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Original Research Article

Determination of Microwave and Convective Drying Characteristics of Coriander Leaves

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ABSTRACT

Coriander leaves, which weighs 50 ±0.07 g with moisture of 7.531 ± 0.411 [$kg_{(moisture)}$ $kg^{-1}_{(dry\ matter)}$], were dried using three drying methods, microwave, convective and natural drying. Drying continued until leaves moisture was reduced to 0.102 ± 0.0002 [$kg_{(moisture)}$ $kg^{-1}_{(dry\ matter)}$]. Drying treatments in microwave drying powers were 100, 500 and 1000 W and drying periods lasted 9 – 76 min for microwave drying. While natural drying was lasted for 6 days, convective drying (50°C) was continued for 169 minutes. In this study, measured values of moisture were compared with predicted values obtained from several thin-layer equations. The best model for both 1000 W and 100 W microwave drying was Alibas's model. Whereas the best model was determined as Verma's model at 500 W, the most appropriate model was modified Henderson Pabis's model in convective drying at 50°C. The optimum drying period, color and chlorophyll content were obtained by using the microwave drying at 500 W.

Keywords: Chlorophyll, Color, Convective drying, Combined drying, Coriander leaves, Microwave drying, Natural drying

INTRODUCTION

Coriander (*Coriandrum sativum* L.) is an annual herb in the family Apiaceae (Matloup et al. 2017, Mandal and Mandal 2015), also known as Chinese parsley (Buthelezi et al. 2016). Leaves of coriander are particularly rich in L-ascorbic acid, pro-vitamin A, beta carotene, and Vitamin K, in addition, coriander is an important food source in terms of nutrients such as carbohydrates, dietary fiber, manganese, iron, magnesium, selenium and potassium (Pragalyaashree et al. 2013, Divya et al. 2012, Mahendra and Bisht 2011, Bhuiyan et al. 2009, Coşkuner and Karababa 2007, Purseglove et al. 1981, Pirbalouti et al. 2017). Coriander leaves are extremely effective in reducing the level of cholesterol in the blood as well as clear up skin disorders such as fungal infections, dryness and eczema (Wichtl 1994, Said et al. 1996, Emamghoreishi et al. 2005). They can be helpful in curing diarrhea given rise to microbial and fungal action (Reuter et al. 2008). Coriander can prevent mouth ulcers, anemia, osteoporosis, conjunctivitis, diabetes, stomach disorders such as vomiting and nausea, allergic reactions such as seasonal allergies and rhinitis (Emamghoreishi et al. 2005, Gray and Flatt 1999, Cortés-Eslava et al. 2004, Medhin et al. 1986, Kubo et al. 2004, Al-Said et al. 1987, Emamghoreishi and Heidari-Hamedani 2016, Benjumea et al. 2005, Vejdani et al. 2006). If coriander is not consumed immediately after harvesting, it deteriorates very quickly (Alibas Ozkan et al. 2007). Therefore, drying of coriander is a rational idea in order to prolong its usage period (Soysal 2004).

Drying, which reduces the moisture activity of the agricultural products, is one of the most traditional preservation methods (Calderón-Oliver et al. 2016). It reduces the formation of ethylene in the product as well as slowing enzyme activity (Alibas 2010, Akpinar and Bicer 2005). There are many drying methods that are widely used today, but the most common method among them is sun drying all over the world (Alibas Ozkan et al. 2007). Sun drying is the cheapest and natural drying method (Rabha et al. 2017), but this method has many disadvantages including being vulnerable to contamination and having longer drying time (Alibas Ozkan et al. 2007). It also need large drying area and much labour (Sangwan et al. 2011). Due to these disadvantages, instead of sun drying, convective drying has been widely used in the drying of fruits and vegetables (Motevali et al. 2016). The initial investment costs of convective drying are much lower than other methods such as microwave drying and vacuum drying; in addition, it can be used for almost every food item. Also, the construction of convective drying facilities is not complex (Alibas 2006). However, this method has also several disadvantages. Longer drying period; high energy need; nonhomogeneous drying; loss of vitamins, minerals, nutrient elements and color parameters

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according to fresh product are just a few of these disadvantages (Alibas 2006, Soysal 2004). Microwave drying is an alternative drying method to sun drying and convective drying. Short drying period; low energy demand; uniform moisture distribution; amount of vitamin, minerals and nutrient elements close to fresh product in addition to conservation of color parameters have made microwave drying more advantageous than other drying methods (Soysal 2004, Sarimeseli 2011). Microwave drying is a particularly successful method for drying spices (Soysal 2004). The preservation of odor and color for spices is an extremely important issue because of directly affect the sales quality (Alibas 2010). Precisely for this reason, microwave drying is the most convenient method for drying spices. Many researchers have successfully dried a wide variety of spices such as parsley (Soysal 2004), peppermint (Torki-Harchegani et al. 2016), nettle (Alibas 2010) and chard (Alibas 2006) using microwave radiation.

Thin layer drying is the process of drying one layer of sample leaves; many mathematical models are used to describe this drying process, since mathematical modeling is important for performance improvements of drying systems (Denis Bas and Boyacı 2007, Vega-Gálvez et al. 2008, Cihan et al. 2007). Thin layer drying models are divided into three categories as theoretical, semi-empirical and empirical (Ozdemir and Devres 1999, Midilli and Kucuk 2003).

The aims of this study were (i) to evaluate the efficacy of microwave and air drying for coriander leaves; (ii) to compare the measured findings obtained during the drying of coriander leaves with the predicted values obtained through fourteen thin layer drying equations; (iii) to determine the best fit using statistical analysis; (iv) to examine the changes in color and chlorophyll as SPAD of the product after drying; and (v) to determine the optimum drying method for drying coriander leaves considering the color, chlorophyll and drying period.

MATERIALS AND METHODS

Fresh coriander leaves

Fresh coriander leaves (*Coriandrum sativum* L.) used for the drying experiments were harvested from plants in the Gursu county of Bursa. The coriander leaves were selected from healthy, uniform plants and were stored at a temperature of 4°C ± 0.5 until the drying process. Three different samples, each weighing 50 ± 0.07 g, were kept in the drying oven at 105°C for 24 h after which the moisture content of the coriander leaves decreased to 7.53 ± 0.41 on a dry basis.

Drying equipment and drying method

The technical specifications of the programmable, multifunctional microwave oven used in the study (Electrolux EVY7800AAX, USA) were as follows: 230 ± 10 V~, 50 Hz and 3000 W. When operating in the microwave function, the power produced by the oven was continuous. The oven can be operated at microwave output powers of 100, 200, 300, 400, 500, 600, 700, 800, 900 and 1000 W in microwave function whereas it can be adjusted with 1°C accuracy among 30°C and 230°C in convective drying. Thus, there were two different ways of drying – using a microwave oven or convective oven. The area of the combined oven is 800x430x210 mm, and a Teflon tray with dimensions 410x320 mm was used in all drying process.

Microwave drying treatments were 100, 500 and 1000 W while convective drying treatment was 50°C. Also, natural drying treatments were conducted in room in which climatic conditions were 25±1°C and 60±5% relative humidity.

Drying trials were conducted in triplicate for each drying condition, and mean moisture content as a function of drying period was calculated. Weight of coriander leaves during drying was measured by an electronic balance (Radwag WYC 2000, Poland) with an accuracy of 0.01 g.

Tests were repeated three times at each microwave power level, and the average weight loss was reported. The moisture ratio (MR) in these model equations was defined as follows (Eq. 1):

$$M_R = \frac{M - M_e}{M_0 - M_e}$$

where; M is moisture content in any time [$kg_{(moisture)}\ kg^{-1}{}_{(dry\ matter)}$], M_0 is the initial moisture content [$kg_{(moisture)}\ kg^{-}$

^{1}(dry matter)] and M_e is the equilibrium moisture content [kg(moisture) kg^{-1}(dry matter)].
Drying rate (*DR*) during drying experiments was calculated using the following equation (Eq. 2):

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

where; M_t is the moisture content at *t* time and M_{t+dt} is the moisture content at *t* +*dt* [kg(moisture) kg^{-1}(dry matter)].

Data analysis

This research was conducted using a randomized plots factorial experimental design, and all measures were tested in triplicate. Mean differences were tested using LSD test at 0.01 significance levels.
Fourteen empirical and semi-empirical thin-layer drying equations (Eq. 3 -16) were used in this study and are listed in Table 1. Nonlinear regression analyses of these equations were made using SPSS 17.0 and were performed to estimate the parameters *k*, k_0, k_1, k_2, *a*, *b*, *c*, *g*, *h* and *n* of empirical and semi-empirical equations (Table 1).

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

No	*Model name*	*Model equation*	*Eq.No*	*References*
1	Page	$M_R = \exp(-kt^n)$	(Eq.3)	Page 1949
2	Logarithmic	$M_R = \text{a} \exp(-kt) + c$	(Eq.4)	Yagcioglu et al. 1999
3	Two-term	$M_R = \text{a} \exp(-k_0 t) + b \exp(-k_1 t)$	(Eq.5)	Henderson 1974
4	Thomson	$t = a \ln(M_R) + b[\ln(M_R)]^2$	(Eq.6)	Thomson et al. 1968
5	Diffusion approach	$M_R = \text{a} \exp(-kt) + (1-a) \exp(-kbt)$	(Eq.7)	Kassem 1998
6	Verma ve ark.	$M_R = a \exp(-kt) + (1-a) \exp(-gt)$	(Eq.8)	Verma et al. 1985
7	Modified Henderson and Pabis	$M_R = \text{a} \exp(-kt) + b \exp(-gt) + c\, exp(-ht)$	(Eq.9)	Karathanos 1999
8	Modified Page Equation-II	$M_R = \exp[-k(t/L^2)^n]$	(Eq.10)	Diamente and Munro 1993
9	Midilli ve ark.	$M_R = a \exp(-kt^n) + bt$	(Eq.11)	Midilli et al. 2002
10	Weibull distribution	$M_R = a - b\, exp[-(kt^n)]$	(Eq.12)	Babalis et al. 2006
11	Aghbashlo ve ark.	$M_R = \exp[-k_1 t/(1 + k_2 t)]$	(Eq.13)	Aghbashlo et al. 2009
12	Jena ve Das	$M_R = a \exp(-kt + b\sqrt{t}) + c$	(Eq.14)	Jena and Das 2007
13	Demir ve ark.	$M_R = \text{a} \exp(-kt)^n + c$	(Eq.15)	Demir et al. 2007
14	Alibas	$M_R = a \exp[(-kt^n) + bt] + c$	(Eq.16)	Alibaş 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).

Mathematical formulations

The coefficient of determination (R^2) was the primary criterion for selecting the most suitable equation to describe the microwave and convective drying curves of coriander leaves. The correlation was used to test the linear relationship between the measured and estimated values, which were calculated from the following equation (Eq. 17):

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

where; R^2 is the coefficient of correlation, $M_{Rexp,i}$ is the experimental moisture ratio found in any measurement, $M_{Rpre,i}$ is the predicted moisture ratio for this measurement and *N* is the total number of observations.

The standard error of estimate (*SEE*) provides information on the long-term performance of the correlations by allowing for a comparison between the actual deviations of predicted and measured values term by term. The ideal value of *SEE* is zero, and *SEE* was calculated as follows (Eq. 18):

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

where; n_i is the number of constants.

The root mean square error (*RMSE*) was computed from the following equation (Eq. 19) and provided information on the short-term performance of the correlations.

$$RMSE = \sqrt{\frac{[\sum_{i=1}^{N}(M_{R_{exp,i}}) - \sum_{i=1}^{N}(M_{R_{pre,i}})]^2}{N}}$$

Chi square (χ^2) was the mean square of the deviations (Eq. 20) between the experimental and predicted moisture levels. Lower values of χ^2 indicated a better goodness of fit.

$$\chi^2 = \frac{[\sum_{i=1}^{N}(M_{R_{exp,i}}) - \sum_{i=1}^{N}(M_{R_{pre,i}})]^2}{N - n_i}$$

Color parameters

Leaf color was determined by two readings on each of the different symmetrical faces of the leaf using a Minolta CR 10 colorimeter (Konica-Minolta, Osaka, Japan), calibrated with a white standard tile. The color brightness coordinate *L* measures the whiteness value of a color and ranges from black at 0 to white at 100. The chromaticity coordinate "*a*" measures red when positive and green when negative while the chromaticity coordinate "*b*" measures yellow when positive and blue when negative. Chroma (C) and hue angle (α°) were read directly on the colorimeter. Ten measurements were made at each trial and the average of these measurements was taken for each color parameters.

Chlorophyll content

The chlorophyll contents of both dried and fresh coriander leaves were measured by SPAD meter as SPAD. Ten measurements were made in each trial, and the averages of these measurements were taken.

RESULTS AND DISCUSSION

Drying curves

The moisture–time diagrams of coriander leaves were presented in Figure 1. Evidently, a reduction in drying time occurred with the increase in microwave powers. The drying periods of coriander leaves from an initial moisture content of 7.531 ± 0.411 [$kg_{(moisture)}\ kg^{-1}_{(dry\ matter)}$] to a moisture content of 0.102 ± 0.0002 [$kg_{(moisture)}\ kg^{-1}_{(dry\ matter)}$] were 76, 19.5 and 9 min in microwave powers of 100, 500 and 1000 W, respectively. Drying period was significantly shortened with increasing microwave output powers (Sarimeseli, 2011, Soysal 2004, Maskan 2010, Alibas 2010). The drying time at the 500 W was approximately 2 times longer than that of 1000 W while it was nearly 4 times shorter than that of 100 W. The drying time was reduced by 18.78, 8.67 and 2.22 times when the leaves were dried at 1000, 500 and 100 W, respectively, compared with the drying treatment at 50°C.

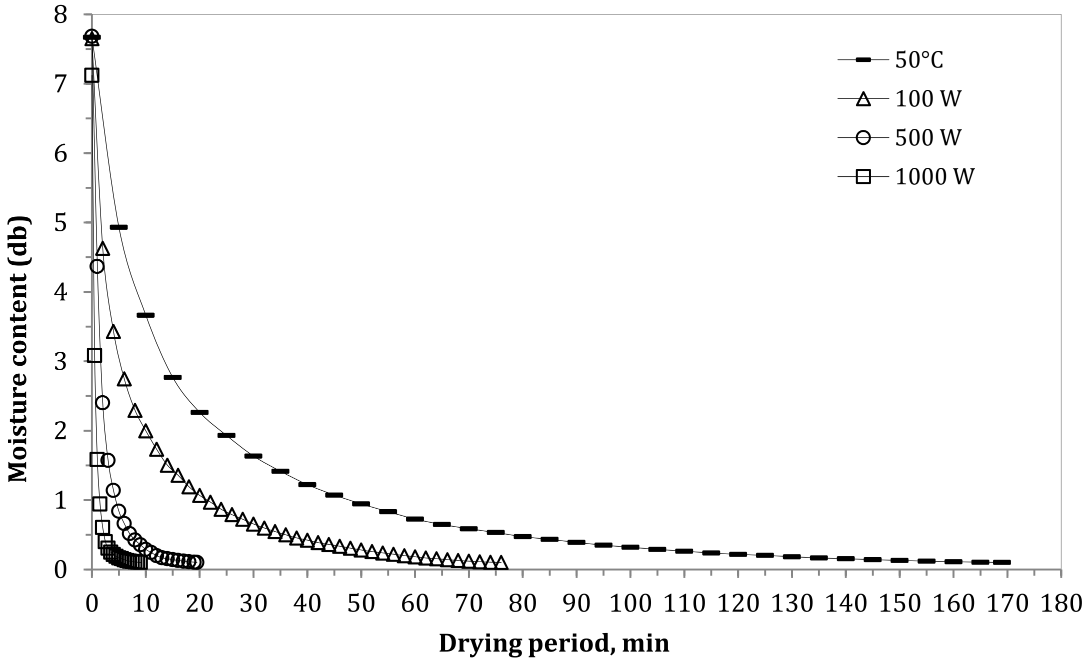

Figure 1. Moisture content on dry basis depend on drying time curves of coriander leaves.

drying rates [kg(moisture) kg^{-1}(dry matter) min^{-1}] are shown in Figure 2. The average drying rates of the coriander leaves at the microwave output powers of 100, 500 and 1000 W were 0.056, 0.285 and 0.826 [kg(moisture) kg^{-1}(dry matter) min^{-1}], respectively whereas the average drying rate during the convective drying at 50°C was 0.030 [kg(moisture) kg^{-1}(dry matter) min^{-1}]. The moisture content of the material was very high during the initial phase of the drying, which resulted in a higher absorption of microwave power and higher drying rates because of the higher moisture diffusion. The loss of moisture in the product caused a decrease in the absorption of microwave power and resulted in a fall of the drying rate as the drying progressed. The drying rates decreased with the decreasing microwave output powers; therefore. Several researchers found similar findings (Feng 2002, Maskan 2000, Soysal 2004, Alibas 2006).

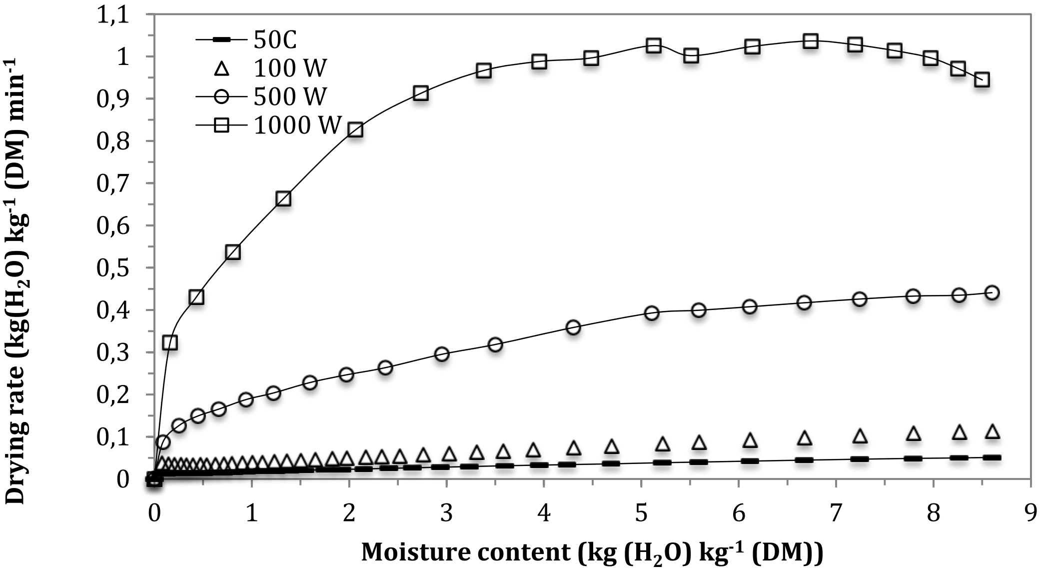

Figure 2. Drying rate curves of coriander leaves depend on moisture content on dry basis.

The moisture ratios related to drying period of both experimental data and predicted ones were taken in Figure 3. According to the Figure, the 64.74% of the total moisture was removed from the coriander leaves in the first fifteenth minute of the convectional drying that was the longest drying method with 169 minutes in total. Similarly, the 95.78%of the total moisture was evaporated from the material in the first 150th seconds of the 1000 W of microwave drying that was the shortest drying method with 9 minutes in total. The results were in parallel with the other studies in the literature (Soysal 2004, Alibas Ozkan et al. 2007, Sarimeseli 2011).

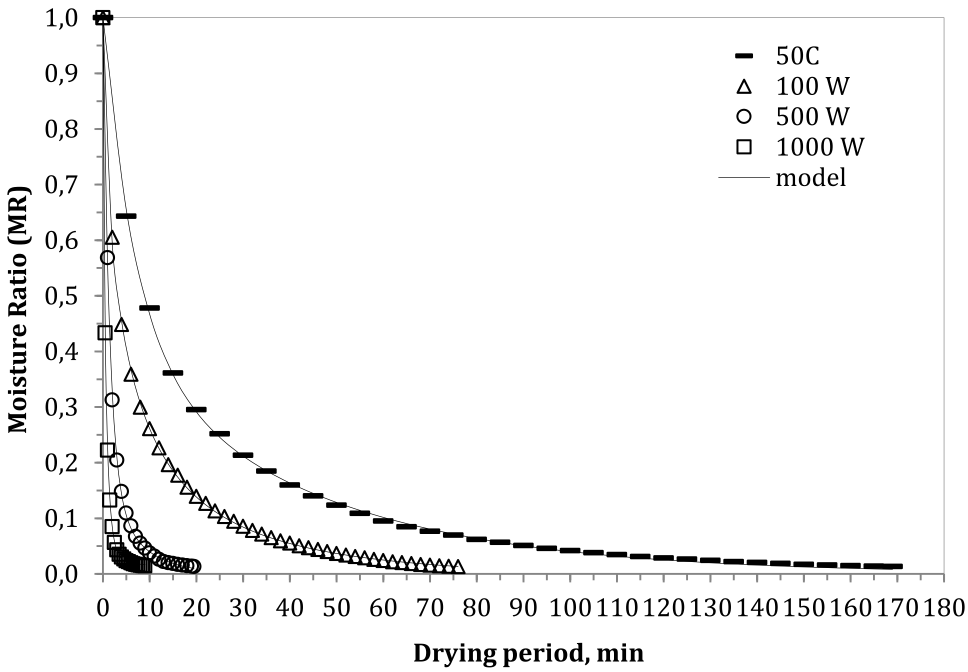

Figure 3. Moisture ratio depend on drying time of coriander leaves; Diagram was modeled according to 50°C, Modified Henderson and Pabis Equation; 500 W, Verma et al.; 100 W and 1000 W, Alibas Equation.

Modeling of drying data

The coefficient of correlation (R^2), standard error of estimate (*SEE*), root mean square error (*RMSE*) and chi-square (χ^2) related to fourteen thin-layer drying models defined by various researchers were shown in Table 2. The drying constant and all coefficients related to fourteen thin-layer drying models were taken in Table 3.

According to Table 2, the best model for both 1000 W and 100 W microwave drying was found in Alibas model with 0.9999 and 0.9998 coefficients of determination, respectively. Whereas the best model was determined with the value of 0.9995 according to Verma's model at 500 W, the most appropriate model was obtained with the value of 0.9998 as Modified Henderson Pabis's model at 50°C temperature. In this study, the drying constants were found as 0.4788, 0.1453, 0.3732 and 1.0101 for 1000 W, 500 W, 100 W and 50°C, respectively.

Table 2. Statistical data of thin layer drying models for microwave and convective drying methods.

	1000 W					***500 W***			
No	R^2	***SEE***	***RMSE***	χ^2	*No*	R^2	***SEE***	***RMSE***	χ^2
1	0.9971	0.0127	$2.9773\ 10^{-02}$	$9.9072\ 10^{-04}$	1	0.9957	0.0161	$2.8562\ 10^{-02}$	$9.0167\ 10^{-04}$
2	0.9976	0.0124	$2.9350\ 10^{-10}$	$1.0229\ 10^{-19}$	2	0.9961	0.0157	$6.8472\ 10^{-10}$	$5.4697\ 10^{-19}$
3	0.9996	0.0053	$1.9817\ 10^{-03}$	$4.9743\ 10^{-06}$	3	0.9995	0.0056	$6.0991\ 10^{-04}$	$4.5951\ 10^{-07}$
4	0.9493	0.6521	$2.2812\ 10^{-01}$	$5.8163\ 10^{-02}$	4	0.9887	0.6730	$2.7098\ 10^{-01}$	$8.1161\ 10^{-02}$
5	0.9996	0.0050	$2.3391\ 10^{-03}$	$6.4972\ 10^{-06}$	5	0.9995	0.0056	$4.6678\ 10^{-03}$	$2.5420\ 10^{-05}$
6	0.9996	0.0052	$1.5660\ 10^{-03}$	$2.9122\ 10^{-06}$	6	**0.9995**	**0.0055**	$\mathbf{1.1992\ 10^{-03}}$	$\mathbf{1.6778\ 10^{-06}}$
7	0.9999	0.0032	$3.4401\ 10^{-03}$	$1.7296\ 10^{-05}$	7	0.9995	0.0060	$3.2486\ 10^{-03}$	$1.4775\ 10^{-05}$
8	0.9973	0.0131	$2.9773\ 10^{-02}$	$1.0526\ 10^{-03}$	8	0.9957	0.0165	$2.8561\ 10^{-02}$	$9.5170\ 10^{-04}$
9	0.9995	0.0059	$2.7509\ 10^{-03}$	$9.5857\ 10^{-06}$	9	0.9976	0.0127	$3.8647\ 10^{-03}$	$1.8450\ 10^{-05}$
10	0.9998	0.0034	$1.5220\ 10^{-12}$	$2.9343\ 10^{-24}$	10	0.9982	0.0111	$2.1302\ 10^{-09}$	$5.6056\ 10^{-18}$
11	0.9998	0.0038	$4.1024\ 10^{-03}$	$1.8810\ 10^{-05}$	11	0.9991	0.0072	$2.9475\ 10^{-03}$	$9.6025\ 10^{-06}$
12	0.9997	0.0044	$2.8957\ 10^{-11}$	$1.0621\ 10^{-21}$	12	0.9976	0.0126	$1.5436\ 10^{-09}$	$2.9432\ 10^{-18}$
13	0.9976	0.0128	$1.1398\ 10^{-10}$	$1.6456\ 10^{-20}$	13	0.9961	0.0162	$1.3029\ 10^{-09}$	$2.0970\ 10^{-18}$
14	**0.9999**	**0.0027**	$\mathbf{4.0402\ 10^{-12}}$	$\mathbf{2.2153\ 10^{-23}}$	14	0.9984	0.0107	$1.2897\ 10^{-04}$	$2.1831\ 10^{-08}$
	100 W					***50°C***			
No	R^2	***SEE***	***RMSE***	χ^2	*No*	R^2	***SEE***	***RMSE***	χ^2
1	0.9995	0.0043	$9.7497\ 10^{-04}$	$1.0020\ 10^{-06}$	1	0.9989	0.0068	$8.9103\ 10^{-03}$	$8.4205\ 10^{-05}$
2	0.9643	0.0375	$7.7421\ 10^{-11}$	$6.4935\ 10^{-21}$	2	0.9803	0.0299	$2.1374\ 10^{-11}$	$4.9967\ 10^{-22}$
3	0.9991	0.0060	$7.9359\ 10^{-03}$	$7.0176\ 10^{-05}$	3	0.9932	0.0176	$3.9117\ 10^{-02}$	$1.7276\ 10^{-03}$
4	0.9971	1.2432	$9.5275\ 10^{-01}$	$9.5680\ 10^{-01}$	4	0.9996	1.0030	$6.4723\ 10^{-01}$	$4.4430\ 10^{-01}$
5	0.9991	0.0060	$6.5642\ 10^{-03}$	$4.6680\ 10^{-05}$	5	0.9995	0.0048	$4.5865\ 10^{-03}$	$2.3008\ 10^{-05}$
6	0.9991	0.0059	$7.4106\ 10^{-03}$	$5.9494\ 10^{-05}$	6	0.9880	0.0229	$5.4969\ 10^{-02}$	$3.3049\ 10^{-03}$
7	0.9927	0.0175	$4.6771\ 10^{-02}$	$2.5852\ 10^{-03}$	7	**0.9998**	**0.0030**	$\mathbf{2.5197\ 10^{-03}}$	$\mathbf{7.6622\ 10^{-06}}$
8	0.9995	0.0043	$9.7497\ 10^{-04}$	$1.0298\ 10^{-06}$	8	0.9989	0.0070	$8.9103\ 10^{-03}$	$8.6837\ 10^{-05}$
9	0.9995	0.0043	$7.4257\ 10^{-04}$	$6.1443\ 10^{-07}$	9	0.9952	0.0148	$4.1952\ 10^{-03}$	$1.9870\ 10^{-05}$
10	0.9620	0.0387	$3.7085\ 10^{-10}$	$1.5325\ 10^{-19}$	10	0.9993	0.0058	$3.6514\ 10^{-10}$	$1.5053\ 10^{-19}$
11	0.9886	0.0209	$2.0824\ 10^{-02}$	$4.5709\ 10^{-04}$	11	0.9955	0.0140	$1.5322\ 10^{-02}$	$2.4899\ 10^{-04}$
12	0.9992	0.0058	$8.3735\ 10^{-10}$	$7.8129\ 10^{-19}$	12	0.9985	0.0084	$8.1370\ 10^{-10}$	$7.4754\ 10^{-19}$
13	0.9643	0.0380	$2.2411\ 10^{-07}$	$5.5964\ 10^{-14}$	13	0.9803	0.0303	$5.0286\ 10^{-07}$	$2.8550\ 10^{-13}$
14	**0.9998**	**0.0031**	$\mathbf{4.7863\ 10^{-10}}$	$\mathbf{2.6277\ 10^{-19}}$	14	0.9997	0.0039	$1.8418\ 10^{-10}$	$3.9576\ 10^{-20}$

R^2, coefficient of determination; *SEE*, standard error of estimated; *RMSE*, root mean square error; χ^2, chi square.

Table 3. Coefficients and constants of thin layer drying models for microwave and convective drying methods.

	1000 W – microwave		***500 W – microwave***
No	***Drying constant and coefficients***	***No***	***Drying constant and coefficients***
1	k=1.4421, n=0.7176,	1	k=0.6365, n=0.7620,
2	k=1.5987, a=0.9671, c=0.0246	2	k=0.5609, a=0.9622, c=0.0279
3	k_1=1.8693, a=0.1048, k_0=0.2806, b=0.8932	3	k_1=0.1461, a=0.8338, k_0=0.7105, b=0.1689
4	a=0.3887, b=0.2781	4	a=0.0094, b=0.4244
5	k=1.8849, a=0.8905, b=0.1551	5	k=0.7220, a=0.8114, b=0.2223
6	k=1.8748, a=0.8945, g=0.2820	6	**k=0.1453, a=0.1674, g=0.7069**
7	k=0.2536, a=0.0846, b=0.7696, c=0.1459, g=1.5846, h=5.3656	7	k=0.1601, a=0.1906, b=0.4429, c=0.3698, g=0.7297, h=0.7297
8	k=6.2802, n=0.7176, L=2.7874	8	k=3.8808, n=0.7620, L=3.2747
9	k=1.4694, n=0.7749, a=1.0008, b=0.0023	9	k=0.6219, n=0.8114, a=1.0041, b=0.0010
10	k=1.5369, n=0.8185, a=0.0180, b=-0.9823	10	k=0.6265, n=0.8517, a=0.0201, b=-0.9832
11	k_1=1.9639, k_2=0.3116	11	k_1=0.6643, k_2=0.0993
12	k=0.9947, a=0.9813, b=-0.5344, c=0.0191	12	k=0.4067, a=0.9801, b=-0.2199, c=0.0223
13	k=1.3361, n=1.1965, a=0.9671, c=0.0246	13	k=0.7151, n=0.7844, a=0.9622, c=0.0279
14	**k=0.4788, n=0.9994, a=0.9835, b=0.4773, g=0.0170**	14	k=0.1732, n=0.9995, a=0.9865, b=0.1726, g=0.0179

	100 W – microwave		***50°C – convective***
No	***Drying constant and coefficients***	***No***	***Drying constant and coefficients***
1	k=0.3593, n=0.5691,	1	k=0.1724, n=0.6392,
2	k=0.1161, a=0.7654, c=0.0252	2	k=0.0590, a=0.8869, c=0.0396
3	k_1=0.3843, a=0.3838, k_0=0.0480, b=0.5572	3	k_1=0.0319, a=0.3955, k_0=0.3435, b=0.6137
4	a=-2.3597, b=1.2187	4	a=-4.2433, b=2.9152
5	k=0.4194, a=0.5608, b=0.1153	5	k=0.1417, a=0.5924, b=0.1634
6	k=0.0481, a=0.3853, g=0.3905	6	k=1.0012, a=0.3171, g=0.0353
7	k=0.1367, a=0.1434 10^{+05}, b=-0.2197 10^{+05}, c=0.7624 10^{+04}, g=0.1373, h=0.1384	7	**k=1.0101, a=0.0965, b=0.3513, c=0.5521, g=0.0213, h=0.1055**
8	k=0.5890, n=0.5691, L=1.5440	8	k=0.9637, n=0.6392, L=3.8423
9	k=0.3639, n=0.5649, a=1.0037, b=-1.0574 10^{-05}	9	k=0.1113, n=0.7659, a=1.9608, b=0.0001
10	k=0.0895, n=0.1861, a=-4.7648, b=-5.7806	10	k=0.1647, n=0.6634, a=0.0097, b=0.9939
11	k_1=0.2191, k_2=0.0519	11	k_1=0.0823, k_2=0.0169
12	k=0.0192, a=0.9984, b=-0.3652, c=0.0065	12	k=0.0198, a=0.9904, b=-0.1807, c=0.0159
13	k=0.3816, n=0.3718, a=0.8499, c=0.0457	13	k=0.2469, n=0.2391, a=0.8869, c=0.0396
14	**k=0.3732, n=0.6588, a=1.0377, b=0.0452, g=-0.0364**	14	k=0.2092, n=0.8413, a=1.0236, b=0.0729, g=-0.0218

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).

Chlorophyll Content and Color Parameters

Chlorophyll content and color parameters of different drying method were shown in Table 4. According to Table 4, the best chlorophyll content was observed in microwave drying at 500 W while the worst amount was determined in convective drying at 50°C. The best method in terms of brightness of color was found as natural drying in comparison to fresh coriander leaves. A darkening was observed in the surface of dried material in all of the other drying methods. Dried coriander leaves with the darkest surface were obtained in convective and microwave drying methods at 100 W, respectively. Excluding natural drying, the best color parameter in terms of brightness was obtained at 500 W of microwave drying. It was followed by microwave drying at 1000 W.

Table 4. Comparison of some quality parameters of dried coriander with microwave, convective and natural drying methods.

Drying Method	*Chlorophyll*** *(SPAD)*	*Color Parameters*				
		L*	***a****	***b****	***C****	***α****
Fresh	55.05 ± 1.16^{a}	44.2 ± 0.79^{a}	-7.10 ± 0.19^{b}	28.38 ± 1.47^{d}	24.46 ± 1.40^{a}	107.20 ± 1.20^{e}
1000 W – Microwave	65.28 ± 0.96^{b}	36.47 ± 1.22^{b}	-7.08 ± 0.27^{b}	19.97 ± 0.40^{d}	21.19 ± 0.44^{a}	109.52 ± 0.58^{d}
500 W – Microwave	75.53 ± 1.89^{a}	38.75 ± 1.23^{a}	-7.10 ± 0.43^{b}	22.00 ± 0.46^{c}	23.14 ± 0.47^{b}	107.88 ± 1.04^{c}
100 W – Microwave	68.33 ± 1.51^{b}	30.55 ± 1.00^{b}	-2.38 ± 0.23^{a}	16.33 ± 0.36^{b}	16.51 ± 0.36^{b}	98.32 ± 0.78^{b}
50°C – Convective	54.30 ± 1.13^{c}	30.27 ± 1.17^{c}	-1.97 ± 0.21^{a}	15.00 ± 0.62^{a}	15.13 ± 0.63^{b}	97.40 ± 0.55^{a}
Natural	61.22 ± 0.87^{c}	43.93 ± 0.98^{c}	-6.10 ± 0.19^{a}	22.70 ± 0.67^{a}	23.51 ± 0.64^{b}	105.10 ± 0.65^{a}

L, brightness/darkness; *a*, greenness/redness; *b*, yellowness/blueness; *C*, Chroma; *α°*, hue angle
** p<0.01 Column mean values with different superscripts are significantly different.

The best drying method in terms of greenness was determined to microwave drying at 500 W in comparison to fresh coriander leaves. It was followed by microwave drying at 1000W and natural drying, respectively. Color of dried coriander leaves was turned to yellow during both microwave drying at 100 W and convective drying at 50°C. Similar findings were found by several researchers (Alibas 2006, Alibas Ozkan 2007).

CONCLUSIONS

Coriander leaves were dried using three different drying methods, i.e. microwave, convective and natural drying. The best thin layer-drying model was found in Alibas model in both 1000 W and 100 W. The best model was determined with the value of 0.9995 according to Verma's model at 500 W whereas the most appropriate model was found with the value of 0.9998 as Modified Henderson Pabis's model at 50°C temperature. The most convenient drying method for the drying of coriander leaves was microwave drying at 500 W with regard to drying period, color parameters and chlorophyll content.

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