SEMINA Ciências Agrárias

DOI: 10.5433/1679-0359.2022v43n5p1941

Effects of solar tunnel drying, shade drying and microwave drying methods on the drying kinetics of strawberry *(Fragaria ananassa)*

Efeitos dos métodos de secagem em túnel solar, secagem à sombra e secagem por microondas na cinética de secagem de morango *(Fragaria ananassa)*

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Highlights

Influence of whole and halved strawberry samples on drying properties.
Determination of the optimum drying method and the temperature value.
Determination of the mathematical thin layer drying model based on experimental data.

Abstract

Whole and halved strawberries were dried by using three methods, which were solar tunnel drying, shade drying, and microwave drying (180W, 540W, and 900W) to determine drying characteristic and modelling. The researchers measured solar irradiation at ambient and drying air temperatures and air velocity at specific intervals in various parts of the dryer. How microwave drying (180, 540, and 900 W) affected the drying time and drying ratio of the whole and halved strawberry samples was investigated. In addition, the data on the drying process were applied to 5 different mathematical models, which were Weibull distribution, Midilli et al., Jena and Das and Aghbashlo et al. Equation Models. The researchers compared the performance levels of the models according to correlation coefficient (R^2), chi-square value (χ^2), besides the root mean square error (RMSE) between moisture ratios that were observed and predicted. Furthermore, the Weibull Distribution and Midilli et al. models were found to reveal the ratio of drying in a satisfactory way for all the methods of drying.

Key words: Mathematical modelling. Drying. Food. Moisture ratio. Drying rate.

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Received: July 22, 2021 - Approved: May 16, 2022

Resumo

Morangos inteiros e cortados ao meio foram secos usando três métodos, que foram secagem em túnel solar, secagem à sombra e secagem por micro-ondas (180W, 540W e 900W) para determinar a característica de secagem e modelagem. Os pesquisadores mediram a irradiação solar nas temperaturas ambiente e de secagem do ar e a velocidade do ar em intervalos específicos em várias partes do secador. Como a secagem por micro-ondas (180, 540 e 900 W) afetou o tempo de secagem e a proporção de secagem das amostras inteiras e cortadas de morango foi investigado. Além disso, os dados do processo de secagem foram aplicados a 5 modelos matemáticos diferentes, que foram a distribuição de Weibull, Midilli et al., Jena e Das e Aghbashlo et al. Modelos de equação. Os pesquisadores compararam os níveis de desempenho dos modelos de acordo com o coeficiente de correlação (R2), valor do qui-quadrado (χ2), além da raiz do erro quadrático médio (RMSE) entre as razões de umidade observadas e previstas. Além disso, a Distribuição Weibull e Midilli et al. os modelos revelaram a proporção de secagem de forma satisfatória para todos os métodos de secagem.
Palavras-chave: Modelagem matemática. Secagem. Alimentos. Taxa de umidade. Taxa de secagem.

Introduction

Strawberry fruit is a widely grown hybrid species of the Fragaria genus of the Rosaceae family, which is grown for its fruits worldwide (Atacan, 2018). Due to its high adaptability, strawberry is one of the most common fruit species in the world. Strawberry fruit grows naturally under very different ecological conditions or is grown for economic purposes from humid subtropical ecologies such as Japan, India, Colombia, Australia, Ecuador, and Florida, and from polar regions that are always bright day and night in summer to the Equatorial zone, and from irrigable deserts to places with a total rainfall of approximately 250 mm (Özbahçali & Aslantaş, 2015). The data of FAO indicate that while the amount of production of strawberry was about 8,861,381 tonnes in 2020 around the world, this value was approximately 546.525 tonnes in Turkey (Food and Agriculture Organization of the United Nations [FAOSTAT], 2020). Strawberry is among the fruits with delicate and perishable properties. Since strawberries have a high respiratory rate, they can spoil in a short time without the organisms that cause rotting (Macias, 2013). It has a large volume of consumption, which includes fresh product or ready-made foods such as concentrate juice, jelly, jam, ice cream, pies, milkshakes, bakery products, and chocolates (Ertekin et al., 2014). In addition, it can be preserved by major food storage methods such as freezing, osmotic, microwave, and air drying (Macias, 2013).

Traditional methods such as drying in shade and sun have some disadvantages due to the insufficient quality standards in agricultural products. High temperature and prolonged drying cause heat damage in the product and adversely affect the texture, color, odor, and nutritional value of the products, reducing the quality and therefore the market value (Macias, 2013). However, it is also known that drying methods in open sun and shade reduce the content of moisture in products that have perishable properties and thus prevent the product from deteriorating. However, despite the many disadvantages of drying in open sun and shade, these methods are still preferred to protect agricultural products in tropical and subtropical countries of the world (Mohammed et al., 2020).

Therefore, dryers are used for the drying process which have different heating and power sources, as well as shade and sun drying, which is commonly used because of its low cost (Kamarulzaman et al., 2021). Solar tunnel and microwave dryers are an alternative to sun and shade drying methods. Strawberry fruit is one of the products dried in solar tunnel type dryers. When strawberries are exposed to direct sunlight, undesirable color changes occur. Therefore, strawberries are one of the products that should be protected from direct sunlight. Delicate products such as strawberries should be dried in indirect sun dryers. It is important to design solar drying systems considering the drying conditions of certain crops, cost effectiveness, and energy efficiency requirements (Kumar et al., 2016). Several studies have been reported involving the design of a low-cost dryer that is optimized with data from laboratory studies on sun drying of strawberry both to decrease drying time and to improve the quality of raisins, and the development of a solar tunnel dryer with a radial fan and integrated collector (Amer, 2019; Rodriguez-Ramirez et al., 2021). In addition to these, there are important advantages of microwave drying method like a short drying time, low consumption of energy, and maximum color preservation, taste, odor, aroma, and nutrient content (Alıbas, 2015).

Modeling the drying process mathematically is a significant part of drying technology (Naderinezhad et al., 2016). Mathematically modeling and simulating drying curves under various circumstances is highly significant for obtaining more efficient studies. In this context, several studies have been carried out on mathematical modeling of post-harvest processes to simulate the process. The drying kinetics should be determined by modeling the drying process because the drying property of each agricultural product is unique, and changes based on drying conditions and methods.

Various research studies have been presented in the literature on the application of different drying methods for strawberry samples (Amami et al., 2017; Adak et al., 2017; Prosapio & Norton, 2017; Szandzinska et al., 2016).

This study aimed to figure out the drying behavior of strawberry fruit at the final moisture values determined by drying in solar tunnel type dryer, shade, and a microwave dryer method, and to determine the optimum drying method and the temperature value. Moreover, the study determined the effect of whole and halved strawberry samples on drying properties. In addition, the mathematical thin-layer drying model was determined by comparing five different model equations that best describe it based on experimental data.

Materials and Methods

Sample Preparation

To obtain consistent results from the experiments conducted in Isparta,Turkey fresh strawberry fruits (Fragaria x ananassa) with the same brand were bought from local supermarkets and kept in the refrigerator at +4°C for 1 day before drying. The researchers washed strawberries using cold water, manually decamped and sorted them, and then divided them into two parts (whole fruits and halves). The drying process, at each drying type, continued until the final moisture content of about 10 ±0.5% (w.b.) from an initial value of 73.62±0.5% (w.b.).

Solar Tunnel Drying of Strawberries

The researchers used a tunnel type solar dryer that was designed and built in the Department of Agricultural Machinery and Technologies Engineering at Isparta University of Applied Sciences (Figure 1).The dryer used in the study consisted of a drying tunnel, a flat plate solar collector, a small axial fan, and a solar cell module. All parts are located on a frame made of metal. The solar collector has hexagonal channels. Its base is painted black and is directly connected to the drying tunnel. The solar collector is covered with a transparent polycarbonate sheet. A 150-W solar cell module is installed in the dryer to move the air by means of the fan support. The collector has as surface area that is 2 m long and 1.9 m wide. The area of the drying tunnel is exactly twice the area of the collector. The solar tunnel dryer faces south in the east-west direction and does not have shade between 9:00 am and 5:00 pm. The drying air temperature, the inner temperature of strawberry, and the relative humidity were detected using K-type thermocouples and DT-3 hygrometer (TBT, China), respectively. A hotwire anemometer was used to measure drying air velocity at the outlet of the tunnel.

Shade drying

In order to dry the strawberry samples in shade, they were first washed with clean water and then dried. As in the solar tunnel dryer, the samples were whole and divided into two and arranged in aluminum trays having dimensions of 20 cm x 20 cm., Before the strawberry specimens were exposed to shade, the researchers recorded the ambient air temperature, the mean wind speed, and solar radiation values using a K-type thermocouple, DT-3 hygrometer, and hotwire anemometer.

Figure 1. The experimental solar tunnel dryer.

The samples were spread evenly on a sample tray with a single layer and after that, they were immediately exposed to shade. The experiments in the shade also started at 09:00 in the morning and continued until 17:00 in the evening. The losses that occurred in the content of moisture of the samples were determined by measuring the changes in weight at 2-h intervals during the drying process.

Microwave drying

The drying experiments of strawberries were carried out using an Arcelik MD 594 (Turkey) microwave oven with a maximum output of 800 W operating at 2450 MHz (12.24 cm wavelength) with specifications of 230 V, 50 Hz, and 2650 W. The microwave oven in which the trials were carried out could operate at five different microwave output powers: 180, 360, 540, 720, and 900W.

The researchers took the strawberry samples out of the refrigerator and kept them at room temperature for 2 h before they were dried in the microwave oven for the experiments. About 100 g of strawberry samples were then weighed using an (Sartorius GP3202, Germany) digital balance with a precision of 0.001 g. The drying process was carried out by drying whole and halved strawberry samples with 180, 540, and 900 W microwave power. During the drying trials, each sample was located in the middle of the rotating glass of the microwave oven. Each experiment was carried out in 3 replicates in line with a predetermined schedule related to the microwave power and time. Finally, the average of the obtained results was taken.

Moisture content

The content of moisture was calculated by drying 50 grams of strawberry fruit in a hot air oven at 105°C for 24 h. The measurement was performed three times for each experiment and averaged.

$$Moisture(\%) = \frac{m_i - m_f}{m_f} \times 100 \qquad (1)$$

Where, m_i = initial mass in g, mf = final or bone dry mass in g. The experiments are conducted in a closed room to reduce moisture content variation of air with weather change.

Moisture ratio

The moisture ratio (MR) of the strawberry samples is determined using the Equation (2) below.

$$MR = \frac{M_t - M_e}{M_0 - M_e} \qquad (2)$$

where MR is moisture ratio (dimensionless), Mt is moisture content of sample at any t time ($kg_{water}/kg_{dry\ solids}$), Me is equilibrium moisture content ($kg_{water}/kg_{dry\ solids}$), and Mo is the initial moisture ($kg_{water}/kg_{dry\ solids}$) $(M_t-M_e)/(M_0-M_e)$ was simplified to (Mt/M0) = MR because the relative humidity of the drying air for solar drying experiments fluctuated continuously, so an accurate Me could not be predicted. Besides, M_e is small compared to M or M0, so the error involved in simplification is negligible (Doymaz & Pala, 2002).

Drying rate

The drying rate was a highly significant parameter when it comes to drying kinetics. In order to reveal the association of the drying duration of strawberries and the drying rate, the drying rate of strawberry slices was determined as follows:

$$DR = \frac{M_{t+\Delta t} - M_t}{\Delta t} \quad (3)$$

where DR is the drying rate (kgwater/kgdry solids min), Mt and Mt+dt are the moisture contents at t and t+dt respectively, and t is the drying time (min) (Beige, 2016).

Mathematical modeling

Continuous data on moisture content that were obtained according to different densities of microwave power and different size characteristics were turned into moisture content. Table 1 shows five different mathematical models that are used for the moisture ratio of strawberry samples in the literature. The non-linear regression analysis of equations was carried out with Sigma Plot 12.0 statistical software and the drying parameters and coefficients (a, b, c, k, k_1, k_2, n) of these equations were calculated. The determination of the best mathematical model was based upon three statistical values of the correlation coefficient R^2 obtained by the non-linear analysis under different drying conditions, the chi-square value of χ^2, and the root mean square error (RMSE) (Izli & Polat, 2019; Doymaz et al., 2015). They were chosen as the criteria for goodness of fit. The equations of R2, χ^2 and RMSE were given in (4), (5) and (6), respectively:

$$R^2 = 1 - \frac{\sum_{i=1}^{N}\left(MR_{exp,i} - MR_{pre,i}\right)^2}{\sum_{i=1}^{N}\left(\overline{MR}_{exp} - MR_{pre,i}\right)^2} \quad (4)$$

$$\chi^2 = \frac{\sum_{i=1}^{N}\left(MR_{exp,i} - MR_{pre,i}\right)^2}{N - z} \quad (5)$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}\left(MR_{pre,i} - MR_{exp,i}\right)^2}{N}} \quad (6)$$

where MRexp and MRpre are experimental and predicted values of moisture ratio, respectively. The value z is the number of constants in the model and N is the total number of observations.

Table 1
Mathematical models tested for the values of moisture ratio of strawberry

No	Model name	Model Equation	References
1	Weibull distribution	$MR=a-b\exp(-(kt^n))$	Babalis et al. (2006)
2	Midilli et al.	$MR=a\exp(-kt^m)+b\,t$	Midilli et al. (2002)
3	Page	$MR=\exp(-kt^n)$	Akpinar (2011)
4	Jena and Das	$MR = a\exp(-kt + b\sqrt{(t)}) + c$	Jena et al. (2007)
5	Aghbashlo et al.	$MR=\exp(-k_1t/1+k_2t)$	Aghbashlo et al. (2009)

Statistical analysis

Sigma Plot (Scientific Graph System, version 12.00) software was used to perform the statistical analysis. Non-linear regression analysis was carried out by means of Sigma-Plot (version 12.00) in order to calculate equation parameters. The results of the regression analysis include microwave drying of strawberry samples under solar tunnel drying, shade and various microwave output powers; R^2, coefficient of determination; χ^2, chi-square value, and RMSE, the root mean square error.

Results and Discussion

Drying conditions of strawberries

Drying of the strawberry samples was performed in July 2018. It was sunny and there was no rain during the experiment. Figure 2a shows the pattern of temperature for drying in solar tunnel and in shade. The temperature of air was almost averagely 9ºC higher in solar tunnel than in shade. Figure 2b presents the alteration of air velocity as a function of time is given. The velocity values acquired from fans reached the peak at about the midday. The values of air velocity were in synchrony with air temperatures, and thus they modulated the temperature of drying. Higher levels of energy that the collector received at the high solar irradiance caused an increase in the drying air temperature that was equated by higher values of air velocity (Figure 2b). Figure 2b shows solar irradiance as function of time. The levels of solar irradiances were low in the morning and afternoon because of the changes in the angles of the sun. Generally, direct measurement of the rate of airflow of the solar tunnel dryer was not easy as there were variations of air velocity based on time and position perpendicular to the flow. The fan worked continuously during the time in which the solar cell module provided power.

Drying characteristics of strawberries

Figure 3 shows the moisture content of strawberry fruit according to wet base depending on the drying time. The total drying times of 3120 and 3120 min were determined for the whole and halved strawberry samples in solar tunnel type drying conditions, respectively. The total drying times of 6240 and 3360 min were determined for the whole and halved strawberry samples which were dried in shade, respectively. In addition, the drying processes of whole strawberry samples at microwave power densities of 180W, 540W, and 900W took 30, 16, and 10 min, respectively (Figure 3). Finally, the drying process of the halved strawberry samples took 38 min at 180W microwave power density, 16 min at 540W microwave power density, and 10 min at 900W microwave power density (Figure 4). The drying time was reduced due to the rising microwave energy (Prabhanjan et al., 1995; Soysal, 2004).

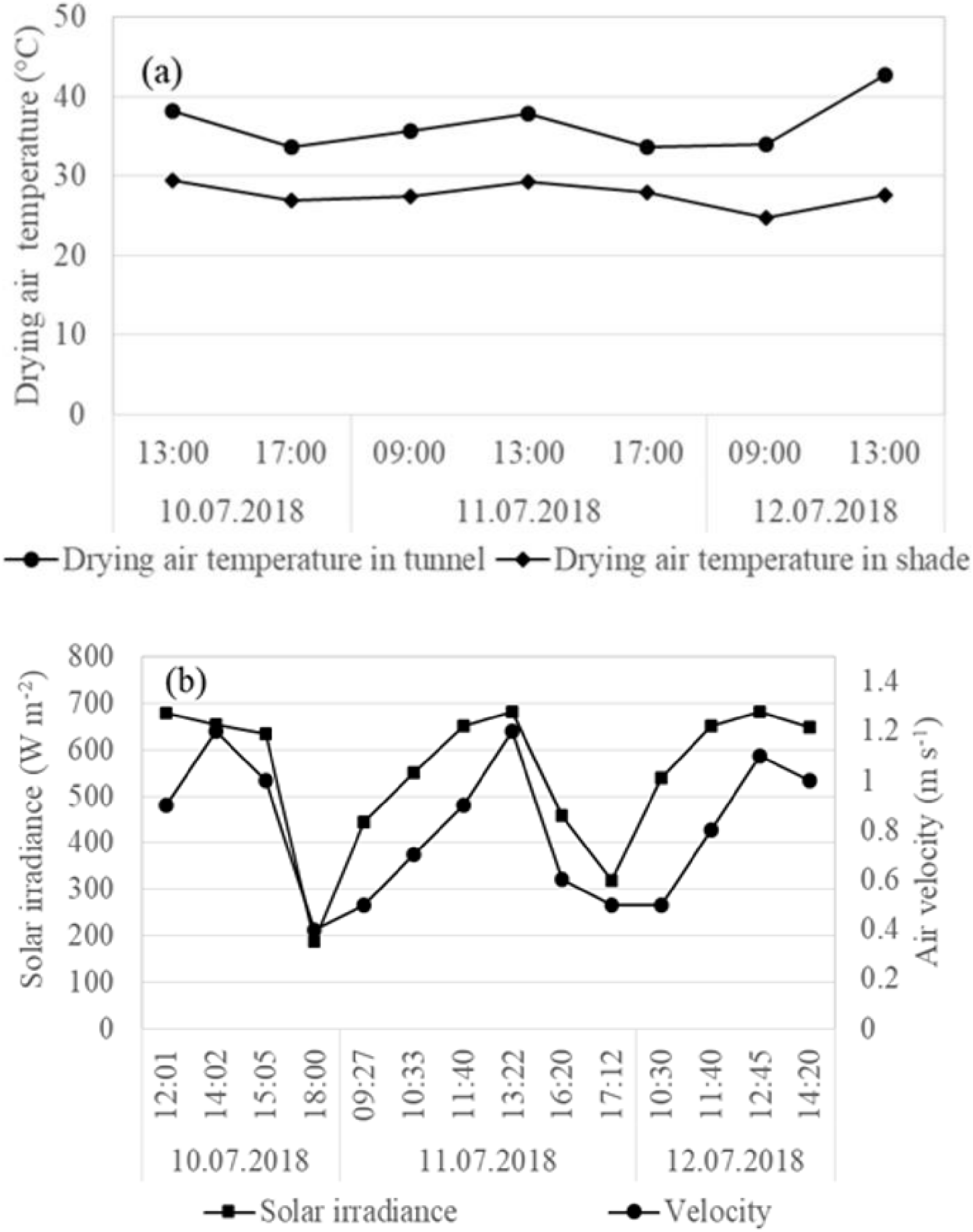

Figure 2. Variation of drying air temperature in solar tunnel and in shade (a) solar irradiance and air velocity as a function of time for solar tunnel dryer (b).

When all results were considered in terms of the total drying time, expectedly, the shortest total drying time (10 min) was obtained by drying the whole and halved strawberry samples in 900W microwave drying conditions, while the longest time (6240 min) was obtained under shade drying conditions for all the strawberry samples. The results of the drying process for the strawberry samples bore similarities to the results of other studies on drying various foods (Doymaz, 2014). El-Beltagy et al. (2007) conducted experiments on drying with strawberry fruit in a thin-layer solar dryer consisting of a drying chamber and a solar collector. Strawberry fruits prepared in different shapes (whole, halved, quarter, and 3 mm discs) were pre-treated using various solutions. In this study, the drying times required for whole, halved, quarter, and disc strawberry samples to reach their final moisture contents of 18.5%, 13.1%, 11.5%, and 11.3% (d.b.) were 28, 26, 20, and 24 h, respectively. The findings are in parallel with some studies in the literature.

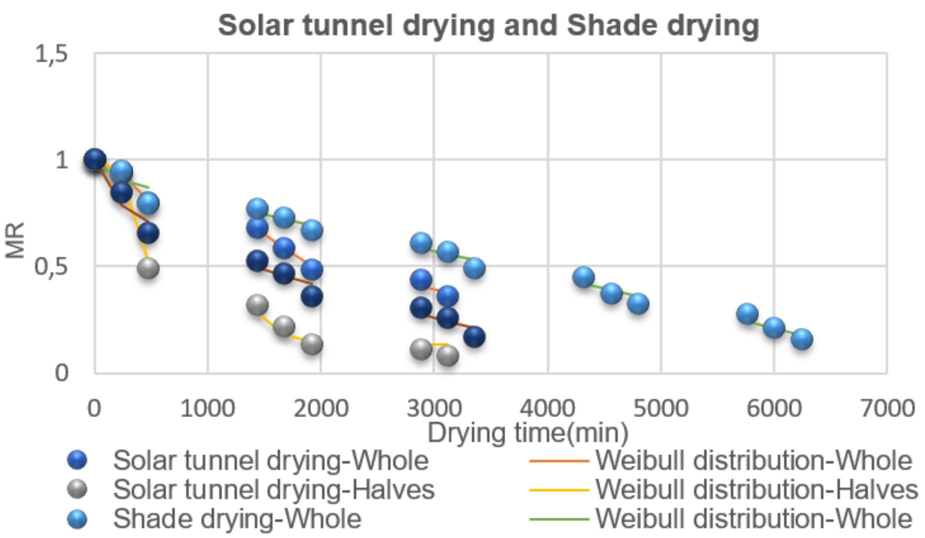

Figure 3. Comparison of the experimental curve obtained with the estimated data on the Weibull distribution and Midilli et al. equations during strawberry fruits drying with the solar tunnel drying and shade drying methods.

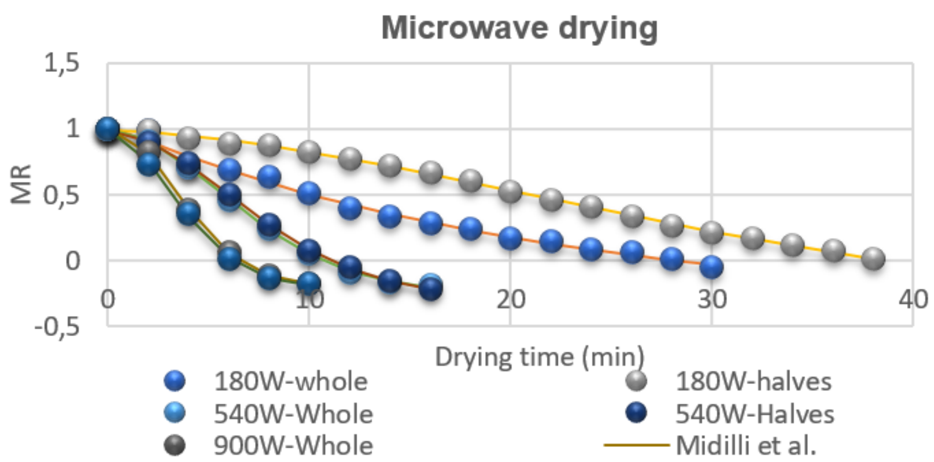

Figure 4. Comparison of the experimental curve obtained with the estimated data on the Weibull distribution and the equations of Midilli et al. during strawberry fruit drying with different microwave power densities.

Equation (eq.3) was used to calculate the drying rates of strawberry samples. A careful examination of the drying rate curves shows that the drying process that occurred during the falling rate period and the constant rate period was not observed in these curves. Higher drying rates were recorded at the start of the drying processes, which dropped due to decreasing moisture content of the strawberry samples. These findings agree with the findings of studies on strawberry drying in the literature (Doymaz, 2008; Ertekin et al., 2014; Kırmaci et al., 2008).

Accordingly, the total drying rates were determined as 0.2116 kg [H_2O] kg^{-1} dry solids.min for solar tunnel type dryer, 0.1119 kg [H_2O] kg^{-1} dry solids.min for shade drying, and 10.04, 9.175, and 16.135 kg [H_2O] kg^{-1} dry solids.min for microwave output powers of 180W, 540W, and 900W for the whole strawberry samples, respectively. The total drying rates to reach the final moisture content of the halved strawberry samples were 0.709, 0.1670, 2.905, 8.685, and 13.720 kg [H_2O] kg^{-1} dry solids.min at solar tunnel dryer, shade, and microwave powers of 180W, 540W, and 900W, respectively.

An increase was observed in drying rates due to higher microwave output powers. The drying times of both the whole and halved strawberry samples were significantly shortened with the 540W and 900W microwave method when compared to the other methods of drying. The higher the temperature of the drying air becomes, the higher the drying rate is. Consequently, the appearance of higher vapor pressure of water in the material at higher temperatures and the increase of the evaporation degree cause higher drying rates at high temperatures (Doymaz & Aktas, 2018). At the same time, the decrease in the thickness causes water molecules to proceed less to reach the surface, and as a result, the drying rate is faster in the two divided samples. It has been reported that the smaller the sample thickness, the greater the amount of moisture to be transported per unit time. In this sense, this study was compatible with studies on drying carried out with different fruits in the literature. Previous studies determined that the decrease in the sample thickness brought about higher drying rates (Sacilik & Elicin, 2005).

Evaluation of the models

Two different drying models were designated for all drying conditions in line with R^2, RMSE, and chi-square values of all the drying models. Table 2 indicates that the Weibull distribution model and the model equations of Midilli *et al.* have the greatest R^2 value and the smallest χ^2 and RMSE values. Moreover, the constant and coefficients (a, b, c, k, k_1, k_2, and n) related to the models are given in Table 2. Therefore, these two model equations were chosen to represent thin layer drying of the whole and halved strawberry samples.

Table 2
Estimated coefficients and statistical data obtained from different drying models

Drying Models		Solar tunnel drying		Shade drying		Microwave drying					
						180W		540W		900W	
		whole	halves	whole	halves	whole	halves	whole	halves	whole	halves
Weibull	a	1.0025	1.0197	0.4588	-0.5978	-0.3150	-0.4447	-0.2400	-0.2755	-0.1884	-0.2029
	b	25.4436	0.9179	-0.5454	-1.6014	-1.3376	-1.4293	-1.2368	-1.2656	-1.1939	-1.1967
	k	7.1297	18.8575	0.0797	0.0642	0.0451	0.0025	0.0195	0.0179	0.0443	0.0657
	n	-0.1656	-1.5947	0.6778	0.5645	1.0381	1.6864	1.8766	1.8488	2.0048	1.8077
	R^2	0.9758	0.9741	0.9304	0.9494	0.9882	0.9987	0.9996	0.9995	0.9996	0.9990
	RMSE	0.0246	0.05173	0.01828	0.05260	0.03523	0.01147	0.00861	0.00983	0.17864	0.01429
	χ^2	0.0019	0.01372	0.00134	0.00481	0.00047	0.00027	0.0001	-1.3248	0.07638	0.001737
Midilli et al.	a	1.0032	1.0307	1.0042	1.0039	1.0225	0.9890	0.9976	0.9910	1.0045	0.9920
	b	-0.0011	0.0013	0.0014	-0.0018	-0.0060	-0.0059	-0.0137	-0.0148	-0.0182	-0.0195
	k	0.0275	0.0566	0.0459	0.1023	0.0518	0.0015	0.0154	0.0135	0.0370	0.0588
	n	0.8634	1.0436	0.6491	0.5724	1.0633	1.8883	2.0429	2.0364	2.1832	1.9584
	R^2	0.9755	0.9516	0.9301	0.9632	0.9884	0.9989	0.9994	0.9996	1.0000	0.9985
	RMSE	0.0246	0.03488	0.01816	0.05251	0.03498	0.01048	0.01049	0.59886	0.01078	0.01702
	χ^2	0.0020	0.01091	0.00135	0.00480	0.00083	0.00025	-0.0003	0.03095	0.00082	0.00163
Page	k	0.0245	0.0586	0.0472	0.0902	0.0297	0.0014	0.0114	0.0096	0.0301	0.0570
	n	0.9302	0.9777	0.5861	0.6564	1.3763	2.0581	2.3801	2.4160	2.5259	2.1957
	R^2	0.9753	0.9472	0.9292	0.9486	0.9803	0.9918	0.9520	0.9520	0.9615	0.9510
	RMSE	0.0247	0.03890	0.01848	0.05300	0.04556	0.02897	0.09611	0.09543	0.01088	0.09836
	χ^2	0.0020	0.01344	0.00136	0.00501	0.01984	0.00436	0.12314	0.42158	0.00022	0.01314
Jena and Das	a	0.9096	0.9747	0.3592	0.6708	1.4002	-2.2270	2.3911	3.0370	2.1173	1.7747
	k	0.0108	0.0343	0.0307	0.0300	0.0235	-0.0051	0.0259	0.5182	0.0478	0.5641
	b	-0.0216	-0.0686	-0.0537	-0.0562	-0.0471	0.0102	-0.0519	0.9636	-0.0956	0.8718
	c	0.0840	0.0656	0.6329	0.3001	-0.3722	3.2625	-1.3125	-1.9708	-1.0555	-0.7309
	R^2	0.9749	0.9515	0.9206	0.9327	0.9882	0.9952	0.9816	0.9854	0.9731	0.9802
	RMSE	0.02483	0.03422	0.03314	0.06066	0.03532	0.02211	0.05960	0.05257	0.08197	0.06247
	χ^2	0.00204	0.01063	0.00157	0.00677	0.00136	-0.0011	-0.0138	0.82173	0.01789	0.00925
Aghbashlo et al.	k_1	0.0207	0.0611	0.0272	0.0562	0.0537	0.0172	0.0886	0.0802	0.1489	0.1710
	k_2	0.0022	0.0046	0.0429	0.0319	-0.0206	-0.0220	-0.0625	-0.0625	-0.1000	-0.1000
	R^2	0.9748	0.9488	0.9296	0.9426	0.9846	0.9977	0.9440	0.9473	0.9453	0.9469
	RMSE	0.0268	0.03568	0.01985	0.05602	0.04032	0.01538	0.10386	0.06971	0.07149	0.10236
	χ^2	0.0020	0.52701	0.00134	0.00620	0.02549	0.00104	0.007079	1.00795	0.01177	0.01929

For all the strawberry samples dried in a solar tunnel dryer, R^2 values varied between 0.9744 and 0.9758 in all the models examined, while R^2 values for the whole and halved strawberry samples in the Weibull model were 0.9758 and 0.9741, respectively. When examined in the same way, the RMSE values that were obtained in modeling studies performed with a solar tunnel type dryer varied between 0.0246 and 0.0354 and between 0.03422 and 0.05173 for the whole and halved strawberry samples, respectively. In addition, the χ^2 values obtained as a result of the modeling studies varied between 0.0019 and 0.0040 and between 0.01063 and 0.52701 for the whole and halved strawberry samples, respectively.

The results indicated that the Weibull distribution model was a better model to explain the properties of strawberry dried in a solar tunnel dryer for both the whole and halved strawberry samples. Similarly, with the data obtained from the drying of all the strawberry samples dried in shade, the Weibull distribution model equation was shown to be the best model equation. Furthermore, the values obtained from the model of Midilli et al. were more reasonable compared to the other models for shade drying of halved strawberry samples.

For the process of shade drying, the highest R^2, the lowest χ^2, and the lowest RMSE values were found between 0.9064 and 0.9304, 0.00134 and 0.00174, and 0.01816 and 0.01981, respectively, for the whole strawberry samples. Likewise, the R^2, χ^2, and RMSE values in all mathematical models examined for the halved strawberry samples dried in shade drying varied between 0.9180 and 0.9632, 0.00480 and 0.00679, and 0.5251 and 0.06692, respectively. The Weibull distribution drying model was determined for the whole strawberry samples according to the values of R^2, RMSE, and chi-square of all the drying models in shade drying. In addition, when the R^2, RMSE, and chi-square values of all the drying models were calculated for the halved strawberry samples, the drying model of Midilli et al. was determined to be the most optimum model equation

In a similar study, the model of Midilli et al. was used to predict the drying behavior of V. amygdalina under open sun and in shade drying. Therefore, the model equation of Midilli et al. may be used to predict the drying behavior of V. amygdalina plant in both open sun and shade in this study (Oluwaseun et al., 2018).

The R^2 values of the Midilli et al. model were calculated as 0.9884 at 180W microwave power density for the whole strawberry samples, 0.9989 at 180W microwave power density for the halved strawberry samples, 0.9996 at 540W microwave power density for the halved strawberry samples, and finally 1.000W at 900W microwave power density for the whole strawberry samples. On the other hand, the R^2 values of the Weibull distribution model were calculated as 0.9996 at 540W microwave power density for all the strawberry samples and 0.9990 at 900W microwave power density for the split strawberry samples, respectively.

The chi-square values for the model of Midilli et al. were 0.00083 and 0.00082 for 180W and 900W microwave powers for the whole strawberry samples, respectively; on the other hand, they were determined as 0.00025 and 0.03095 for microwave powers of 180W and 540W, respectively, for the halved strawberry samples. On the other hand, the chi-square values of the Weibull distribution model were calculated as 0.0001 at 540W power density in the whole strawberry samples and 0.001737 at 900W power density for the halved strawberry samples. For microwave power densities, the Weibull distribution and Midilli et al. models, for which the estimated data are closest to the experimental data, are shown to be the optimum models.

Özbek and Dadali (2007) dried mint leaves of different weights at various microwave power ranges. They modeled the data obtained by drying mint leaves with various thin-layer drying models. According to their findings, the model of Midilli et al. produced and they found that the results that were the closest to the experimental data. Evin (2011) dried rosehip fruit at 90W, 180W, 360W, 600W, and 800W by microwave drying method and modeled the experimental data with ten different thin-layer drying models. Accordingly, the Page model gave the results closest to the experimental data.

In their study carried out on a thin-layer halogen dryer of strawberry, Al-Hilphy and Alrikabi (2013) stated that the Page model at 60°C is the most suitable model equation. In the combined microwave-fan assisted convection drying study of strawberry fruit, Karaaslan and Balta (2014) stated that the model of Midilli et al. perfectly fit all data points with lower values of SEE and RSS and higher values of R^2. Vega-Galvez et al. (2012) dried golden strawberry fruit at 4 different temperatures (60°C, 70ºC, 80°C, and 90°C) and they reported that the model of Midilli et al. best fits the R^2 and χ^2 values calculated by applying the experimental data to 11 different models.

Conclusions

This study investigated the drying properties of whole and halved strawberry samples in different drying methods at varying air temperatures and microwave powers. The drying of strawberry samples at each temperature and microwave power took place in the falling rate period; the study found out no constant rate period of drying. Temperatures and microwave powers significantly influenced the drying rate. Increases in microwave power decreased the drying time. This study used the experimental data for whole and halved strawberry samples in order to assess various thin-layer drying models. Of these, the Weibull Distribution model and the model by Midilli et al. produced the optimum results among all three drying methods. The association of the model parameters and the drying conditions was revealed and reported in order to estimate the moisture ratio according to the drying time.

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