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Modeling Microwave Drying Characteristics of Sweet Potato and the Effects on Nutrients Availability

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Abstract
A study of microwave oven drying characteristics and its effects on the fibre, ash and carbohydrate content of sweet potato slice was carried out. The samples were dried from moisture content of 70.71 to 12.7 $g_{water} / g_{dry\ matter}$ in Microwave dryer. Fourier and exponential models were applied to determine the drying kinetics of the sweet potato slice. The drying curves were graphically used to present the relationships between moisture ratio and drying time. Equation for predicting the fibre, ash and carbohydrate content under combined effect of microwave power and slice thickness were developed. The regression of moisture ratio with time of drying for the sweet potato slice shows that fourier model gave the best fit with the following parameters: Sum of Square Error (SSE) from 0.0000294 to 0.000645, Coefficient of Determination (R^2) from 0.09987 to 1 and Root Mean Square Error (RMSE) from 0.00384 to 0.01692. Exponential model: Sum of Square Error (SSE) from 0.0212 to 0.07875, Coefficient of Determination (R^2) from 0.8729 to 0.9531 and Root Mean Square Error (RMSE) from 0.05504 to 0.08461. The effective moisture diffusion of the sweet potato slice varied from 1.5279 X 10^{-5} to 4.6562 X 10^{-5} for Microwave drying. The Fourier model was recommended for prediction of drying rate for sweet potato slices within the range of moisture content studied.

Keywords: Modeling, RSM, Sweet potato, Microwave oven, Drying, Nutrients.

1.0 Introduction

Sweet Potato (*Ipomoea batatas* family of *Convolvulaceae*) is a dicotyledonous plant that belongs to the morning glory family. It is an important and valuable staple crop worldwide (FAO, 1987). Nigeria ranks second in Africa after Uganda with the production figure of 2,883,408 tonnes which has shown an increasing trend over the years. According to Onwueme and Sinha (1991) it contains Vitamin A, B, and C, and Minerals such as Potassium (K), Sodium (Na), Chlorine (Cl), Phosphorus (P) and Calcium (Ca). Among other root and tuber crops, sweet potato contains higher contents of carbohydrates, vitamins, minerals and protein than other vegetables (Shih *et al.,* 2007).

The significant advantages of drying is its ability to preserve nutrients and protect it by removing the moisture that bacteria, yeasts and molds need to live, in order to ensure better storage system, better colour, flavour and easy transportation. The primary disadvantage is the reduction of some sensitive nutrients. Salimi *et al.* (2009) investigated the effect of dryer (hot air flow and microwave) on the main composition and water reabsorbing capacity of dried potato products which showed that the microwave maintain the value and texture of food products due to drying time reduction. Falade and Solademic (2010) found page and modified page model appropriate for thin layer drying of 3-15mm thick slices of sweet potato at 50ºC and 80ºC. Bakal *et al.* (2011) and Senadeera *et al.* (2013) reported that the page model best described the drying behaviour of potato.

In order to achieve high drying characteristic and nutrients availability from the methods of drying, it is important to optimize the factors that significantly enhance the processes. Therefore the aim of this present study is to determine the effect of drying methods of sweet potato on their nutritional qualities and drying characteristics at different process conditions. The difference between this work and other works done is the use of different drying models (fourier and exponential models) in predicting the drying kinetics and evaluating the results using RSM (general factorial method).

2.0 Material and method

2.1 Materials Preparation

Sweet Potato (*Ipomoea batatas*) samples for the experiment were purchase from Benin in Edo State, Nigeria. The Sweet Potato (SP) was peeled using kitchen knife, after which it was soak in lukewarm water to avoid risk of losing their nutritional properties and to regain water that was lost during peeling (Manaa *et al.,* 2013).

2.2 Description of Experiment

All experimental procedures were carried out at Nigeria Institute for Oil-palm Research (NIFOR) Central Analytical Laboratory. The drying took place in microwave oven at different Slice Thickness (ST) of 3mm, 4mm, 6mm, and Microwave Power (P) of 90W, 100W, 120W.

2.3 Method of Drying

Seventy grammes (70g) of the sample of sweet potato was sliced into different slice thickness and was used for the moisture content determination while another Seventy grammes (70g) was used for drying experiments. The drying process was monitored every 30mins and the weight duly recorded.

2.4 Determination of Proximate Composition

The proximate analysis viz; Moisture content, ash, crude fibre, carbohydrate, were carried out according to stipulated procedure laid down for analysis by Association of Organic and Analytic Chemists (AOAC) 1948; Bakare, 1985; Tell and Magarty, 1984; Onyeonwu, 2000.

2.5 Curve Fittings

MATLAB was used in curve fitting involving computations, graphs and simulations. Fourier and Exponential models fitted the experimental data so well and gave good predictions. The models were authentically validated by comparing the predicted data with the experimentally observed data. The goodness of fit for these models was based on the error analysis which gave a good range of coefficient of determination (R^2), Sum of Square Error(SSE) and Root Mean Square Error (RMSE).

2.6 Determination of Effective Moisture Diffusion

The effective moisture diffusivity (D_{eff}) is an index of mass transfer in drying process (Sacilik, 2007). The parameter in the solution of fick's diffusion equation was used to obtain the effective diffusion coefficient as stated in equation (1). The drying rate constant (k) is a function of the square of thickness ($L/2$) and diffusion coefficient (D_e).

$$D_e = KL^2/\pi^2 \quad (1)$$

2.7 Statistical Analysis of Nutrients Composition

All experimental data collected were analyzed using Response Surface Methodology (RSM) as shown in table 1 at P value < 0.05 was used to separate the significantly or non significantly different means. A set of 27 experiments each were performed for the drying of sweet potato. The study of the processes consists of 3 responses, 2 factors and 3 blocks.

2.8 Experimental Design and Data Analysis

The experiment was designed in two-factorial split plot-design, under drying conditions of microwave power of 90, 100, 120W and slice thickness of 3, 4, 6mm while the responses are fibre, Ash, Carbohydrate.

3.0 Results and Discussions

3.1 Drying Curve

Drying curves of the slices were described by plotting the moisture ratio against drying time. Curve fittings were performed using MATLAB tool box while Analysis of Variance (ANOVA) was performed with RSM software. From figures 1, 2 and 3, the falling rate period witnessed in the drying could be explained to be as a result of increase in surface water loss because a higher air temperature causes a higher reduction of the moisture until it gets to a point when water movement from the interior to the surface begins to reduce. This phenomenon was highly reported for agricultural materials (Pathare and Sharma 2006). Mr3, Mr4 and Mr6 represent the Moisture ratio at a specified slice thickness of 3mm, 4mm and 6mm respectively.

Table 1: General Factorial for the Optimization of Microwave Sweet Potato Drying

Std	Run	Block	Factor 1 A:Power Watts	Factor 2 B:ST mm	Response 1 Fibre %	Response 2 Ash %	Response 3 Carbohydrate %
19	1	Block 1	90	6	2.50	4.30	85.72
10	2	Block 1	90	4	2.50	4.10	84.05
7	3	Block 1	120	3	1.50	2.00	91.76
22	4	Block 1	100	6	2.00	3.40	89.61
13	5	Block 1	100	4	2.00	3.60	88.66
16	6	Block 1	120	4	1.00	2.40	89.85
1	7	Block 1	90	3	2.00	4.00	85.75
4	8	Block 1	100	3	1.00	2.80	88.87
25	9	Block 1	120	6	1.50	2.90	89.61
17	10	Block 2	120	4	0.80	2.20	86.85
8	11	Block 2	120	3	1.30	1.70	90.00
2	12	Block 2	90	3	1.80	3.70	80.80
14	13	Block 2	100	4	1.50	3.30	87.60
26	14	Block 2	120	6	1.30	2.70	86.61
23	15	Block 2	100	6	1.70	3.00	87.51
5	16	Block 2	100	3	0.80	2.50	88.00
20	17	Block 2	90	6	2.20	4.00	81.70
11	18	Block 2	90	4	1.80	3.60	80.15
3	19	Block 3	90	3	2.20	4.30	90.70
21	20	Block 3	90	6	2.80	4.60	89.74
15	21	Block 3	100	4	2.50	3.90	89.72
9	22	Block 3	120	3	1.70	2.30	93.52
6	23	Block 3	100	3	1.20	3.10	89.74
12	24	Block 3	90	4	3.20	4.60	87.95
18	25	Block 3	120	4	1.20	2.60	92.85
24	26	Block 3	100	6	2.30	3.80	91.71
27	27	Block 3	120	6	1.70	3.10	92.61

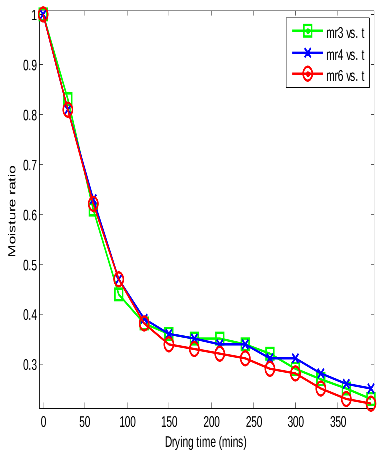


Figure 1: A plot of moisture ratio against drying time (Microwave sweet potato at 90W)

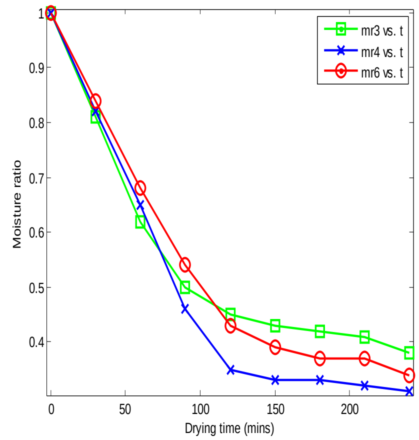


Figure 2: A plot of moisture ratio against drying time (Microwave sweet potato at 100W)

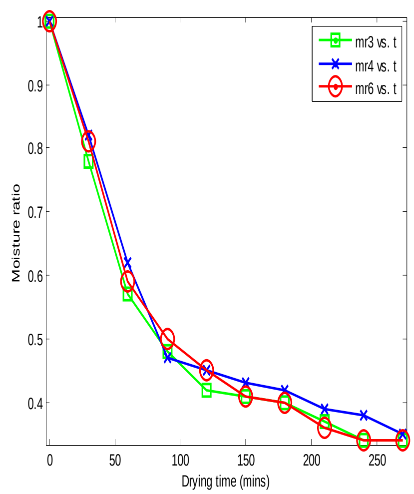


Figure 3: A plot of moisture ratio against drying time (Microwave sweet potato at 120W)

3.2 Moisture Diffusivity

From the experimental data analysis, the drying rate constant (k) was used to determine the moisture diffusion. The effective moisture diffusion of Sweet potato varied from 1.5279 X 10^{-5} to 4.6562 X 10^{-5}, for Microwave oven. Rufus (2012) reported lower effective moisture diffusion of sweet potato as 7.76 X 10^{-9} to 1.2 X 10^{-8} m^2/s. The variation could be due to species used and approximation of value. The results of drying constants and effective moisture diffusivity are presented in table 2

3.3 Drying Model

The Fourier models in tables 3a and 3b showed the best fits for modeling the drying kinetics of sweet potato as compared to Exponential model in table 4. Considering the values of Sum of Square Error (SSE) from 0.0000294 to 0.000645, Coefficient of Determination (R^2) from 0.09987 to 1 and Root Mean Square Error (RMSE) from 0.00384 to 0.01692. The premise is that the lower the RMSE and SSE and higher the R^2 the better the fit and model. This results range agreed with Aishi and Feiyan (2014) whose values are as follows R-square from 0.9617 to 0.9997 and RMSE from 0.011894 to 0.007530, using logarithm model. The Fourier model in Matlab software is graded up to the eight term with 95% confidence bound. MR = a0 + a1*cos(x*w) + b1*sin(x*w) + a2*cos(2*x*w)+b2*sin(2*x*w) shows the two term Fourier equation where a0-b2 are coefficients, x is time and w is drying constant. The choice of the model is based on its reliability, robust analysis techniques and ability to process experimental data independently.

Table 2: Diffusion Co-efficient of Microwave Drying at different Power and Slice thickness of Sweet Potato

S/N	Power(watts)	Thickness(mm)	Drying rate constant(k)	Diffusion coefficient (De) m²/s
1	90	3	-0.004747	1.8036×10^{-5}
		4	-0.006466	2.1838×10^{-5}
		6	-0.005452	2.7620×10^{-5}
2	100	3	-0.004787	1.8188×10^{-5}
		4	-0.004524	1.5279×10^{-5}
		6	-0.004836	2.4499×10^{-5}
3	120	3	-0.01102	4.1871×10^{-5}
		4	-0.011	3.7151×10^{-5}
		6	-0.009191	4.6562×10^{-5}

Table 3a: Fourier Model of Microwave Drying of Sweet Potato at different Power and Thickness.

Parameters			Goodness of Fit		
Power(w)	ST(mm)	Model expression	SSE	R^2	RMSE
90	3	$a_o+a_1*cos(t*W)+\ldots+b_4*sin(4*t*W)$	7.08E-05	0.9999	0.004207
100	3	$a_o+a_1*cos(t*W)+\ldots+b_2*sin(2*t*W)$	0.000113	0.9997	0.006145
120	3	$a_o+a_1*cos(t*W)+\ldots+b_3*sin(3*t*W)$	0.000258	0.9994	0.01135
90	4	$a_o+a_1*cos(t*W)+\ldots+b_5*sin(5*t*W)$	0.000225	0.9997	0.01062
100	4	$a_o+a_1*cos(t*W)+\ldots+b_2*sin(2*t*W)$	0.000645	0.9988	0.01466
120	4	$a_o+a_1*cos(t*W)+\ldots+b_3*sin(3*t*W)$	0.000311	0.9993	0.01248
90	6	$a_o+a_1*cos(t*W)+\ldots+b_5*sin(5*t*W)$	2.94E-05	1	3.84E-03
100	6	$a_o+a_1*cos(t*W)+\ldots+b_2*sin(2*t*W)$	0.000104	0.9998	0.005893
120	6	$a_o+a_1*cos(t*W)+\ldots+b_3*sin(3*t*W)$	0.000573	0.9987	0.01692

3.5 Analysis of Variance (ANOVA)

The Analysis of Variance (ANOVA) was carried out to determine the significance of individual factors and their interaction on the responses. Tables 5, 6 and 7 showed the ANOVA result of sweet potato for microwave oven drying. The model F-value (<0.0001) and the p-value for microwave drying for Ash, Fibre and Carbohydrate showed the significance of the model and the predictability of the response variable within the confidence bound of 95%. Coefficient of Variation (CV) value less than 10% indicates good precision. Coefficient of Determination (R-squared) showed 97% (Ash), 73% (fibre) and 81% (carbohydrate) prediction of the response.

3.6 The 3D Response Surface Plot

The nature of the response surface curves showed the interaction among the variables. Figures 7 and 8 give the interactive effect of thickness and power on nutrients, a significant decrease in power and thickness increased the yield of fibre and ash. And an increase in power and increase in thickness increased the yield of carbohydrate.

Table 3b:Continuation of Fourier Model of Microwave Drying of Sweet Potato at different Microwave Power and Thickness

a_0	a_1	a_2	a_3	a_4	a_5	b_1	b_2	b_3	b_4	b_5	b_6	W
0.4665	0.2777	0.1779	0.06528	0.012		0.02658	-0.05151	-0.0365	-0.01599		0.01136	0.01136
0.6799	0.3118	0.009525				-0.2294	-0.1248				0.01264	0.01264
0.5952	0.3168	0.09397	-0.005362			0.08433	0.1191	0.0291			-0.01518	-0.01518
5.29E+07	-8.37E+07	4.04E+07	-1.08E+07	1.15E+06	2.61E+04	2.82E+07	-3.08E+07	1.60E+07	-4.20E+06	4.43E+05	-0.00151	-0.001511
0.5677	0.345	0.08332				-0.1282	-0.09277				0.01291	0.01291
0.4874	0.281	0.1982	0.03244			0.0859	-0.08294	-0.06488			0.01251	0.01251
-3.74E+09	6.12E+09	-3.32E+09	1.13E+09	-2.17E+08	1.74E+07	1.19E+09	-1.34E+09	7.37E+08	-2.11E+08	2.51E+07	1.02E-03	0.001023
-26.53	35.02	-7.491				13.43	-7.37				0.00347	0.003467
-3.50E+10	5.25E+10	-2.10E+10	3.49E+09			1.42E+09	-1.14E+09	2.84E+08			0.00018	0.0001793

Table 4: Exponential Model of Microwave Drying of Sweet Potato at different Microwave Power and Thickness.

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

Table 5: ANOVA for Response Surface Quadratic Model (MW Fibre of Sweet potato)

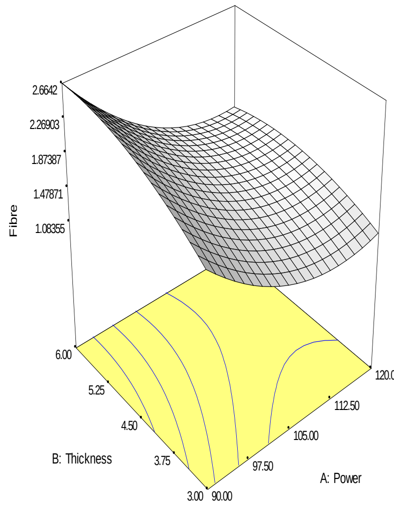
Source	Sum of Squares	DF	Mean Square	F Value	Prob > F	
Block	1.74	2	0.87			
Model	5.99	5	1.2	10.45	< 0.0001	Significant
A-power	4.64	1	4.64	40.49	< 0.0001	
B-thickness	1	1	1.0013	8.74	0.0081	
A^2	0.64	1	0.64	5.61	0.0286	
B^2	0.16	1	0.16	1.4	0.2510	
AB	0.15	1	0.15	1.34	0.2615	
Residual	2.18	19	0.11			
Cor Total	9.91	26				
Std. Dev.	0.34		R-Squared	0.7333		
Mean	1.78		Adj R-Squared	0.6631		
C.V.	19.043		Pred R- Squared	0.482		
PRESS	4.23		Adeq Precision	11.5163		

Table 6: ANOVA for Response Surface Quadratic Model (MW Ash of Sweet potato)

Source	Sum of Squares	DF	Mean Square	F Value	Prob > F	
Block	1.74	2	0.87			
Model	15.0076	5	3.0015	106.24	< 0.0001	Significant
A-Power	12.3	1	12.3	435.43	< 0.0001	
B-Thickness	1.77	1	1.77	62.62	< 0.0001	
A^2	0.52	1	0.52	18.43	0.0004	
B^2	0.32	1	0.32	11.15	0.0034	
AB	0.27	1	0.27	9.71	0.0057	
Residual	0.54	19	0.028			
Cor Total	17.29	26				
Std. Dev.	0.17		R-Squared	0.9655		
Mean	3.28		Adj R-Squared	0.9564		
C.V.	5.13		Pred R-Squared	0.9344		
PRESS	1.02		Adeq Precision	32.00563		

Table 7: ANOVA for Response Surface Quadratic Model (MW Carbohydrate of Sweet potato)

Source	Sum of Squares	DF	Mean Square	F Value	Prob > F	
Block	135.14	2	67.57			
Model	145.18	5	29.036	16.025	< 0.0001	Significant
A-Power	114.83	1	114.83	63.37	< 0.0001	
B-Thickness	11.69	1	11.69	10.93	0.03459	
A^2	26.22	1	26.22	14.47	0.0012	
B^2	7.17	1	7.17	3.96	0.0612	
AB	5.016	1	5.016	2.77	0.1125	
Residual	34.43	19	1.81			
Cor Total	314.75	26				
Std. Dev.	1.35		R-Squared	0.8083		
Mean	88.21		Adj R-Squared	0.7579		
C.V.	1.53		Pred R-Squared	0.6203		
PRESS	68.19		Adeq Precision	17.3675		



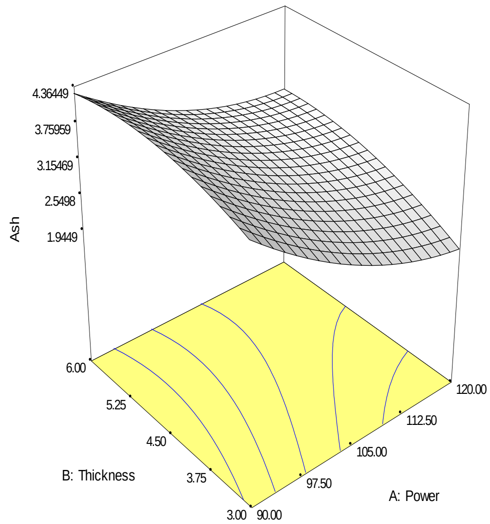


Figure 4: 3D surface plot of Thickness vs Power (Microwave SP Fibre content)

Figure 5: 3D surface plot of Thickness vs Power (Microwave SP Ash content)

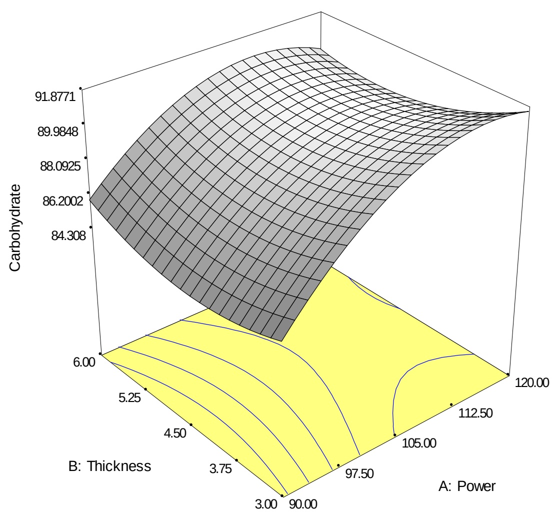


Figure 6: 3D surface plot of thickness vs power (Microwave SP Carbohydrate content)

3.7: Developing Models for Optimizing Nutrients Yield

In a regression equation, independent variable with one factor showed the effect of that particular factor on the expected response. A positive sign means that an increase in the variable would cause an increase in the response while a negative sign denote a decrease in the response. The regression equations (2), (3) and (4) could be used to estimate the amount of Fibre, Ash and Carbohydrate as a function of slice thickness and microwave power.

$$Fibre\ (\%) = 18.8850 - 0.36233 * P + 1.41752 * ST + 1.6667\varepsilon^{-3} * P^2 \quad (2)$$
$$Ash\ (\%)=25.29031 - 0.39974 * P + 0.58044 * ST + 1.5000\varepsilon^{-3} * P^2 - 0.11667 * ST^2 + 6.4795\varepsilon^{-3} * P * ST \quad (3)$$
$$Carbohydrate\ (\%)=+46.8098 + 2.5299 * P - 2.3067 * ST - 0.0106 * P^2 + 0.5567 * ST^2 + 0.0277 * P * ST \quad (4)$$

The p-value (probability of error value) was used to check the significance of each regression coefficient, p-value less than 0.05 in tables 5, 6 and 7 were used to eliminate insignificant model terms from equations (2), (3) and (4) resulting to final model equation as shown in equations (5), (6) and (7).

$$Fibre\ (\%) = 18.8850 - 0.36233 * P + 1.41752 * ST + 1.6667\varepsilon^{-3} P^2 \quad (5)$$
$$Ash(\%)=25.29031 - 0.39974 * P + 0.58044 * ST + 1.5000\varepsilon^{-3} * P^2 - 0.11667 * ST^2 + 6.4795\varepsilon^{-3} * P * ST \quad (6)$$
$$Carbohydrate\ (\%) = 46.8098 + 2.5299 * P - 2.3067 * ST - 0.0106 * P^2 \quad (7)$$

4.0. Conclusion

The following conclusions were drawn from this work;
The drying behaviour of sweet potato was studied under microwave oven drying. It showed that drying of this crop took place in the falling rate period. The Fourier model was able to predict better than other models tested. The deduction from the curve fitting using MATLAB software showed that in microwave drying, the drying kinetic is more efficient at 120W and 90W. Analysis of Variance (ANOVA) was used to predict the significant difference at $p<0.05$, from the RSM. Optimal values of the processes parameters were established by general factorial design, which showed that there is significant difference on the effect of drying method, thickness and the interaction of drying method and thickness on the nutrients.

5.0 Recommendation

- It is recommended that future work should cover the radiation residue in products dried in microwave device.
- It is recommended that future work on the effect of pretreatments on the drying of foods in microwave ovens.

6.0 Acknowlegments

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