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The Effect of Drying Methods on Color and Chlorophyll Content of Parsley Leaves

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A R T I C L E I N F O

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A B S T R A C T

Parsley leaves (*Petroselinum crispum* L.) weighing 100 ± 0.09 g were dehydrated from moisture content of 82.24 ± 0.07% to 10.01 ± 0.02 % (wet basis) using the microwave (*MD*), convective (*CD*), solar oven (*SOD*), sun (*SD*) and natural (*ND*) drying. Drying in *MD*, *CD*, *SOD*, *SD*, and *ND* was completed at 18±1.15, 61±0.58, 255±10, 330±5.29, and 1530±11.55 min, respectively. The energy consumption of MD and CD was measured as 0.213±0.009 and 0.427±0.015 kWh, respectively. In microwave drying, 700 W microwave output power was applied while convective drying was used with 50°C temperature and 1m/s air velocity. The sun and solar oven drying processes were carried out under the same conditions at the same time. The average temperature of the system during the solar oven drying was 81.7±1.5°C whereas the airflow in the system was 0.5 m/s. The data obtained from the experiments were also modeled using twelve different thin-layer drying equations, and thus the theoretical data were obtained. According to these theoretical data, the best model in the microwave and natural drying was Alibas's equation while the most suitable model in the solar and convective drying was modified Henderson and Pabis's model. On the other hand, it was seen that the best model in the solar oven drying was the Page equation. As a result, considering both quality and drying parameters, it was determined that MD and SOD were the most suitable method for drying of parsley leaves.

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Introduction

The parsley plant (*Petroselinum crispum* L.) is a spice that is native to countries of southern Europe and the Mediterranean region and belongs to the Apiaceae (synonym: Umbelliferae) family. On account of its aromatic property, it is widely used, both as a fresh or dried herb, to enhance the flavor of the food, as well as a garnish, and for seasoning. The oleoresins and the essential oils obtained from the herb and the seeds are used mainly as fragrances in perfumery, but also the food industry. Besides the leaves and the seeds, the roots of parsley are used in the pharmaceutical industry. The dried parsley flakes are used as a seasoning for instant soups and sausages. In the cosmetic industry, parsley extracts are being used to produce soaps and creams. Parsley has a high nutritional value because it is rich in vitamin C and E, riboflavin, thiamin, b-carotene, and many organic minerals (Soysal, 2004; Bakowski and Michalik, 1986; Michalik and Dobrzanski, 1987; Athar et al., 1999).

Due to the presence of many essentials compounds, it is utilized as a diuretic, hypertensive, hypotensive, carminative, stomachic, nervine, abortifacient, emmenagogic, and nutritive agent (Robbers and Tyler, 1999; Kreydiyyeh and Usta, 2002; Soysal, 2004). The characteristic odor of parsley is due to the presence of monoterpene hydrocarbons, mainly β -phellandrene, p-mentha-1,3,8-triene, 4-isopropenyl-1-methylbenzene, and terpinolene (Díaz-Maroto et al., 2002). Parsley, like many other herbal plants, is highly seasonal. It also contains a high level of moisture content and thus is prone to quick spoilage. Due to such characteristic nature of this plant, parsley leaves are subjected to many postharvest treatments, such as drying and freezing, in order to prevent the early spoilage and to increase shelf life.

Drying is a process of dehydration or desiccation, used to decrease the moisture of the biomaterial to prevent microbial growth. It is the oldest and the most common method of preservation known to humankind. It is a vital process for preserving food because of its effect on the quality of the dried product. Drying of agricultural products is essential, for reducing the moisture content to a level which helps in safe storage over an extended period. Also, the moisture loss brings about a substantial reduction in the weight and volume, minimizing packaging, storage, and transportation costs (Akpinar, 2006). Among various known methods of drying, sun drying (natural convection) is the most widely used method. Despite many limitations, such as labor-intensive, low-quality end products, inability to manage huge quantities over large areas, sun drying is still being practiced in many tropical and subtropical countries throughout the world. Since the sun drying method has many disadvantages, convective drying methods are widely being used (Motevali et al., 2011). These methods are not only cheaper than microwave and vacuum drying but can be applied almost to all kinds of biomaterials. Although convective drying has many benefits, it also has its limitations. Prolonged drying periods, high energy need, nonhomogeneous drying, loss of nutrients, color and aroma are few of such limitations (Alibas, 2006; Soysal, 2004).

On the other hand, microwave drying has several advantages over the sun and convective drying. Microwave drying is a particularly successful method for drying spices (Soysal, 2004). Many researchers have successfully dried a wide variety of spices such as parsley (Soysal, 2004), peppermint, nettle (Alibas, 2010) and chard (Alibas, 2006) using microwave radiation.

Drying is an energy-intensive operation and is often to be accountable for 7-15% of the nation's industrial energy, in most industrialized countries (Akpinar et al., 2006). Industrialist, nowadays are thus looking for alternative sources of energy; and solar energy is the excellent source of alternative energy due to its abundance, inexhaustibility, and non-pollutant nature. Moreover, it is cheap, renewable and environmental friendly (Basunia and Abe, 2001; Akpinar et al., 2006). Recently, many new hybrid techniques and devices such as solar convective ovens, are being utilized to tackle the problem of high electricity consumption often with low thermal efficiencies. The solar convective ovens are not only energy efficient but also are very fast and use a brief period to complete the drying processes.

The aim of this study was to i) dry the parsley leaves with microwave, convective, sun, solar oven and natural drying methods; ii) measure the energy consumption of different drying methods; iii) model the experimental data obtained from drying using twelve thin-layer drying equations; iv) determine the color parameters and chlorophyll content of dried parsley leaves, and v) find the drying method closest to fresh leaves according to drying period, energy consumption, color, and chlorophyll content.

Material and Methods

Material

The parsley used in the study was purchased from a local market in Nilüfer district of Bursa province. The parsley leaves were selected from healthy plants. Until the drying process was completed, the parsley leaves were stored in the refrigerator at 4°C. The study was carried out as triplicates. All drying processes were performed simultaneously with different systems.

Drying Systems and Process

Five different drying methods were used: microwave (MD), convective (CD), sun (SD), solar oven (SOD) and natural (ND) drying. Parsley leaves, which weigh 100±0.09 g, were used in all drying methods. All drying processes were carried out from 82.24±0.07% of initial moisture to 10.01±0.02% of final moisture.

Microwave drying (Electrolux EVY7800AAX, USA) trials were performed at 700 W in a dryer with dimensions of 800×430×210 mm and operating conditions of 3000 W, 230±10V~ and 50 Hz. The area of the microwave dryer tray was 410×320 mm. A diffuser placed between the magnetron and the drying tray provided the uniformity of the microwave rays reaching the dried product.

Convective drying operations were carried out in a dryer (Arçelik MD 592, Turkey) with operating conditions of 2900 W, 230V~ and 50 Hz at 50°C temperature and 1 m/s air velocity. The round drying tray with 280 mm diameter, was turned to the right for one minute, and then rotated in the reverse direction for one minute without stopping. This process continued until the end of the drying process. The weight loss in the material was recorded at every five min. The resistances were placed on the upper surface of the dryer and the fan on the rear surface of the oven.

Solar oven consists of three parts: mirror reflector, glass cage, and collector surface. While mirror reflector was made of the unbreakable mirror with dimensions of 1920 × 600 mm, glass cage was manufactured with dimensions of 707 × 508 × 300 mm. The black painted collector surface consisting of a large number of curved blades provided heating of the drying air and was manufactured in dimensions of 1390 × 575 × 240 mm. Mirror surface, which can be adjusted up and down in six different levels, was attached to reflect the sun's rays to the glass cage, where the products are placed, and to the collector surface, where the drying air is heated. Therefore, the length of the reflective mirror is equal to the sum length of the two parts. The width of the mirror is arranged in such a way that the sun rays could be reflected evenly all over the cage and collector surface. The wire tray where the products were laid out as thin layers was placed parallel to the lid, just below the glass cover of the glass cage. The air heated by the reflection effect on the collector surface was blown from the bottom of the cage to the tray. The drying air is heated using a bypass system, i.e., it is continuously circulated through the closed system consisting of a glass cage and collector without exiting the system. Although the fan speed could be adjusted between 3.5 and 0.5 m/s, it was kept at 0.5 m/s in order to prevent the parsley leaves from flying. The fan received its electricity from the solar panel. The solar oven was directed towards the sun manually. During drying, the solar oven was placed in an area that could receive direct sunlight without any shade. Before the drying process of parsley leaves by solar oven started, it was placed under the sun for about two hours. Solar oven used in this study was given in Figure 1.

The sun drying processes were carried out in a transparent wire cage, which can receive sunlight directly. This wire cage with dimensions of 1535 × 637 × 160 mm prevented the product from flying away and protected it from insects. During drying, the transparent cage, where the product was laid as a thin layer, was placed on a non-shaded area that could receive direct sunlight.

Figure 1 Solar oven dryer

The sun and solar oven drying processes were carried out under the same conditions at the same time. On the days of these drying experiments, the air temperatures were 33.6±5.2°C, 30.4±3.3°C and 34.3±4.1°C, the wind speeds were 5.1±1.2 km/h, 2.9±0.7km/h and 3.8±0.9 km/h, and the relative humidity of the air was 40.2±5.1%, 42.7±8.2% and 55.3±5.6%, respectively. During the solar oven drying, the airflow of the system remained constant at 0.5 m/s, whereas the system temperature changed at 79.9, 83.2 and 82.0°C on the first, second and third day, respectively. The three-day average temperature of the solar oven drying system was 81.7 ± 1.5°C.

Natural drying processes were carried out in a controlled room conditions with a temperature 25±1°C and a relative humidity of 60±5% and without direct sunlight. In order to prevent mold formation, parsley leaves were ventilated by opposite face for 3 hours during the natural drying.

During the different drying process, the measurements for weight loss were taken periodically. For solar oven drying (SOD) and sun drying (SD) the weight loss was measured every 10 minutes, in the similar manner the measurements for convective drying (CD) were taken at an interval of 5 minutes, for microwave drying (MD) the interval was at 1 minute; whereas for natural drying (ND), the weight loss was taken at every two hours.

Time-dependent weight measurements were conducted for each set of drying experiment. The moisture ratio (MR) was calculated using the following equation, and the average moisture loss was reported (Eq. 1):

$$M_R = \frac{M}{M_0} \qquad (1)$$

Where; *M* is the initial moisture content at a given time [$kg_{(moisture)}\ kg^{-1}_{(dry\ matter)}$] and M_0 is the initial moisture content [$kg_{(moisture)}\ kg^{-1}_{(dry\ matter)}$]

During drying experiments, the drying rate (*DR*) was calculated using the following equation (Eq. 2):

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

Where; *Mt* is the moisture content at *t* time, and *Mt+dt* is the moisture content at *t+dt* [kg(moisture) kg−1 (dry matter)].

Energy Consumption

Except for microwave and convective drying, there is no consumption of electricity in other drying methods since they benefit directly or indirectly from sunlight. The electricity consumed by microwave and convective dryers was measured using an electric counter (Alibas, 2006).

Color and Chlorophyll Content

The color and chlorophyll content of the parsley leaves were measured two times, before and after the drying processes. The color of parsley leaves was measured using a colorimeter (Konica-Minolta CR-10, Japan) capable of measuring according to the Lab scale. The brightness of the color was indicated by "L," the brighter the color, the higher the value of "L." The negative values of "a" represented the greenness of the color, while the positive values indicated the redness of the product. Similarly, the negative numbers of "b" showed that the color is blue, while the positive numbers represented the yellowness in the sample. "C" indicates chroma values, while hue angle is represented by "α." Both values are automatically measured with the colorimeter, just like "L," "a" and "b." The color was measured by bringing the product in contact with the optical eye at the bottom of the colorimeter.

The chlorophyll content of the sample was measured directly with a SPAD meter (Konica Minolta SPAD-502 Plus, Japan). Chlorophyll was assumed to increase as the SPAD values in the product rose (Yilmaz and Alibas, 2017).

Mathematical Formulations

The coefficient of determination (R^2) was the primary criterion for selecting the most appropriate equation to describe the microwave drying curves of parsley leaves. In order to test the linear relationship between the measured and estimated values, the following equation was used to calculate the correlation (Eq. 3):

$$R^2 = \frac{\sum_{i=1}^{N} (M_{R_{exp,i}} - M_{R_{exp_{mean,i}}})^2 - (M_{R_{pre,i}} - M_{R_{exp,i}})^2}{\sum_{i=1}^{N} (M_{R_{exp,i}} - M_{R_{exp_{mean,i}}})^2} \qquad (3)$$

where; *R2* is the coefficient of correlation, *MRexp,i* is the experimental moisture ratio found in any measurement, *MRpre,i* is the predicted moisture ratio for this measurement and *N* is the total number of observations.

The standard error of estimate (*SEE*) gives information on the performance of the correlations by allowing for a comparison between the actual deviations of predicted and measured values term by term. Zero is the ideal value of *SEE* and is calculated as follows (Eq. 4):

$$SEE = \sqrt{\frac{\sum_{i=1}^{N} (M_{R_{exp,i}} - M_{R_{pre,i}})^2}{N - n_i}} \qquad (4)$$

Where; *ni* is the number of constants.

Data Analysis

This study was carried out using a randomized plots factorial experimental design and was tested in triplicate. The LSD test at 0.01 significance levels was used to test mean differences by JUMP (7.0).

Table 1 Mathematical thin-layer drying models used for the approximation.

No	Model name	Equations	Eq.No	References
1	Page	$M_R= \exp(-kt^n)$	(Eq.5)	Page, 1949
2	Two-term	$M_R= a \exp(-k_0t) + b \exp(-k_1t)$	(Eq.6)	Henderson, 1974
3	Thomson	$t=a \ln(M_R) + b[\ln(M_R)]^2$	(Eq.7)	Thomson et al., 1968
4	Diffusion approach	$M_R= a \exp(-kt)+(1-a) \exp(-kbt)$	(Eq.8)	Kassem, 1998
5	Verma et al.	$M_R=a \exp(-kt) +(1-a) \exp(-gt)$	(Eq.9)	Verma et al., 1985
6	Modified Henderson and Pabis	$M_R= a \exp(-kt)+b \exp(-gt)+c \exp(-ht)$	(Eq.10)	Karathanos, 1999
7	Modified Page Equation-II	$M_R= \exp[-k(t/L^2)^n]$	(Eq.11)	Diamante and Munro, 1993
8	Midilli et al.	$M_R=a \exp(-kt^n)+bt$	(Eq.12)	Midilli et al., 2002
9	Weibull distribution	$M_R=a-b \exp[-(kt^n)]$	(Eq.13)	Babalis et al., 2006
10	Aghdashlo et al.	$M_R=\exp(-k_1t/1+k_2t)$	(Eq.14)	Aghdashlo et al., 2009
11	Jena and Das	$M_R=a \exp(-kt+b\sqrt{t}) +c$	(Eq.15)	Jena and Das, 2007
12	Alibas	$M_R=a \exp[(-kt^n)+bt]+c$	(Eq.16)	Alibas, 2012

M_R, moisture ratio; a, b, c, g, h, coefficients; t, drying period, min; n, drying constant; k, k_0, k_1, k_2, special drying constant, min^{-1}; L, thickness of material (mm).

Twelve theoretical, empirical and semi-empirical thin-layer drying equations (Eq. 5 -16) were used in this research and are listed in Table 1. Using NLREG (6.2), nonlinear regression analyses were done to estimate the drying constants and coefficients of these equations (Table 1).

Results and Discussion

Drying Curves

The time-dependent moisture content of all drying methods is shown in Figure 2. According to the figure, it is determined that the shortest drying time in all drying methods is microwave drying, followed by solar oven drying, convective drying, sun drying, and natural drying. Within the scope of this data, microwave drying, which has the shortest drying time, lasted 1512, 312, and 237 minutes less than natural, sun and convective drying respectively. Solar oven drying, on the other hand, was completed in 3.38 times slower than microwave drying. Compared to other drying methods, there was little difference in terms of drying period between solar oven and microwave drying methods. When two drying methods that consume electricity are compared to each other, the microwave drying period is found to be about 14 times shorter than convective drying. Karatas et al. (2016) reported that ripe red hot pepper was dried with microwave and sun drying methods in 3 hours and ten days, respectively. Akpinar et al. (2006) determined that the drying duration of sun-dried and convective dried parsley leaves were 240 and 390 minutes, respectively. Essalhi et al. (2018) indicated that the drying time of solar dried grapes was 1.68 times less than the direct sun drying. Patil and Gawande (2018) dried amla candy (Indian gooseberry candy), which had 80% moisture, in a solar tunnel dryer for 36 sunshine hours and reduced the moisture of the product to 18%. In the same period, the moisture content of the direct sun-dried product was reduced to 33%. Alibas (2006) found that the chard leaves, which were dried in 650W, 39 times more than the drying process at 50°C. Ozkan et al. (2007) stated that drying of spinach leaves at 750 W took approximately 17 times longer than convective drying at 50°C temperature. Alibas (2007) found a difference of 14.67 fold between drying of nettle leaves at 750 W and drying at 50°C. Similarities to drying time in the microwave and convective drying were also found by different authors (Wang et al., 2018; Díaz et al., 2003; Andrés et al., 2004; Davidson et al., 2004).

Figure 3 depicts the drying rates-dependent moisture contents for all drying methods. From the figure, the average drying rate of 0.2970 in microwave drying was significantly higher than the other ones; on the contrary, the average drying rate of natural drying was approximately 149 times lower than microwave drying. Similarly, the average drying rate of solar oven drying was 24.5 times higher than natural drying. In the case of solar oven drying without any energy consumption, the average drying rate was found to be six times less than microwave drying. This was quite a good average, given the fact that the electricity was not consumed. The average drying rate of convective and sun drying was almost similar to each other whereas these drying methods were 5 and 8.5 times shorter than natural drying, respectively. Essalhi et al. (2018) indicated that the average drying rate of solar dried grapes was nearly two times more than the direct sun drying. Yilmaz and Alibas (2017) determined that the average drying rate of coriander leaves dried at 1000W was about 28 times higher than drying at 50°C. Alibas (2006) found that chard leaves dried at 650 W and 50°C have the average drying rate 1.25 and 0.04 [$kg_{(moisture)}\ kg_{(drymatter)}^{-1} min^{-1}$], respectively. Akpinar et al. (2006) found that the average drying rates of sun and convective dried parsley leaves were very close to each other. Similar findings were found by many researchers (Soysal, 2004; Maskan, 2000; Wang et al., 2018; Díaz et al., 2003; Andrés et al., 2004; Davidson et al., 2004).

Both estimated and measured moisture ratios associated with drying period are reported in Figure 4, for all drying methods. According to this figure, 69.20% of the moisture in the parsley leaves was evaporated in the second minute of microwave drying. Only 6% of moisture was removed from the parsley leaves in the last 10 minutes. The moisture loss at the beginning of microwave drying was much higher than the loss of moisture at the end of the drying. Unlike microwave drying, the moisture loss in the solar oven drying was more uniform. The fast drying phase, where a large part of the moisture in the product evaporates, continued for 1/3 of the total drying period; therefore, only 29% of the remaining moisture in parsley leaves was evaporated in the last 2/3 of the drying period. Similar results were found in natural, convective and sun drying, which lasted longer than other ones. The findings were in parallel with some researchers (Alibas, 2006; Soysal, 2004; Wang et al., 2018).

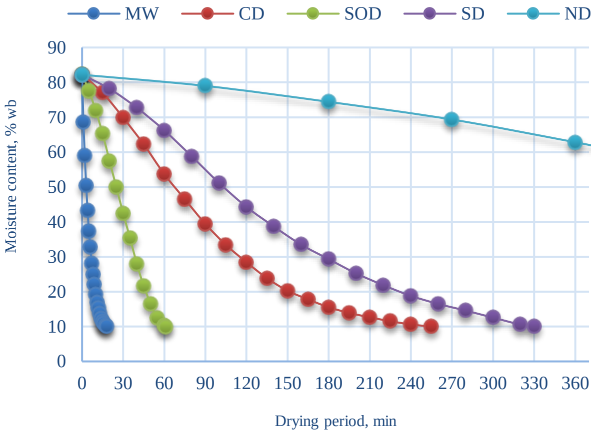

Figure 2 Time-dependent moisture content of dried parsley leaves using different drying methods

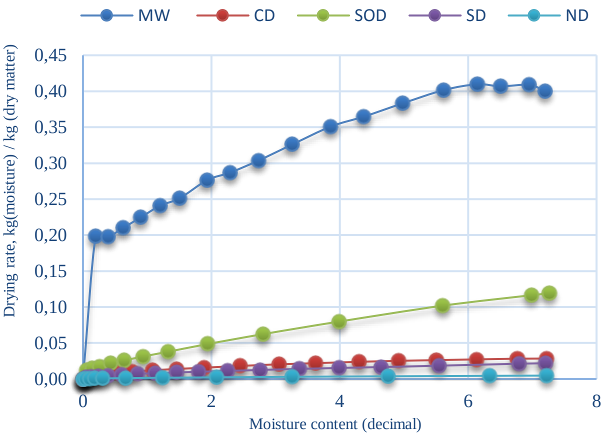

Figure 3 Drying rates depending on the moisture content of dried parsley leaves using different methods

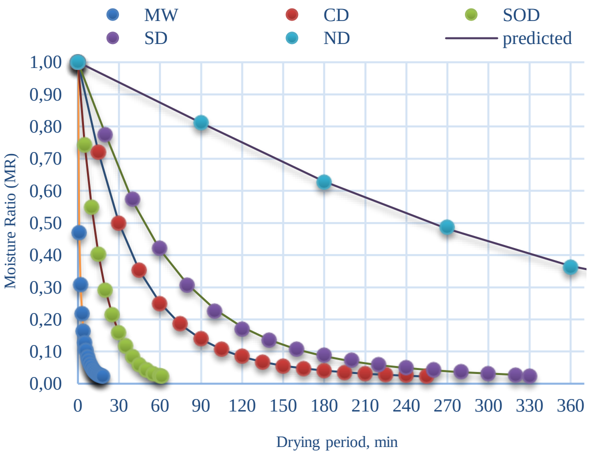

Figure 4 Time-dependent moisture ratios of dried parsley leaves using different methods: MD, SOD and ND were modeled by Alibas equation while SOD and CD were also used modified Henderson and Pabis's model

Modeling of Drying

The regression coefficients and standard errors determined by the twelve thin-layer drying equations are shown in Table 2 together with the drying constant and coefficients determined by the estimation of the equations. The model that made the closest estimate to the data measured in the solar oven, microwave, and natural drying was the Alibas equation; whereas the best estimate was the modified Henderson and Pabis equation in other ones. Very high estimation results were obtained through these models because the regression coefficients of the best prediction models in all drying methods were between 0.9998 and 1.0000. The experimental data obtained from the drying method were estimated using similar drying models by many researchers (Yilmaz and Alibas, 2017).

Energy Consumption

Table 3 shows the drying time and energy consumption by running drying methods. Solar oven, sun, and natural drying methods did not consume any energy. There was no energy consumption of solar oven, sun and natural drying methods due to direct or indirect use of solar energy. In contrast to others, energy consumption was measured only in the microwave and convective drying methods. The energy consumption of the microwave drying was equal to 4.5 times that of convection drying. Alibas (2007) found that energy consumption at 50°C was five times higher than 650 W during drying nettle leaves. Motevali et al. (2011) determined that the energy consumption of fresh sour pomegranate at 300 W was 40 times higher than 50°C and 1 m/s. Similar findings were found by Wang et al. (2018).

Color Parameters and Chlorophyll Content

The chlorophyll content as SPAD and color parameters of all drying methods is shown in Figure 5; in addition, the general appearance of the dried parsley leaves after drying by all the methods used in this study is given in Figure 6. The closest brightness (*a*) of the fresh parsley leaves was measured in microwave drying, while the least was for sun drying. The greenness of the dried leaves by the solar oven method was highly close to that of microwave drying. Similar results were also observed for brightness (*L*), yellowness (*b*) and Chroma (*C*). The nearest hue angle to fresh parsley was measured in microwave-dried leaves, followed by natural, solar oven, convective and sun drying methods. The differences between the greenness of the drying methods were also clearly seen in Figure 5. When looking at the figure, it was recognized that yellowing occurred in natural drying. Patil and Gawande (2018) reported that the color value of amla candy, dried in the solar tunnel dryer, was more preserved than sun-dried. Alibas (2006) indicated that the closest color parameters to fresh chard leaves were in microwave drying and color loss occurred in convective drying.

The chlorophyll content of microwave-dried leaves was almost the same as those measured in solar oven drying. While the chlorophyll in natural and convective drying with the lowest chlorophyll content was parallel with each other, the chlorophyll measured in the microwave and natural drying was very close. The chlorophyll content in the solar oven drying was twice as much as the sun drying. Yilmaz and Alibas (2017) found that the closest chlorophyll content to the fresh coriander leaves was in microwave drying, and the chlorophyll of convective dried products significantly decreased.

Table 2 Statistical data, drying constants and coefficients of thin layer drying models for microwave drying, convective drying and solar oven drying.

DM	M	R^2	SEE	Constants and Coefficients					
	1	0.9993	0.0062	k=0.7817	n=0.5867				
	2	0.9990	0.0081	k_0=0.1829	a=0.3301	b=0.6681	k_1=1.1801		
	3	0.9918	0.5244	a=0.0891	b=0.5409				
	4	0.9988	0.0084	k=1.2359	a=0.6709	b=0.1432			
	5	0.9990	0.0079	k=0.1831	a=0.3306	g=1.1838			
Microwave	6	0.9999	0.0025	k=1.5560	a=0.5146	b=0.0499	c=0.4347	g=0.0467	h=0.3141
Drying	7	0.9993	0.0064	k=1.1219	n=0.5867	L=1.3604			
	8	0.9999	0.0023	k=0.7703	n=0.6187	a=1.0012	b=0.0008		
	9	0.9999	0.0024	k=0.7963	n=0.6273	a=0.0168	b=-0.9868		
	10	0.9979	0.0110	k_1=0.8241	k_2=0.1826				
	11	0.9998	0.0033	k=0.1603	a=0.9785	b=-0.6359	c=0.0221		
	12	1.0000	0.0008	k=1.3166	n=0.8088	a=1.0294	b=0.5926	c=-0.0294	
	1	0.9976	0.0139	k=0.0301	n=0.9231				
	2	0.9998	0.0046	k_0=0.0246	a=0.9636	b=0.0423	k_1=0.0023		
	3	0.9912	7.7584	a=-10.1699	b=4.6860				
	4	0.9967	0.0162	k=0.1670	a=0.0455	b=0.1266			
	5	0.9997	0.0048	k=0.0018	a=0.0369	g=0.0243			
Convective	6	1.0000	0.0015	k=1.4332	a=-0.0492	b=0.9472	c=0.1020	g=0.0275	h=0.0061
Drying	7	0.9976	0.0143	k=0.5468	n=0.9231	L=4.8048			
	8	0.9995	0.0062	k=0.0252	n=0.9781	a=1.0051	b=0.0001		
	9	0.9997	0.0047	k=0.0226	n=1.0162	a=0.0269	b=-0.9749		
	10	0.9990	0.0091	k_1=0.0248	k_2=0.0018				
	11	0.9998	0.0045	k=0.0249	a=0.9741	b=0.0062	c=0.0270		
	12	0.9997	0.0050	k=1.0612	n=1.0002	a=0.9759	b=1.0383	c=0.0266	
	1	1.0000	0.0018	k=0.0570	n=1.0230				
	2	0.9999	0.0039	k_0=0.0614	a=0.3085	b=0.6966	k_1=0.0614		
	3	0.9993	0.5575	a=-7.0632	b=-0.0268				
	4	1.0000	0.0020	k=0.0747	a=-5.3431	b=0.9675			
	5	1.0000	0.0019	k=0.0633	a=1.0480	g=0.1747			
Solar Oven	6	1.0000	0.0022	k=1.5085	a=-0.0113	b=19.3512	c=-18.3427	g=0.0546	h=0.0542
Drying	7	1.0000	0.0019	k=0.2579	n=1.0230	L=2.0901			
	8	1.0000	0.0019	k=0.0561	n=1.10291	a=0.9989	b=2.1040		
	9	1.0000	0.0020	k=0.0568	n=1.0247	a=0.0006	b=0.9992		
	10	0.9999	0.0022	k_1=0.0597	k_2=-0.0009				
	11	1.0000	0.0021	k=0.0632	a=1.0009	b=0.0097	c=-0.0011		
	12	1.0000	0.0013	k=0.0041	n=1.2129	a=0.9986	b=-0.0535	c=0.0013	
	1	0.9777	0.0142	k=0.0150	n=0.9850				
	2	0.9991	0.0093	k_0=-0.0019	a=0.0111	b=1.0029	k_1=0.0149		
	3	0.9986	4.0356	a=-22.9203	b=4.0471				
	4	0.9976	0.0143	k=0.0423	a=0.0160	b=0.3292			
	5	0.9977	0.0146	k=0.0143	a=1.0157	g=1.8765			
Sun	6	0.9998	0.0042	k=0.9995	a=-0.0752	b=0.0800	c=0.9951	g=0.0037	h=0.0172
Drying	7	0.9977	0.0146	k=0.9724	n=0.9850	L=8.2881			
	8	0.9983	0.0079	k=0.0113	n=1.0611	a=1.0035	b=0.0001		
	9	0.9996	0.0062	k=0.0102	n=1.0938	a=0.0303	b=-0.9694		
	10	0.9982	0.0124	k_1=0.0148	b=0.0005				
	11	0.9997	0.0052	k=0.0173	a=0.9736	b=0.0182	c=0.0269		
	12	0.9996	0.0063	k=2.6885	n=1.0004	a=0.9738	b=2.6783	c=0.0287	
	1	0.9991	0.0105	k=0.0021	n=1.0453				
	2	0.9995	0.0083	k_0=0.0029	a=1.0524	b=-0.0524	k_1=1.0000		
	3	0.9996	0.0396	a=128.9032	b=11.6021				
	4	0.9995	0.0077	k=9.7849	a=-0.0597	b=0.0003			
	5	0.9995	0.0079	k=0.0029	a=1.0524	g=1.0001			
Natural	6	0.9998	0.0053	k=0.3757	a=-1.0378	b=1.2176	c=0.8202	g=0.2344	h=0.0361
Drying	7	0.9991	0.0103	k=0.0057	n=1.0698	L=1.7071			
	8	0.9999	0.0040	k=0.0015	n=1.0031	a=1.1074	b=1.3642		
	9	0.9999	0.0033	k=0.0014	n=1.1236	a=0.0214	b=-0.9807		
	10	0.9985	0.0135	k_1=0.0026	k_2=-8.7424				
	11	0.9403	0.0869	k=0.0101	a=0.8429	b=0.0966	c=0.0991		
	12	0.9999	0.0032	k=1.0047	n=1.0003	a=0.9794	b=1.0040	c=0.0210	

DM: Drying Models, M: Model, R^2, coefficient of determination; *SEE*, standard error of estimated; a, a_0, b, c, g, h, coefficients; t, drying period, min; n, drying constant; k, k_0, k_1, k_2, special drying constant , min^{-1}; L, thickness of material (mm).

Figure 5 SPAD and color parameters of dried parsley leaves by different methods: L, brightness; a, greenness; b, yellowness; C, Chroma; α, hue angle; S, chlorophyll approach as SPAD

Conclusion

In this study, parsley leaves were dehydrated with microwave, convective, solar oven, sun, and natural drying. The parsley leaves were dried from the initial moisture content of 82.24±0.07% to final moisture content of 10.01±0.02%. In terms of the drying period, microwave drying at 700 W was found to be 3.39, 14.17, 18.33 and 85 times shorter than the solar oven, convective, sun and natural drying, respectively. The experimental data were modeled using twelve different drying models previously found by different researchers. The best-predicted model for microwave, natural and solar oven drying was Alibas equation; whereas the best-estimated model for the convective and sun drying was modified Jena and Das's equation. While only microwave and convective drying consumed energy, other drying methods did not spend electricity because of using solar energy either directly or indirectly. The color parameters and chlorophyll content closest to fresh were determined in the microwave and solar oven drying; however, these parameters in other drying methods were highly decreased compared to fresh leaves. Consequently, the microwave and solar oven drying of the parsley leaves was the most suitable method in terms of drying parameters such as drying period and energy consumption as well as quality parameters such as color and chlorophyll contents.

Table 3 Drying time and energy consumption of dried parsley leaves by different drying methods

Drying Methods	DP** (min)	EC** (kWh)
MD	18.00 ± 1.15^{a}	0.213 ± 0.009^{b}
CD	255.00 ± 10.00^{c}	0.950 ± 0.012^{c}
SOD	61.00 ± 0.58^{b}	0.000 ± 0.000^{a}
SD	330.00 ± 5.29^{d}	0.000 ± 0.000^{a}
ND	1530.00 ± 11.55^{e}	0.000 ± 0.000^{a}

**P<0.01; Column mean values with different superscripts are significantly different. DP, Drying period; EC, Energy consumption

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