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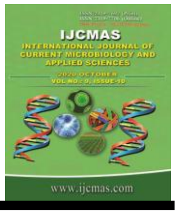

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Mathematical Modeling of Foamed Nagpur Mandarin Juice in Microwave Drying

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The drying study was carried out in microwave drying at various microwave power from 180 to 900 W at varying drying bed thickness. The drying characteristics and energy consumption during microwave drying of foamed Nagpur mandarin juice were reported. During the experiments, the foamed Nagpur mandarin juice was dried from initial to final moisture content of 79.94 % to 1.59 per cent (wb). The experimental data were fitted to five drying models. The models were compared using the coefficient of determination, root mean square error and reduced chi-square. The Midilli *et al.* model; Jene and Das; welbulli distribution model was best described the drying curve of foamed Nagpur mandarin juice.

Introduction

Microwave heating is based on the transformation of alternating electromagnetic field energy into thermal energy by affecting the polar molecules of a material. Compared with hot air drying, microwave drying reduces the decline in quality, and provides rapid and effective heat distribution in the material as well (Diaz *et al.,* 2003). Tippayawong *et al.,* (2008) reported that the conventional practice results in low overall efficiency, approximately 30% and around 35%–45% of energy input is wasted as hot gas exhaust. In microwave drying, the quick absorption of energy by water molecules causes rapid evaporation of water, resulting in high drying rates of the food.

The drying time can be greatly reduced by applying the microwave energy to the dried material. Due to the concentrated energy of a microwave drying system, only 20%-35% of the floor space is required, as compared to conventional heating and drying equipment (Vadivambal and Jayas, 2007; Maskan, 2000). Also, it has also been suggested that microwave energy should be applied in the falling rate period for drying (Maskan, 2000).In the drying industry, the most important aim is to use lowest energy to extract the most moisture for obtaining optimum product storing conditions.

Several drying methods are used in the drying of plants and foodstuff. The use of microwave technique in the drying of products has become common because it minimizes the quality loss and provides rapid and effective heat distribution in the product as well. Besides, high quality dried product is acquired via microwave drying in addition to the reducing in drying period and energy conservation while drying (Balbay *et al.*, 2011; Zhang *et al.*, 2006; Evin *et al.*, 2012; Alibas-Ozkan *et al.*, 2007).

Thin layer drying is the process of drying in one layer of sample particles or leaves. 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 (Kardum *et al.*, 2011). Thin layer drying models can be categorized as theoretical, semi-empirical an empirical models (McMinn, 2006; Alibas, 2014). The aim of this study was to (i) investigate the kinetics of the thin layer drying of foamed Nagpur mandarin juice, (ii) compare the developed several theoretical, empirical and semi-empirical mathematical models and estimate the constant of several models, (iii) determine the best fit using statistical analysis.

Materials and Methods

The fully ripe Nagpur mandarin fruit was chosen and the fruit was peeled. The peeled fruit was used for the extraction of juice for further processing in juicer. The foamed juice was prepared using 2.10% soy protein isolate, 2.75% GMS, 1.75% CMC, 5.10% sugar and whipping time 8 min. Average initial moisture content of foamed Nagpur mandarin juice were determined by using a standard oven method at 105±2ºC for 6 h (Aghbashlo *et al.*, 2009).

Experimental set-up and methods

The microwave oven (LG model MC=9280XC) has been used to dry foamed Nagpur mandarin juice. The foam was uniformly spread over a plate lined with teflon and a drying process was performed at 180, 360, 540, 720 and 900 W with bed thickness 2, 4 and 6 mm. All tests have been repeated three times and the average readings have been recorded. The drying data was recorded until the sample attained constant moisture content (db).

Modelling of convective drying of Nagpur Mandarin juice

In order to select the appropriate model for the process studied, the experimental value of drying curves were fitted to nineteen thin-layer drying models as shown in Table 1. Nonlinear regression analyzes were performed using Statistica 9.0. The model fitting was assessed by evaluating the coefficient of determination (R^2) and the residual plots were the primary criterion for choosing the best equation to describe the drying curves. In addition to R^2, the goodness of fit was determined by various statistical parameters such as reduced chi-square (χ^2), mean bias error (MBE), root mean square error (RMSE), standard error of estimated (SEE) and mean deviation modulus (P) (Togrul and Pehlivan, 2002; Erketin *et al.*, 2004; Demir *et al.*, 2004; Franco, *et al.*, 2015).

Adequacy of fit of various empirical models

Modeling the drying behavior of different agricultural products often requires the statistical methods of regression and correlation analysis. In particular, for the use of the statistical application (Statistica Software) for the purpose of modifying the mathematical model, linear and non-linear regression modelings are important resources in discovering the relationship between various variables. The determination coefficient (R^2) and plots of residuals were the primary criterions for selecting the best equation to define the drying curves. In addition to R^2, the goodness of fit was determined by various statistical parameters such as reduced chi-square (χ^2), mean bias error (MBE), root mean square error (RMSE) and mean deviation modulus (P) (Gomez and Gomez, 1983).

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

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

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

$$E_{RMS} = \left[\frac{1}{N}\sum_{i=1}^{N}\left(M_{R,pre,i} - M_{R,\exp,i}\right)^2\right]^{1/2}$$

$$\mathrm{MBE} = \frac{1}{\mathrm{N}}\sum_{\mathrm{i}=1}^{\mathrm{N}}\left(\mathrm{MR}_{\mathrm{pre,i}} - \mathrm{MR}_{\mathrm{exp,i}}\right)$$

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

$$R^2 = \frac{\sum_{i=1}^{n}(MR_i - MR_{pre,i}).\sum_{i=1}^{n}(MR_i - MR_{exp,i})}{\sqrt{[\sum_{i=1}^{n}(MR_i - MR_{pre,i})]^2.[\sum_{i=1}^{n}(MR_i - MR_{exp,i})]^2}}$$

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

$$P(\%) = \frac{100}{N}\sum_{i-1}^{N}\left|\frac{Experimentalvalue - Predictedvalue}{Experimentalvalue}\right|$$

Standard 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”.

$$\mathrm{SEE} = \sqrt{\frac{\sum_{\mathrm{i}=1}^{\mathrm{N}}\left(\mathrm{M}_{\mathrm{R_{exp}}} - \mathrm{M}_{\mathrm{R_{pre}}}\right)^2}{\mathrm{N} - \mathrm{n_j}}}$$

Where, M_{Rexpi} is experimental moisture ratio found in any measurement, $M_{Rpre,}$ is predicted moisture ratio found in any measurement, N is number of observations, z is number of drying constants and n_j is number of constants.

As one with the largest deciding factor, the least mean relative percent variance, the decreased chi-square and the RMSE, the best model was chosen (Sarsavadia *et al.*, 1999; Sacilik *et al.*, 2006).

While the statistical metrics typically offer a fair means to comparing simulations, they do not scientifically mean if the predictions of the experiment vary substantially from their calculated equivalents, that is, not statistically significantly (Saravadia *et al.*, 1999).

Results and Discussion

Overall regression coefficients in moisture content with time

The initial moisture content of the foamed Nagpur mandarin juice was ranging 79.94 to 79.59 per cent (wb) for all the samples investigated and after drying up to nearly constant wet attained, the moisture content was reduced in the range of 4.767 to 1.385 per cent (db).

The drying data were statistically analysed and regression equations of exponential form were predicted as

$$MC = Ae^{-kt}$$

Where, MC is moisture content of the Nagpur mandarin juice during drying, t is time in min, A and k are constants.

From Table 2, the R^2 value for various thickness of drying bed at varying microwave power was found more than 0.99 which shows a good correlation between the data collected.

Overall coefficient in drying rate

It can be observed from the Table 3 that as the drying proceeds, the moisture content of the sample decreased and the rate of drying also decreased. The rate of drying was higher for high microwave power.

Table.1 Mathematical model used for Nagpur Mandarin juice

Sr. No.	**Name of the model**	**Model /equation**
1	Lewis/ Newtons' model	$MR = e^{-kt}$
2	Henderson and Pabis	$MR = ae^{-kt}$
3	Modified Henderson and Pabis	$MR = ae^{kt} + be^{k_0 t} + ce^{k_1 t}$
4	Pages' model	$MR = e^{(-kt)^2}$
5	Logarithmic	$MR = ae^{-kt} + c$
6	Two- term model	$MR = ae^{-kt} + be^{-nt}$
7	Two–term exponential	$MR = ae^{-kt} + (1-a)e^{-kat}$
9	Diffusion approach	$MR = ae^{-kt} + (1-a)e^{-kbt}$
10	Simplifed Fick's diffusion	$MR = ae^{(-c(t/L^2))}$
11	Verma *et al.,*	$MR = ae^{-kt} + (1-a)e^{-gt}$
12	Midilli *et al.,*	$MR = ae^{(-kt^n)} + bt$
13	Wang and sing	$\square\square = 1 + (\square\square) + (\square(\square^2))$
14	Thomose	$t = a\ln(MR) + b(\ln(MR)^2$
15	Welbulli distribution	$MR = a - be^{(-(kt^n))}$
16	Aghlasho *et al.,*	$MR = e^{\left(\frac{-k_1 t}{1} + k_2 t\right)}$
17	Logistic	$MR = \frac{a_0}{(1 + a\,e^{(kt)})}$
18	Jena and Das	$MR = a\,e^{\left(-kt + b\,t^{\left(\frac{1}{2}\right)}\right)} + c$
19	Demir *et al.,*	$MR = a\,e^{(-kt)^n} + c$

a, b, c, k, g and n = model coefficients, t = drying time, min and MR = moisture ratio

Table.2 Overall regression coefficients with R^2

S.N.	Microwave power, W	Thickness of drying bed, mm	Regression coefficient		Coefficient of determination, R^2
			A	K	
1.	180	2.0	390.627	0.108	0.9953
2.	360	2.0	391.733	0.146	0.9962
3.	540	2.0	432.158	0.230	0.9892
4.	720	2.0	452.963	0.209	0.9938
5.	900	2.0	482.092	0.274	0.9983
6.	180	4.0	394.143	0.084	0.9994
7.	360	4.0	336.873	0.049	0.9496
8.	540	4.0	470.551	0.176	0.9966
9.	720	4.0	625.641	0.286	0.9956
10	900	4.0	422.846	0.272	0.9969
11	180	6.0	511.366	0.089	0.9987
12	360	6.0	505.768	0.158	0.9940
13	540	6.0	381.974	0.161	0.9925
14	720	6.0	469.608	0.256	0.9955
15	900	6.0	389.539	0.166	0.9989

Table.3 Predicted equations of drying rate during microwave drying of foamed Nagpur mandarin juice

SN	MP, W	DBT, mm	Equation predicted	R^2
1	180	2	$y = -0.000x^2 + 0.045x + 9.772$	0.752
2	360	2	$y = -0.000x^2 + 0.067x + 12.31$	0.860
3	540	2	$y = -0.000x^2 + 0.066x + 16.35$	0.933
4	720	2	$y = -0.000x^2 + 0.083x + 17.44$	0.960
5	900	2	$y = -0.000x^2 + 0.083x + 23.32$	0.947
6	180	4	$y = -8E-05x^2 + 0.020x + 8.110$	0.774
7	360	4	$y = -0.000x^2 + 0.050x + 9.739$	0.845
8	540	4	$y = -0.000x^2 + 0.076x + 13.62$	0.808
9	720	4	$y = -0.000x^2 + 0.133x + 16.81$	0.943
10	900	4	$y = -0.000x^2 + 0.148x + 20.34$	0.962
11	180	6	$y = -9E-05x^2 + 0.023x + 7.337$	0.756
12	360	6	$y = -0.000x^2 + 0.095x + 9.568$	0.863
13	540	6	$y = -0.000x^2 + 0.075x + 12.94$	0.978
14	720	6	$y = -0.000x^2 + 0.057x + 16.32$	0.866
15	900	6	$y = -0.000x^2 + 0.103x + 17.17$	0.921

MP is microwave power, DBT is drying bed thickness, y is drying rate and x is moisture content

Table.4 Overall values for statistical parameters used in drying of foamed Nagpur mandarin juice

Sr. no.	**Drying models**	**Statistical parameters**					
		R^2	**χ^2**	**MBE**	**E_{RMS}**	**SEE**	P(%)
1	Lewis/ Newtons' model	0.9822	0.0033	0.0014	0.0094	-0.5301	32.4405
2	Henderson and Pabis	0.9881	0.0022	-0.0077	0.0076	-0.7978	26.1543
3	Modified Henderson and Pabis	0.9930	0.0013	-0.0047	0.0057	-2.3986	14.0606
4	Pages' model	0.9822	0.0033	0.0014	0.0094	-0.7967	30.6203
5	Logarithmic	0.9988	0.0002	0.0000	0.0024	-1.1998	1.3744
6	Two- term	0.9893	0.0020	-0.0069	0.0070	-1.5979	24.3106
7	Two–term exponential	0.9913	0.0015	-0.0022	0.0056	-0.7985	20.2203
8	Diffusion approach	0.9967	0.0006	-0.0034	0.0039	-1.1994	13.3830
9	Simplifed Fick's diffusion	0.9882	0.0021	-0.0077	0.0076	-1.1979	26.2777
10	Verma *et al.,*	0.9675	0.0054	0.0200	0.0074	-1.1943	1.6580
11	Midilli *et al.,*	0.9994	0.0001	0.0000	0.0017	-1.5999	0.0886
12	Wang and sing	0.9985	0.0003	0.0016	0.0028	-0.7997	0.5303
13	Thomose	0.9965	0.9431	0.2293	0.1321	0.1581	4.9798
14	Welbulli distribution	0.9994	0.0001	0.0000	0.0017	-1.5999	0.0286
15	Aghlasho *et al.,*	0.9822	0.0033	0.0014	0.0094	-0.7967	30.8004
16	Logistic	0.9973	0.0005	-0.0022	0.0033	-1.1995	9.1850
17	Jena and Das	0.9993	0.0001	0.0005	0.0018	-1.5998	0.3236
18	Demir *et al.,*	0.9973	0.0005	0.0000	0.0034	-1.5997	5.3055

Table.5 Drying constants of most satisfactory models at different microwave power and drying bed thickness during drying of foamed mandarin juice

Name of Model	**DBT (mm)**	**MP, W**	**Drying constant**							
			Artificial foaming agent				**Natural foaming agent**			
			K	**N**	**A**	**B**	**K**	**N**	**A**	**B**
Midilli *et al*	2	180	0.012	1.364	0.978	-0.003	0.012	1.398	1.002	0.000
		360	0.027	1.195	0.992	-0.005	0.010	1.576	1.004	0.000
		540	0.070	0.969	1.000	-0.007	0.017	1.438	1.018	-0.001
		720	0.053	0.964	1.009	-0.013	0.017	1.450	1.018	-0.004
		900	0.043	1.393	1.001	-0.003	-0.059	0.325	0.997	-0.057
	4	180	0.010	1.313	0.996	-0.003	0.003	1.808	0.984	0.001
		360	0.026	1.142	1.012	-0.003	0.004	1.853	0.965	0.000
		540	0.039	1.094	1.011	-0.007	0.015	1.413	1.011	-0.002
		720	0.062	1.143	1.014	-0.002	0.000	0.000	1.015	-0.038
		900	0.076	1.109	1.017	-0.004	0.000	0.000	1.027	-0.043
	6	180	0.006	1.523	0.980	0.000	0.011	1.464	1.001	0.001
		360	0.035	1.182	1.014	0.001	0.002	2.002	0.971	0.002
		540	0.052	0.916	1.014	-0.010	0.007	1.693	1.000	0.000
		720	0.065	1.139	1.006	-0.001	0.000	0.000	1.042	-0.037
		900	0.023	1.337	0.992	-0.007	0.000	0.000	1.023	-0.041
Welbulli dis	2	180	0.013	1.319	-0.189	-1.168	0.012	1.395	-0.005	-1.007
		360	0.026	1.159	-0.272	-1.264	0.010	1.577	-0.005	-1.009

		540	0.057	0.946	-0.398	-1.399	0.017	1.429	-0.047	-1.065
		720	0.034	0.952	-0.937	-1.946	0.018	1.416	-0.153	-1.170
		900	0.043	1.371	-0.074	-1.076	0.007	1.736	-0.304	-1.288
	4	180	0.010	1.265	-0.304	-1.300	0.003	1.852	0.068	-0.916
		360	0.024	1.119	-0.228	-1.240	0.004	1.866	0.018	-0.947
		540	0.034	1.068	-0.383	-1.395	0.016	1.392	-0.104	-1.115
		720	0.060	1.130	-0.074	-1.088	0.011	1.518	-0.195	-1.189
		900	0.072	1.095	-0.132	-1.149	0.006	1.770	-0.173	-1.138
	6	180	0.006	1.523	0.002	-0.978	0.010	1.487	0.059	-0.942
		360	0.035	1.201	0.035	-0.978	0.002	2.074	0.085	-0.888
		540	0.033	0.905	-0.912	-1.926	0.007	1.700	0.007	-0.993
		720	0.065	1.130	-0.033	-1.039	0.007	1.576	-0.278	-1.275
		900	0.022	1.284	-0.306	-1.298	0.006	1.858	-0.028	-1.016
Jena and Das	2	180	0.03	1.41	0.04	-0.43	0.042	1.186	0.061	-0.202
		360	0.04	1.43	0.02	-0.43	0.062	1.192	0.103	-0.221
		540	0.05	1.35	-0.01	-0.35	0.067	1.205	0.096	-0.220
		720	0.03	1.77	0.00	-0.76	0.059	1.422	0.078	-0.434
		900	0.11	1.21	0.10	-0.21	-0.004	-14.546	-0.003	15.555
	4	180	0.02	1.58	0.03	-0.60	0.042	1.221	0.094	-0.272
		360	0.04	1.29	0.03	-0.29	0.054	1.243	0.097	-0.289
		540	0.04	1.42	0.02	-0.41	0.053	1.307	0.072	-0.323
		720	0.10	1.10	0.06	-0.10	0.040	1.724	0.054	-0.743
		900	0.10	1.15	0.05	-0.15	0.031	2.278	0.041	-1.303
	6	180	0.04	1.12	0.08	-0.16	0.061	1.003	0.110	-0.039
		360	0.08	0.98	0.07	0.01	0.066	1.077	0.146	-0.146
		540	0.03	1.68	-0.01	-0.67	0.059	1.246	0.106	-0.282
		720	0.10	1.05	0.05	-0.05	0.029	2.139	0.045	-1.161
		900	0.04	1.63	0.04	-0.64	0.065	1.405	0.107	-0.440

The predicted equation of third order drying rate during microwave drying of foamed Nagpur mandarin juice are given at Table 3 with R^2 value for various thickness of drying bed at varying microwave power. It can be seen from the table that for all experiments, the coefficients of determination is more than 0.75 which shows a good correlation between the data collected.

Mathematical modelling

To determine the most suitable drying equation, the moisture ratio data of foamed with artificial and natural foaming agent at different microwave power and thickness of drying bed were fitted into the eighteen thin-layer drying models in their linearized form using regression technique. Among all these models, the best model suitable to fit the data were selected on basis of highest values of R² and the lowest value of reduced mean square of the deviation (χ^2) and root mean square error (E_{RMS}), Mean bias error (MBE), Standard error of estimation (SEE) and (P%) should be less than 10%. The overall statistical parameters for different models used for dried juice. From Table 4, it shows that the R^2 value was found greater than 0.9675. Thus all models were best fitted for drying of foamed Nagpur mandarin juice in various microwave power and drying bed thickness using different foaming agents.

The highest values of coefficient of determination (R^2) and the lowest values of lowest value of reduced mean square of the deviation (χ^2) and root mean square error (E_{RMS}), Mean bias error (MBE), Standard error of estimation (SEE) and (P%)was obtained for Midllee *et al.*, Welbulli distribution and Jena and Das drying model. The details are presented in Appendix F. Hence, Midllee *et al.*, Welbulli distribution and Jena and Das drying model was found to be the most satisfactory among the models to represent the thin-layer drying of Nagpur mandarin juice for artificial and natural foaming agent.

The result shows that the overall highest value of R^2 and the lowest values of χ^2, E_{RMS}, and MBE were found to be 0.9994, 0.00010, 0.000, 0.00168, -1.5999 and 0.08863 in Midllee *et al.*, model; 0.9994, 0.00010, 0.000, 0.001695, -1.5999 and 0.08863 in Welbulli distribution model and 0.9993, 0.0001, 0.0005, 0.0018, -1.5998 and 0.3236 in Jena and Das drying model (Table 2). The data on drying constants are presented in Table 5.

This was another confirmation of the suitability of Midllii model to thin layer drying, which has been reported by Bhagyashree *et al.*, (2013) for air drying of Long Pepper and Koua *et al.*, (2009) for thin layer solar drying of mango, banana and cassava. The Midilli *et al.*, model was selected as the suitable model to represent the thin layer drying has also been suggested by others to describe drying of various food products such as Chayjan and Kaveh (2016) for egg plant slices, Celma *et al.*, (2009) for tomato, Meziane, (2011) for olive pomace Arslan and Ozcan, (2011) for savory leaves, Ertekin and Yaldiz, (2004) for eggplants, thin layer drying of potato, apple and pumpkin slices (Akpinar, 2006), mint leaves (Doymaz, 2006), Potato slices (Darvishi. 2012), sultan grapes fruit (Karaaslan, *et al.*, 2017), Sri Lankan Black Pepper (Amarasinghe *et al.*, 2018, mulberry (Evin 2011), turpin slices (Chayjan and Kaveh, 2016). Demirhan and Ozbek (2011) determined that the semi-empirical Midilli *et al.*, model gave a better fit for all drying conditions applied of microwave dried celery leaves among the eight thin-layer drying models proposed. Evin (2012) found that the Midilli model precisely represented the microwave drying behavior of *G. tournefortii*. Sarimeseli (2011) found that the coriander leaves were dried with microwave radiation and the semi-empirical Midilli *et al.*, model was the best model of six thin-layer drying models.

Weibull distribution was found to be the best descriptive model for all the drying experiments of thin layer drying. Similar results were reported by various researchers (Karaaslan, *et al.*, 2017; Alibas 2014a and b; Amarasinghe *et al.*, 2018; Al-Harahsheh *et al.*, 2009; Evin 2012; Demirhan and Ozbek 2011; Sarimeseli 2011; Alibas, 2012; Karaaslan and Tuncer 2008).

References

Aghbashlo, M., M.H.Kianmehr, and A.Arabhosseini.2009. Modeling of thin-layer drying of potato slices in length of continuous band dryer. *Energy Conversion and Management*, 50 (5):1348–1355.

Amarasinghe, B. M. W. P. K., Aberathna, A. J. M. L. M. and Aberathna, K. K. P. P. (2018). Kinetics and Mathematical Modeling of Microwave Drying of Sri Lankan Black Pepper (*Piper nigrum*). International *Journal of Environmental and Agriculture Research (IJOEAR)* ISSN:[2454-1850] 4 (2), 6.

Al-Harahsheh, M., Al-Muhtaseb, A. H., and Magee, T. (2009). Microwave drying kinetics of tomato pomace: Effect of osmotic dehydration. *Chemical Engineering and Processing: Process Intensification*, *48*(1), 524-531. https://doi.org/10.1016/j.cep.2008.06.010

Akpinar, E.K. 2006. Determination of suitable thin layer drying curve model for some vegetables and fruits. *Journal of Food Engineering*, 73 (1): 75–84.

Alibas, I.2007. Energy consumption and colour characteristics of nettle leaves during microwave, vacuum and convective drying. *Biosystems Engineering,* 96 (4):495–502.

Alibas, Ilknur (2014b). Mathematical modeling of microwave dried celery leaves and determination of the effective moisture diffusivities and activation energy *Food Sci. Technol (Campinas)*. 34(2); Campinas. https://doi.org/10.1590/S0101-20612014005000030

Alibas, I. (2014a). Microwave, air and combined microwave-air drying of grape leaves (*Vitis vinifera* L.) and the determination of some quality parameters. *International Journal of Food Engineering*, *10*(1), 69-88. https://doi.org/10.1515/ijfe-2012-0037

Bhagyashree P, Vanita B., and Sneha D. (2013). Thin layer drying of long pepper (Piper longum L.). *Journal of Spices and Aromatic Crops*, *22*(1), 31-37. www.indianspicesociety.in/josac/index.php/josac

Chayjan, R. A. and Kaveh, M. (2016). Drying characteristics of eggplant (*Solanum melongena* L.) slices under microwave-convective drying. *Res. Agr. Eng.*, 62: 170–178.

Celma, F. Cuadros, F. and Lopez-Rodriguez. (2009). Characterisation of industrial tomato by-products from infrared drying process. *J. Food Bioprod. Proc.*, 87: 282-291.

Diaz, G.R., J.Martı´nez-Monzo, P.Fito, and A.Chiralt.2003. Modelling of dehydration–rehydration of orange slices in combined microwave/air drying. *Innovative Food Science and Emerging Technologies,* 4(2): 203–209.

Demir, V., Gunhan, T., Yagcioglu, A. K. and Degirmencioglu, A. (2004). Mathematical modelling and the determination of some quality parameters of air-dried bay leaves. Biosystems Engineering, 88(3): 325-335.

Doymaz, I.2006. Thin-layer drying behaviour of mint leaves.*Journal of Food Engineering*, 74(3): 370–375.

Darvishi, Hosain and Eisa, Hazbavi. (2012). Mathematical Modeling of Thin-Layer Drying Behavior of Date. Palm. Global Journal of Science Frontier Research. Mathematics and Decision Sciences. 12 (10); Online ISSN: 2249-4626 and Print ISSN: 0975-5896.

Demirhan, E. and Ozbek, B. (2011). Thin-layer drying characteristics and modeling of celery leaves undergoing microwave treatment. *Chemical Engineering Communications, 7*(198); 957-975. http:// dx.doi.org/10.1080/00986445.2011.545298

Ertekin, C., andO.Yaldiz.2004. Drying of eggplant and selection of a suitable thin layer drying model. *Journal of Food Engineering*, 63 (3): 349–359.

Evin, A. (2011). Thin layer drying kinetics of *Gundelia tournefortii* L. *Food Bioprod. Process*, 90: 323-332.

Evin, D. (2012). Thin layer drying kinetics of Gundelia tournefortii L. *Food and Bioproducts Processing*, 90, 323-332. http://dx.doi. org/10.1016/j.fbp.2011.07.002

Franco, T. S., Perussello, C. A., Ellendersen, L. D. S. N. and Masson, M. L. (2015). Foam mat Drying of Yacon Juice: Experimental Analysis and Computer Simulation. *Journal of Food Engineering*, 158, 48–57.

Gomez, K. A. and Gomez, A. A. (1983). *Statistical procedure for Agriculture Research.* John Wiley and sons, New york pp 356-422.

Koua, K. B., Fassinou, W. F., Gbaha, P. and Toure, S. (2009). Mathematical modelling of thin layer solar drying of mango, banana and cassava, *Energy*, 34:1594-1602.

Karaaslan, Sevil, Kamil Ekinci and Davut Akbolat (2017). Drying characteristics of sultan grapes fruit in microwave drying. *Polish Academy of sciences Cracow Branch*, IV/1/2017, 1317–1327. DOI: http://dx.medra.org/10.14597/infraeco.20

17.4.1.101.

Karaaslan, S. N. and Tuncer, I. K. (2008). Development of a drying model for combined microwave-fan assisted convection drying of spinach. *Biosystems Engineering, 100,* 44-52. http://dx.doi.org/10.1016/j. biosystemseng.2007.12.012

Maskan, M. 2000. Microwave/air and microwave finish drying of banana. *Journal of Food Engineering,* 44 (2): 71-78.

McMinn, W.A.M., M.A.M.Khraisheh, and T.R.A.Magee.2006. Modelling the mass transfer during convective, microwave and combined microwave-convective drying of solid slabs and cylinders. *Food Research International,* 36 (9-10): 977–983.

Midilli, A., H.Kucuk, and Z.Yapar.2002. A new model for single layer drying. *Drying Technology,* 20 (10):1503–13.

Ozcan, M. M. and Haciseferogullari, H. (2007). The strawberry (*Arbutus unedo* L.) Fruits Chemical composition, physical properties and mineral contents, *Journal of Food Engineering*., 78:1022-1028.

Sarimeseli, A. (2011). Microwave drying characteristics of coriander (*Coriandrum sativum* L.) leaves. *Energy Conversion and Management, 52,* 1449-1453. http://dx.doi.org/10.1016/j.enconman.2010.10.007

Sarsavadia, P. N., Sawhney, R. L., Pangavhane, D. R. and Singh, S. P. (1999). Drying behaviour of brined onion slices. *J Food Eng* 40: 219–26.

Sacilik, K., Elicin, A. K. and Unal, G. (2006). Drying kinetics of Uryani plum in a convective hot-air dryer. *J Food Eng* 76: 362–68.

Tippayawong, N., C.Tantakitti, and S. Thavornun.2008. Energy efficiency improvements in long an drying practice. *Energy,* 33 (7): 1137–1143.

Togrul, I. T. and Pehlivan, D. (2002). Mathematical modeling of solar drying of Apricots in thin layer. *Journal of Food Engineering*. 55: 209 - 216.

Vadivambal, R., and D.S.Jayas.2007. Changes in quality of microwave-treated agricultural products-a review. *Biosystems Engineering,* 98 (1): 1–16.

Verma, Shankar, Bhatnagar, Prerak and Yadav Aruna (2012). Physico- chemical, yield and yield attributing characteristics of Nagpur Mandarin (Citrus reticulata Blanco) orchards surveyed in Jhalawar district of Rajasthan, *Asian J. Hort*., 7(2): 437-441.

Zhang, J., Zhang, M., Shan, L. and Fang, Z. (2007). Microwave-vacuum heating parameters for processing savory crisp bighead carp (*Hypophthalmichthys nobilis*) slices. *J Food Engineering* 79: 885-891.

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