THIN LAYER DRYING CHARACTERISTICS OF CARROT AND MODELING THE MICROWAVE DRYING PROCESS

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Abstract. In this study, carrot slices at different thicknesses (4mm, 7mm and 10 mm) were dried using a microwave conveyor belt dryer. The effect of microwave power (1.05kW, 1.5kW and 2.1kW) and conveyor belt speed (0.175m/min and 0.245m/min) on some drying characteristics (drying rate, drying time, moisture content) of carrot was investigated. According to the obtained results, color change (the quality criteria), energy consumption, optimum conveyor belt speed and drying power were determined. Afterwards, some drying models available in the literature were compared with each other to determine the moisture content of the products at a specific time. Also, the artificial neural network method was used to predict the moisture content of the products.

Keywords: microwave conveyor dryer, carrot, moisture content, color analysis.

1. INTRODUCTION

Drying applied to foodstuffs has several purposes. The most of these is avoid distortion of the product during storage. By reducing the moisture content is provided protection of the quality feature as taste, smell, and nutritional value. Another objective of the drying process, the efficiency of products is enhanced reducing the volume of products.

Homeland of Carrot is central Asia and the Near East. Its production is made of seed and its root is eaten [1]. Carrot is widely used as fresh and dried in human nutrition. When carrot with 80-90% moisture is dried, its volume decreases and storage life increases. Dried carrot powder is used in soups and seasonings [2]. Carrots are usually dried in tunnels or continuous conveyor dryer.

Drying is a complicated process which involves simultaneous heat and mass transfer. Water molecule transport has a closen relationship with the drying process, including molecular diffusion, such as capillary motion, liquid diffusion, vapor diffusion and hydrodynamic. In microwave drying, the heat is resulted from the conversion of microwave energy into thermal energy within the moist materials and provides desired heat and pressure in order to dry material quickly. In order to overcome these problems and reduce the drying time to achieve an efficient and rapid heat transfer process, the use of microwaves for drying food has been developed. Microwave is a rapid method for drying food [3]. The application of microwave heating for food materials is recently of special interest. Therefore, it has been the subject of investigations and several recent researchers have demonstrated the significant advantages of microwave drying [4]. Microwave drying process is a relatively inexpensive method that has attracted the attention of many investigators. Many studies [5-12] have been done on microwave drying or microwave assisted drying for a great variety of food products.

The aim of this study is to investigate the effects of the drying parameteres on carrot drying process and apply reggression analyses methods to express the drying kinetics by using obtained experimental data and also predict the moisture content of the carrots by the use of the artificial neural network method. The effect of microwave power and conveyor belt speed on some drying characteristics (slice thickness, drying time, moisture content) of carrot was investigated experimentally for various values of microwave power and conveyor belt speed in a microwave dryer. Furthermore, a colour analysis was conducted to investigate the effects of microwave drying on the product colour quality.

2. MATERIAL AND METHOD

Fresh carrots were obtained from the store of a local market (Tekirdağ, Turkey). The microwave cavity was a rectangular shape with a cross-sectional area of 500 mm x 400 mm x 3500 mm (width x height x depth). The microwave power was generated by means of 3 magnetrons of 700W each for a maximum of 2.1kW at 2.45GHz. During the drying process, the conveyor belt speed was to regulate and could be set at the potentiometer of control unit. Periodically the samples were removed from each oven in order to measure their average weight with a Presica XB 620 M (Precisa Instruments AG, Dietikon, Switzerland).

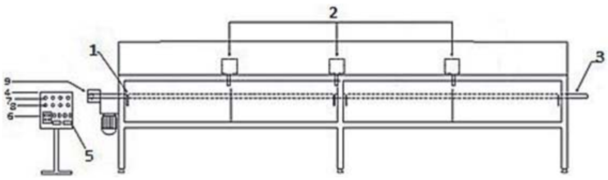

Fig.1. *A schematic diagram of microwave conveyor dryer (1. Drying chamber, 2. Magnetron, 3. Conveyor belt, 4. Control panel, 5. Main swtich, 6. Speed control, 7. Power (on/off), 8. Microwave power control, 9. Electric motor).*

2.1. Drying procedure

In order to determine the moisture content, the carrots were initially dried in an oven at 105°C for 24 h and the dried mass was measured. The moisture content of the carrots with respect to the wet weight was 93±0.5%. Prior to the drying experiment, the carrots were washed with tap water, peeled and cut into slices with thickness of 4 mm, 7 mm and 10 mm. No pre-treatment was applied to the samples before the experiment carried out.

The drying could be controlled by the speed of conveyor belt and microwave power. The microwave power was generated by means of 3 magnetrons. Drying experiments were carried out for microwave powers of 1.05kW, 1.5kW and 2.1kW, conveyor belt speed of 0.175m/min and 0.245m/min respectively and applied for each thickness. Drying tests were repeated three times for each test in order to minimize the uncertainties in the results. The development of the drying process was followed by weighting the bars containing carrot in regular intervals of threeminutes on a digital scale with an accuracy of ±0.001g. After each test, the color parameters of the dried product were measured.

3. MODELING

3.1. Modeling of the thin-layer drying

For the investigation of drying characteristics of carrot, it is important to model the drying behaviour effectively. In this study, the experimental drying data of carrot at different microwave powers were fitted into five commonly used thin-layer drying models, listed in Table 1. Moisture ratio of samples during drying is generally calculated by the following equation [1]:

$$MR = m/m_o \qquad (1)$$

The least squares method is commonly used to simulate the drying behavior, especially of biological material models presented up to now. In this method, the coefficients in the models are determined by minimizing the sum of the squared differences between the experimental and the theoretical moisture ratios. A better suitability between the model results and the empirical data is reached when the correlation coefficient (r) will be closer to 1 and the standard error (e_s) and the chi-square (χ^2) will be closer to 0. These parameters are defined in Eqs. (2-4). The moisture ratio (MR) in the model equations is defined in Eq.(1).

$$r=\frac{n_o\sum_{i=1}^{n_o} MR_{pre,i}MR_{exp,i}-\sum_{i=1}^{n_o} MR_{pre,i}\sum_{i=1}^{n_o} MR_{exp,i}}{\sqrt{n_o\sum_{i=1}^{n_o}(MR_{pre,i})^2-\left(\sum_{i=1}^{n_o} MR_{pre,i}\right)^2}\sqrt{n_o\sum_{i=1}^{n_o}(MR_{exp,i})^2-\left(\sum_{i=1}^{n_o} MR_{exp,i}\right)^2}} \qquad (2)$$

$$e_s=\sqrt{\frac{\sum_{i=1}^{n_o}(MR_{pre,i}-MR_{\exp,i})^2}{n_o}} \qquad (3)$$

$$\chi^2=\frac{\sum_{i=1}^{n_o}(MR_{pre,i}-MR_{\exp,i})^2}{n_o-n_c} \qquad (4)$$

Where $MR_{pre,i}$ is the i*th* predicted moisture ratio, $MR_{exp,i}$ is the i*th* experimental moisture ratio, n_o is the number of observations and n_c is the number of coefficients in the drying model.

Table I

Various mathematical models used in modeling of drying [13]

Name	Model equation
Verma *et al.*	$mr = a\ exp(-kt) + (1-a)exp(-gt)$
Page	$mr = exp(-kt^n)$
Henderson& Pabis	$mr = a\ exp(-kt)$
Two term	$mr = a_1 exp(-k_1 t) + a_2\ exp(-k_2 t)$
Logarithmic	$mr = a_0 + a\ exp(-kt)$

3.2. Artificial Neural Networks Model

In this study, a multi-layer perceptron network model with back propagation training algorithm has been used. Multi-layer perceptron networks, also known as multilayer feed-forward networks are one of the most widely used and successful neural network types, which are applied to a wide range of applications for prediction and process modeling [14]. In a multilayer perceptron, the neurons are arranged into an input layer, an output layer and one or more hidden layers. One of the most difficult tasks in ANN model development is to find the optimal network architecture. This network architecture is to be selected out of several network configurations comprising the combination of various model parameters namely, the number of hidden layers, and number of neurons in hidden layers, different transfer functions and training algorithms. On the other hand the number of hidden layers and neurons within each hidden layer can be varied based on the complexity of the problem and data. In this study the trial and error approach with iteration technique was adopted to build the ANN model.

In this study, the trial and error approach with iteration technique was adopted to build the ANN model. The artificial neural network architecture has been developed by using data obtained from drying experiments of carrots. The training procedure was performed by using randomly selected 286 data while 279 data points were utilized for testing of network performance. The number of the neurons in the input layer and output layer are equal to the number of input and output parameters respectively. The input layer consisted of four neurons corresponding to microwave powers, conveyor belt speed, slice thickness and drying time while the output layer had one neuron representing the moisture ratio of the carrots.

In order to determine optimum number of hidden layers and the number of neurons within the each hidden layer a range of training tests were done with two hidden layers each having different neuron numbers. On the other hand in the literature, the most popular and commonly used logarithmic sigmoid (LS) and hyperbolic tangent sigmoid (HT) activation codes were used during these tests:

$$\text{logsig} = \frac{1}{1 + \exp(-n)} \qquad (5)$$

$$\text{tansig} = \frac{1 - e^{-2n}}{1 + e^{2n}} \qquad (6)$$

Hyperbolic logarithmic sigmoid activation codes including 69 neurons and tangent hyperbolic activation codes including 32 neurons were used in the first and second hidden layers respectively. Figure 2 shows the schematic view of the neural network architecture proposed and used in this study.

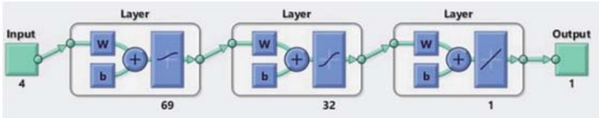

Fig. 2. *Neural network architecture for modeling the drying process of carrots*

The accuracy of a trained network was measured by calculating the mean square error (e_s) of the test partition. The optimum hidden layer number and the optimum neuron number within the each layer were determined as the minimum value of e_s reached.

4. RESULTS AND DISCUSSION

4.1 Modeling Results

Curve fitting computations was carried out on the five drying models relating the drying time and moisture ratio. The results show that the most appropriate model in describing drying curves of carrot is the Page Model for 4mm of slices and the Logarithmic Model for 7mm and 10mm of slices at 0.175m/min. Also, the most appropriate model in describing drying curves of carrot is the Midilli et al. model for 4mm and 10mm of slices and the Logarithmic Model for 7mm of slices at 0.245m/min. It was determined that the most appropriate model is the Page model, Midilli model and Logarithmic model in describing drying curves of carrot for the experiments. In Figures 3-8, the predicted moisture ratio values of carrots under different conditions were compared with the experimental model, empirical model and ANN model results. A remarkable agreement between the predicted and experimental results can also be obviously seen in these figures. It is concluded that the ANN model used in this study predicts the drying behavior of carrots more accurately in comparison to the best fitted empirical models available in the literature. All these results indicate the ability and the performance of the proposed neural network model in predicting carrots drying behavior under different drying conditions.

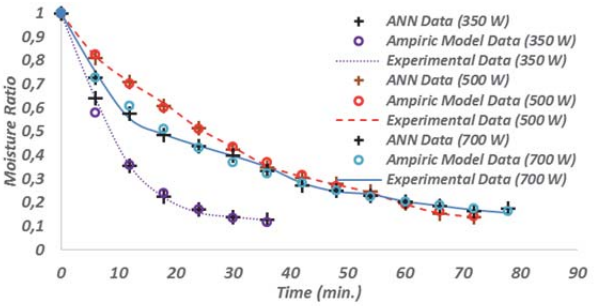

Fig.3. *Comparison of Page model and ANN results with experimental data for various microwave powers at 0.175m/min conveyor belt speed for thickness of 4mm carrot slices.*

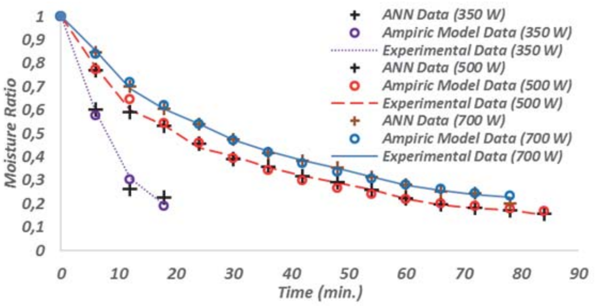

Fig.4. *Comparison of Logaritmic model and ANN results with experimental data for various microwave powers at 0.175m/min conveyor belt speed for thickness of 7mm carrot slices.*

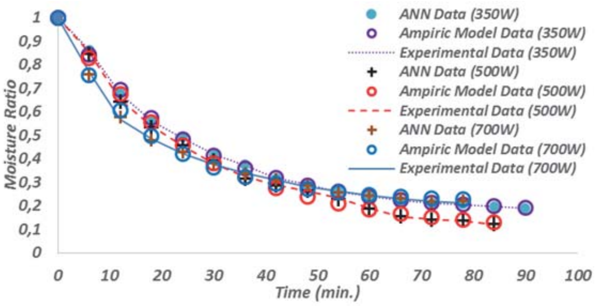

Fig.5. *Comparison of Logaritmic model and ANN results with experimental data for various microwave powers at 0.175m/min conveyor belt speed for thickness of 10mm carrot slices.*

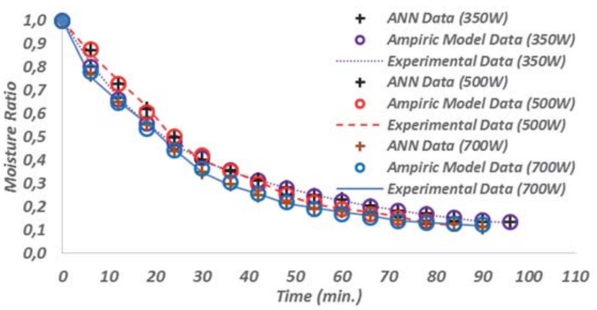

Fig.6. *Comparison of Midili model and ANN results with experimental data for various microwave powers at 0.245m/min conveyor belt speed for thickness of 4mm carrot slices.*

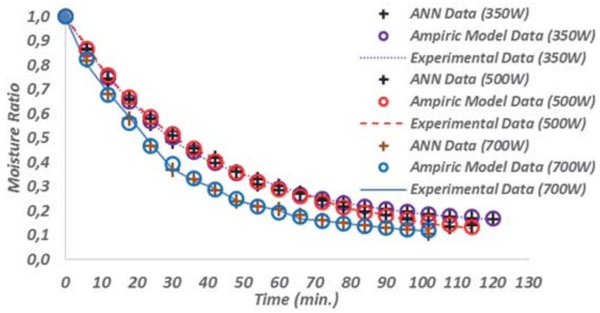

Fig.7. *Comparison of Logaritmic model and ANN results with experimental data for various microwave powers at 0.245m/min conveyor belt speed for thickness of 7mm carrot slices.*

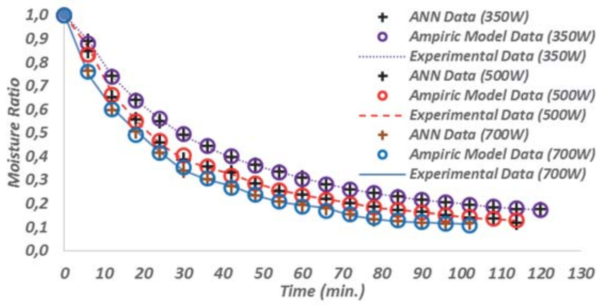

Fig.8. *Comparison of Midilli model and ANN results with experimental data for various microwave powers at 0.245m/min conveyor belt speed for thickness of 10mm carrot slices.*

4.2. Color Analyses Results

The color change was measured and expressed as the *L**, *a** and *b**. In accordance with the increase of the microwave power and belt speed, Carrot slices got higher *L** value. Drying methods have a significant effect on the color changes of carrot slices. Color product is the other quality parameter that needs to be monitored during carrot drying. L* values of carrot slices with 4mm increased during the drying. L*, a* and b* values at 1.5kW (0.175m/min) dried samples were the highest among the other dried samples which were closer to the L*, a* and b* values of fresh sample ($P<0.05$). Pictures of the dried carrot slices for various slice thicknesses can be seen in Fig.9.

4.3. Energy Consumption

By the means of counter in the control panel, energy consumption was recorded during start and finish of drying in the microwave. As the microwave power increases, the energy consuption increases. The reason of that is; as less heat is generated in the low microwave power, more time is required for the transfer in the biological material and for the transfer of the heat from the product to the environment. Thus, time required for the water in the product to reach the evaporation temperature is prolonged and the energy spent for the evaporation is reduced. This prevents the achievement of efficient drying. Consequently, the lowest energy consumption value for 4mm slice thickness is 0.175m/min and 1.5kW. It is belived that low energy consumption and short drying time will make this drying system useful for not only in the food industry but in all of the industrial areas (heating, drying, chemistry etc.) as well. In this study, the possibility of solving the time and energy consumption problem by microwave belt systems is proved.

Microwave power Beld speed Carrot slice thickness	2.1kW 0,245m/min 4mm	2.1kW 0,245m/min 7mm	2.1kW 0,245m/min 10mm
Fresh sample			
Dried sample			

Fig.9. *Pictures of the dried carrot slices in different slice thicknesses*

Table II

Values of energy consumption of the carrot slices

	Values microwave power and belt speed	Energy Consumption (kWh)
4 mm thickness	0.175 m/min - 1.05 kW	104.9
	0.175 m/min - 1.50 kW	112.3
	0.175 m/min - 2.10 kW	116.0
	0.245 m/min - 1.05 kW	123.8
	0.245 m/min - 1.50 kW	127.3
	0.245 m/min - 2.10 kW	129.7
	Values microwave power and belt speed	Energy Consumption (kWh)
7 mm thickness	0.175 m/min - 1.05 kW	105.9
	0.175 m/min - 1.50 kW	112.7
	0.175 m/min - 2.10 kW	116.0
	0.245 m/min - 1.05 kW	124.3
	0.245 m/min - 1.50 kW	128.3
	0.245 m/min - 2.10 kW	130.7
	Values microwave power and belt speed	Energy Consumption (kWh)
10 mm thickness	0.175 m/min - 1.05 kW	109.4
	0.175 m/min - 1.50 kW	112.7
	0.175 m/min - 2.10 kW	116.0
	0.245 m/min - 1.05 kW	124.3
	0.245 m/min - 1.50 kW	128.3
	0.245 m/min - 2.10 kW	130.7

5. Conclusions

The concluding observations are as follows:

The most appropriate model in describing drying curves of carrot slices is the Page, Midlli and Logarithmic model for belt speed and microwave power.

Drying time increased with decreasing of microwave power level and this caused to decrease in consumed energy amount. The minimum energy consumption values were measured as 104.9kWh for 1.5kW power level, 0.175 belt speed and 4mm layer thickness.

Color analysis is important for foods especially holding the quality for the production and for the commerce. The color criteria were most appropriate to those of carrot slices obtained at 1.5kW and 0.175m/min for slice thickness of 4mm.

Nomenclature

m	moisture content of carrot at certain time (g water/g wet matter)
MR	dimensionless moisture content
$MR_{pre.i}$	i*th* predicted moisture ratio
$MRexp.i$	ith experimental moisture ratio
n_c	number of coefficients
n_o	number of observations
P	the microwave power (W)
r	correlation coefficient values
e_s	standard error
t	the time (s)
$\chi 2$	chi-square
$L*$	lightness
$a*$	redness and greenness
$b*$	blueness and yellowness

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