As. J. Food Ag-Ind. **2013**, 6(02), 72-85

OPEN ACCESS

Asian Journal of Food and Agro-Industry

ISSN 1906-3040

Available online at www.ajofai.info

Research Article

Effect of microwave treatment on drying characteristics and quality parameters of thin layer drying of coconut

Jeyan Arthur Moses[1], P. Karthickumar[1], V.R. Sinija[1], K. Alagusundaram[1] and B. K. Tiwari[2]

[1]Indian Institute of Crop Processing Technology, Thanjavur, India.

[2]Department of Food and Consumer Technology, Manchester Metropolitan University, Manchester, United Kingdom.

Email: jeyan_pfe11@iicpt.edu.in

Abstract

The commercial value of desiccated coconut at present faces issues related to inferior productquality, high costs and the risk of contamination. The objective of this study was to investigate the feasibility of microwave technique for coconut drying. The coconut drying characteristics were studiedat five microwave output power levels ranging from 180 to 900 W.Quality characteristics such as colour and rehydration rates of both the conventionaland microwave techniques were also compared. Several mathematical models were evaluated to describe the drying kinetics. TheMidilli model was found to be the best fitfor the microwave drying behaviour of coconut with R^2> 0.995, *RMSE*< 0.026 and χ^2< 0.001 at all microwave power levels. The effective moisture diffusivity varied from 3.037 × 10^{-08} to 14.274× $10^{-08}$$m^2$/sinapplied powerlevels of 180 to 900W respectively. Drying rate constant (*k*) was found to increase with an increase in applied microwave power. Microwave drying at power levels of 180 and 360 W showed better results in terms of colour. However, higherrehydration capacity was noted for samples dried at 720 and 900 W.In both cases, the quality of conventionally dried coconut powder was found to be inferior. This study shows that the microwave technique can be used to achieve betterquality end product.

Keywords:mathematical model,effective diffusivity,rehydration capacity,quality, India.

Introduction

Coconut (*Cocosnucifera L.*) is a commercial crop of the humid tropics widely grown and consumed in various forms. South Asian countries produce over 45 million tons of coconut annually [1]. Commonly available coconut-based products include desiccated coconut (DC), coconut oil, coconut flour and coconut milk. Among these, DC is used as an ingredient in various food and food products such as confectionery, chocolate and ice cream industries. Commercially DC is generally sold and consumed as dried shredded/particulate coconut with preferred white colour and fresh like taste and flavour. DC is commercially available with a moisture content of about 3% d.b.[2]. It is also the most common form of coconut available in regions where coconut is not grown. Increased consumer demand for white and fresh coconut like flavour of DC, have propelled the production

and availability of DC in various grades. However, the DC industry in Asia at present faces issues of longer drying time and energy requirement, along with inferior product quality. Poor quality of DC is mainly attributed to the drying phase, which is the most important unit operation in this context [3].

Drying of food materials is an intricate phenomenon of simultaneous heat and mass transfer. Numerous studies have been conducted to emphasise the drying characteristics of fruit [4], vegetables [5], spices [6], oilseeds [7], nuts [8] and their by-products [9]. The search for alternative drying techniquesto produce superior product quality is the imperative need of the DC industry. Microwave drying could be a possible alternative, owing to the multiple benefits it offers. This includes shorter drying time, improved product quality, lesser floor space requirements, lower operational costs, minimal heat losses, higher retention of flavour compounds and better rehydration characteristics [10]. However, no reported research is available to study the applicability of microwave drying in the DC industry. Therefore, the objective of this study was to investigate the suitability of various drying models to describe the microwave drying behaviour of coconut. A comparison study was also conducted to compare the colour and rehydration rates of conventional tray drying process with microwave drying process.

Materials and Methods

Experimental procedure

Manufacture of desiccated coconut

Raw coconuts (maturity ~ 10 months) were procured from RBK farms - Rajapalayam, Tamil Nadu, India. Raw coconut samples were manually de-hulled and shelled. After trimming and splitting, the coconut flesh was chopped into uniform pieces (~ 1 cm) using a mechanical coconut chopper (SoubhaghyaEnterprises, Erode, India). In order to inactivate microorganisms, the chopped coconut was soaked in 50 ppm chlorine solution for 5 min[11]. Subsequently, samples were used for drying trials. A visual examination was also carried out to avoid any foreign matter contamination.

MW drying experimental setup

Microwave drying trials were conducted in a microwave oven (IFB, Model: 30SC3) with outer dimensions 300 × 539 × 438 mm. It consists of a magnetron that generates the microwave energy, a waveguide to carry this energy to the stainless steel oven cavity and a wave stirrer to ensure that the product is uniformly exposed to microwave energy. All drying trials were carried out by using 100 g coconut sample spread uniformly in a thin layer over a dish. The samples were exposed to varying power levels ranging from 180 W – 900 W. All experiments were conducted in triplicate.

Drying kinetics

The initial and final moisture contents of the sample were determined by using standard AOAC procedures [12] and were noted as change in sample weight with respect to the drying time. Moisture content of the coconut (g H_2O/g dry matter) was determined using the Eq. 1:

$$M = \frac{(W_o - W) - W_i}{W_i} \qquad [1]$$

where, M is the moisture content of the coconut (in g H_2O/ g dry matter), W_o is initial weight of sample, W is the amount of water removed, W_i is dry matter present in the sample. Drying rate (R) was calculated using Eq. 2.

$$R = \frac{M_t - M_{t+dt}}{dt} \qquad [2]$$

where, M_t is the moisture content at any time '*t*' and $M_{t+dt}$is the moisture content at time '*t+dt*'. The dimensionless moisture ratio (*MR*) was calculated using Eq. 3.

$$MR = \frac{(M_t - M_e)}{(M_o - M_e)} \quad [3]$$

where, M_t is moisture content of the coconut at specified time (g H_2O/g dry matter); M_o is the initial moisture content and M_e is the EMC (Equilibrium Moisture Content) of the product.

Mathematical modelling of microwave drying

Drying characteristics of a product can be described by using appropriate mathematical models to understand the drying behaviour under various conditions. The changes in drying constant (*k*, min^{-1}), exponent (*n*) and other model coefficients with varying microwave power levels can be described by several empirical models. Drying curves (*MR* versus time) during microwave drying were fitted to eleven models as listed in Table 1. Curve fitting was performed by using non-linear least squares regression analysis based on Levenberg–Marquardt algorithm [13] of MATLAB *ver.* 2010*b*.

Table 1.Various thin layer drying models available in literature.

Sl. no.	Model name	Model Equation	Reference
1	Newton	$MR = exp(-kt)$	O'Callaghan*et al.* (1971)
2	Page	$MR = exp(-kt^n)$	Page (1949)
3	Henderson &Pabis	$MR = a\ exp(-kt)$	Henderson &Pabis (1961)
4	Logarithmic	$MR = a\ exp(-kt) + b$	Yagcioglu*et al.* (1999)
5	Midilli*et al.*	$MR = a\ exp(-kt^n) + b$	Midilli*et al.* (2002)
6	Wang & Singh	$MR = 1 + at + bt^2$	Wang & Singh (1978)
7	Logistic	$MR = b/(1 + a\ exp(kt))$	Chandra & Singh (1995)
8	Two term	$MR = a\ exp(-kt) + b\ exp(-k_1 t)$	Henderson (1974)
9	Verma*et al.*	$MR = a\ exp(-kt) + (1 - a)\ exp(-bt)$	Verma*et al.* (1985)
10	Two-term exponential	$MR = a\ exp(-kt) + (1 - a)\ exp(-kat)$	Sharaf-Elden*et al.* (1980)
11	Diffusion	$MR = a\ exp(-kt) + (1 - a)\ exp(-kbt)$	Yaldiz&Erketin (2001)

where, M_R is the moisture ratio (dimensionless); *k* and $k_1$are drying coefficients (sec^{-1}); *n* is the exponent (dimensionless); *t* is the time (min); *a* and *b* are coefficients (dimensionless) for their corresponding models.

Statistical analysis

Statistical tests were performed to check the validity of the fitted drying model. The goodness of fit was analysed based on the root mean square error (*RMSE*, Eq. 4), residual sum of squares (*RSS*, Eq. 5), Chi-square value (χ^2, Eq. 6) and coefficient of determination (R^2, Eq. 7) values.These parameters can also be used to evaluate the experimental results for selecting the best fit Eq. to describe the microwave drying behaviour of coconut.

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{N}\left(MR_{e,i} - MR_{p,i}\right)^2\right]^{0.5} \quad [4]$$

$$RSS = \sum_{i=1}^{N}\left(MR_{e,i} - MR_{p,i}\right)^2 \quad [5]$$

$$\chi^2 = \frac{\sum_{i=1}^{N}\left(MR_e - MR_p\right)^2}{N - n} \quad [6]$$

$$R^2 = \frac{RSS}{TSS} \qquad [7]$$

where, MR_e is the experimental moisture ratio; MR_p is the predicted moisture ratio; N is the number of experimental data points, n is the number of parameters and TSS is the total sum of squares. The model with the least $RMSE$, RSS and highest regression coefficient (R^2) value is considered to offer the best fit with the idea that the model is able to closely represent experimental data.

Calculation of effective diffusivity

Effective moisture diffusivity is an important parameter to design and model transport processes including dehydration, adsorption and desorption of moisture during subsequent storage [14]. The drying characteristics of biological products in the falling rate period can be described by employing Fick's law of diffusion. Crank [15] employed Fick's law of diffusion Eq. for various geometries including rectangle, cylinder and sphere. Eq. 8 was used to calculate the effective diffusion from drying surface with a slab geometry assuming that the initial moisture distribution was uniform.

$$MR = \frac{8}{\pi^2}\sum_{n=0}^{\infty}\frac{1}{(2n+1)^2}\exp\left(-\frac{(2n+1)^2\pi^2 D_{eff}\, t}{4L_0^2}\right) \qquad [8]$$

where D_{eff} is the effective diffusivity (m^2/s) and L_0 is the half-thickness of slab (m). This may be further simplified to a logarithmic form as Eq. 9 [16].

$$\ln MR = \ln\frac{8}{\pi^2} - \frac{\pi^2 D_{eff}\, t}{4L_0^2} \qquad [9]$$

The effective diffusivities are determined by plotting the experimental drying data in terms of *ln(MR)* versus drying time *t* in Eq. 9. The plot of *ln(MR)* vs.*t* yields a straight line with a slope(Eq. 10), from which the D_{eff} can be calculated.

$$Slope = \frac{\pi^2 D_{eff}}{4\, L_0^2} \qquad [10]$$

Quality of desiccated coconut

Coconut samples dried at various power levels were compared with commercially adapted tray drying process for colour and rehydration ratio. Briefly, coconut samples were dried in a thin layer at $80\pm2^{o}C$ for 155 min. Conventional drying conditions were based on commercially adapted process.

Colour measurement

The colour of the dried product was measured by using a Hunter Colorlab (CR-400, Color Quest XE; Hunter Lab; USA). Colour values were noted as L (lightness to darkness), a (redness to greenness) and b (yellowness to blueness). All measurements were conducted in triplicate. The total change in colour during the drying is expressed as ΔE (Eq. 14).

$$\Delta E = \sqrt{(L_o - L)^2 + (a_o - a)^2 + (b_o - b)^2} \; [14]$$

where L_o, a_o and b_o refer to the hunter color values of fresh coconut. Browning index was calculated by using Eq. 15[17].

$$\mathrm{BI} = \frac{(100(x-0.31))}{0.17} \qquad [15]$$

where

$$x = \frac{(a+1,75L)}{(5.645L+a-3.012b)} \quad [16]$$

Rehydration capacity
For rehydration studies, 2 $\pm$ 0.02 g of dried samples wereimmersed in distilled water (30 $\pm$ 2ºC) and samples were drawn at regular intervals of 10 min.Prior to weighing, sampleswere allowed to drain over a mesh for 1 min to remove surface moisture. Experiments were stopped at the end of 1 h. Moisture content was determined by using standard AOAC procedure [12].Rehydration curve obtained was fitted to the Peleg's model (Eq. 17) [18].

$$M = M_0 + \frac{t}{s_1 + s_2\, t} \quad [17]$$

where $M$is the moisture content at a specific time (g/g d.b.) during rehydration, $M_0$is the initial moisture content (g/g d.b.), $t$is the rehydration time (s), $k_1$is the kinetic rate constant (s.(g d.b./g)) and $k_2$is the characteristic constant of the model (g d.b./g). If the rehydration time is sufficiently long, the equilibrium moisture content (M_e) can be expressed using Eq. 18.

$$M_e = M_0 + \frac{1}{s_2} \quad [18]$$

The residual (SSR) and estimated variance of error are calculated using Eq. 19 and Eq. 20 respectively.

$$SSR = \sum_{i=1}^{N}\left(R_{e,i} - R_{p,i}\right)^2 \quad [19]$$

$$\sigma^2 = \frac{(\mathrm{SSR})_{\min}}{m-p} \quad [20]$$

where, $R_{e,i}$ and $R_{p,i}$are the expected and predicted values, *m* is the observation number and *N* is the total number of observations.

Results and Discussion

Analysis of drying curves
The moisture content versus time curves for microwave drying of coconut as influenced by varying microwave power levels was studied. For a reduction in moisture content from 55% w.b. to around 5% w.b., it took about 7-27 min at power levels ranging from 180 – 900W. A significant reduction ($p<0.05$) in drying time was observed with an increase in microwave power from 180 to 900 W. During drying, 'oil spitting'; which is the phenomenon of oil seepage to the coconut's surface is known to interfere with the drying rates [19]. Drying rates calculated as the quantity of moisture removed per unit time per unit weight of dry of matter (kg H_2O/ kg dry matter sec) were significantly influenced by applied microwave output power. The drying rate curves for coconut dried at varying microwave output powers are presented in Figure 1. Peak drying rate value was found to increase from 0.06 at 180 W to 0.29 kg H_2O/ kg dry matter.sec at 900 W, respectively. A rapid reduction in drying rates with a reduction in moisture content can be justified by the fact that microwave power absorption and subsequent heating depends on the moisture content of the product. Similar findings were also reported for microwave drying of banana[17]. Heat generation within the product that creates vapour pressure differences between the product surface and core is a characteristic feature of microwave volumetric heating [20]. Hence at higher microwave output power levels (540 W, 720 W and 900 W), the constant drying rate period was less compared to other periods of drying curve as shown in Figure 2. Similar reduction in constant drying rate period is reported during microwave drying of tomato pomace[21]. Sourаki*et al.*, [22] explained this

phenomenon as a lowering in microwave drying efficiency at lower microwave output power levels with lowering moisture content that does not allow the development of isothermal drying conditions.

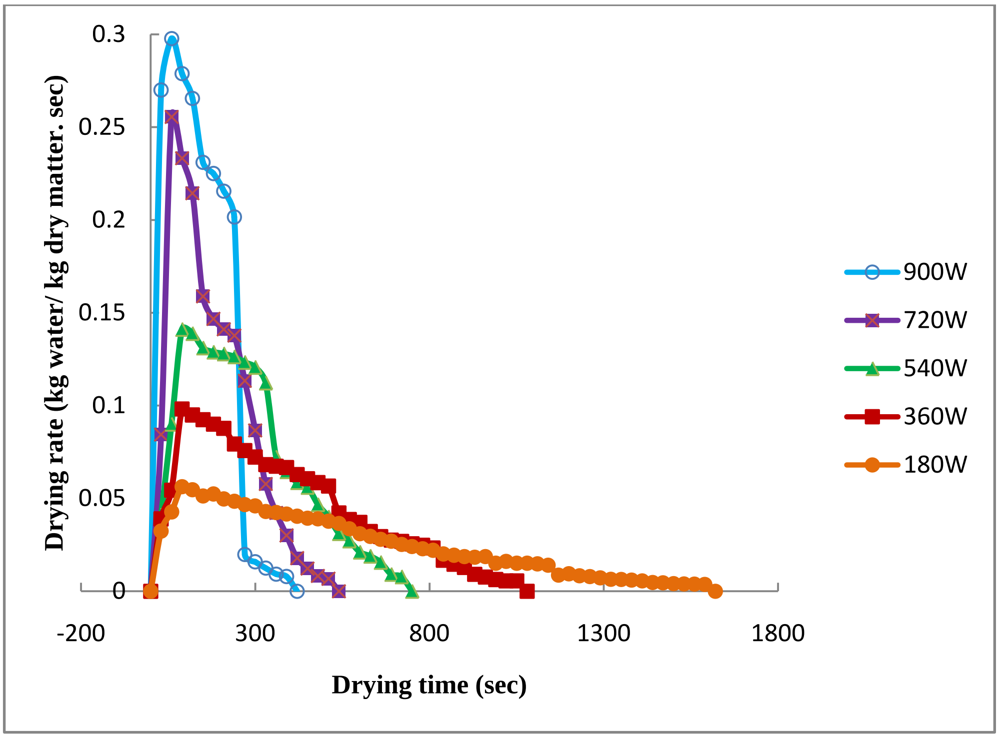

Figure 1. Change in drying rate during microwave drying of coconut.

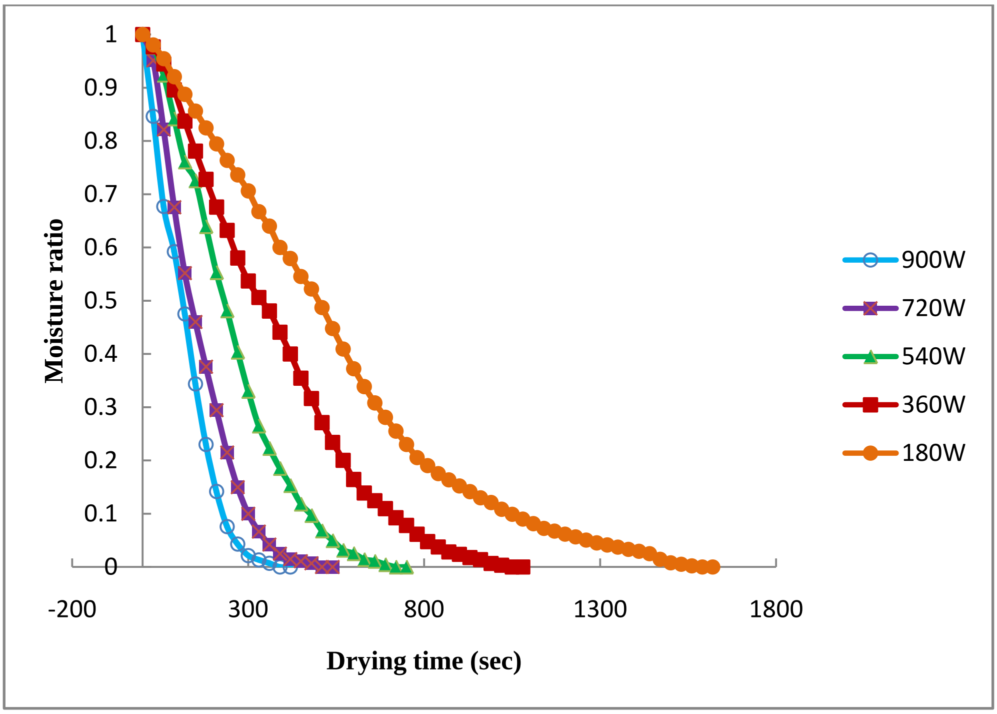

Figure 2. Change in moisture ratio during microwave drying of coconut.

Modelling drying curves

Figure 3 shows the changes in moisture ratio with drying time for different microwave output power levels. Model parameters for various mathematical models are presented in Table 2. The drying rate constant '*k*' is observed to be directly proportional to the microwave output power. Similar results were observed by Drouzas*et al.*, [23] during microwave drying of model fruit gels.This further explains the steeper drying curves with increasing microwave power levels as shown in Figure 3. Table 2 shows that most models showed higher R^2 values (R^2>0.90). However, theMidilli*et al.*, [24] model was found to be the best to describe the drying kinetics of coconut in a microwave environment. This is because of high R^2 values (R^2> 0.99), low RMSE values (RMSE<0.026) and χ^2 values below 0.001 for all drying curves. The Midillimodel was also found to best describe the microwave drying behaviour of other agricultural products such as parsley [25] and mint leaves [26].

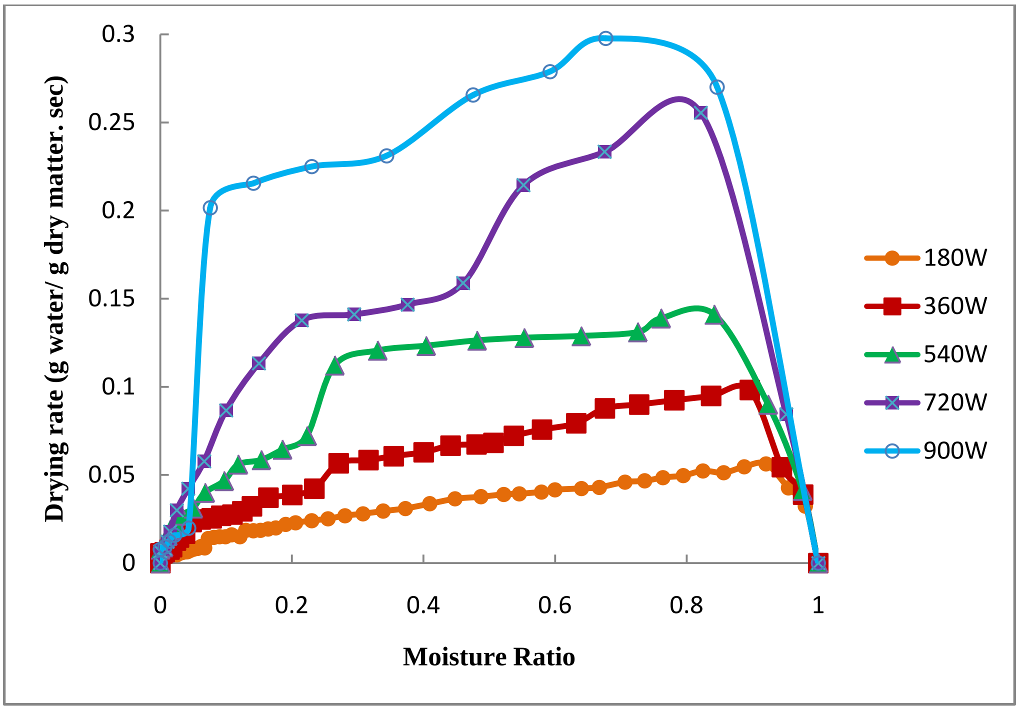

Figure 3. Change in drying rate versus moisture ratio.

Table 2.Coefficients of various models for thin layer microwave drying of coconut.

Microwave Power (W)		180	360	540	720	900
Model	**Newton**					
Model constants	*k*	1.75E-03	2.53E-03	3.72E-03	6.01E-03	7.89E-03
Statistical parameters	R^2	0.9843	0.9840	0.9782	0.9852	0.9813
	SSE	0.2506	0.1851	0.1801	0.0822	0.0543
	RMSE	0.0681	0.0717	0.0849	0.0676	0.0623
	χ^2	1.40E-03	1.20E-03	6.00E-04	1.90E-03	4.40E-03
Model	**Page**					
Model constants	*k*	6.41E-05	1.09E-04	7.95E-05	4.09E-04	9.21E-04
	n	1.5090	1.5121	1.6711	1.5080	1.4248
Statistical parameters	R^2	0.9982	0.9970	0.9992	0.9988	0.9940
	SSE	0.0100	0.0128	0.0026	0.0028	0.0108
	RMSE	0.0137	0.0191	0.0104	0.0128	0.0288

	χ^2	0.0037	0.0033	0.0004	0.0003	0.0032
Model	**Henderson and Pabis**					
Model constants	*k*	1.97E-03	2.84E-03	4.24E-03	6.64E-03	8.38E-03
	a	1.1366	1.1342	1.1550	1.1196	1.0720
Statistical parameters	R^2	0.9767	0.9751	0.9682	0.9791	0.9769
	SSE	0.1530	0.1167	0.1131	0.0537	0.0455
	RMSE	0.0537	0.0577	0.0686	0.0562	0.0591
	χ^2	0.0272	0.0221	0.0209	0.0145	0.0125
Model	**Logarithmic**					
Model constants	*k*	1.38E-03	1.81E-03	2.78E-03	5.02E-03	6.18E-03
	a	1.2525	1.3035	1.3178	1.2069	1.1717
	b	-0.1715	-0.2324	-0.2198	-0.1252	-0.1353
Statistical parameters	R^2	0.9895	0.9929	0.9859	0.9892	0.9884
	SSE	0.0589	0.0279	0.0425	0.0229	0.0187
	RMSE	0.0337	0.0287	0.0430	0.0379	0.0395
	χ^2	0.0000	0.0000	0.0000	0.0000	0.0000
Model	**Midilli*et al.***					
Model constants	*k*	4.26E-05	1.53E-04	8.26E-04	5.20E-04	8.29E-04
	n	1.5670	1.4440	1.6600	1.4600	1.4312
	a	0.9755	0.9917	0.9943	1.0070	0.9724
	b	-1.59E-06	-3.74E-05	-1.42E-05	-2.60E-05	-6.06E-05
Statistical parameters	R^2	**0.9987**	**0.9983**	**0.9993**	**0.9990**	**0.9951**
	SSE	**0.0075**	**0.0067**	**0.0020**	**0.0022**	**0.0079**
	RMSE	**0.0121**	**0.0143**	**0.0096**	**0.0121**	**0.0267**
	χ^2	**0.0004**	**0.0005**	**0.0002**	**0.0004**	**0.0018**
Model	**Wang and Singh**					
	a	-1.30E-03	-1.80E-03	-2.70E-03	-4.40E-03	-5.70E-03
	b	4.21E-07	8.35E-07	1.81E-06	4.73E-06	7.97E-06
Statistical parameters	R^2	0.9950	0.9972	0.9925	0.9963	0.9968
	SSE	0.0459	0.0220	0.0416	0.0136	0.0058
	RMSE	0.0294	0.0251	0.0416	0.0282	0.0211
	χ^2	0.0164	0.0100	0.0150	0.0069	0.0016
Model	**Logistic**					
Model constants	*k*	1.17E-03	1.69E-03	9.23E-03	1.05E-02	1.06E-02
	a	-2.2651	-2.2928	0.1282	0.4726	2.8066
	b	-1.1941	-1.2090	1.0555	1.4902	4.4638
Statistical parameters	R^2	0.9743	0.9743	0.9978	0.9982	0.9940
	SSE	0.5458	0.4050	0.0163	0.0081	0.0108
	RMSE	0.1024	0.1091	0.0266	0.0225	0.0288

	χ^2	0.0061	0.0063	0.0025	0.0025	0.0277
Model	**Two term**					
Model constants	*K*	1.9	2.84E-03	4.24E-03	6.64E-03	8.38E-03
	a	0.7548	0.5569	0.9052	0.9621	0.8104
	b	0.3819	0.5773	0.2497	0.1574	0.2617
	k_1	1.97E-03	2.84E-03	4.24E-03	6.64E-03	8.39E-03
Statistical parameters	R^2	0.9767	0.9751	0.9682	0.9791	0.9769
	SSE	0.1530	0.1167	0.1131	0.0537	0.0455
	RMSE	0.0548	0.0595	0.0717	0.0598	0.0643
	χ^2	0.0272	0.0222	0.0209	0.0145	0.0125
Model	**Verma*et al.***					
Model constants	*k*	3.89E-03	4.82E-03	1.07E-03	1.28E-02	1.54E-02
	a	-6.2851	7.5615	-3.0953	-15.2450	-13.8180
	b	3.37E-03	5.53E-03	1.50E-03	1.20E-02	1.45E-02
Statistical parameters	R^2	0.9968	0.9950	0.9839	0.9981	0.9925
	SSE	0.0199	0.0232	0.0631	0.0049	0.0139
	RMSE	0.0195	0.0261	0.0524	0.0175	0.0340
	χ^2	0.0046	0.0068	0.0047	0.0016	0.0044
Model	**Two term exponential**					
Model constants	*k*	0.5728	8.1553	11.4330	20.9201	0.0115
	a	0.0030	3.10E-04	3.20E-04	2.90E-04	1.9116
Statistical parameters	R^2	0.9842	0.9840	0.9782	0.9853	0.9914
	SSE	0.2551	0.1854	0.1804	0.0823	0.0164
	RMSE	0.0694	0.0728	0.0867	0.0696	0.0356
	χ^2	0.0012	0.0014	0.0083	0.0020	0.0056
Model	**Diffusion approximation**					
Model constants	*k*	3.71E-03	5.28E-03	8.29E-03	1.27E-02	1.53E-02
	a	-16.5490	-25.8140	-31.2960	-24.8810	-15.4480
	b	0.9442	0.9637	0.9655	0.9611	0.9482
Statistical parameters	R^2	0.9968	0.9949	0.9968	0.9980	0.9925
	SSE	0.0196	0.0230	0.0117	0.0049	0.0139
	RMSE	0.0194	0.0260	0.0225	0.0175	0.0340
	χ^2	0.0045	0.0059	0.0045	0.0014	0.0045

Effective diffusivity

The effective moisture diffusivity was determined by the method of slopes. The logarithm of moisture ratio values (*ln(MR)*), were plotted against microwave drying time (*t*). The relationship between *ln (MR)* and drying time (*t*) is show in Figure4 for drying at various microwave output powers. The effective moisture diffusivity values (D_{eff}) obtained by using Eq. 10 is presented in

Table 3. A steady increase was noted with increasing microwave output power levels due to higher mass transfer efficiency.

Table 3.Effective diffusivities at different microwave power levels.

Power (W)	D_{eff} (m^2/s)
180	3.03719 x 10^{-08}
360	4.8595 x 10^{-08}
540	7.28926 x 10^{-08}
720	10.8326 x 10^{-08}
900	14.2748 x 10^{-08}

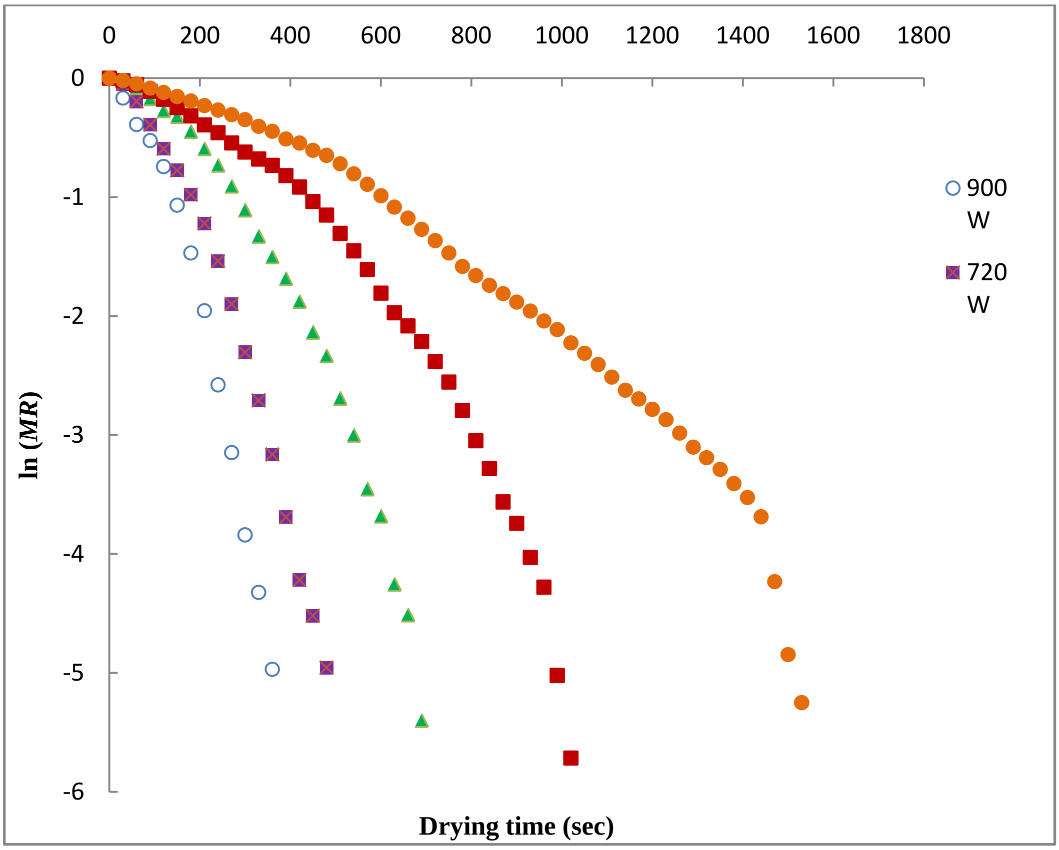

Figure 4.Relationship between ln (*MR*) and drying time at different microwave power levels.

Quality of desiccated coconut (DC)

Effect of drying on colour parameters

DC colour is a primary factor considered by the consumer in assessing the quality and acceptability. A significant change in all the colour parameters (*L*, *a*and *b*) were observed due to microwave dryingas shown in Table 4. The overall colour change (*ΔE*) with respect to the fresh coconut sample, showed an increase with an increase in microwave power levels, with a maximum of 11.74 at 900 W.Colour values closest to that of fresh coconut were obtained at 180 W and 360 W. This could be because of the fact that the phenomena of surface overheating are restricted at lower microwave output power levels. Conventionally dried coconut showed higher values of *ΔE*.Product discolouration may be due to pigment degradation, enzymatic and/or non-enzymatic Maillard browning. In the present study, the reduction in *L* values can be considered as a measure of browning [27]. The BI which denotes the intensity of brown colourwas found to increase from 8.82 to 24.07 with an increase in the power level from 180 W to 900 W respectively.

Table 4.Changes in hunter colour values during different drying conditions.

Treatment	*L*	*a*	*b*	*BI*	*ΔE*
180W	86.82[b]	0.17[g]	7.44[f]	8.89[f]	4.59[f]
360W	84.63[c]	0.74[e]	8.62[e]	11.13[e]	6.45[e]
540W	82.20[d]	1.88[d]	10.21[d]	14.64[d]	9.24[d]
720W	79.03[e]	2.96[b]	12.19[b]	19.16[b]	12.92[b]
900W	76.46[g]	4.33[a]	14.07[a]	24.10[a]	16.30[a]
TD*	78.44[f]	2.77[c]	11.04[c]	17.43[c]	12.51[c]
Fresh sample	87.71[a]	0.47[f]	2.96[g]		
LSD	0.0887	0.0602	0.067	0.106	0.053

* tray dried sample used to compare the quality
[abcdefg]Values followed by same alphabets are not significantly different at $P < 0.05$

Effect of drying on rehydration capacity

The rehydration capacity (*RC*) of a dried product is also considered as one of the importantquality indices[28] because it denotes the physical and chemical changes that occurred in the sample during drying. As can be seen from Figure 5, the moisture uptake of microwave-dried coconut increased with an increase in power level. Nonetheless, the moisture content of microwave dried coconut did not reach to its original moisture content due to the loss in rehydration capacity during the drying process [29]. This may be explained by the structural damage due to rapid drying at higher microwave output powers. Table 5 shows reduction in Peleg's model [17] constant k_1 and k_2 with increasing microwave power levels. The equilibrium moisture content of the samples increased as the microwave output power increased. However, the rehydration capacity of conventionally dried sample was lower than samples dried at higher microwave power levels.

Table 5. Estimated model parameters and statistical analysis of Peleg's model for rehydration at 30°C (for coconut samples dried under different drying conditions).

Model	Treatment	Model parameters			Statistical parameters		
		s_1	s_2	$*M_e$	*SSR*	*σ*	R^2
Peleg's equation	**180 W**	8.5783	1.7172	4.7323	0.0187	0.0017	0.9331
	360 W	5.4284	1.5570	4.7922	0.0110	0.0010	0.9675
	540 W	4.9721	1.2241	4.9669	0.0097	0.0009	0.9818
	720 W	4.0483	1.0538	5.0988	0.0203	0.0018	0.9723
	900 W	3.8106	0.8544	5.3203	0.0291	0.0026	0.9731
	TD**	26.8050	0.7810	5.4303	0.0033	0.0003	0.9958

*calculated from Eq. 18. ** refers to the tray dried sample

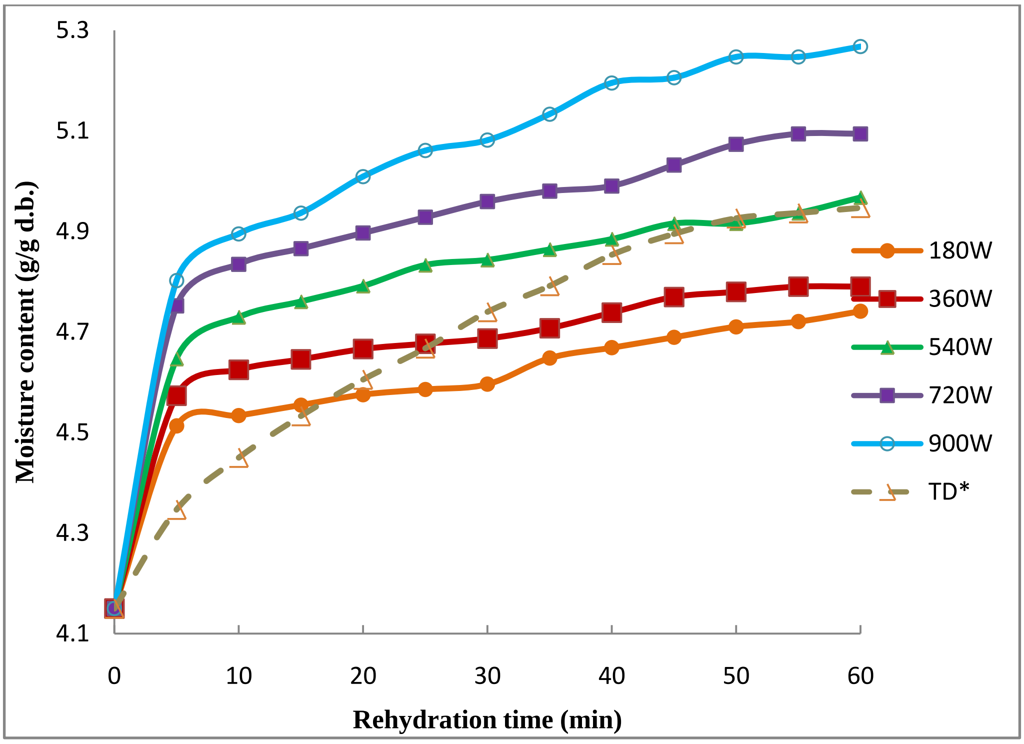

Figure 5.Rehydration capacity of dried product at room temperature.

Conclusion

Based on the results obtained, the following conclusions were made:

- Microwave power absorption and subsequent heating of product is directly proportional to the applied power level. Higher power levels are characterised with higher drying coefficient (*k*) values and hence higher drying rates.
- At higher microwave output power levels, the constant drying rate period is less evident.
- Midilli model gave the best fit for all experimental data points.
- Effective diffusivity values showed an increasing trend with rising microwave output power levels.
- Overall changes in the dried product's colour (with respect to the colour of fresh coconut) were minimal at lower power levels.
- Rehydration capacity of samples dried at higher microwave power levels are higher than those dried at lower microwave output power levels and the conventionally dried sample.
- Further research is required to study the effect of varying sample mass and the effect of microwave energy on the product's oil quality.

References

1. FAO (2011).FAOSTAT database. *Food Balance Sheets*.

2. Niamnuy, C. and Devahastin, S. (2005). Drying kinetics and quality of coconut dried in a fluidized bed dryer. ***Journal of Food Engineering,*** 66(2), 267-271.

3. Kumar, S., Senanayake, G., Visvanathan, C. and Basu, B. (2003). Desiccated coconut industry of Sri Lanka: opportunities for energy efficiency and environmental protection. ***Energy Conversion and Management,*** 44(13), 2205-2215.

4. Yaldiz, O., Ertekin, C. and Uzun, H.I. (2001).Mathematical modeling of thin layer solar drying of sultana grapes.***Energy,*** 26(5), 457-465.

5. 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(1), 44-52.

6. Murthy, T.P.K. and Manohar, B. (2012).Microwave drying of mango ginger (*Curcuma amada*Roxb): prediction of drying kinetics by mathematical modelling and artificial neural network.***International Journal of Food Science and Technology,*** 47(6), 1229–1236.

7. Gowen, A.A., Abu-Ghannam, N., Frias, J. and Oliveira, J. (2008). Modeling dehydration and rehydration of cooked soybeans subjected to combined microwave–hot-air drying. ***Innovative Food Science and Emerging Technologies,*** 9(1), 129-137.

8. Moreira, R., Chenlo, F., Chaguri, L. and Vázquez, G. (2005). Mathematical modelling of the drying kinetics of chestnut (*CastaneaSativa Mill.*): Influence of the natural shells. ***Food and Bioproducts Processing,*** 83(4), 306-314.

9. Doymaz, I., Gorel, O. and Akgun, N.A. (2004).Drying characteristics of the solid by-product of olive oil extraction.***Biosystems Engineering,*** 88(2), 213-219.

10. Vadivambal, R. andJayas, D.S. (2007). Changes in quality of microwave-treated agricultural products—a review.***Biosystems Engineering,*** 98(1), 1-16.

11. Niamnuy, C. and Devahastin, S. (2005). Effects of geometry and operating conditions on the mixing behavior of an in-line impinging stream mixer.***Chemical Engineering Science,*** 60(6), 1701-1708.

12. AOAC (2000). Official methods of analysis of AOAC International (17th ed.).Washington, DC: AOAC International.

13. Marquardt, D.W. (1963). An algorithm for least-squares estimation of nonlinear parameters. ***Journal of the Society for Industrial & Applied Mathematics,*** 11(2), 431-441.

14. Pathare, P.B. and Sharma, G.P. (2006). Effective moisture diffusivity of onion slices undergoing infrared convective drying. ***Biosystems Engineering,*** 93(3), 285-291.

15. Crank, J. (1975). The mathematics of diffusion, Clarendon.

16. Tütüncü, M.A. and Labuza, T.P. (1996).Effect of geometry on the effective moisture transfer diffusion coefficient. ***Journal of Food Engineering,*** 30(3), 433-447.

17. Maskan, M. (2001).Kinetics of colour change of kiwifruit during hot air and microwave drying. ***Journal of Food Engineering,*** 48(2), 169-175.

18. Peleg, M. (2006). An empirical model for the description of moisture sorption curves**. *Journal of Food Science,*** 53(4), 1216-1217.

19. Fernando, W.J.N. andThangavel, T. (1987).Vacuum drying characteristics of coconut. ***Drying Technology, ****5*(3), 363-372.

20. Wang, J. and Sheng, K. (2006).Far-infrared and microwave drying of peach.***LWT-Food Science and Technology,*** 39(3), 247-255.

21. Al-Harahsheh, M., Al-Muhtaseb, A.A.H. and Magee, T.R.A. (2009). Microwave drying kinetics of tomato pomace: Effect of osmotic dehydration. ***Chemical Engineering and Processing: Process Intensification,*** 48(1), 524-531.

22. Souraki, B.A., Andres, A. and Mowla, D. (2009).Mathematical modeling of microwave-assisted inert medium fluidized bed drying of cylindrical carrot samples. ***Chemical Engineering and Processing: Process Intensification,*** 48(1), 296-305.

23. Drouzas, A.E., Tsami, E. and Saravacos, G.D. (1999). Microwave/vacuum drying of model fruit gels. ***Journal of Food Engineering,*** 39(2), 117-122.

24. Midilli, A., Kucuk, H. and Yapar, Z. (2002).A new model for single-layer drying.***Drying Technology,*** 20(7), 1503-1513.

25. Soysal, Y., Öztekin, S. and Eren, Ö. (2006). Microwave drying of parsley: Modelling, kinetics, and energy aspects. ***Biosystems Engineering,*** 93(4), 403-413.

26. Özbek, B. andDadali, G. (2007).Thin-layer drying characteristics and modelling of mint leaves undergoing microwave treatment. ***Journal of Food Engineering,***83(4), 541-549.

27. Ibarz, A., Pagan, J. and Garza, S. (1999). Kinetic models for colour changes in pear puree during heating at relatively high temperatures. ***Journal of Food Engineering,*** 39(4), 415-422.

28. McMinn, W.A.M. and Magee, T.R.A. (1997).Quality and physical structure of a dehydrated starch-based system. ***Drying Technology,*** 15(6-8), 1961-1971.

29. Krokida, M.K. and Philippopoulos, C. (2005).Rehydration of dehydrated foods.***Drying Technology,*** 23(4), 799-830.