Modeling the carrot slices (*daucus carota*) drying characteristics using microwave oven

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Abstract: A study of the effects of Microwave drying of carrot slices was carried out. The samples were dried from moisture content of 70.71 to 10.7% (wb). Empirical models were developed for predicting the drying kinetics of the Carrot slices at different microwave powers and slice thicknesses. The drying curves were graphically used to present the relationships between moisture ratio and time of drying. The following fit parameters were obtained using Henderson and Pabis model: coefficient of determination (R^2) from 0.8729 to 0.9531, error sum of squares (SSE) ranging from 0.0212 to 0.07875, and root mean square error (RMSE) from 0.05504 to 0.08461. Fourier model gave a better fit with the following parameters: coefficient of determination (R^2) from 0.9991 to 1.000, error sum of squares (SSE) ranging from 0.000121 to 0.001034, and root mean square error (RMSE) from 3.32×10^{-03} to 0.02274. Effective moisture diffusivity (D_e) ranged from 9.7422×10^{-10} to 1.9962×10^{-09} m^2 s^{-1} while the drying constant (k) ranged from 5.7×10^{-05} to 0.00022 s^{-1}. Fourier model was therefore suggested as a very suitable method for predicting the drying characteristics of the carrot slices.

Keywords: carrot, microwave, drying characteristics, drying characteristics, moisture diffusivity

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1 Introduction

Carrot (*Daucus carota*), family (*Apiaceae*) is a dicotyledonous plant that belongs to the Apiaceae family. According to FAOSTAT (2016), the global carrot and turnips production in 2014 was estimated to be about 38.8 million tones, with China being the world's leading carrot producing country for many years, with 45% of the global carrot production coming from China. Nigeria ranked 31st among the world's carrot production with annual production of about 229,334 tones, harvested area of 26,182 hectares and yields of 0.8 t/ha (FAOSTAT, 2016).

In Nigeria, carrot is widely cultivated in the northern parts such as Zaria, Sokoto, Kano, and Jos. It can be eaten whole or used in salads, fried rice, Preparation of soups, beverages, wine, stews, curries, pies and jam as blended agents as reported by Lingappa and Naik (1997). Carrot is one of the most important sources of carotenoids, and has a reputation as a help in maintaining eye health (Olalude et al., 2015). It contains appreciable amounts of vitamins, minerals, dietary fibre (Doymaz, 2004; Prakash et al., 2004), and the highest β-carotene among human foods which is a precursor of vitamin A (Bao and Chang, 1994; Berger et al., 2008; O'neil et al., 2001; Bureau and Bushway, 1986).

Drying plays important role in preservation of crops nutrients and viability by removing the moisture that bacteria, yeasts and enzymes need to live. The primary disadvantage is the reduction of some heat-sensitive nutrients.

A number of researches have been published on the effects of drying on the nutritional quality of heat sensitive nutrients such as Ascorbic acid (Vitamin C) and thiamin (Fennema, 1982). Donald (2014) reported that the best method of drying carrots was to cut them cross-wise into thin slices, which exposed a great deal of surface area to the effects of the heated air blowing across them in the dryer. Reiger et al. (2005) reported that the drying temperature below 70ºC and 90ºC had stability for

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β-Carotene and lycopene retention during the dehydration process.

Wei et al. (2010), reported on three different combined microwave drying methods of carrot pieces in terms of drying rate, drying uniformity, product colour, rehydration ratio, retention of β-carotene, vitamin-C and energy consumption. Microwave-enhanced spouted bed dryer and microwave vacuum dryer produced the best results for all the factors above. The solar cabinet drier retained the least quantities of β-carotene content during dehydration of carrots as compared to fluidized bed and microwave drying (Prakash et al., 2004).

Babak et al. (2014) carried out an investigation of microwave application in drying agricultural products. Their research findings showed that increasing microwaves power caused drying time to considerably reduce and drying rate to increase. Minimum drying time, according to their findings, occurs in the highest microwave power. However, they observed that the quality of products can be impaired by high microwave power.

In order to achieve optimal quality in dried carrot, there is need to develop models that will optimize drying conditions under any chosen method. Therefore, the objectives of this paper are to develop models for predicting the drying characteristics of carrot, and to investigate the effect of drying conditions of microwave oven on β-Carotene and Vitamin C in carrot slices.

2 Materials and methods

2.1 Sample preparation

Carrot (*Daucus carota*) for the experiments was procured peeled and washed in lukewarm water as suggested by Manaa et al. (2013) to avoid risk of losing their nutritional properties that were lost during peeling. The samples were subsequently sliced with sharp stainless table knife into thicknesses of 3 mm, 4 mm and 6 mm.

2.2 Description of experiment

The experiments and tests, including proximate analysis, were carried out in the Central Analytical Laboratory of Nigeria Institute for Oil-palm Research (NIFOR), Benin City from February to March 2018. The drying experiments were carried out in microwave oven at microwave powers of 90 W, 100 W and 120 W and three slice thicknesses of 3 mm, 4 mm and 6 mm.

2.3 Method of drying

One hundred forty gram of sample of carrot slices of thickness, 3 mm, 4 mm and 6 mm was used for the drying experiment while 70 g was used for the moisture content determination in three replicates. The drying process was monitored every 30 mins and the weight of the drying samples were obtained using electronic balance of 0.001 g accuracy. Before weighing, the samples were allowed to cool in the desiccators to avoid moisture re-absorption and buoyancy effect on the weighing balance. The weights were measured and recorded until a steady weight was reached. These were repeated for the three microwave powers for each slice thickness.

2.4 Proximate analysis

The proximate analysis was conducted to determine the quantities of Moisture, β-carotene and vitamin-C in the samples before and after the drying experiments according to AOAC (1984), Bakare (1985), Tell and Magarty (1984) and Onyeonwu (2000).

2.5 Drying kinetic models

Matlab soft ware was used in the data analysis and curve fitting. Fourier and exponential models were successfully employed in fitting the experimental data. The drying curves were plotted using data obtained from the drying experiments. These curves were subsequently used in determining the drying characteristics of the samples. The models' goodness of fit were estimated based on RSME, SSE and R^2.

2.6 Determination of moisture diffusivity

The coefficient of moisture diffusion (D_{eff}) is an index of mass transfer in drying process (Sacilik, 2007). The one term solution of fick's diffusion equationand Henderson and pabis equations are presented in Equations (1) and (2) and wereused to estimate the effective diffusion coefficient (D_{eff}) as shown in Equation 3.

$$MR = \frac{8}{\pi} e^{-\frac{\pi^2 D_e}{L^2}} t \quad (1)$$

$$f(t) = MR = A^*\exp(k^*t) \quad (2)$$

where, t is the drying time; A is the pre-log factor; k is drying rate constant and L is half the slice thickness of drying sample. Comparing Equations (1) and (2) it is easy to see that $A=\frac{8}{\pi}$, and $k=\frac{\pi^2 D_{eff}}{L^2}$, therefore making D_{eff} is expressed as shown in Equation (3).

$$D_{eff}=\frac{kL^2}{\pi^2} \tag{3}$$

2.7 Determination of drying rate constant

The experimental data were plotted and Matlab toolbox was used in performing curve fitting analysis. Exponential and Fourier's models fitted the data most adequately with good fit parameters. The drying constants (k) were determined by rearranging Equation (3) and making k the subject of the expression as shown in Equation (4).

$$k=\frac{\pi^2 D_e}{L^2} \tag{4}$$

2.8 Effects of drying on nutrients availability

Data collected from the proximate analyses of the samples before and after drying were analyzed using general factorial design of Design Expert. The experiments were designed in split plot factorial design at three levels of microwave power of 90, 100, 120 W and three levels of thickness; 3 mm, 4 mm, 6 mm. The response variables were β-carotene and Vitamin-C content.

3 Results and discussion

3.1 Drying curve fitting

Drying curves comprise the plots the moisture ratio, (MR) against drying time, (t) at microwave powers of 90 W, 100 W and 120 W and shown in Figures 1, 2 and 3 respectively. Curve fitting analyses were performed using Matlab tool box to develop appropriate empirical models that describe the drying characteristics of the chips. The drying curves show that most part of the drying visibly took place in the falling rate period (Figures 1 to 3). This trend can be attributed to decreasing surface moisture as drying time increases, which was as a result of the longer time it took moisture to travel from the interior to replace the fast surface water evaporation as drying progressed. This phenomenon has been widely reported for agricultural products and other similar porous materials (Pathare and Sharma, 2006).

The exponential and Fourier models have very good fit parameters of R^2, SSE and RMSE. The constants and goodness of fit of Henderson and Pabis (exponential) models are presented in Table 1. The drying constant and moisture diffusivity are presented in Table 2.

3.3 Moisture diffusivity

The results of drying constants and effective moisture diffusivity are presented in Table 2. The effective moisture diffusion of Carrot varied from 1.9962×10^{09} to 3.05484×10^{-09} m^2 s^{-1}.

Fourier models and their constants are presented in Table 3 and the goodness of fit parameters are presented in Table 4.

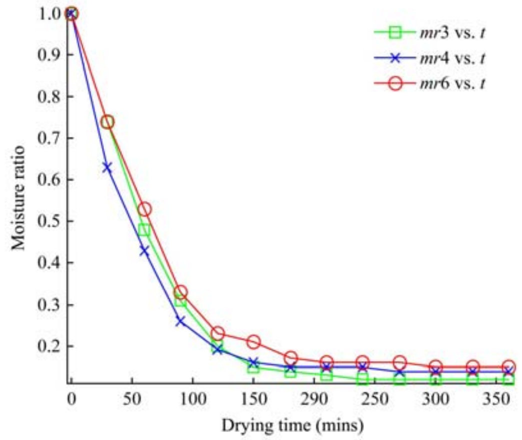

Figure 1 Moisture ratio against time at microwave power of 90 W

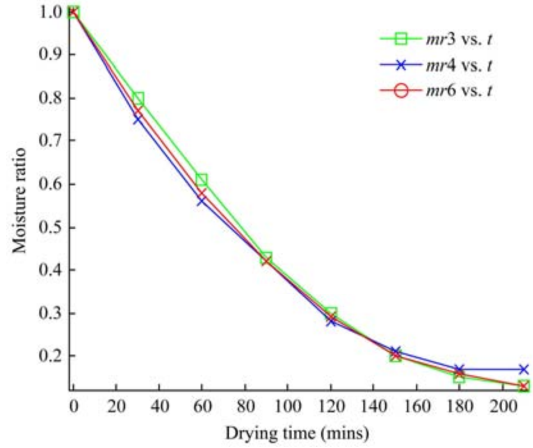

Figure 2 Moisture ratio against time at microwave power of 100 W

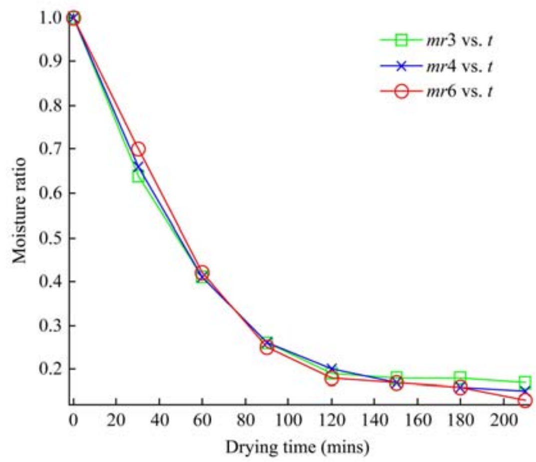

Figure 3 Moisture ratio against time at microwave power of 120 W

Table 1 Exponential model of microwave drying of carrot slices at different microwave power and thickness

Parameters			Coefficients		Goodness of fit		
Power (W)	ST (mm)	Model expression	A	B	SSE	R^2	RMSE
90	3	$F(x) = a*\exp(b*x)$	0.9163	–0.00475	0.04023	0.8903	0.07581
100	3	$F(x) = a*\exp(b*x)$	0.8884	–0.00479	0.05362	0.8739	0.08187
120	3	$F(x) = a*\exp(b*x)$	0.9838	–0.01102	0.04514	0.9531	0.06406
90	4	$F(x) = a*\exp(b*x)$	0.9654	–0.00647	0.03543	0.9325	0.07115
100	4	$F(x) = a*\exp(b*x)$	0.9036	–0.00452	0.05333	0.8729	0.08165
120	4	$F(x) = a*\exp(b*x)$	0.9269	–0.011	0.07875	0.9034	0.08461
90	6	$F(x) = a*\exp(b*x)$	0.9654	–0.00545	0.0212	0.9531	0.05504
100	6	$F(x) = a*\exp(b*x)$	0.9094	–0.00484	0.04225	0.9043	0.07267
120	6	$F(x) = a*\exp(b*x)$	0.9543	–0.00919	0.06093	0.9351	0.07442

Table 2 Drying constants and diffusion coefficient for different microwave powers and slice thickness

microwave power (W)	Slice Thickness (mm)	Drying constant (s^{-1})	Diffusion coefficient ($m^2\ s^{-1}$)
90	3	–0.00017	2.26242E-09
	4	–0.00016	1.9962E-09
	6	–0.00017	3.05484E-09
100	3	–0.00021	2.86332E-09
	4	–0.00021	2.5938E-09
	6	–0.00022	3.96978E-09
120	3	–5.7E-05	7.7946E-10
	4	–5.2E-05	6.3366E-10
	6	–5.3E-05	9.7422E-10

Table 3 Fourier model of microwave drying of carrot at different microwave power and thickness

Fourier Model expression: $mr = a_0 + a_1*\cos(x*w) + b_1*\sin(x*w) + ... + a_5*\cos(5*x*w) + b_5*\sin(5*x*w)$

Parameter		Coefficients									
Power (W)	ST (mm)	a_0	a_1	a_2	a_3	a_4	b_1	b_2	b_3	b_4	w
90	3	0.4657	0.4516	0.09488	–0.01134		–0.2746	–0.2125	–0.04958		0.009711
100	3	0.3208	0.7299	–0.05105			–0.2366	–0.3893			0.006317
120	3	–2.62E+08	3.50E+08	–8.75E+07			1.21E+06	–6.05E+05			–4.75E-05
90	4	7.76E+08	–1.23E+09	5.99E+08	–1.64E+08	1.91E+07	1.69E+08	–1.67E+08	7.09E+07	–1.16E+07	–0.00072
100	4	3.80E+06	–5.06E+06	1.27E+06			7.82E+04	–3.90E+04			–0.00014
120	4	0.8161	3.46E-01	–1.62E-01			–7.98E-01	–1.43E-01			0.01133
90	6	0.4771	4.31E-01	9.82E-02	–0.0088		–2.30E-01	–1.87E-01	–0.04286		0.01028
100	6	–1.09E+06	1.46E+06	–3.64E+05			1.21E+06	–6.05E+05			–0.00017
120	6	0.5363	4.41E-01	2.30E-02			–3.26E-01	–1.71E-01			0.0138

Where mr = moisture ratio.

Table 4 Fourier model fit parameters for microwave of carrot

Power (W)	ST (mm)	Model expression	SSE	R^2	RMSE
90	3	$a_0+a_1*\cos(t*W)+\ldots+b_2*\sin(3*t*W)$	0.000127	0.9999	0.005046
100	3	$a_0+a_1*\cos(t*W)+\ldots+b_2*\sin(2*t*W)$	4.43E-05	0.9999	0.004708
120	3	$a_0+a_1*\cos(t*W)+\ldots+b_2*\sin(2*t*W)$	8.06E-05	0.9999	6.35E-03
90	4	$a_0+a_1*\cos(t*W)+\ldots+b_2*\sin(4*t*W)$	0.000307	0.9996	0.01012
100	4	$a_0+a_1*\cos(t*W)+\ldots+b_2*\sin(2*t*W)$	0.000301	0.9995	0.01227
120	4	$a_0+a_1*\cos(t*W)+\ldots+b_2*\sin(2*t*W)$	2.57E-05	1	0.003583
90	6	$a_0+a_1*\cos(t*W)+\ldots+b_2*\sin(3*t*W)$	0.0009	0.999	0.01342
100	6	$a_0+a_1*\cos(t*W)+\ldots+b_2*\sin(2*t*W)$	0.000111	0.9998	0.007446
120	6	$a_0+a_1*\cos(t*W)+\ldots+b_2*\sin(2*t*W)$	1.35E-05	1	0.002596

4 Conclusion

An investigation of the drying characteristics of carrot was carried out. It was observed that the constant rate drying period was very short while greater part of the drying took place in the falling rate period. The Fourier and Henderson and Pabis (exponential) drying models were developed and found to describe the drying process under the prevailing conditions. Fourier model gave a better fit with the following parameters: coefficient of determination (R^2) from 0.9991 to 1.000, error sum of squares (SSE) ranging from 0.000121 to 0.001034, and root mean square error (RMSE) from 3.32×10^{-03} to 0.02274. Effective moisture diffusivity (D_e) ranged from 9.7422×10^{-10} to 1.9962×10^{-09} m^2 s^{-1} while the drying constant (k) ranged from 5.7×10^{-05} to 0.00022 s^{-1}. The Fourier model is recommended for the prediction of the drying rate for the carrot slices within the range of moisture content studied.

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