.*	MR=a exp(-kt)+(1-a) exp(-gt)	Verma *et al*. 1985
10	Wang and Singh	MR=1+at+bt^2	Babalis *et al*. 2006

Table 2

Results of nonlinear regression analysis of fitting the ten drying models to the experimental data for solar tunnel drying of plum samples

	Solar tunnel drying		
No	R^2	SEE	RSS
1	0.9119	0.0544	0.0504
2	0.9455	0.0416	0.0312
3	0.9920	0.0164	0.0046
4	0.9911	0.0178	0.0051
5	0.9119	0.0515	0.0504
6	0.9830	0.0232	0.0097
7	0.9930	0.0158	0.0040
8	0.9926	0.0158	0.0042
9	0.9926	0.0158	0.0042
10	0.9770	0.0270	0.0132

CONCLUSIONS

Plum samples were dried using a solar tunnel dryer. During the experiment, relative humidity and temperature of drying air, solar irradiation, and moisture reduction from plum samples were measured. Among the all model tested, Two Term Model was the best descriptive model for solar tunnel drying of thin layer plum.

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