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Selection of a the Best Suitable Thin-Layer Drying Mathematical Model for Vacuum Dried Red Chili Pepper

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ABSTRACT

Red Chili pepper (*Capsicum frutescens* L.) with 50 (±0.02) g weight and 6.12 ± (0.02) humidity on dry basis were dried in vacuum oven using combined 2 different temperature (50 - 75°C) and 3 different pressure (0.05, 7 and 13 kPa) until the humidity fell down to 0.16 ± (0.01) on dry basis. Vacuum drying processes were completed between 3 and 19.17 h. In this study, measured values were compared with predicted values obtained from twenty one thin layer drying theoretical/semi-empirical/empirical equations. Models whose coefficient of correlation (R^2) values are highest were chosen to be the best models. According to this, the best models of combined 50°C temperature with vacuum levels (0.05, 7 and 13 kPa) was found to be "Modified Henderson & Pabis" Model, combined 75°C temperature with vacuum levels (0.05, 7 and 13 kPa) was found to be "Alibas" Model.

Key Words: Chili pepper, moisture content, thin-layer drying models, vacuum drying.

Notation

M	initial moisture content, $kg_{(moisture)}\ kg^{-1}{}_{(dry\ matter)}$
W_0	initial weight of sample, kg
W	amount of evaporated water, kg
W_1	dry matter content of sample, kg
MR	moisture ratio
M_e	equilibrium moisture content, $kg_{(moisture)}\ kg^{-1}{}_{(dry\ matter)}$
k, k_0, k_1, k_2	drying constant, min^{-1}
$a, a_0\ b, c\ g\ h$	coefficients, dimensionless
n	exponent, dimensionless
t	drying time, min
L	sample thickness, m
R^2	coefficient of correlation, decimal
χ^2	chi square
$RMSE$	root mean square error
$M_{Rexp,i}$	stands fort the experimental moisture ratio found in any measurement
$M_{Rpre,i}$	predicted moisture ratio for this measurement
N	total number of observations
n_i	number of constants
SEE	standard error of estimated

INTRODUCTION

Chili pepper is the fruit of plants from the genus Capsicum, members of the nightshade family, Solanaceae. Chili peppers originated in the Americas. It used in both food and medicine (Anonymous 2011). Red chilies contain high amounts of vitamin C and carotene (provitamin A). In addition, peppers are a good source of most B vitamins, and vitamin B_6 in particular. They are very high in potassium, magnesium, and iron (Anymous 2011). The substances that give chili peppers their intensity when ingested or applied topically are capsaicin (8-methyl-N-vanillyl-6-nonenamide) and several related chemicals, collectively called capsaicinoids (Kosuge et al. 1961). Capsaicin is a safe and effective topical analgesic agent in the management of arthritis pain, herpes zoster-related pain, diabetic neuropathy, postmastectomy pain, and headaches (Yarbro et al. 2005).

Drying is defined as a process of moisture removal due to simultaneous heat and mass transfer. It is also one of the methods of food preservation, which provides longer shelf-life, lighter weight for transportation and smaller space for storage (Ertekin and Yaldız 2004). Different drying methods are used in agricultural products. Sun drying is the most common methods used to preserve agricultural products in most tropical countries. But

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this technique is extremely whether dependent, and has the problems of contamination with dust, soil, sand particles and insects (Toğrul 2006). Convective drying of foods are low energy efficiency and long drying time.

Moreover, this method leads to serious injuries such as the worsening of the taste, colour and nutritional content of the product, decline in the density and water absorbance capacity and shifting of the solutes from the internal part of the drying material to the surface, due to the long drying period and high temperature (Drouzas et al. 1999, Lin et al. 1998, Yongsawatdigul and Gunasekaran 1996, Alibas 2007). The major disadvantages of air-drying are the longer drying period and higher drying temperature. Quality of the dry-product declines as a result of these disadvantages (Sharma and Prasad 2001).

Vacuum drying is a drying technique which is used for drying of various products, retaining their colour and vitamin content (Methakhup et al. 2005). Vacuum enhances the mass transfer because of an increased pressure gradient between the inside and outside of the sample to dry and maintains a low temperature level essential for thermolabile products (Pere and Rodier 2002). Better product quality with respect to traits such as taste, flavour and rehydration can be retained via high-degree vacuum treatment (Drouzas and Schubert 1996). The key benefits of vacuum drying include lower process temperatures, less energy usage and hence greater energy efficiency, improved drying rates, and in some cases, less shrinkage of the product (Montgomery et al. 1997). Vacuum drying has been successfully applied to many fruits and vegetables and other heat-sensitive foods. Vacuum dried materials are characterised by better quality retention of nutrients and volatile aroma. However, the cost of the process is high (Tsami et al. 1998).

Thin layer drying is the process of drying in one layer of sample particles or slices. Many mathematical models are used in order to describe the thin layer drying process. Mathematical modeling of thin layer drying is important for performance improvements of drying systems (Cihan et al. 2007).Thin layer drying models fall into three categories as theoretical, semi-empirical an empirical (Ozdemir and Devres 1999, Midilli and Kucuk 2003).

The aim of this study is (1) to investigate the kinetics of thin layer drying of Chili pepper, (2) to compare the developed several empirical and semi-empirical mathematical models and estimate the constant of several models, (3) to determine the best fit using statistical analysis.

MATERIALS AND METHODS

Fresh chili pepper

Plants of fresh Chili peppers used in the drying experiments were provided from local supermarket of Bursa. They were stored at a temperature of 4 ± 0.5°C until the drying process (Alibas 2010). Five different samples, each being 50± 0.02g, were kept in the drying oven at 105°C for 24 h, after which the moisture content of Chili pepper fell down to 0.16 ± 0.01 on dry basis.

Drying equipment and drying method

Drying treatment was performed in a laboratory type vacuum oven (Nuve EV 0180, Turkey) with technical features of 220 V ~, 50 Hz, 3.5 A and 800 W. The temperature of vacuum oven has a sensitivity of 1°C, max temperature being 250°C. The area on which vacuum drying is carried out was 300 x 200 x 250 mm in size. An analogous vacuum-meter which indicates the vacuum value in terms of mmHg exists on the vacuum oven. Time adjustment is done with the aid of a programmable clock located on the oven.

Vacuum-temperature combinations were obtained in vacuum trials by combining three different vacuum levels i.e. 0.05,7 and 13 kPa and two different temperature regimes at 50 and 75°C, and the trials were realised under the combinations of 50°C-0.05kPa, 50°C-7kPa, 50°C-13kPa, 75°C-0.05kPa, 75°C-7kPa and 75°C-13kPa. A laboratory type greasy vacuum pump (Carpanelli MMDE80B4, Italy) was used in the vacuum drying trials whose operating conditions were 220/240 V ~, 50/60 Hz and 5.1/4.8 A. The vacuum pump is increased the least vacuum value within 20 sec.

Chili peppers which were being dried were removed from the oven periodically (every 5 min) during the drying period, and the moisture loss was determined by weighing the plate using digital balance (Sartorious EX 2000A, Germany) with 0.01g precision (Alibas 2010). All weighing processes were completed in 10 s during the drying process.

Drying tests were replicated three times at each vacuum drying trial and averages weight loss are reported. Moisture content [$kg_{(moisture)}\ kg^{-1}_{(dry\ matter)}$] was determined using the following equation:

$$M = \frac{(W_o - W) - W_1}{M_1} \quad (1)$$

where M is initial moisture content [$kg_{(moisture)}\ kg^{-1}_{(dry\ matter)}$], W_0 is initial weight of sample, W is amount of evaporated water, W_1 is dry matter content of sample. The moisture ratio *(MR)* in these model equations is defined as follows:

$$MR = \frac{M - M_e}{M_o - M_e} \quad (2)$$

where M is initial moisture content [$kg_{(moisture)}\ kg^{-1}_{(dry\ matter)}$], M_e is equilibrium moisture content [$kg_{(moisture)}\ kg^{-1}_{(dry\ matter)}$].

Data analysis

Twenty one empirical and semi empirical thin-layer drying models given in Table 1 have been taken into account in this study. Non-Linear regression analyses of these equations [Eq (3)-Eq (24)] were made by using SPSS 17.0. Non-linear regression analysis was performed to estimate the parameters *k,k₀*, k_1, k_2, *a*, a_0, *b, c, g, h, L* and *n* of empirical and semi empirical equations in Table 1.

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

No	*Model name*	*Model equation*	*Eq No*	*References*
1	Lewis	$M_R = \exp(-kt)$	(3)	(Lewis 1921)
2	Page	$M_R = \exp(-kt^n)$	(4)	(Page 1949)
3	Modified Page	$M_R = \exp[-(kt)^n)]$	(5)	(Overhults et al. 1973)
4	Henderson & Pabis	$M_R = a\exp(-kt)$	(6)	(Henderson and Pabis 1961)
5	Yagcioglu et al. (Logarithmic)	$M_R = a\exp(-kt) + c$	(7)	(Yagcioglu et al. 1999)
6	Two-term	$M_R = a\exp(-k_0 t) + b\exp(-k_1 t)$	(8)	(Henderson 1974)
7	Two-term exponential (Approximation of diffusion)	$M_R = a\exp(-kt) + (1-a)\exp(-kat)$	(9)	(Sharaf-Elden et al. 1980)
8	Wang & Singh	$M_R = 1 + at + bt^2$	(10)	(Wang and Singh 1978)
9	Thomson	$t = a.\ln(M_R) + b[\ln(M_R)]^2$	(11)	(Thomson et al. 1968)
10	Diffusion approach	$M_R = a\exp(-kt) + (1-a)\exp(-kbt)$	(12)	(Kasem 1998)
11	Verma et al.	$M_R = a\exp(-kt) + (1-a)\exp(-gt)$	(13)	(Verma et al. 1985)
12	Modified Henderson & Pabis	$M_R = a\exp(-kt) + b\exp(-gt) + c\exp(-ht)$	(14)	(Karathanos 1999)
13	Simlified Fick's diffusion (SFFD) equation	$M_R = a\exp[-c(t/L^2)]$	(15)	(Diamente and Munro 1991)
14	Modified Page equation-II	$M_R = \exp[-k(t/L^2)^n]$	(16)	(Diamente and Munro 1993)
15	Midilli et al.	$M_R = a\exp(-kt^n) + bt$	(17)	(Midilli et al. 2002)
16	Weibull distribution	$M_R = a - b\exp[-(kt^n)]$	(18)	(Babalis et al. 2006)
17	Aghbashlo et al.	$M_R = \exp(-k_1 t / 1 + k_2 t)$	(19)	(Aghbashlo et al. 2009)
18	Logistic	$M_R = a_0 /(1 + a\exp(kt))$	(20)	(Chandra and Singh 1995)
19	Jena & Das	$M_R = a\exp(-kt + b\sqrt{t}) + c$	(21)	(Jena and Das 2007)
20	Demir et al.	$M_R = a\exp(-kt)^n + c$	(22)	(Demir et al. 2007)
21	Alibas	$M_R = a\exp((-kt^n) + bt) + g$	(23)	New Model

M_R, moisture ratio; *a*, a_0, *b, c, g, h,* coefficients and *n,* microwave drying exponent specific to each equation; *k*, k_0, k_1, k_2, drying coefficient specific to each equation; *t*, time; *L*, thickness.

Mathematical formulations

The regression coefficient *(R^2)* was primary criterion for selecting the most suitable equation to describe the microwave drying curves of Chili peppers. The correlation can be used to test the linear relation between measured and estimated values, which can be calculated from the equation:

$$R^2 = \frac{\sum_{i=1}^{N}(M_{R_{\exp,i}} - M_{R_{\exp_{mean,i}}})^2 - (M_{R_{pre,i}} - M_{R_{\exp,i}})^2}{\sum_{i=1}^{N}(M_{R_{\exp,i}} - M_{R_{\exp_{mean,i}}})^2} \tag{24}$$

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

Standart error of estimated (*SEE*) provides information on the long term performance of the correlations by allowing a comparison of the actual deviation between predicted and measured values term by term. The ideal value of *SEE* is "zero". The *SEE* is given as:

$$SEE = \sqrt{\frac{\sum_{i=1}^{N}(M_{R_{\exp,i}} - M_{R_{pre,i}})^2}{N - n_i}} \tag{25}$$

where n_i is called number of constants.

The root mean square error (RMSE) may be computed from the following equation which provides information on the short term performance.

$$RMSE = \sqrt{\frac{[\sum_{i=1}^{N}(M_{R_{\exp,i}}) - \sum_{i=1}^{N}(M_{R_{pre,i}})]^2}{N}} \tag{26}$$

Chi square (χ^2) is the mean square of the deviations between the experimental and predicted moisture levels. The lower are the values of the reduced χ^2, the better is the goodness of fit.

$$\chi^2 = \frac{[\sum_{i=1}^{N}(M_{R_{\exp,i}}) - \sum_{i=1}^{N}(M_{R_{pre,i}})]^2}{N - n_i} \tag{27}$$

Mathematical modeling of vacuum drying curves

The thin-layer drying models, describing the drying process, can be distinguished in three main categories, namely the theoretical, the semi theoretical and the fully empirical ones (Sharaf-Eldeen and Hamdy 1979). In this study, experimental data which were measured 50°C-0.05kPa, 50°C-7kPa, 50°C-13kPa, 75°C-0.05kPa, 75°C-7kPa ad 75°C-13kPa vacuum drying levels were measured theoretical/semi-empirical/empirical thin-layer drying models defined in Table 1 and statistical data of these models such as *SEE*, R^2, *RMSE* and χ^2 and constant and coefficients (*a*, a_0, *b, c, g, h, n, k*, k_0, k_1, k_2, *and L*) were determined. The model in which R^2 was highest was chosen to be the best model in the study where vacuum drying levels of 50°C-0.05kPa, 50°C-7kPa, 50°C-13kPa, 75°C-0.05kPa, 75°C-7kPa ad 75°C-13kPa were used.

RESULTS AND DISCUSSION

Vacuum drying curves

Value of moisture ratio (M_R) depending on time (*t*) of Chili pepper dried with 50°C-0.05kPa, 50°C-7kPa, 50°C-13kPa, 75°C-0.05kPa, 75°C-7kPa ad 75°C-13kPa vacuum drying levels were given in Fig 1. Fig.1, a reduction in drying time occurred with the increasing temperature and decreasing vacuum level. The time required for the lowering of moisture content of Chili peppers to 0.16 from 6.12 on dry basis varied between 3 and 19.17 h depending on the vacuum and temperature level. A marked decline was observed in the drying period of Chili peppers with the increasing temperature level and decreasing vacuum level (Alibas 2007, Alibas 2009, Methakhup et al. 2005). Drying time at 50 °C temperature was found as 7.5, 11.67 and 19.17 h for 0.05, 7 and 13 kPa, respectively, and at 75 °C, it was found as 3, 3.67 and 4.33 h for 0.05, 7 and 13 kPa vacuum values, respectively. Increase in temperature level in vacuum drying had an important effect on the reduction of drying time. The extent of drying realised at 50 °C temperature and 13 kPa vacuum value with the longest drying period was 6.39 times higher compared with the drying process realised at 75 °C and 0.05 kPa , with the shortest drying period. Similar findings was found by several researchers (Alibas 2007, Alibas 2009, Arévalo-Pinedo and Murr 2006, Jena and Das 2007, Wu et al. 2007, Arévalo-Pinedo and Murr 2007, Lee and Kim 2009, Bazyma et al. 2006, Artnaseaw et al. 2010).

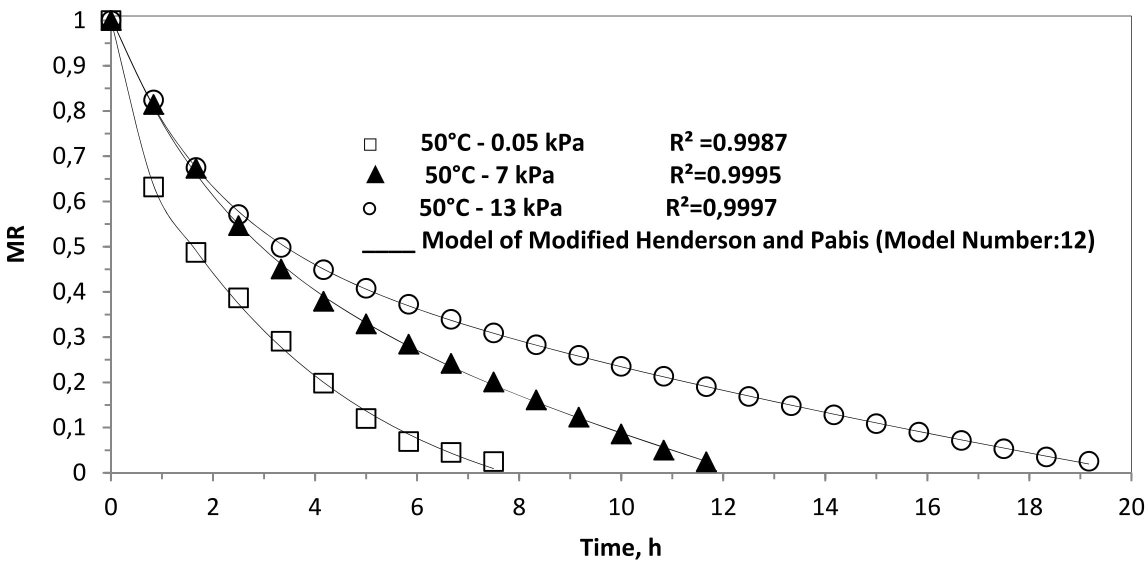

Figure 1. Moisture ratio versus time, comparing experimental curve with the predicted one (——) through “Modified Henderson & Pabis” model’s equation (model no:12) for 50°C-0.05kPa, 50°C-7kPa and 50°C-13kPa vacuum drying levels.

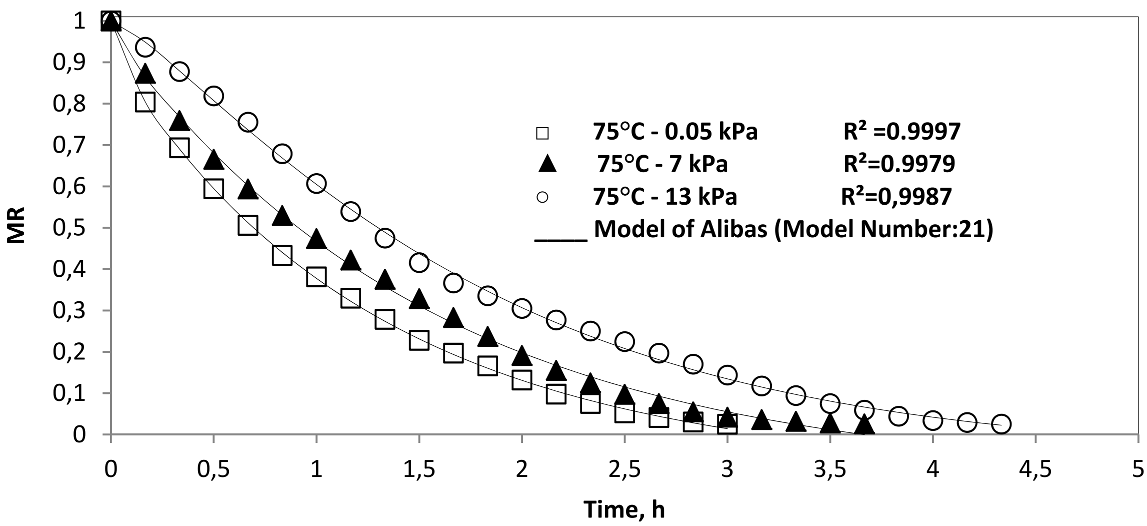

Figure 2. Moisture ratio versus time, comparing experimental curve with the predicted one (——) through “Alibas” model’s equation (model no:21) for 75°C-0.05kPa, 75°C-7kPa and 75°C-13kPa vacuum drying levels.

Mathematical modeling

In this study, twenty one thin-layer drying models defined by various researchers in Table 1. Coefficient of correlation (R^2), standard error of estimated (*SEE*), root mean square error (*RMSE*) and chi-square (χ^2) in the vacuum drying of thin layer drying models, shown in Table 2. The coefficient of correlation (R^2) was one of the primary criterion for selecting the best model to define the vacuum drying curves of Chili peppers. In the study thin-layer drying model in which (R^2) value is most close to “1.0000” and RMSE, (χ^2) and (SEE) values are smallest was chosen to be the most optimum model. According to Table 2, among all drying tests, the drying model where constant of coefficient (R^2) is the highest at 50°C-0.05 kPa, 50°C-7 kPa and 50°C-13 kPa vacuum drying levels was Modified Henderson & Pabis’s Model. Within vacuum drying trials dried of 75°C-0.05 kPa, 75°C-7 kPa and 75°C-13kPa drying levels, coefficient of correlation (R^2) of Alibas model is more close to values “1.0000” compared with the other twenty thin-layer drying model defined in the literature. Therefore Modified Henderson & Pabis’s Model was defined as the most optimal model in which estimation value are closest to experimental data for 50°C-vacuum levels and Alibas’s Model was defined as the most optimal model in which estimation value are closest to experimental data for 75°C-vacuum levels. The vacuum drying constants and the coefficients of the thin-layer drying models, shown in Table 3. Mathematical modeling of vacuum drying was conducted by several researchers in drying literature (Jena and Das 2007, Chen and Lamb 2007, Liu et al. 2009).

Table 2. Statistical results obtained from different thin-layer drying models for the different microwave power density

	50°C-0.05kPa				***50°C-7kPa***				***50°C-13kPa***			
No	***SEE***	***R^2***	***RMSE***	***χ^2***	***SEE***	***R^2***	***RMSE***	***χ^2***	***SEE***	***R^2***	***RMSE***	***χ^2***
1	0.0335	0.9884	1.5796 10^{-02}	2.772 10^{-04}	0.0207	0.9949	1.0579 10^{-02}	1.1991 10^{-04}	0.0428	0.9717	7.1987 10^{-03}	5.4075 10^{-05}
2	0.0326	0.9902	1.7553 10^{-02}	3.8512 10^{-04}	0.0213	0.9950	1.0471 10^{-02}	1.2650 10^{-04}	0.0233	0.9920	1.2207 10^{-02}	1.6256 10^{-04}
3	0.0356	0.9884	1.5796 10^{-02}	3.1188 10^{-04}	0.0214	0.9949	1.0580 10^{-02}	1.2915 10^{-04}	0.0438	0.9704	7.1995 10^{-03}	5.6545 10^{-05}
4	0.0337	0.9896	7.5466 10^{-03}	7.1188 10^{-05}	0.0212	0.9951	7.7007 10^{-03}	6.8424 10^{-05}	0.0342	0.9828	1.0064 10^{-02}	1.1050 10^{-04}
5	0.0347	0.9903	3.4757 10^{-10}	1.7258 10^{-19}	0.0199	0.9960	1.9789 10^{-11}	4.8950 10^{-22}	0.0338	0.9839	2.2889 10^{-10}	5.9874 10^{-20}
6	0.0362	0.9910	2.1537 10^{-03}	7.7305 10^{-06}	0.0230	0.9951	7.7007 10^{-03}	8.0865 10^{-05}	0.0200	0.9947	1.0619 10^{-02}	1.3530 10^{-04}
7	0.0355	0.9885	1.6899 10^{-02}	3.5698 10^{-04}	0.0214	0.9949	1.0522 10^{-02}	1.2775 10^{-04}	0.0438	0.9717	7.1987 10^{-03}	5.6533 10^{-05}
8	0.0616	0.9652	4.3039 10^{-02}	2.3155 10^{-03}	0.0452	0.9775	3.7171 10^{-02}	1.5943 10^{-03}	0.0778	0.9106	9.7463 10^{-02}	1.0363 10^{-02}
9	0.1994	0.9944	9.1595 10^{-02}	1.0487 10^{-02}	0.3838	0.9902	3.4144 10^{-01}	1.3452 10^{-01}	0.9659	0.9743	1.0489 10^{+00}	1.2001 10^{+00}
10	0.0380	0.9884	1.5796 10^{-02}	3.5643 10^{-04}	0.0223	0.9949	1.0579 10^{-02}	1.3990 10^{-04}	0.0448	0.9717	7.1987 10^{-03}	5.9225 10^{-05}
11	0.0296	0.9930	1.5832 10^{-02}	3.5807 10^{-04}	0.0217	0.9952	9.4341 10^{-03}	1.1125 10^{-04}	0.0448	0.9717	7.1987 10^{-03}	5.9225 10^{-05}
12	**0.0151**	**0.9987**	**9.1735 10^{-06}**	**2.1038 10^{-10}**	**0.0080**	**0.9995**	**3.1241 10^{-05}**	**1.6267 10^{-09}**	**0.0045**	**0.9997**	**1.4489 10^{-07}**	**2.7990 10^{-14}**
13	0.0337	0.9896	7.5466 10^{-03}	8.1358 10^{-05}	0.0212	0.9951	7.7007 10^{-03}	7.4126 10^{-05}	0.0342	0.9828	1.0064 10^{-02}	1.1576 10^{-04}
14	0.0326	0.9902	1.7553 10^{-02}	4.4013 10^{-04}	0.0213	0.9950	1.0471 10^{-02}	1.3705 10^{-04}	0.0233	0.9920	1.2207 10^{-02}	1.7030 10^{-04}
15	0.0196	0.9973	1.6748 10^{-04}	4.6751 10^{-08}	0.0943	0.9173	7.0929 10^{-07}	6.8603 10^{-13}	0.0924	0.8854	2.1822 10^{-05}	5.7142 10^{-10}
16	0.0186	0.9976	1.3913 10^{-12}	3.2260 10^{-24}	0.0459	0.9804	2.0291 10^{-09}	5.6142 10^{-18}	0.0159	0.9966	3.4355 10^{-13}	1.4163 10^{-25}
17	0.0354	0.9885	1.6979 10^{-02}	3.6035 10^{-04}	0.0214	0.9950	1.0289 10^{-02}	1.2215 10^{-04}	0.0309	0.9859	1.9284 10^{-02}	4.0570 10^{-04}
18	0.0360	0.9896	7.5469 10^{-03}	8.1365 10^{-05}	0.0221	0.9951	7.4962 10^{-03}	7.0242 10^{-05}	0.0350	0.9828	1.0064 10^{-02}	1.1575 10^{-04}
19	0.0172	0.9980	2.0682 10^{-12}	7.1287 10^{-24}	0.0155	0.9978	2.8636 10^{-10}	1.1182 10^{-19}	0.0178	0.9957	4.0777 10^{-10}	1.9954 10^{-19}
20	0.0375	0.9903	1.7133 10^{-07}	4.8923 10^{-14}	0.0208	0.9960	4.1069 10^{-07}	2.3000 10^{-13}	0.0346	0.9839	1.2521 10^{-09}	1.8814 10^{-18}
21	0.0193	0.9979	5.2801 10^{-05}	5.5759 10^{-09}	0.0134	0.9985	1.5458 10^{-11}	3.2586 10^{-22}	0.0156	0.9969	3.3035 10^{-09}	1.3785 10^{-17}
	75°C-0.05kPa				***75°C-7kPa***				***75°C-13kPa***			
No	***SEE***	***R^2***	***RMSE***	***χ^2***	***SEE***	***R^2***	***RMSE***	***χ^2***	***SEE***	***R^2***	***RMSE***	***χ^2***
1	0.0194	0.9954	2.0267 10^{-02}	4.3358 10^{-04}	0.0286	0.9906	2.6595 10^{-02}	7.3942 10^{-04}	0.0433	0.9803	4.1783 10^{-03}	1.8129 10^{-05}
2	0.0200	0.9954	2.0328 10^{-02}	4.6184 10^{-04}	0.0235	0.9940	2.7233 10^{-02}	8.1224 10^{-04}	0.0140	0.9980	9.2550 10^{-03}	9.2508 10^{-05}
3	0.0200	0.9954	2.0267 10^{-02}	4.5909 10^{-04}	0.0293	0.9906	2.6595 10^{-02}	7.7463 10^{-04}	0.0441	0.9803	4.1783 10^{-03}	1.8854 10^{-05}
4	0.0192	0.9957	1.5599 10^{-02}	2.7195 10^{-04}	0.0286	0.9910	3.2802 10^{-02}	1.1784 10^{-03}	0.0348	0.9877	3.8620 10^{-02}	1.6109 10^{-03}
5	0.0142	0.9978	2.2571 10^{-11}	6.0499 10^{-22}	0.0149	0.9977	1.9784 10^{-10}	4.5014 10^{-20}	0.0173	0.9968	1.3994 10^{-11}	2.2030 10^{-22}
6	0.0190	0.9963	1.0107 10^{-02}	1.2940 10^{-04}	0.0301	0.9910	3.2802 10^{-02}	1.3025 10^{-03}	0.0362	0.9877	3.8620 10^{-02}	1.7509 10^{-03}
7	0.0197	0.9955	1.9600 10^{-02}	4.2937 10^{-04}	0.0224	0.9945	2.6011 10^{-02}	7.4103 10^{-04}	0.0151	0.9977	1.2262 10^{-02}	1.6240 10^{-04}
8	0.0435	0.9782	4.9093 10^{-02}	2.6936 10^{-03}	0.0262	0.9925	3.2236 10^{-02}	1.1382 10^{-03}	0.0174	0.9969	6.6228 10^{-03}	4.7370 10^{-05}
9	0.0524	0.9970	4.7425 10^{-02}	2.5137 10^{-03}	0.0957	0.9932	1.9634 10^{-02}	4.2220 10^{-04}	0.0754	0.9969	8.3349 10^{-02}	7.5027 10^{-03}
10	0.0206	0.9954	2.0267 10^{-02}	4.8778 10^{-04}	0.0300	0.9906	2.6595 10^{-02}	8.1336 10^{-04}	0.0451	0.9803	4.1781 10^{-03}	1.9639 10^{-05}
11	0.0163	0.9971	9.6642 10^{-03}	1.1091 10^{-04}	0.0222	0.9949	2.4853 10^{-02}	7.1035 10^{-04}	0.0147	0.9979	8.8733 10^{-03}	8.8578 10^{-05}
12	0.0063	0.9996	3.7478 10^{-06}	2.0529 10^{-11}	0.0152	0.9978	1.8732 10^{-04}	4.7473 10^{-08}	0.0176	0.9972	1.9033 10^{-04}	4.6577 10^{-08}
13	0.0192	0.9957	1.5599 10^{-02}	2.8895 10^{-04}	0.0286	0.9910	3.2802 10^{-02}	1.2373 10^{-03}	0.0348	0.9877	3.8620 10^{-02}	1.6780 10^{-03}
14	0.0200	0.9954	2.0328 10^{-02}	4.9071 10^{-04}	0.0235	0.9940	2.7233 10^{-02}	8.5286 10^{-04}	0.0140	0.9980	9.2550 10^{-03}	9.6362 10^{-05}
15	0.0079	0.9994	1.6410 10^{-04}	3.4111 10^{-08}	0.0159	0.9975	5.0502 10^{-04}	3.0874 10^{-07}	0.0123	0.9986	2.2143 10^{-04}	5.7557 10^{-08}
16	0.0072	0.9995	2.3106 10^{-14}	6.7623 10^{-28}	0.0151	0.9977	3.4384 10^{-12}	1.4312 10^{-23}	0.0125	0.9986	5.5412 10^{-10}	3.6045 10^{-19}
17	0.0192	0.9957	1.8024 10^{-02}	3.6310 10^{-04}	0.0169	0.9969	1.5435 10^{-02}	2.6092 10^{-04}	0.0163	0.9973	1.0839 10^{-02}	1.2688 10^{-04}
18	0.0189	0.9961	1.0594 10^{-02}	1.3329 10^{-04}	0.0204	0.9957	1.3622 10^{-02}	2.1338 10^{-04}	0.0152	0.9978	6.0232 10^{-03}	4.0814 10^{-05}
19	0.0063	0.9996	9.1446 10^{-13}	1.0592 10^{-24}	0.0148	0.9978	2.3824 10^{-11}	6.8706 10^{-22}	0.0124	0.9986	2.1845 10^{-14}	5.6020 10^{-28}
20	0.0147	0.9978	9.1001 10^{-10}	1.0489 10^{-18}	0.0152	0.9977	3.7467 10^{-06}	1.6993 10^{-11}	0.0177	0.9971	1.5200 10^{-09}	2.7122 10^{-18}
21	**0.0063**	**0.9997**	**2.5467 10^{-10}**	**8.8022 10^{-20}**	**0.0150**	**0.9979**	**3.4989 10^{-11}**	**1.5643 10^{-21}**	**0.0124**	**0.9987**	**1.1675 10^{-10}**	**1.6727 10^{-20}**

Table 3. Coefficients obtained from different thin-layer drying models for the different microwave power density

	Constant and Coefficients		
No	***50°C-0.05kPa***	***50°C-7kPa***	***50°C-13kPa***
1	k=0.4165	k=0.2303	k=0.1651
2	k=0.4554 n=0.9197	k=0.2361 n=0.9848	k=0.2463 n=0.8008
3	k=0.6780 n=0.6143	k=0.4754 n=0.4846	k=0.4098 n=0.4028
4	k=0.4049 a=0.9720	k=0.2282 a=0.9911	k=0.1499 a=0.9156
5	k=0.3742 a=0.9925 c=-0.0287	k=0.2067 a=1.0184 c=-0.0391	k=0.1666 a=0.8994 c=0.0320
6	k=0.3924 m=-0.5836 a=0.9658 b=-0.0004	k=0.2282 m=0.2282 a=0.5284 b=0.4627	k=0.1286 m=0.9535 a=0.7812 b=0.2254
7	k=0.4760 a=0.6765	k=0.2358 a=1.1611	k=0.1651 a=1.0002
8	a=-0.2996 b=0.0234	a=-0.1749 b=0.0083	a=-0.1210 b=0.0039
9	a=-1.2101 b=-0.0896	a=-2.3467 b=-0.2557	a=-3.2537 b=-0.2327
10	k=0.4165 a=0.9999 b=0.9998	k=0.2303 a=0.9998 b=0.9998	k=0.1651 a=0.9997 b=1.0001
11	k=0.3737 a=0.8963 g=26.6110	k=0.2250 a=0.9774 g=2.2761	k=0.1651 a=1.0597 g=0.1651
12	**k=0.0051 a=-0.1480 b=0.1863 c=0.9617 g=24.6206 h=0.2460**	**k=0.0151 a=-2.2903 10^2 b=0.4967 c=2.2953 10^2 g=0.4561 h=0.0152**	**k=0.0069 a=-2.0050 b=2.5284 c=0.4824 g=0.0184 h=0.5127**
13	a=0.9720 c=0.0162 L=0.2000	a=0.9911 c=0.0091 L=0.2000	a=0.9156 c=0.0060 L=0.2000
14	k=0.0236 n=0.9197 L=0.2000	k=0.0099 n=0.9848 L=0.2000	k=0.0187 n=0.8008 L=0.2000
15	k=0.4632 n=0.6928 a=0.9980 b=-0.0201	k=-0.0553 n=-4.6990 a=0.7675 b=-0.0716	k=-0.1582 n=-2.7719 a=0.6610 b=-0.0376
16	k=0.3261 n=0.6589 a=-0.4060 b=1.4043	k=0.2246 n=0.9112 a=-0.1021 b=1.1033	k=0.2275 n=0.6340 a=-0.2497 b=1.2603
17	k_1=0.4283 k_2=0.0081	k_1=0.2277 k_2=-0.0020	k_1=0.2095 k_2=0.0311
18	k=0.4049 a_0=0.2833 10^6 a=0.2915 10^6	k=0.2292 a_0=1.1114 10^2 a=1.1151 10^2	k=0.1499 a_0=0.2071 10^6 a=0.2262 10^6
19	k=0.1221 a=1.2361 b=-0.2569 c=-0.2380	k=0.1345 a=1.1315 b=-0.1035 c=-0.1261	k=0.0420 a=1.1834 b=-0.2165 c=-0.1680
20	k=0.8769 a=0.9925 n=0.4267 c=-0.0287	k=0.2825 a=1.0184 n=0.7319 c=-0.0391	k=0.2079 a=0.8994 n=0.8015 c=0.0320
21	k=0.0029 n=0.6904 a=1.8853 10^2 b=0.0009 g=-1.8753 10^2	k=0.3408 10^2 n=0.9990 a=1.3816 b=0.3389 10^2 g=0.3748	k=0.2263 n=0.7109 a=1.4838 b=0.0409 g=-0.4751
	75°C-0.05kPa	***75°C-7kPa***	***75°C-13kPa***
1	k=1.0176	k=0.8141	k=0.5940
2	k=1.0188 n=0.9934	k=0.7793 n=1.1090	k=0.4983 n=1.2725
3	k=0.9879 n=1.0300	k=0.9127 n=0.8921	k=0.4548 n=1.3059
4	k=1.0012 a=0.9842	k=0.8287 a=1.0181	k=0.6407 a=1.0789
5	k=0.8767 a=1.0162 c=-0.0496	k=0.6535 a=1.0835 c=-0.0972	k=0.4698 a=1.1855 c=-0.1476
6	k=1.2898 m=1.2853 a=-0.7919 10^2 b=0.8016 10^2	k=0.8287 m=0.8287 a=0.8081 b=0.2101	k=0.6407 m=0.6407 a=0.6126 b=0.4663
7	k=1.0906 a=1.2938	k=1.0093 a=1.5854	k=0.8512 a=1.8322
8	a=-0.7450 b=0.1453	a=-0.5963 b=0.0920	a=-0.4442 b=0.0511
9	a=-0.4973 b=-0.0405	a=-0.6048 b=-0.0538	a=-0.8568 b=-0.0991
10	k=1.0176 a=0.9998 b=0.9999	k=0.8141 a=0.9999 b=1.0001	k=0.5940 a=1.0001 b=0.9999
11	k=0.9931 a=1.0005 g=-1.4537	k=1.2056 a=-0.1370 10^3 g=1.2095	k=1.0717 a=0.1430 10^3 g=1.0772
12	k=0.0185 a=-0.0943 b=0.0923 c=1.0018 g=10.3094 h=0.7551	k=0.2512 a=-0.4494 b=0.7148 c=0.7179 g=0.5611 h=0.5611	k=0.0997 a=-0.3019 b=0.6674 c=0.6708 g=0.4332 h=0.4332
13	a=0.9842 c=0.0401 L=0.2000	a=1.0181 c=0.0332 L=0.2000	a=1.0789 c=0.0256 L=0.2000
14	k=0.0416 n=0.9934 L=0.2000	k=0.0220 n=1.1090 L=0.2000	k=0.0083 n=1.2725 L=0.2000
15	k=0.9023 n=0.8599 a=0.9958 b=-0.0296	k=0.7135 n=0.9975 a=0.9899 b=-0.0203	k=0.4933 n=1.1989 a=1.0041 b=-0.0082
16	k=0.7779 n=0.8379 a=-0.1526 b=1.1494	k=0.6474 n=0.9727 a=-0.1123 b=1.1041	k=0.4791 n=1.1898 a=-0.0446 b=1.0489
17	k_1=0.9787 k_2=-0.0275	k_1=0.6862 k_2=-0.0917	k_1=0.4505 k_2=-0.1105
18	k=1.0894 a_0=5.9726 a=5.1512	k=1.0918 a_0=2.0964 a=1.1644	k=0.9452 a_0=1.7256 a=0.7119
19	k=0.6093 a=1.1096 b=-0.2136 c=-0.1106	k=0.5990 a=1.1100 b=-0.0522 c=-0.1130	k=0.6311 a=1.0770 b=0.1767 c=-0.0831
20	k=0.7805 a=1.0162 n=1.1233 c=-0.0496	k=0.9753 a=1.0835 n=0.6701 c=-0.0972	k=0.9519 a=1.1855 n=0.4936 c=-0.1476
21	**k=0.1310 n=0.2847 a=1.0946 b=-0.7101 g=-0.0946**	**k=0.0206 n=-0.0942 a=1.1051 b=-0.6380 g=-0.1050**	**k=0.1709 10^3 n=1.0006 a=1.0509 b=0.1704 10^3 g=-0.0512**

CONCLUSIONS

The effects of different vacuum and temperature levels on the drying of Chili peppers were evaluated based on the drying parameters such as the drying time and moisture ratio. Drying period was completed between 3 and 19.17 h at combined different temperature (50-75°C) with vacuum (0.05, 7 and 13 kPa) levels.

Drying tests were done at the microwave power density values of 50°C-0.05kPa, 50°C-7kPa, 50°C-13kPa, 75°C-0.05kPa, 75°C-7kPa and 75°C-13kPa. Twenty-one different drying models were used in the study and coefficient of correlation (R^2), standard error estimated (*SEE*), root mean square error and chi-square ($\chi 2$) values and constant and coefficients of these models were calculated.

Among all drying tests, the drying model where constant of coefficient (R^2) is the highest at 50°C-0.05kPa, 50°C-7kPa and 50°C-13kPa drying levels was Modified Henderson & Pabis Model and at 75°C-0.05kPa, 75°C-7kPa and 75°C-13kPa drying levels was Alibas Model.

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