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# An Experimental Study on Drying of Pistacia Terebinthus in a Fixed Bed Dryer

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**Abstract:** In this study, drying behaviours of the outer shell peeled Bittim (Pistacia terebinthus) with initial moisture content of 42.2% (dry basis (d.b)) was investigated in a novel fixed bed drying system. The drying experiments were performed at different temperatures (40 °C, 60 °C and 80 $^o$C), air velocities (0.5 m/s and 1 m/s) and weights (30 g and 40 g). A constant rate period was not observed in the drying of bittims; all the drying process occurred in falling rate period. Three models in literature were selected to fit the experimental data. The fit quality of models was evaluated using the coefficient of determination ($R^2$), sum square error (SSE) and root mean square error (RMSE). Balbay and Sahin model has a good agreement with the experimental data and gave the best results for bittims in a fixed bed system.

**Keywords:** drying, heat transfer, bittim nut.

## Nomenclature

| | |
|---|---|
| DR | Drying rate, g water / g dry matter min. |
| MR | moisture ratio(-) |
| $MR_{ei}$ | ith experimental moisture ratio(-) |
| $M_t$ | moisture content at time t, g water / g dry matter |
| $M_0$ | initial moisture content, g water / g dry matter |
| $M_e$ | equilibrium moisture content, g water / g dry matter |
| $MR_{pi}$ | $i^{th}$ predicted moisture ratio |
| $M_{t+dt}$ | Moisture content at t+dt, g water/g dry matter |
| N | number of observations |
| RMSE | root mean square error |
| SSE | sum square error |

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$R^2$ coefficient of determination

## 1 Introduction

Bittim (Pistacia terebinthus) plant is known as terebinth and turpentine tree, which is a species of Pistacia. It is grown in the western regions of Morocco, Portugal and the Canary Islands and also in south, southeast Anatolian and Mediterranean regions of Turkey. The nut looks like a small, globular (or spherical) drupe 5-12 mm long, red to black when it is ripe. All parts of the plant have a strong resinous smell. The tree of bittim is growing approximately 10-11 m tall. Bittim nuts are used as snack nut, pastry inner material, coffee material and soap material made from its oil in Siirt, Turkey [Balbay (2012)].

Drying is a preservation method simply by depriving the water in foods. The water spoils the food by the help of microorganisms and enzymes. Therefore, it is important to reduce water activity in terms of improving long shelf life (flavor, texture, color of food etc.). The applied energy for drying is important by means of energy costs and quality products [Balbay et al. (2011);Syahrul et al. (2002)]. In order to provide the heat of vaporization of moisture and remove it from the food surface, adequate forced air is required [Kashaninejad and Tabil (2009)]. If the initial temperature is too low, the drying food may spoil before it dries. If the temperature is too high, the food surface may harden so that the interior dries much more slowly.

The objectives of this research were: (1) to determine drying conditions of Bittims with respect to different air temperatures and velocities; (2) to determine drying behaviors of fixed bed drying system; and (3) to compare experimental measurements with the different mathematical models available in the literature.

## 2 Experimental Set-up

The experimental set-up was designed and fabricated in the laboratory in order to dry some fruits and vegetables. A three dimensional solid drawing of this drying system is shown in Fig. 1. It consists of an air compressor, a steel frame, two air filters, a flow meter, a thermometer & hygrometer, an electrical heater, a thermometer, an insulated pipe, a drying cap, a glass tube, a digital scale, a heater controller, and a notebook.

Air supplied from the compressor after filtered by inlet and outlet filters with respectively was heated by electrical heater and fed to the drying cap. The temperature of the heating medium was controlled by using a PID process controller having an accuracy of $\pm 0.5$ ˚C connected to the electrical heater. Air velocity was measured by using a calibrated flow meter. In order to keep the temperature constant,

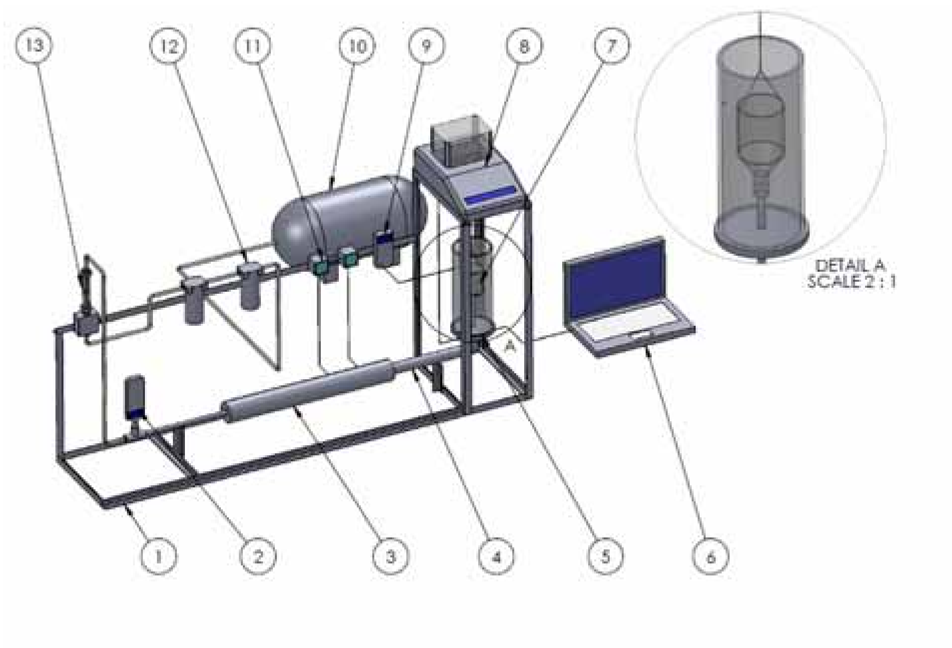


Figure 1: The schematic view of experimental set-up

the glass tube was insulated by rock wool.

Before performing the drying experiment, the initial moisture content of bittims were determined by oven drying at a temperature of 130 ˚C for 6 h with respect to standard method ASAE [ASAE (2005)]. To determine equilibrium moisture content, the weight of 100 g of natural outer shell peeled bittims was put down in the high-temperature oven at 130 ˚C and continued until no further changes in their mass were observed. Therefore, the initial moisture content of bittims was obtained as 42.2 %(d.b).

Bittim nuts used in the experiments were harvested in October in Siirt province, Turkey. The appearance of bittim nuts are presented as harvested, unpeeled and peeled in Fig. 2. Nuts were classified with respect to ripeness and separated from outer shell. After this process, they were washed in order to obtain a clean surface and left on clean surface about 20 minutes. The experiments were performed at different air temperatures (40, 60 and 80 $^{o}$C), air velocities (0.5 and 1 m/s) and weights (30 and 40 g). Generally, a 30 g weight of samples was used in each experiment. The thickness of the samples (30 g) was about 0.03 m in the drying cap. Before starting each run the data acquisition system was switched on and air temperatures were then set to the experimental desired temperature value. The weight of bittims was measured by a digital balance and recorded at 5 minutes interval for all temperature range selected for the study. Moreover, ambient temperature, air relative humidity, air velocities, and inlet-outlet temperature of inside the drying chamber were recorded during the experiments. Drying tests were replicated two times at each inlet air temperature and average values were reported.


Figure 2: The appearance of bittim **a)** Harvested; **b)** Natural outer shell unpeeled; **c)** Peeled; **d)** Dried

## 3 Analysis of Drying Behaviours

Moisture ratio (MR) is usually calculated using the following Eq.1. However, MR was simplified to $M_t/M_0$ since $M_e$ is relatively small compared to $M_t$ and $M_0$ [Midilli and Kucuk (2003)].

$$MR = \frac{M_t - M_e}{M_0 - M_e} \tag{1}$$

The variations of MR as a function of drying time at temperatures of 40, 60 and 80 $^oC$ are shown in Fig.3. High temperature drying accelerates moisture removal compared to low temperature drying. The drying air temperatures have a significant effect on the drying behaviors of bittims.

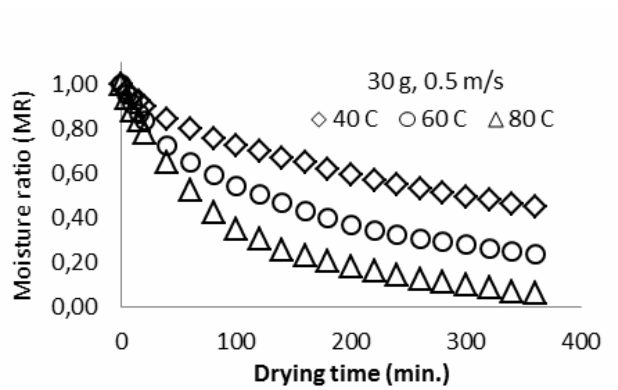


Figure 3: Variation of moisture ratio with drying time at different temperatures

The velocity of drying air does not have effect on the increase of MR as much as temperature. Since, the capacity of air to remove moisture principally depends on its operating temperature. The temperature of drying air affects the drying time of bittims much more than air velocity. Increasing the temperature gradually increases the MR of bittims for the same period of drying time and decreases the total drying time since heat transfer is increased.

The drying rates of bittims were calculated by the following equation:

$$DR = \frac{M_{t+dt} - M_t}{dt} \tag{2}$$

Fig. 4 presents drying rate versus drying time of bittims at the different temperatures. As can be seen in figure, during the period of decreasing drying rate, the

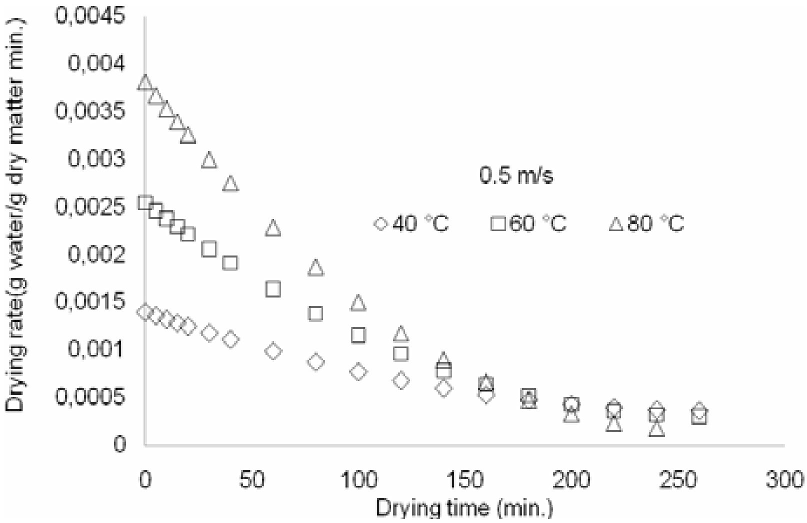


Figure 4: Variation of drying rate with drying time at different temperatures

effect of moisture content continuously decreases. DR of bittims increases with the increase in air temperature.

The effect of weight of 30 g and 40 g bittims at temperature of 60 $^{o}$C and constant air velocity of 0.5 m/s is presented in Fig. 5. The weight of 30 g bittims requires shorter processing time than the weight of 40 g.

## 4 Mathematical Modeling of Drying Curves

The analysis for non-linear regression was performed by using MATLAB (version 2009a). In order to select a suitable drying curve, each model given in Tab. 1 was fitted to the experimental MR data. The values of $R^2$, SSE and RMSE were considered to select the best model.

$R^2$ is one of the primary criterions to select the fit quality of these models [Midilli and Kucuk (2003)], which has a range from 0 to 1. In addition to $R^2$, RMSE are

Table 1: Mathematical models applied to drying curves in this work

| No | Model Name | Model | References |
|---|---|---|---|
| 1 | Page | $\mathrm{MR} = \exp(-\mathrm{kt^n})$ | [Page (1949)] |
| 2 | Wang and Singh | $\mathrm{MR} = 1 + \mathrm{at} + \mathrm{bt}^2$ | [Wang and Singh (1978)] |
| 3 | Balbay and Şahin | $\mathrm{MR} = (1 - \mathrm{a})\exp( - \mathrm{kt^n}) + \mathrm{b}$ | [Balbay and Şahin (2012)] |

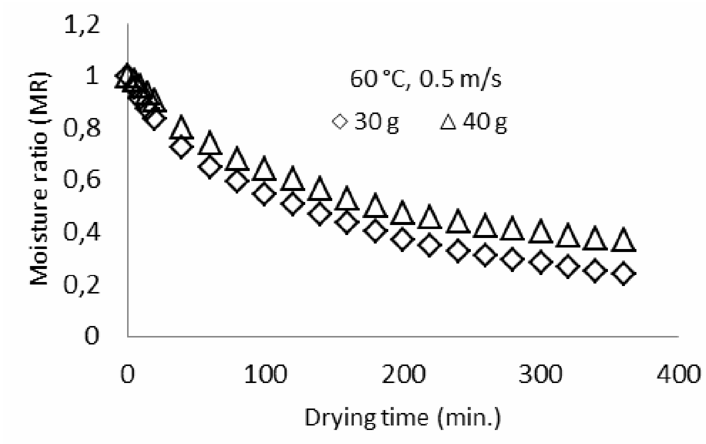


Figure 5: Variation of moisture ratio with drying time at different weights

used to determine the quality of the fit too [Meziane (2011); Togrul and Pehlivan (2003)]. The RMSE and SSE can be calculated as follows.

$$\mathrm{RMSE} = \left[\frac{1}{N}\sum_{i=1}^{N}(\mathrm{MR}_{ei} - \mathrm{MR}_{pi})^2\right]^{1/2} \tag{3}$$

$$\mathrm{SSE} = \frac{1}{N}\sum_{i=1}^{N}(\mathrm{MR}_{ei} - \mathrm{MR}_{pi})^2 \tag{4}$$

where, $MR_{ei}$ is the ith experimental MR. $MR_{pi}$ is the ith predicted MR, N is the number of observations and z is the number of constants in the model. The higher $R^2$ and the lower RMSE values, the better are goodness of fit [Doymaz (2008);Hii et al. (2009);Akpinar and Bicer (2008)].

The data of MR obtained from the drying experiments were analyzed using MATLAB software to the 3 mathematical models listed in Tab. 1. The models were fitted to observed data, and compassion was performed using goodness-of statistical parameters. The values of $R^2$, SSE and RMSE were determined by non-linear regression analysis for different air temperatures (40 ˚C, 60 ˚C and 80 ˚C). The calculated values were presented in Tab. 2. Balbay and Sahin model has a good agreement with the experimental data and gave the best results for bittim. The $R^2$, SSE and RMSE values range from 0.9994 to 0.9996, 0.00001995 to 0.000725 and 0.003531 to 0.006731, respectively. Fig. 6 shows the graph of variation of experimental and predicted moisture ratio by Balbay and Sahin model with drying time at different temperatures and air velocity of 0.5 m/s. As can be seen in Fig. 6, Balbay and Sahin model have a good agreement with the experimental data for different temperatures.

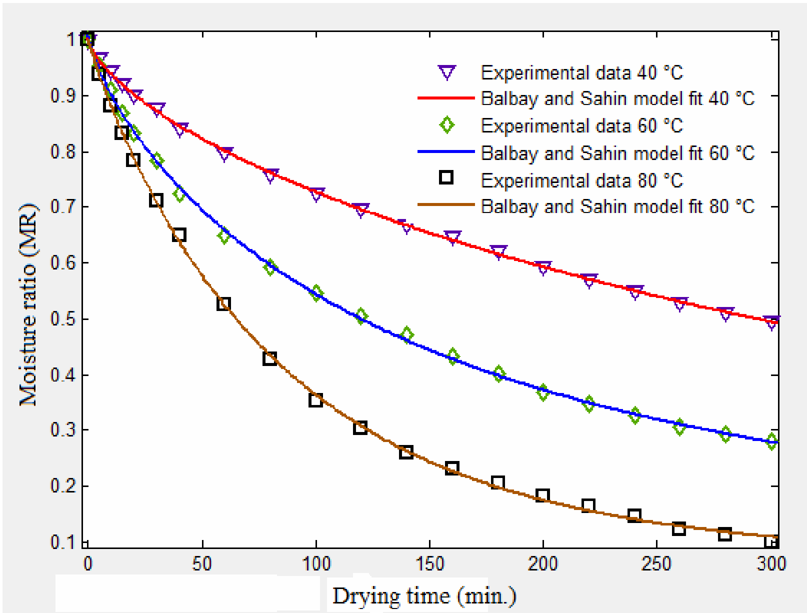


Figure 6: Variation of experimental and predicted moisture ratio with drying time by Balbay and Sahin model at different temperatures and 0.5 m/s air flow rate

## 5 Conclusion

Drying behaviours of bittim with initial moisture content of 42.2% (d.b) was investigated as a function of drying conditions in a newly designed drying system. The drying experiments in designed system were carried out at different temperatures of drying air (40, 60 and 80 $^o$C) and air velocities(0.5, and 1 m/s). A constant rate period was not observed in the drying of bittims, all the drying rate process was seen to occur in falling drying rate period. In order to select a suitable drying curve, three models were fitted to the experimental MR data. Balbay and Sahin model showed a good agreement with the experimental data. The $R^2$, SSE and RMSE values range from 0.9994 to 0.9996, 0.00001995 to 0.000725 and 0.003531 to 0.006731, respectively.

Table 2: Selected drying models for describing Bittim (Pistacia Terebinthus) drying data

| **Models** | **Temperature** | **Constants** | **R2** | **SSE** | **RMSE** |
|---|---|---|---|---|---|
| Page | 40 | k = 0.01195, n = 0.7137 | 0.9996 | 0.0002154 | 0.00356 |
| | 60 | k = 0.02139, n = 0.7224 | 0.9986 | 0.001528 | 0.009482 |
| | 80 | k = 0.02038, n = 0.8399 | 0.9982 | 0.003227 | 0.01378 |
| Wang and Sing | 40 | a =- 0.00317, b = 5.216e-006 | 0.9823 | 0.00889 | 0.02287 |
| | 60 | a = -0.005438, b = 1.064e-005 | 0.975 | 0.02697 | 0.03984 |
| | 80 | a =- 0.007667, b =1.643e-005 | 0.9741 | 0.04635 | 0.05222 |
| Balbay and Sahin | 40 | a=-0.1771, b=-0.1748, k=0.01131, n=0.6857 | 0.9996 | 0.0001995 | 0.003531 |
| | 60 | a=0.1095, b=0.1178, k=0.02158, n=0.7664 | 0.9994 | 0.0006999 | 0.006614 |
| | 80 | a=0.07052, b=0.07185, k=0.01611, n=0.9283 | 0.9996 | 0.000725 | 0.006731 |

## References

**Akpinar, E. K.; Bicer, Y.** (2008): Mathematical modeling of thin layer drying process of long green pepper in solar dryer and under open sun. *Energy Conversion and Management*, vol. 49, pp. 1367–1375.

**ASAE**, (2005): *Standard for measurement of moisture in grin and seed*, Agricultural Engineers Yearbook.

**Balbay, A**. (2012): The modeling of temperature controlled microwave drying of bittims (Pistacia Terebinthus). *Energy Education Science and Technology Part A: Energy Science and Research,* vol. 28, no. 2, pp. 525-530.

**Balbay, A.; Şahin, O.; Karabatak, M.** (2011): An investigation of drying process of shelled pistachio in a newly designed fixed bed dryer system by using artificial neural network. *Drying technology,* vol. 29, pp. 1685-1696.

**Balbay, A.; Sahin, O.** (2012): Microwave drying kinetics of thin layer liquorice root. *Drying technology,* vol. 30, pp. 859-864.

**Doymaz, I**. (2008): Convective drying kinetics of strawberry. *Chemical Engineering Process,* vol. 47, pp. 914–919.

**Hii, C. L.; Law, C. L.; Cloke, M.** (2009): Modeling using a new thin layer drying model and product quality of cocoa. *Journal of Food Engineering,* vol. 90, pp. 191–198.

**Kashaninejad, M.; Tabil, L. G.** (2009): Resistance of bulk pistachio nuts (Ohadi variety) to airflow. *Journal of Food Engineering,* vol. 90, pp. 104-109.

**Meziane, S.** (2011): Drying kinetics of olive pomace in a fluidized bed dryer. *Energy Conversion and Management,* vol. 52, pp. 1644-1649.

**Midilli, A.; Kucuk, H.** (2003): Mathematical modeling of thin layer drying of pistachio by using solar energy. *Energy Conversion and Management,* vol. 44, pp. 1111-1122.

**Page, G. E.** (1949): Factors influencing the maximum rates of air drying shelled corn in thin layers. M.S. thesis, Department of Mechanical Engineering, Prude University, Prude, USA.

**Syahrul, S.; Hamdullahpur, F.; Dinçer, I.** (2002): Exergy analysis of fluidized bed drying of moist particles. *Exergy,* vol. 2, pp. 87-98.

**Togrul, I. T.; Pehlivan, D.** (2003): Modelling of drying kinetics of single apricot. *Journal of Food Engineering*, vol. 58, pp. 23–32.

**Wang, C. Y.; Singh, R. P.** (1978): A single drying equation for rough rice. *Transactions of American Society of Agricultural Engineers,* vol. 11, pp. 668–672.