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Mushroom Drying in Air Heated Solar Collector Drying System and Modeling of Drying Performance with Artificial Neural Network

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Abctract
In this study, an air heated solar collector (AHSC) dryer was designed to determine the drying characteristics of the mushroom. In the experiments thinly sliced mushroom samples were used. Collector inlet and outlet air temperatures, drying chamber inlet and outlet air temperatures, ambient temperature, radiation, air velocity and drying rate were considered as parameters affecting the drying feature. The results obtained were presented as a function of drying time. Moisture content (MC), moisture ratio (MR) and drying rate (DR) values obtained from the experiments were modeled with 3-layer artificial neural network (ANN) using Logsig Activation function and Backpropagation learning function. Mean square error (MSE) was used to determine of the statistical validity of the developed model. As a result, drying behavior of mushroom was successfully predicted by ANN for existing drying conditions.

Keywords: Solar Collector, Food drying, Predictive model, Artificial neural networks

Hava ısıtmalı Güneş Kollektörlü Gıda Kurutma Sisteminde mantar kurutulması ve Kurutma Performansının Yapay Sinir Ağı ile Modellenmesi

Öz
Bu çalışmada, mantarın kuruma özelliğini tespit etmek üzere hava ısıtmalı güneş kollektörlü (HIGK) kurutucu tasarlanmıştır. Deneylerde ince dilimlenmiş mantar örnekleri kullanılmıştır. Kollektör giriş ve çıkış havaları sıcaklıkları, kurutma odası giriş ve çıkış havaları sıcaklıkları, çevre sıcaklığı, ışınım, hava hızı ve kuruma hızı; kuruma özelliğini etkileyen parametreler olarak düşünülmüştür. Elde edilen sonuçlar, kurutma zamanının fonksiyonu olarak sunulmuştur. Deneylerden elde edilen nem içeriği (Nİ), ayrılabilir nem oranı (ANO) ve kurutma hızı (KH) değerleri, Logsig Aktivasyon fonksiyonu ve Backpropagation öğrenme fonksiyonu kullanılarak 3 katmanlı yapay sinir ağları (YSA) ile modellenmiştir. Geliştirilen modelin istatistiksel geçerliliğinin belirlenmesinde ortalama kareli hata (OKH) kullanılmıştır. Sonuç olarak mevcut kurutma şartları için oluşturulan YSA ile mantarın kuruma davranışları başarılı bir şekilde tahmin edilmiştir.

Anahtar Kelimeler: Güneş kollektörü, Gıda kurutma, Tahminsel model, Yapay sinir ağları

1. Introduction

Solar energy is a clean energy source that does not run out of reserves and does not pollute the environment. Because of its ability to easily convert to heat energy, this energy is widely used in the drying of agricultural products all over the world. The simplest benefit from drying out from solar energy is to spread outdoor agricultural products on the exhibition grounds. Outdoor drying is completed in a long time and the quality of the dried products obtained is low. For this reason, solar energy dryers are needed for quality and quick drying of commercial vegetables and fruits in our country (Tahran et al., 2007). Drying is the removal of water or other liquids from gases, liquids or solids. The most common use of drying is to evaporate water or volatile substances from solid materials by thermal

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methods. In drying applications, the heat required to evaporate the moisture is transferred by convection from the solid surface contacting the article to be dried, radiation, or the substance to be dried by bringing the substance to be dried directly into contact with the hot gases (Gungor et al., 2009). Various studies have been carried out in the national and international literature in the field of solar energy supported food drying. Hajar and his friends have dried pears with an indirect solar drying system. They designed an air absorber for this solar dryer. This absorbent consists of two corrugated aluminum plates. The two corrugated plates are fixed to form parallel cylinders which allow the air to circulate through the collector. After 24 hours of drying, the mass of pear specimens reduced from 997.3 g to 135.13 g and thermal efficiency of drying chamber was found as % 11.11 (Hajar et al., 2017). Gülcimen and colleagues have dried basil and the drying parameters have been investigated experimentally and theoretically using the newly developed solar air collector dryer. At the end of the drying experiments, the total basil mass was found to fall from 0.250 kg to 0.029 kg. It was observed that the efficiency of the collector increased in the same direction, and the air flow changed between 29% and 63%. Among the models in the literature for the drying curves, the Page Model was found to be the most suitable model for the drying process. In addition, a new mathematical model for basil drying curves was designed (Gulcimen et al., 2016). Durmus and Kurtbas have been dried the apricots in the airy solar collector and vertically positioned tray dryer. Drying performance was examined. Experiments have shown that drying speed depends on dryer air speed and temperature, collector performance, dried product thickness, and contact surface area (Durmus et al., 2002). Chen carried out experimental studies on the solar energy assisted food drying system, which was formed from the dryer compartment and the solar air heater. Lemon slices were chosen as an example and dried. It has been observed that the moisture content of the lemon (wet) decreases by 75-85% by 7-8% and the heat efficiency of the dryer is 30.86% according to the measurements made during drying (Chen et al., 2005). Today, many studies have been done about the modeling of solar energy assisted drying systems with ANN. Winiczenko et al. have experimentally investigated the effects of drying temperature and air velocity on drying the apple product in convective drying. In apple drying, they have used genetic algorithm (GA) and Pareto optimization in artificial neural network (ANN) for parameters such as volume ratio (VR) and humidity content (MC). The maximum modeling error in ANN did not exceed 3.24% (Winiczenko et al., 2018.) Azadbakht and his colleagues dried the potato slices using a fluid bed dryer. Exergy and energy analysis for the drying system were done. Azadbakht also used an artificial neural network (ANN) to estimate energy and exergy parameters and simulated the thermodynamic drying process with the generated ANN. The network was able to predict the exergy and energy parameters associated with the drying process with high accuracy. They have shown that artificial neural networks can be used in the intelligent drying process, which has a large share of energy use in the food industry (Azadbakht et al., 2017). Beigi et al. investigated the drying kinetics of coarse rice in deep horizontal drying system under different conditions. The study was about the energy, drying and thermal efficiency of the drying process.

Beigi used artificial neural networks (ANN) to determine drying properties. Low flow rates at high temperatures reduced energy consumption for drying. They pointed out that the artificial neural network modeling technique can be used as a powerful tool (

Beigi et al., 2017). Sevik used mushroom dryer with solar energy collector and solar energy heat pump dryer. In the experiments, mushroom was dried at 45 °C and 55 °C drying air temperature and 0.9 m / s-1.2 m / s air speeds. The moisture content, removable moisture content and drying rate values obtained from the experiments are modeled by ANN using the Levenberg-Marquardt (LM) backpropagation learning algorithm and the Fermi transfer function (Sevik et al., 2014). In this study, moisture content (MC), adjustable moisture content (MR) and drying rate (DR) values of the mushroom dried in the solar collector drying system were calculated. An experimental model was determined by using artificial neural network (ANN) for MC, MR, DR values obtained from the experimental study.

2. Materials and Methods

2.1. Experımental Set-Up

Experimental set up mainly consists of an indirect forced convection solar dryer with a solar air collector (1400 mm x 800 mm), a circulation fan and a drying cabinet (Figure 1). Solar air collector was constructed from stainless steel sheets (thickness, 0.5 mm), outer surface of which is painted with black collector paint. Solar air heater was covered with copper sheet (thickness, 0.4 mm), which was painted with black collector paint. A glass was used as a transparent cover for air heater to prevent top heat losses. The solar panel was directed southward under angle of 23.7° according to the azimuth angle of Elazığ province (Ünal et al., 1986). This angle was fixed by foots. Frame was made of stainless steel sheet.

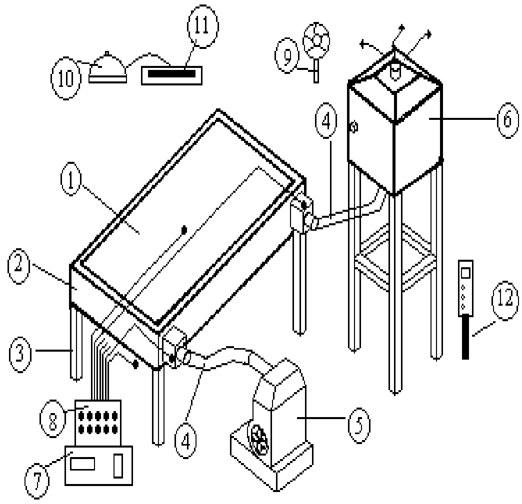

Figure 1. Experimental set-up

1-Solar collector; 2-Frame; 3-Foot; 4-Connection pipe; 5-Circulation fan; 6-Drying cabinet; 7-Channel selector; 8-Digitial thermometer 9-Anenometer; 10- Pyrometer; 11- Digital solar integrator; 12- Hygrometer

Drying cabinet was constructed from wood as a rectangular tunnel (45 cm x 45 cm x 45 cm). Bottom side of the cabinet was a circular tube contracted to the same diameter to connect the main collector tube. The connection to this tube was made with bendable spiral aluminum tube of the same diameter. Drying air was exited from circular pipe at topside of the cabinet. One end of the cabinet was manufactured in type of cover, which was used to load or unload the cabinet. One drying tray (40 cm x 40 cm) was placed inside the drying cabinet. A centrifugal fan (0.0833 m^3/s, 0.25 kW, 220 V, 50 Hz, 1380 min-1) connected to drying cabinet provides air (velocity, 0.4 ms-1). Thickness of mushroom was measured as 1.7±0.2 with a micrometer. Solar drying experiments were carried out during the periods of May 2017 in Elazig, Turkey.

Test started at 9:30 a.m. and continued till 17:30 p.m. Elazig is locate at 38°60'N and 39°28'E and above 950 m of sea level in the eastern part of Anatolia, Turkey.

In the experiments, weather temperature and relative humidity, inlet and outlet temperatures of air in the solar collector, the temperatures at the various points of drying cabinet, humidity, inlet and outlet temperatures of air in the cabinet, wind speeds, the amount of solar radiation, and mass loss of mushrooms were measured at 30 minute intervals. The flow charts of the thin layer forced drying processes are presented in Figure 2.

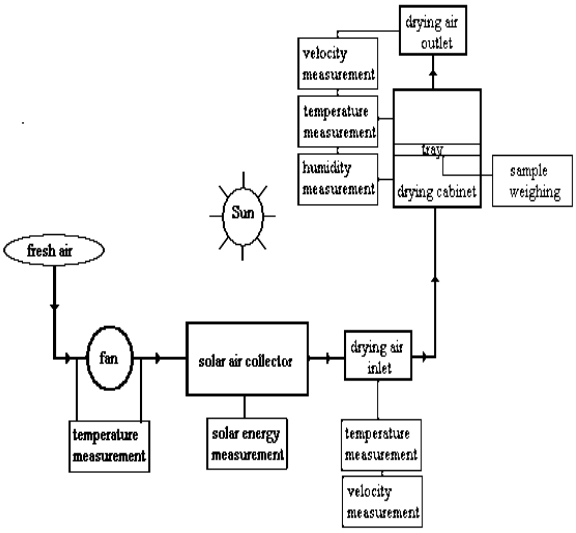

Figure 2. Flow diagram of thin layer forced solar drying process

According to Figure 2., the air was sent to the solar collector with fan at a certain speed. The air was warmed up by the solar collector and sent to the drying cabinet. The hot air in the drying cabinet dried the fungus slices on the trays and exited the drying cabinet.

In the measurements of temperatures, J type iron-constantan thermocouples were used with a manually controlled 20-channel automatic digital thermometer (ELIMKO, 6400, Turkey), with reading accuracy of ±0.1 °C. A thermo hygrometer (EXTECH, 444731, China) was used to measure relative humidity just above mushrooms with reading accuracy of ± % 0.1 . The wind speed was measured by a 0-15 m/s range anemometer (LUTRON, AM-4201, Taiwan), with reading accuracy of ±0.1 m/s. Moisture loss of long mushrooms were recorded during drying for determination of drying curves by digital balance (BEL, Mark 3100, Italy) in the measurement range of 0-3100 g and an accuracy of ±0.01 g. The solar radiation during the operation period of drying system was measured with a Kipp and Zonen pyrometer in ± 0.1 W/m² accuracy and its CC12 model digital solar integrator. The initial and final moisture content of mushrooms was determined at 80 ºC by Unibloc moisture analyzer (Shimadzu MOC63u) in ± 0.001 g accuracy.

2.2. System Analysis

Some general equations used in the drying analysis of the system are given below. For the values of moisture content (MC) according to dry basis in mushroom Equation (1) have been used.

$$MC = \frac{WW\text{-}DW}{DW} \tag{1}$$

In Equation (1); WW is wet weight and DW is dry weight.

Adjustable moisture ratio (MR) values have been calculated using the following formula.

$$MR = \frac{M\text{-}M_e}{M_0\text{-}M_e} \tag{2}$$

Drying speed (DR) values have been calculated from the formula below.

$$DR = \frac{M_{t+dt}\text{-}M_t}{dt} \tag{3}$$

In Equations (2) and (3); *M* is moisture, *Me* is equilibrium moisture, *Mo* is first moisture, *Mt + dt* is moisture content at "t + dt" and *Mt* is moisture content at "t".

2.3. Uncertainties in Experimental Measurements

The uncertainty model developed by Kline and McClintock was used in the uncertainty analysis calculations in the experimental measurements (Kline and F.A. McClintock., 1953). Equation (4) used for uncertainty calculation is given below.

$$W = \left[(a_1)^2 + (a_2)^2 + (a_3)^2 + (a_\infty)^2\right]^{1/2} \qquad (4)$$

The error amount for each variable affecting the measurements according to Equation (4) is defined as "a" and the uncertainty rate is defined as "*W*". The error rates in the drying experiments are given in Table 1. According to Table 1., the maximum error rate is seen in the dry weight (DW) measurements of the mushroom.

Table 1. Total values of errors made in drying experiments.

Parameters causing errors in experiments	Unit	Total error
Total error stemming from heat measurement		
T	° C	±0.173
Total error stemming from time measurement		
t	min	±0.141
Total error stemming from loss of weight		
DW	gr	±0.212
WW	gr	±0.014
Total error stemming from speed measurement		
V	m/s	±0.104
Total error stemming from moisture measurement		
RM	r.H.	±0.200
Total error stemming from solar radiation measurement		
SR	W/m² °C	±0.0025

2.4. Artifical Neural Networks

Artifical neural networks has emerged as a result of artificial simulated efforts of the human brain's working system. Based on certain values, the ANN links the points in the input field to a particular function in the output field (Teti et al., 2010). Artificial neural networks, pattern recognition, estimation, classification, etc. have wide application area. Artificial neural networks learn with examples similar to humans. For this reason, the data set is divided into two parts as training and test cluster (Findik et al., 2010). In this study, Levenberg-Marquardt (LM) backpropagation learning algorithm, Logsig activation function and Backpropagation learning function were used in ANN for the moisture content (*MC*), separable moisture content (*MR*) and drying rate (*DR*) values obtained from experiments. Mean squared error (*MSE*) has been used to compare predicted values to actual values on model evaluation. *MSE* values have been calculated using the following formula by ANN.

$$\boldsymbol{MSE = \frac{1}{n}\sum_{i=1}^{n}(DATA_{exp,i} - DATA_{ANN,i})^2}$$

(5)

In Equation (4); *DATAexp,i* is experimental data and *DATAANN,i* is predicted data.

The time dependent *MC*, *MR*, and *DR* values of the experiments have been calculated from Equations (1), (2), and (3). Solar radiation values were measured with a digital solar integrator. As input data for the network; Time (t), drying air velocity (v), drying air temperature (T), drying air relative moisture (RM) and solar radiation (SR) values were used. As output data; *MC*, *MR*, and *DR* values were used. As a middle layer; Three hidden layers were created and the best solutions were tried to be obtained by changing the number of intermediate layers. The structure of the generated ANN model was given in Figure 3.

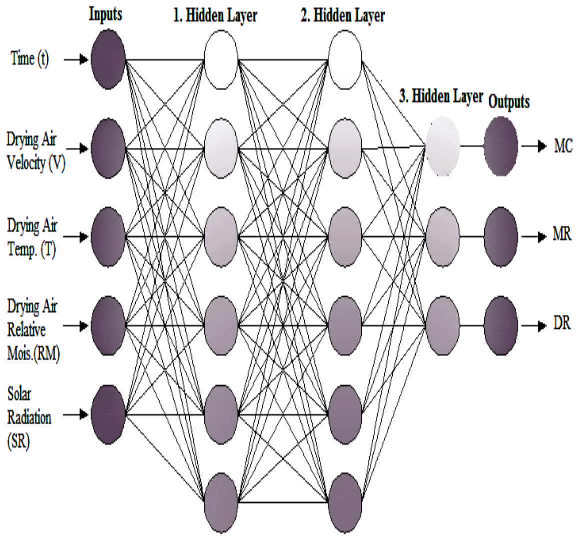

Figure 3. ANN structure

According to Figure 3., the network is composed of 5 layers in total. The input layer of the model contains 5 neurons for 5 inputs, 6 neurons for the first hidden layer, 6 neurons for the second hidden layer, 3 neurons for the third hidden layer and 3 neurons for the output layer.

3. Results and Discussion

Prediction of MC, MR, and DR values with artificial neural network was done using MATLAB 2016a software. A total of 128 data were used in ANN model. 112 data were used for training and 16 data were used for the test. The ANN structure used for MC, MR, and DR is shown in Table 2.

Table 2. Structure of ANN

Structure of ANN used for the estimation of *MC, MR,* and *DR*	
Number of Layers	3
Number of Neurons in Layers	6-6-3
Weight Ratings	Random
Activation Function	Logsig
Transfer Function	Tangent Sigmoid Transfer
Learning Function	Backprogpagatio n
Learning Ratio	0,93
Mean- Squered Error	1e-06

The network learning process has been successfully completed. The performance of the ANN model developed for MC, MR, and DR is shown in Fig. 4.

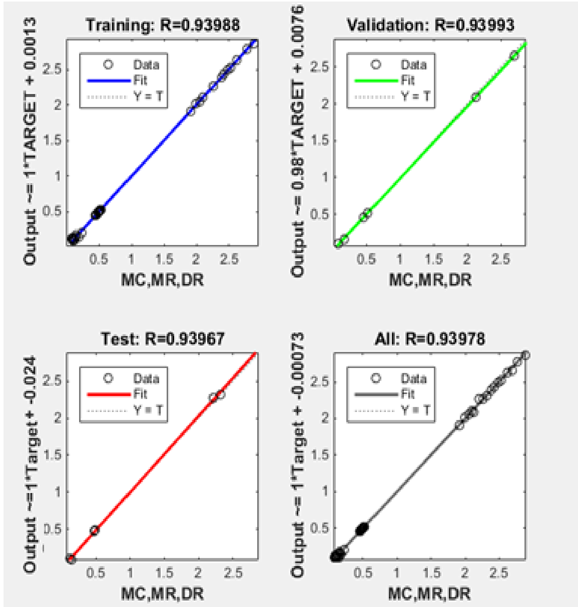

Figure 4. Regression graph for MC, MR and DR

According to Figure 4., since the difference between the all predicted values and the experimental values is very small and negligible, it can be seen that there is a harmony between the values.

4. Conclusion

In this study, mushroom was dried with AHSC drying system. MC, MR and DR parameters were experimentally calculated for different temperature and air velocity values at 30 minute intervals during mushroom drying. ANN was used for estimation of MC, MR and DR parameters. Estimated values with ANN and actual values obtained after the test are shown in Figure. 5-7. As a result, ANN estimation for MC, MR and DR parameters were successfully performed.

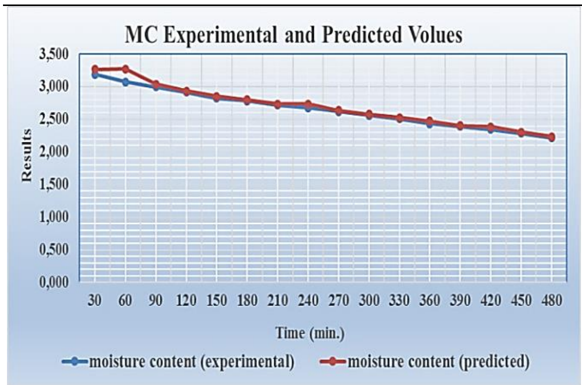

Figure 5. Experimental and predicted moisture content values

The calculated and predicted moisture content values according to Figure 5 are similar for all other minutes except for 30, and 60 minutes.

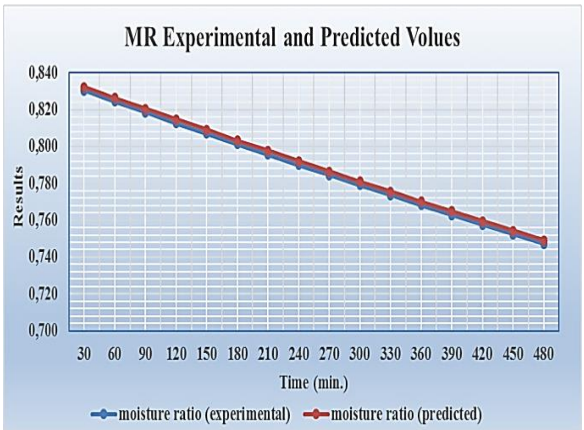

Figure 6. Experimental and predicted moisture ratio values

According to Figure 6, all experimental and predicted moisture ratio are similar.

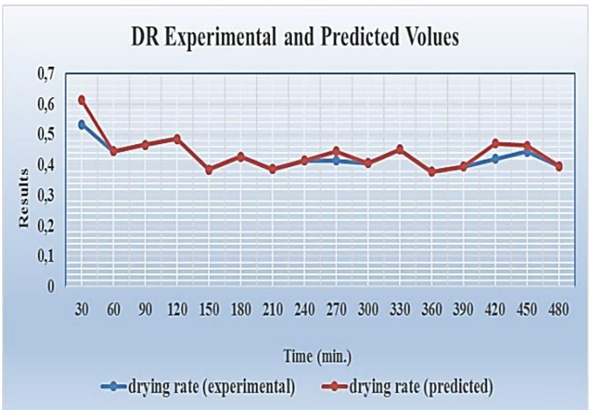

Figure 7. Experimental and predicted drying rate values

The calculated and predicted drying rate values according to Figure 7. are similar for all other minutes except for 30, 270, 420 and 450 minutes.

The fact that the experimental and predictive values in Figures 5-7 differ depends on the error rates of the predictive model used in the ANN. Furthermore; more data can be obtained using products with a longer drying times and a more successful predictive model can be obtained using different computational intelligence methods.

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