International Journal of Advances in Engineering and Management (IJAEM)
Volume 4, Issue 1, Jan 2022 pp: 941-956 www.ijaem.net ISSN: 2395-5252

Optimization, Drying Kinetics and Thermodynamic Properties of Carrot Slices in a Hot Air Drying

EDEANI, N. J., MBAH, G.O. AND CHIME, I. H.
Department Of Chemical Engineering, Enugu State University Of Science And Technology Enugu.

Submission: 18-01-2022 Revised: 28-01-2022 Acceptance: 31-01-2022

ABSTRACT: In this research, drying characteristics, thermodynamic properties and optimization for hot air drying of carrot were reported. The drying characteristics were carried out at 60, 70, and 80^{o}C with slice thickness of 0.4cm, 0.6cm and 0.8cm. The proximate, mineral, vitamin and energy values of the samples were determined. The result of the experiment showed that increase in drying temperature resulted in decreasing the values of composition except carbohydrate. Experimental drying curves showed only a falling drying rate period. The effective moisture diffusion(D_{eff}) values of dried cocoyam slices at hot air drying temperature of 60-80^{o}C were varied in the range of $1.03x10^{-9}$ to $9.18x10^{-10}m^2/s$ for untreated samples and $1.1x10^{-9}$ to $7.11x10^{-10}m^2/s$ for treated samples. The value of activation energy were varied for 38 to 51KJ/mol for untreated and 50 to 56KJ/mol treated dried carrot. The drying rate for the samples was observed in the falling rate period. It is apparent that drying rate decreases continuously as the drying time increases. The value of the enthalpy varied from -2719 to -2897J/mol for untreated and -2713 to -2885J/mol for treated samples. The value of the entropy varied from -275.84 to -302.18J/mol for untreated samples and -257.32 to -266.39J/mol for treated samples. The value of Gibbs free energy varied from 89136 to 103773J/mol for untreated sample and 82974 to 91151J/mol for treated samples. It was observed that enthalpy was negative in all cases, showing that the drying process is exothermic. The page model was the best model to describe the hot air drying behavior of samples with R^2 of 0.99907, X^2 of 0.00007 and RMSE of 0.00006. Based on response surface and desirability functions, the optimum conditions for carrot dryin g were: air temperature,70^{o}C, slice thickness,0.6cm and drying time, 180minutes for untreated and treated carrot respectively. At this point, the predicted responses for moisture content were 0.5709gwater/gsolid, and 0.3473gwater/solid respectively

Keywords: carrot, temperature, slice thickness, drying time, hot air drying, optimisation.

I. INTRODUCTION

Carrot is one of the important root vegetable crops and is highly nutritious because it contains appreciable amount of vitamins B_1, B_2, B_6 and B_{12} (Prakash *et al*, 2004). It also contains many important minerals. Carrot have the highest β-carotene among human foods (Gournicki and Kaleta, 2007). Dried carrots are used in dehydrated soups and in form of powder in pastries and sauces (Erenturk and Erenturk, 2007). Carrot is largely cultivated in the Northern part of Nigeria such as; Zaria, Sokoto, Kano and Jos. Carrot (*Daucus carota L.*) is the most important crop of Apiaceae family (Carlos and Dias, 2014). It is a root vegetable that has worldwide distribution. Carrots were first used for medical purposes and gradually used as food. Carrot is an excellent source of carotene a precursor of vitamin A and fibre in the diet . It also contains abundant amounts of nutrients such as protein, carbohydrates, fibre and sodium (Sing *et al*., 2010). Carrot fleshy roots are used as vegetables for salads, soups and are also steamed or boiled in other vegetable dishes (Chau *et al*., 2004).Drying is a complex process accompanied by physical and structural changes. There is a continuous change in the dimensions of differently shaped food particulates during drying as a result of water removal and internal collapse of the particulates (Senadeera *et al*., 2005). Drying is one of the most common processes used to improve food stability, since it decreases considerably the water activity of the material, reduces microbiological activity and minimizes physical and chemical changes during its storage. Drying is the process of moisture removal due to simultaneous heat and mass transfer under controlled conditions (Gatea, 2011; Gurlek *et al*., 2009). It also causes weight reduction, enhances aesthetic and sensory effects of food. However, the main goal is to reduce moisture content to levels that halt or slow down the growth of spoilage

International Journal of Advances in Engineering and Management (IJAEM)
Volume 4, Issue 1, Jan 2022 pp: 941-956 www.ijaem.net ISSN: 2395-5252

microorganisms and incident of chemical reactions in order to extend the shelf-life of food (Doymaz, 2004). Maskan (2000) mentioned that high quality fast-dried foods have become necessary in the recent times leading to a renewed interest in drying operations. In addition, there is an increased demand for convenient foods including ready to eat and instant products, which are desired to contain the minimum quantities of additives and preservatives. Besides these advantages, drying decreases the bulk of foods by reducing the volume which eases handling and processing operations, in turn reducing packaging, handling and storage and transportation costs (Gatea, 2011 Goyalde, et al, 2009 Gupta, et al 2011). Dried foods can be stored for long periods without deterioration occurring.

Drying kinetics is used to express the moisture removal process and its relation to the process variables. Drying is a complex process accompanied by physical and structural changes. There is a continuous change in the dimensions of differently shaped food particulates during drying as a result of water removal and internal collapse of the particulates (Senadeera *et al.*, 2005).The rate at which foods dry depends on the temperature of the air and the size of food pieces (Fellows, 2000). Water moves from the interior of the food to the surface by the following mechanism: liquid movement caused by capillary forces, liquid diffusion resulting from concentration gradient, diffusion in liquid layers absorbed at solid interfaces and water vapour diffusion due to partial pressure gradients (Sanni, 2015) Optimisation is required to ensure rapid processing while maintaining optimum product quality. Response surface methodology is a powerful tool for optimizing of many engineering applications probably because of its high efficiency, simplicity, and comprehensive theory. It can save a lot of time and can build models accurately and quickly in an optimization design (Nazghelichi et al, 2011). It has been frequently used in the optimisation of food processes (Varnalis et al, 2004,Wani et al, 2008).. The aim of this study was :(a)to determine the influence of hot air drying on the compositon of carrot (b) to investigate drying behaviour of carrot (c) to fit the experimental moisture data to three mathematical models (d) to calculate the enthalpy, entropy and Gibb's free energy of the sample. (e) to optimize the carrot drying in a hot air dryer.

II. MATERIALS AND METHODS

2.1 Sample preparation: Good quality freshly harvested carrot used for the experiments were procured from New Market, Enugu. Hot air dryer were used for the experiment. Composition analyses of the samples were conducted according to the A.O.A.C, 2004. The analyses were done at Energy centre, Nsukka, Enugu, Enugu State.

2.2 Experimental procedure: The samples were peeled with a stainless knife and cut into chips of different thickness of 0.4cm, 0.6cm and 0.8cm using vernier caliper. The sliced samples was pretreated by soaking for 5 min in 0.5% sodium metabisulphite ($Na_2S_2O_5$) solution..There were treated and untreated samples for each. The initial moisture content was determined according to official method (A.O.A.C, 2004). The chips were loaded into the hot air dryer for drying process. Steady state of temperatures was achieved in the dryer before the chips were loaded. The drying process was performed at 60^{o}C, 70^{o}C and 80^{o}C. The samples were removed from the dryer and weighed manually at 30minutes interval to monitor moisture loss. Drying process was truncated when two consecutive sample weights remained constant. The experiments were replicated. The experiment drying data were used to calculate the moisture ratio and drying rate using the following equations:

$$\text{Moisture content (dry basis)} = \frac{\text{initial weight} - \text{final weight}}{\text{final weight}} \quad (2.1)$$

$$\text{Moisture ratio} = \frac{\text{moisture content at a time}}{\text{initial moisture content}} \quad (2.2)$$

The moisture ratio MR. is defined as

$$MR = \frac{M}{M_i} \quad (2.3)$$

MR = Moisture ratio M = moisture content at time t, M_i = initial moisture content

$$\text{Drying rate} = \frac{\text{change in mass of the sample(kg)}}{\text{area of the sample(m}^2\text{) x time(s)}} \quad (2.4)$$

International Journal of Advances in Engineering and Management (IJAEM)
Volume 4, Issue 1, Jan 2022 pp: 941-956 www.ijaem.net ISSN: 2395-5252

2.3:Determination of moisture diffusivity: The simplified equation of Fick's law of moisture diffusion was adapted to determine the effective moisture diffusion from the samples during drying. For slab geometry, Equation 2.2 was simplified according to Srikiatden and Roberts, (2005) which is represented thus:

$$MR = \frac{M-M_e}{M_i-M_e} = \frac{8}{\pi^2}\sum_{n=1}^{\infty}\frac{1}{(2n+1)^2}\exp\left[\frac{-(2n+1)\pi^2 D_{eff}t}{4l^2}\right] \quad (2.5)$$

where D_{eff} is the moisture diffusivity (m^2/s), t is the drying time (s), l is the half of the slab thickness (cm), MR = dimensionless moisture ratio, M = instantaneous moisture content (g water/g solid), M_e = equilibrium moisture content (g water/ g solid), M_i = initial moisture content (g water/ g solid), n is a positive integer. However, due to continuous fluctuation of relative humidity of the drying air in the dryer, Equation (2.5) is simplified in Equation (2.6) according to Dimente and Munro, (1993) and Goyal *et al.*, (2007)

$$MR = \frac{M}{M_i} = \frac{8}{\pi^2}\sum_{n=1}^{\infty}\frac{1}{(2n+1)^2}\exp\left[\frac{-(2n+1)\pi^2 D_{eff}t}{4l^2}\right] \quad (2.6)$$

The Eq.(2.6) can be simplified into

$$MR = \frac{8}{\pi^2}\exp\left[-\frac{\pi^2 D_{eff}t}{4l^2}\right] \quad (2.7)$$

Expressing in logarithm forms

$$\ln MR = \ln\frac{8}{\pi^2} - \left(\frac{\pi^2 D_{eff}}{4l^2}\right)t \quad (2.8)$$

The effective moisture diffusivity (D_{eff}) was calculated from the slope of plot of ln(MR) against drying time (t) according to Doymas, (2004) and is represented in equation (2.9)

$$K = \frac{\pi^2 D_{eff}}{4l^2} \quad (2.9)$$

$$D_{eff} = \frac{4l^2 K}{\pi^2} \quad (2.10)$$

Where K is the slope, l is the half of slab thickness and D_{eff} is the effective moisture diffusivity.

2.4: Determination of activation energy: Activation energy can be defined as the minimum energy required for water molecules to begin the movement from inside to outside of the product. The effect of temperatures often affects the effective moisture diffusivity of the product during drying. The correlation of temperature and moisture diffusion is inversely related as expressed using Arrhenius equation.

$$D_{eff} = D_o\exp\left[-\frac{E_a}{RT}\right] \quad (2.11)$$

Where Do is the pre-exponential factor, E_a is the activation energy in kJ/mol, R is the universal gas constant in, 8.314 J/mol K and T is the absolute air temperature in K. The activation energy was calculated by plotting the natural logarithm of D_{eff} against inverse of the absolute temperature.

2.5: Thermodynamic properties of the samples: Enthalpy is related to the energy needed to remove water bound to the product during the drying process. Entropy is a thermodynamic property that can be associated with the level of disorder between water and product. Gibbs free energy is related to the work needed to make the drying sites available. Thermodynamic properties of food sample drying were obtained using the method described by Jideani and Mpotokwana(2009), according to Eqs 2.12 to 2.14

$$\Delta H = E_a - RT_{abs} \quad (2.12)$$

$$\Delta S = R\left[\ln k - \ln\frac{k_b}{h_p} - \ln T_{abs}\right] \quad (2.13)$$

$$\Delta G = \Delta H - T_{abs}\Delta S \quad (2.14)$$

where:ΔH = enthalpy of activation, J mol^{-1}, ΔS= entropy of activation, J mol^{-1}, ΔG= Gibbs free energy of activation, J mol^{-1}, k_b = Boltzmann constant, 1.38×10^{-23} J K^{-1}, h_p = Planck's constant, 6.626×10^{-34} J /s.

2.6 Drying Models: Thin layer drying models are used to estimate the drying curves for the product. It is used to determine the optimum drying parameters and the performance of the process. Several investigators have proposed numerous mathematical models for the thin layer drying of many agricultural products. This process is advantageous, because a full scale experimentation of different products and configurations of the drying system is time consuming and also costly (Yaldiz *et al.*, 2001).

2.6.1 Newton or Lewis model: Lewis described the moisture transfer from agricultural materials as analogous to the flow of heat from a body immersed in cold fluid. It is a special case of the Henderson and Pabis model where intercept is unity. It is said to be the simplest model because of the single model constant. The model has been widely applied in describing the drying behavior of several food and agricultural products (Onwude et al.,2016). Recently, it has occasionally been found suitable for describing the drying behavior of some fruits and vegetables (Liu and Bakker-Arkema, 1997).

International Journal of Advances in Engineering and Management (IJAEM)
Volume 4, Issue 1, Jan 2022 pp: 941-956 www.ijaem.net ISSN: 2395-5252

$MR = \exp(-kt)$ (2.15)

where k is the drying constant (min^{-1}), MR is the moisture ratio, t is the time.

2.6.2 Page model: The Page model is a two constant empirical modification of the Newton model, whereby the errors associated with using the Newton model are greatly minimized by the addition of a dimensionless empirical constant, n (Zhang et al.,2016, Dimente and Munro, 1993).

$MR = \exp(-kt^n)$ (2.16)

Where k, n are the drying and empirical constants.

2.6.3 Henderson and Pabis or single-term model: This model is the first term of the general solution of the Fick's second law of diffusion. This can also be regarded as a simple model with only two model constants. The Henderson and Pabis model has been effectively applied in the drying of crops such as corn and millet. However, it has not been quite so successful in describing the drying behavior of fruits and vegetables (Henderson and Pabis, 1961).

$MR = a\exp(-kt)$ (2.17)

Where a and k are the constant of the model

The coefficients of the drying mathematical models and the regression/statistical parameters were obtained using Microsoft Excel solver(Microsoft Excel, 2013) (Ofortansi and Oduola,2016).

2.7 Comparison of the fitness of the models

Mathematical modelling of the drying of food products often requires the statistical methods of regression and correlation analysis. Linear and nonlinear regression analyses are important tools to find the relationship between different variables, especially, for which no established empirical relationship exists. Thin layer drying equations require MR variation versus time't'. Therefore, MR data plotted with time t and regression analysis is performed with the selected models to determine the constant values that supply the best appropriateness of models. The validation of models can be checked with different statistical methods. The most widely used method is performing coefficient of determination (R^2), reduced chi-square ($\chi 2$) test and root mean square error (RMSE) analysis. R-squared or coefficient of determination is the measure of how close the statistical data could fit the regression line. The expression for these statistical parameters were written in Eqs (2.16)-(2.18).

$$R^2 = 1 - \left[\frac{\sum_{i=1}^{N}(MR_{pre,i} - MR_{exp,i})^2}{\sum_{i=1}^{N}(MR_{exp,i} - MR_{exp,i})^2}\right] \quad (2.16)$$

$$X^2 = \frac{\sum_{i=1}^{N}(MR_{exp,i} - MR_{pre,i})^2}{N-z} \quad (2.17)$$

$$RMSE = \left(\frac{1}{N}\sum_{i=1}^{N}(MR_{exp,i} - MR_{pre,i})^2\right)^{1/2} \quad (2.18)$$

2.8: Experimental design matrix:

The experiment was designed using Response surface methodology (RSM) of design expert software 11. Central Composite Design (CCD), face center, tool was used in the design process. Temperature, thickness and time were the considered factors while moisture content and drying rate were the expected responses of the study. The design matrix for the experiments is shown in Table 2.1.

Table 2.1 Experiment design matrix

Std	Run	Factor1 Temperature (^oC)	Factor 2 Thickness (cm)	Factor 3 Time (min)	Response 1 Moisture content (gsolid/gwater)	Response 2 Drying rate (kg/m^2s)
9	1	60	0.6	180		
16	2	70	0.6	180		
8	3	80	0.8	300		
5	4	60	0.4	300		
18	5	70	0.6	180		
12	6	70	0.8	180		
19	7	70	0.6	180		
4	8	80	0.8	60		
14	9	70	0.6	300		
2	10	80	0.4	60		
15	11	70	0.6	180		
6	12	80	0.4	300		
13	13	70	0.6	60		
20	14	70	0.6	180		
1	15	60	0.4	60		
3	16	60	0.8	60		

International Journal of Advances in Engineering and Management (IJAEM)
Volume 4, Issue 1, Jan 2022 pp: 941-956 www.ijaem.net ISSN: 2395-5252

17	17	70	0.6	180
11	18	70	0.4	180
7	19	60	0.8	300
10	20	80	0.6	180

III. RESULTS AND DISCUSSIONS

3.1 Composition of carrot

The composition analyses of the carrot are presented in Table (3.1). Composition analysis consists of proximate analysis in terms of moisture, ash, lipid, fiber, protein and carbohydrate contents, minerals, vitamins and energy value. The moisture content of the treated oven-dried samples were all below 10%, which suggests a reduction in the growth of the microorganism thereby increased in shelf life. It was observed that as the temperature increased, the protein content decreased, this is due to denaturation of the protein. The decrease in fat content could be associated with the oxidation of fat during the period of drying. The ash content, moisture content and crude fiber decreased with increasing temperature. The value of carbohydrate increased with increasing temperatures. The mineral analysis consists of phosphorus, calcium, potassium, magnesium and zinc. Vitamins consist of vitamin A, B_6, C, E and K. The values are comparable with reported values of phosphorus 30.4-33mg/100g for water yam and yam by Adegunwa et al, 2011and 23.7-53.0mg/100g from Mululem et al, 2018, 53mg/100g phosphorus, 80mg/100g calcium for carrot by Gopalan et al., 1991.

Table 3.1: Composition of carrot

Composition	Raw sample	Treated oven-dried at 60^{o}C	Treated oven-dried at 70^{o}C	Treated oven-dried at 80^{o}C
Proximate Analysis:				
Protein (%)	1.00	0.88	0.83	0.77
Ash (%)	2.50	2.31	2.13	1.99
Crude fat (%)	0.16	0.15	0.14	0.11
Moisture content (%)	86.25	7.90	7.75	7.61
Crude fibre (%)	2.39	2.35	2.21	2.05
Carbohydrate (%)	7.70	86.54	86.94	87.47
Minerals:				
Phosphorus (mg/100g)	30.4	29.2	28.1	28.0
Calcium (mg/kg)	951.65	951.44	945.12	944.59
Potassium (mg/kg)	75.14	75.34	74.31	74.13
Magnesium (mg/kg)	491.21	489.76	478.34	476.12
Zinc (mg/kg)	12.09	12.01	11.57	11.17
Vitamins:				
Vitamin A (µg/100g)	481.74	475.3	472.1	470
VitaminB_6 (mg/100g)	0.14	0.13	0.12	0.10
Vitamin C (mg/100g)	37.6	37.4	37.0	36.2
Vitamin E (µg/100g)	98.1	97.9	97.2	97.0
Vitamin K (mg/100g)	0.18	0.16	0.15	0.14
Energy:				
Energy (kJ/100g)	3411	3309	3247	3204

3.2 Moisture Content of the dried samples

The dimension of the sample slices and their pretreatments were observed to influence the drying characteristics of the foodstuffs. In other words, the decrease in slice thickness resulted in decrease in drying time. The increase in the drying time with increasing slice thickness was due to the effect on the exposed surface area, resulting in increased diffusion path of moisture out of the sample slices during hot-air drying(Sacilik and Elicin,2006, Falade et al, 2007). The pretreated slices were observed to dry faster than the untreated slices of similar dimension.. The results are comparable to those obtained by other works (Bakal et al,2011, Akpinar and Bicer 2008).

International Journal of Advances in Engineering and Management (IJAEM)
Volume 4, Issue 1, Jan 2022 pp: 941-956 www.ijaem.net ISSN: 2395-5252

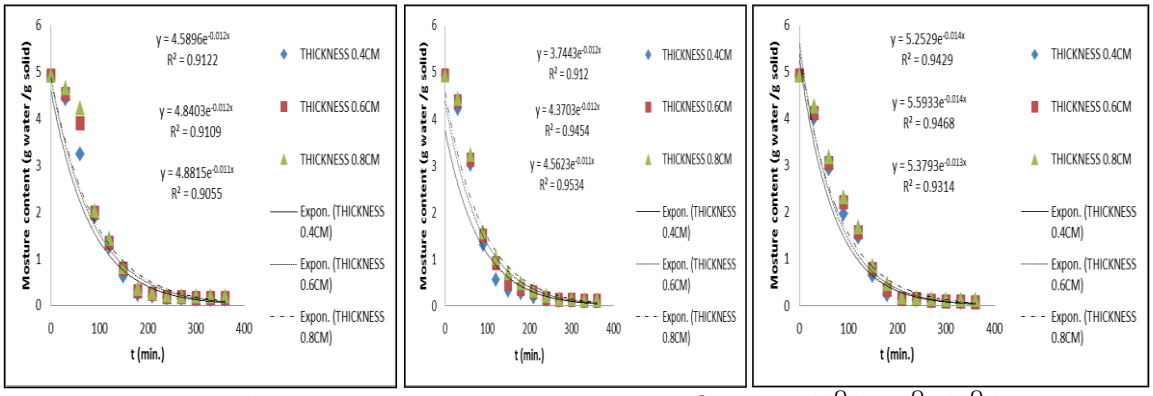


Fig.3.1:Moisture content versus time,untreated carrot at 60^{O}C, 70^{O} , 80^{O}C

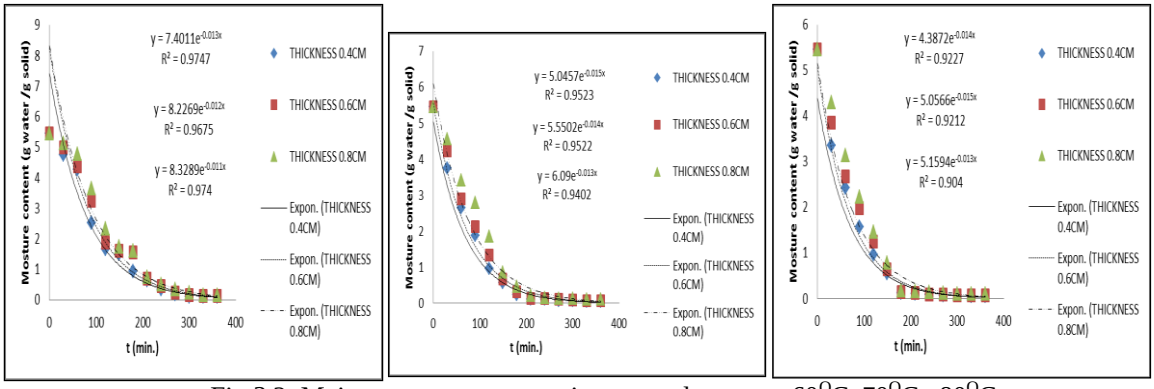


Fig.3.2: Moisture content versus time,treated carrot at 60^{O}C, 70^{O}C, 80^{O}C

3.3 Effective moisture diffusivity of the carrot samples

The effective moisture diffusivity values increased greatly with increasing temperature. The D_{eff} values of dried samples at hot air drying temperature of 60-80^{o}C were varied in the range of $2.59x10^{-9}$ to $9.18x10^{-10}m^2/s$ for untreated carrot samples and $1.1x10^{-9}$ to $7.11x10^{-9}m^2/s$ for treated samples. The graphs of ln(MR) versus time of the food samples are presented in Figures(3.7)-(3.12). To attain linear graphs, the data involving dry basis moisture content versus time were transformed to ln(moisture ratio) versus time (Akpinar and Toraman, 2013). The rate constant were deduced from the models for the determination of the diffusivity. The obtained values of D_{eff} lies in general range of 10^{-12} to $10^{-8}m^2/s$ for drying of food materials (Zogzas et al,1996). The values of D_{eff} are comparable with the reported values of $6.36x10^{-11}$-$9.75x10^{-9}m^2/s$ mentioned for sweet potato hot air drying at 50^{o}C-80^{o}C (Falade and Solademi, 2010) and 3.55 to $19.20x10^{-10}m^2/s$ for potato slices hot air drying at 40-85^{o}C (Hassini et al, 2007).

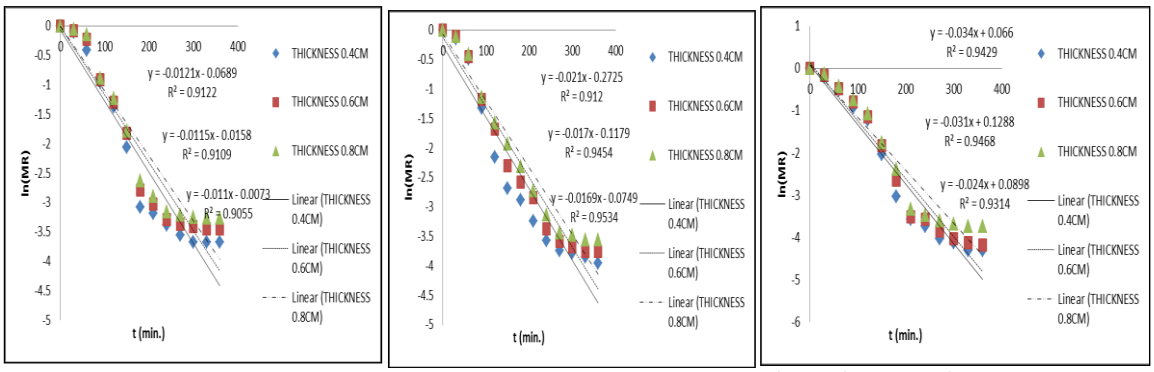


Fig. 3.3: ln(MR)versus time,untreated carrot at 60^{o}C, 70^{o}C and 80^{o}C

International Journal of Advances in Engineering and Management (IJAEM)
Volume 4, Issue 1, Jan 2022 pp: 941-956 www.ijaem.net ISSN: 2395-5252

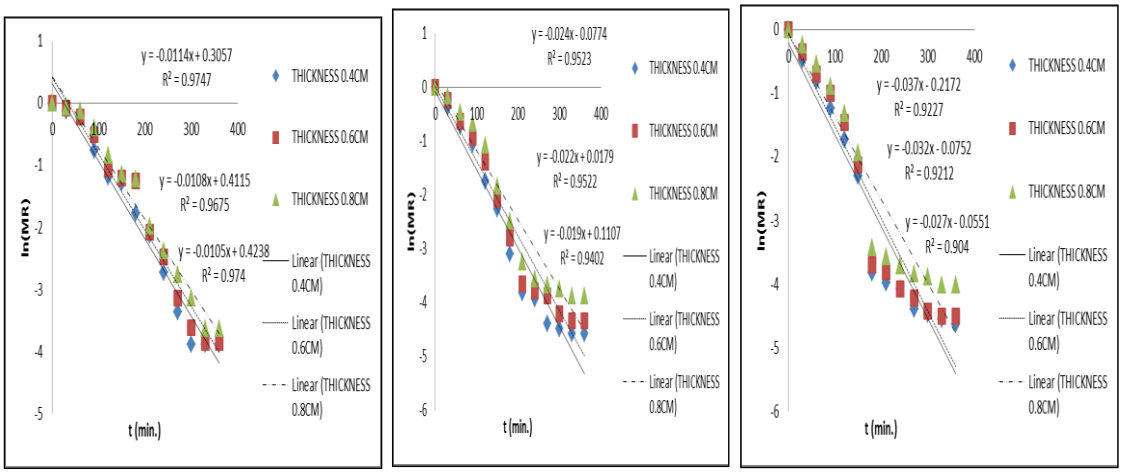


Fig.3.4: ln(MR) versus time, treated carrot at 60°C, 70°C and 80°C

Table 3.2: Effective moisture diffusivity of the Carrot slices

Sample	Temperature (K)	Deff x10^{-10} (m^2/s)	Deff x10^{-10} (m^2/s)	Deff x10^{-10} (m^2/s)
		0.4cm	0.6cm	0.8cm
Untreated carrot	333 343 353	3.27 5.67 9.18	6.19 0.103 0.188	0.119 0.183 0.259
Treated carrot	333 343 353	3.51 7.02 0.11	7.11 0.134 0.207	0.12 0.205 0.335

3.4 Drying Rate

As drying progresses, moisture content decreases. The thinnest of the slices having the least mass recorded the fastest drying rate while the thickest and heaviest slices recorded the slowest rate. This is in agreement with earlier research works (Olawale and Omole, 2012; Tunde-Akintunde and Afon, 2009). In thin-layer drying, temperature plays an important factor affecting the drying rate. The drying rate for the samples was observed in the falling rate period. It is apparent that drying rate decreases continuously as the drying time increases.

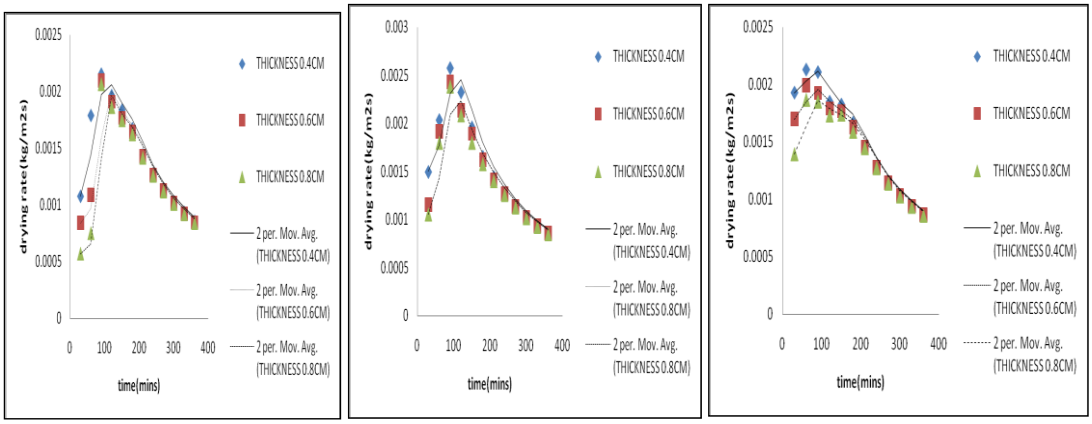


Fig.3.5: Untreated carrot at 60°C, 70°C and 80°C

International Journal of Advances in Engineering and Management (IJAEM)
Volume 4, Issue 1, Jan 2022 pp: 941-956 www.ijaem.net ISSN: 2395-5252

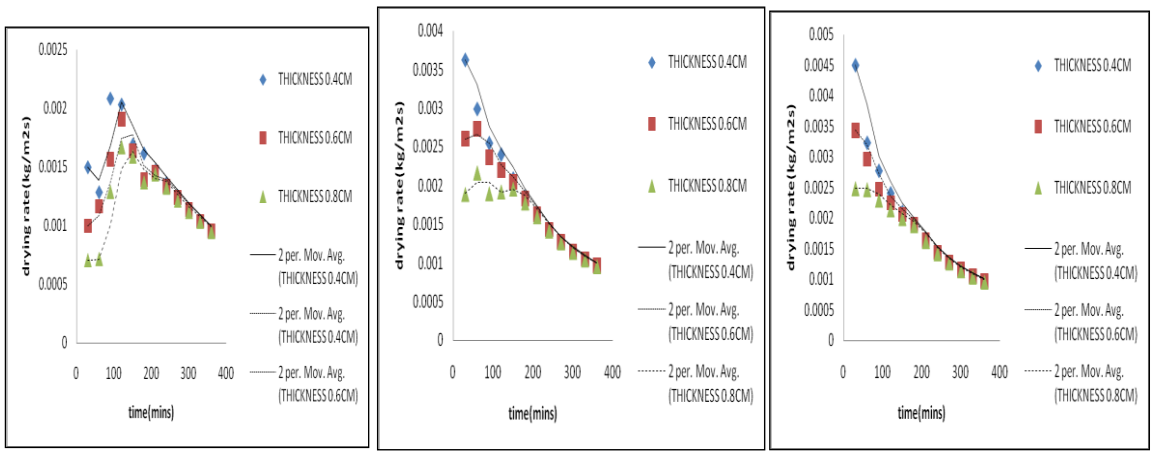


Fig.3.6:Treated carrot at 60°C, 70°C and 80°C

3.5 Activation Energy of the Samples

The values of D_{eff} were fitted to the Arrhenius equation to obtain D_o and activation energy, E_a. The graphical representation of $\ln D_{eff}$ versus 1/temp(1/K) are presented in table 3.3. The results of the activation energy are presented in Tables 4.13 and 4.14. The value of activation energy lie from 12.7 to 110KJ/mol for most food materials (Zogzas et al,1996). The values were comparable with other research work. Babalis, S.J, & Belessiotis VG (2004). report showed activaton energy of carrot at 23-28kJ/mol, while Doymaz(2004) report on carrot was 28.36KJ/mol, Ajala et al (2012) report on cassava was 30.30kJ/mol.

Table 3.3: Activation energy of the Untreated sample

Sample	E_a(KJ/mol) 0.4cm	E_a(KJ/mol) 0.6cm	E_a(KJ/mol) 0.8cm
Untreated carrot	51	48	38
Treated carrot	56	52	50

3.6:Thermodynamic Properties of the Samples

. It was observed that enthalpy was negative in all cases, showing that the drying process is exothermic. This pattern was expected because the elevation of drying temperature increases the excitation of the water molecules in the product and consequently, the order of the water-product system (Correa et al., 2011).

Table 3.4:Enthalpy of samples

Sample	T(K)	ΔH(J/mol) Thickness,0.4cm	ΔH(J/mol) Thickness,0.6cm	ΔH(J/mol) Thickness,0.8cm
Untreated carrot	333	-2719	-2721	-2731
	343	-2802	-2804	-2814
	353	-2885	-2887	-2897
Treated carrot	333	-2713	-2716	-2719
	343	-2796	-2800	-2802
	353	-2879	-2883	-2885

International Journal of Advances in Engineering and Management (IJAEM)
Volume 4, Issue 1, Jan 2022 pp: 941-956 www.ijaem.net ISSN: 2395-5252

Table 3.5: Entropy of the samples

Sample	T(K)	ΔS(J/mol) Thickness,0.4cm	ΔS(J/mol) Thickness,0.6cm	ΔS(J/mol) Thickness,0.8cm
Untreated carrot	333	-275.84	-276.59	-301.70
	343	-276.06	-276.84	-301.94
	353	-276.33	-277.07	302.18
Treated carrot	333	-257.32	-263.68	-265.91
	343	-257.56	-263.92	-266.15
	353	-257.80	-264.16	-266.39

Table 3.6: Gibbs free energy of the untreated samples

Sample	T(K)	ΔG(J/mol) Thickness,0.4cm	ΔG(J/mol) Thickness,0.6cm	ΔG(J/mol) Thickness,0.8cm
Untreated carrot	333	89136.24	89383.41	97734.47
	343	91895.88	92150.53	100752.7
	353	94657.94	94920.08	103773.3
Treated carrot	333	82973.89	85087.84	85827.81
	343	85548.29	87725.84	88488.1
	353	88125.11	90366.27	91150.81

3.7: Models Evaluation using Statistical Criteria

Table 3.7: Drying models

Sample Regression Analysis for carrot at 60,70,80°C for 0.4,0.6,0.8cm Thickness									
Model Name	Thickness(cm)	T(^{0}C)	Coefficients				Regression Parameters		
			K	**A**	**N**	**c**	**R^2**	**RSME**	**X^2**
Lewis	0.4	60	0.01000				0.90097	0.00021	0.00023
		70	0.01004				0.90008	0.00021	0.00023
		80	0.01010				0.90619	0.00029	0.00034
	0.6	60	0.00782				0.90515	0.00049	0.00053
		70	0.00921				0.91808	0.00035	0.00038
		80	0.01005				0.90746	0.00030	0.00035
	0.8	60	0.01010				0.90714	0.00029	0.00034
		70	0.00010				0.90619	0.00029	0.00034
		80	0.00900				0.90757	0.00029	0.00031
Page	0.4	60	0.00033		1.65540		0.99830	0.00011	0.00012
		70	0.00149		1.41420		0.99907	0.00006	0.00007
		80	0.00100		1.44000		0.99270	0.00061	0.00072
	0.6	60	0.00033		1.65540		0.99810	0.00012	0.00013
		70	0.00149		1.41420		0.99970	0.00020	0.00024
		80	0.00101		1.00010		0.99961	0.02897	0.03423
	0.8	60	0.00149		1.41420		0.99970	0.00020	0.00024
		70	0.00101		1.00010		0.99961	0.02897	0.03423
		80	0.00100		1.04410		0.99943	0.02544	0.03006
Henderson	0.0.44	60	0.00855	1.101945			0.9298	0.00047	0.00054

and Pabis		70	0.00865	1.101934			0.9291	0.00045	0.00052
		80	0.00886	1.10917			0.9237	0.00044	0.00051
	0.6	60	0.00892	1.10917			0.90036	0.00038	0.00045
		70	0.00865	1.101934			0.9291	0.00045	0.00052
		80	0.00892	1.10917			0.9211	0.00043	0.00051
	0.8	60	0.00892	1.10917			0.90036	0.00038	0.00045
		70	0.00892	1.10917			0.90036	0.00038	0.00045
		80	0.00892	1.07839			0.9172	0.00032	0.00038

Table 3.7 showed the regression analysis of 0.4cm, 0.6cm and 0.8cm thickness of untreated irish potato at temperature of 60ºC, 70ºC and 80ºC.. The Page model was the best model to describe the hot air drying behavior of carrot with R^2 of 0.99907, X^2 of 0.00007 and RMSE of 0.00006. These results are similar to the work by Wilton et al (2013) on the mathematical models to describe thin-layer drying and to determine drying rate of whole bananas

3.8: RSM Results

Table 3.8: Response Surface Matrix for Untreated Carrot

Std	Run	Factor1 Temperature (^{o}C)	Factor 2 Thickness (cm)	Factor 3 Time (min)	Response 1 Moisture content (gsolid/gwater)	Response 2 Drying rate (kg/m^{2}s)
9	1	60	0.6	180	0.3021	0.00164
16	2	70	0.6	180	0.5717	0.00162
8	3	80	0.8	300	0.1236	0.00248
5	4	60	0.4	300	0.1236	0.00102
18	5	70	0.6	180	0.5717	0.00162
12	6	70	0.8	180	0.4837	0.00158
19	7	70	0.6	180	0.5717	0.00162
4	8	80	0.8	60	3.1670	0.03543
14	9	70	0.6	300	0.1236	0.00102
2	10	80	0.4	60	2.9230	0.00213
15	11	70	0.6	180	0.5717	0.00162
6	12	80	0.4	300	0.0787	0.00103
13	13	70	0.6	60	3.1240	0.00192
20	14	70	0.6	180	0.5717	0.00162
1	15	60	0.4	60	3.2450	0.00179
3	16	60	0.8	60	4.2130	0.00075
17	17	70	0.6	180	0.5717	0.00162
11	18	70	0.4	180	0.2755	0.00165
7	19	60	0.8	300	0.1905	0.00101
10	20	80	0.6	180	0.3450	0.00172

Table 4.33: Response Surface Matrix for Treated Carrot

Std	Run	Factor1 Temperature (^{o}C)	Factor 2 Thickness (cm)	Factor 3 Time (min)	Response 1 Moisture content (gwater/gsolid)	Response 2 Drying rate (kg/m^{2}s)
9	1	60	0.6	180	1.5510	0.00139
16	2	70	0.6	180	0.3492	0.00182
8	3	80	0.8	300	0.1111	0.00114
5	4	60	0.4	300	0.1123	0.00114
18	5	70	0.6	180	0.3492	0.00182

International Journal of Advances in Engineering and Management (IJAEM)
Volume 4, Issue 1, Jan 2022 pp: 941-956 www.ijaem.net ISSN: 2395-5252

12	6	70	0.8	180	0.4560	0.00178
19	7	70	0.6	180	0.3492	0.00182
4	8	80	0.8	60	3.1450	0.00246
14	9	70	0.6	300	0.0811	0.00115
2	10	80	0.4	60	2.4320	0.00323
15	11	70	0.6	180	0.3492	0.00182
6	12	80	0.4	300	0.0616	0.00115
13	13	70	0.6	60	2.8950	0.00273
20	14	70	0.6	180	0.3492	0.00182
1	15	60	0.4	60	4.2520	0.00128
3	16	60	0.8	60	4.7950	0.00071
17	17	70	0.6	180	0.3492	0.00182
11	18	70	0.4	180	0.2450	0.00185
7	19	60	0.8	300	0.2352	0.00111
10	20	80	0.6	180	0.1351	0.00189

3.8: Graphical Results of the RSM

The graphical representations of the predicted versus actual moisture content of untreated and treated carrot are presented in Figures 3.19 and 3.20 respectively. The points clustered along the line of best fit, indicating that the model can adequately describe moisture content of the samples. The 3-D plots of the drying plots of moisture content versus the considered factors of temperature, thickness and time are presented in Figures 3.21-3.23 and Figures 3.24-3.26 for the untreated and treated carrot respectively. The moisture content decreases with increasing temperature, drying time and decreasing sample thickness.

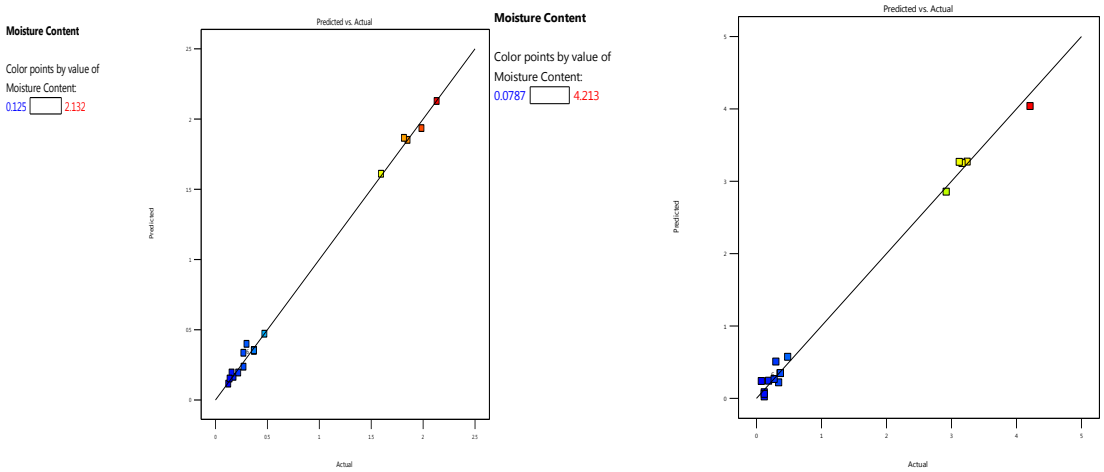
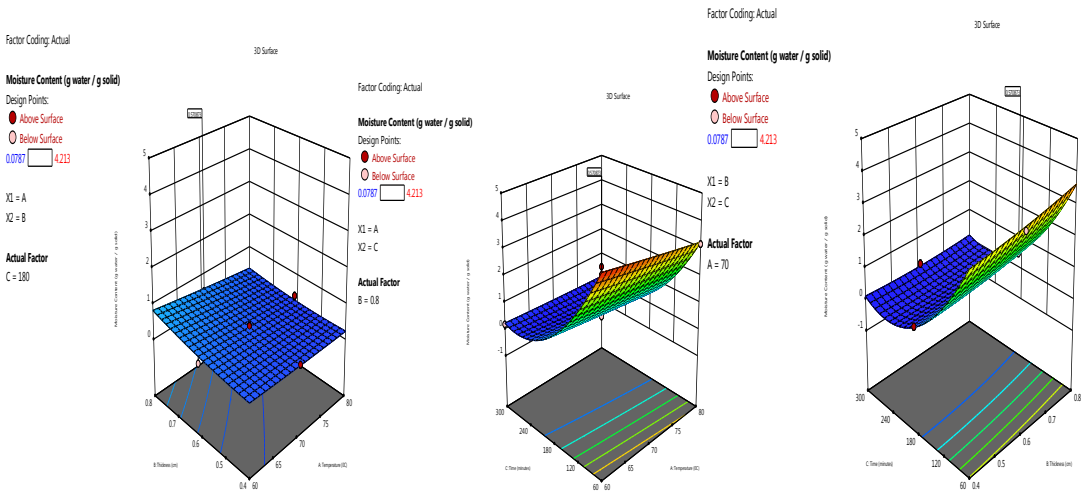


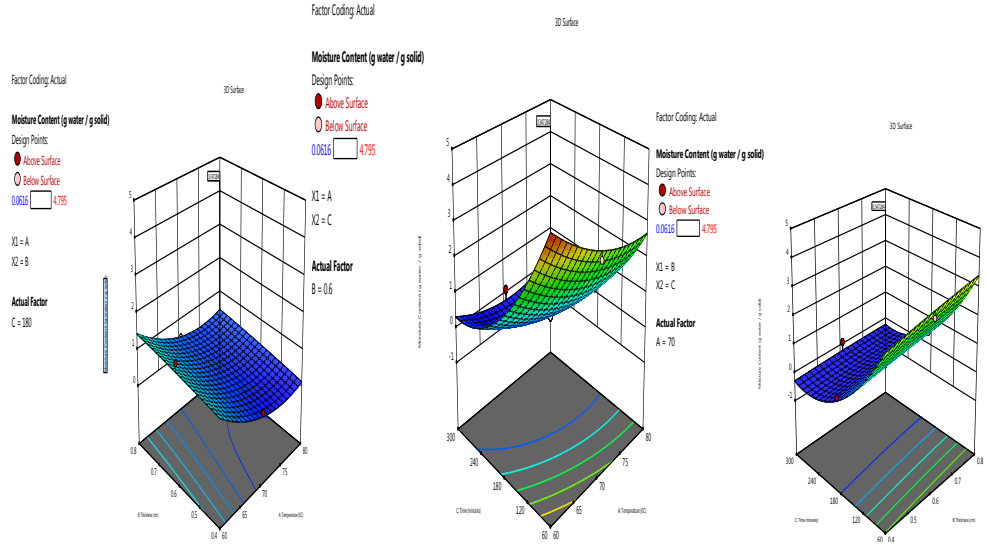
Fig.3.19: Predicted versus actual moisture content of untreated carrot and treated carrot

International Journal of Advances in Engineering and Management (IJAEM)
Volume 4, Issue 1, Jan 2022 pp: 941-956 www.ijaem.net ISSN: 2395-5252



(a) **(b)** **(c)**

Fig 3.20: Profile of response surface and contour plots for drying rate versus (a) temperature and time (b) thickness and time (c) temperature and thickness of the untreated carrot.



(a) (b) (c)

Fig 3.21: Profile of response surface and contour plots for drying rate versus (a) temperature and time (b) thickness and time (c) temperature and thickness of the treated carrot.

Table 3.10: ANOVA for Moisture Content of Untreated carrot

Source	Sum of Squares	Df	Mean Square	F-value	p-value	
Model	35.93	9	3.99	227.34	< 0.0001	Significant
A-Temperature	0.2065	1	0.2065	11.76	0.0065	
B-Thickness	0.2347	1	0.2347	13.36	0.0044	
C-Time	25.70	1	25.70	1463.57	< 0.0001	
AB	0.0696	1	0.0696	3.96	0.0746	
AC	0.1973	1	0.1973	11.23	0.0073	
BC	0.1513	1	0.1513	8.62	0.0149	
A^2	0.0006	1	0.0006	0.0367	0.8520	
B^2	0.0140	1	0.0140	0.7973	0.3929	
C^2	4.76	1	4.76	271.01	< 0.0001	

Residual		0.1756	10	0.0176		
Lack of Fit		0.1756	5	0.0351		
Pure Error		0.0000	5	0.0000		
Cor Total		36.11	19			
Std. Dev.	0.1325	**R^2**				0.9951
Mean	1.05	**Adjusted R^2**				0.9908
C.V. %	12.65	**Predicted R^2**				0.9369
		Adeq Precision				42.8293

Table 3.11: ANOVA for Moisture Content of treated carrot

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	43.10	9	4.79	145.87	< 0.0001	Significant
A-Temperature	2.56	1	2.56	78.01	< 0.0001	
B-Thickness	0.2688	1	0.2688	8.19	0.0169	
C-Time	28.62	1	28.62	871.77	< 0.0001	
AB	0.0012	1	0.0012	0.0355	0.8543	
AC	1.36	1	1.36	41.34	< 0.0001	
BC	0.1468	1	0.1468	4.47	0.0606	
A^2	0.5993	1	0.5993	18.26	0.0016	
B^2	0.0018	1	0.0018	0.0554	0.8187	
C^2	3.40	1	3.40	103.55	< 0.0001	
Residual	0.3283	10	0.0328			
Lack of Fit	0.3283	5	0.0657			
Pure Error	0.0000	5	0.0000			
Cor Total	43.43	19				
Std. Dev.	0.1812	**R^2**				0.9924
Mean	1.12	**Adjusted R^2**				0.9856
C.V. %	16.12	**Predicted R^2**				0.9393
		Adeq Precision				39.2589

3.9: Final Equation in Terms of Coded Factors

Mathematical models (with significant model terms) of the moisture content as function of temperature (A), thickness (B) and time (C) are expressed in Equations (3.1) – (3.2). . In all the sample models, the highest power of the variables is two, indicating that quadratic model is adequate for the description of the moisture content with respect to temperature, thickness and time. It was also observed that there were interactions of the factors in the drying process. The positive signs in the models indicate synergetic effects, while the negative signs show antagonistic effects of the factors. The equation in terms of coded factors can be used to make predictions about the response for given levels of each factor.

Untreated carrot

$$\text{Moisture content} = +0.3466 + 0.1437A + 0.1523B - 1.60C - 0.0933AB + 0.1570AC - 0.1375BC + 0.0153A^2 + 0.0714B^2 + 1.32C^2 \quad (3.1)$$

Treated carrot

$$\text{Moisture content} = +0.3473 - 0.5061A + 0.1639B - 1.69C + 0.0121AB + 0.4119AC - 0.1354BC + 0.4668A^2 - 0.0257B^2 + 1.11C^2 \quad (3.2)$$

3.10: Optimum Parameters of the Moisture Content

The optimum parameters of temperature, thickness and time with corresponding drying rates of the samples are shown in Table 3.12

Samples	Optimum temperature(°C)	Optimum thickness (cm)	Optimum time (minutes)	Optimum moisture content (gwater/gsolid)
Untreated carrot	70	0.6	180	0.5709
Treated carrot	70	0.6	180	0.3473

3.11: Validation of the Results

The validation of the results is presented in Table 3.13. The model of the drying rate was validated by considering the percentage deviation of the predicted data from the experimental data. In all the samples, percentage deviation is less than 5%, which confirm that the models are adequate for the description of the drying process.

Table 3.13: Validation of the optimum results

Samples	Optimum Temp. (ºC)	Optimum Thickness (cm)	Optimum Time (min)	Experimental moisture content (gwater/gsolid)	Predicted moisture content (gwater/gsolid)	Percentage deviation (%)
Untreated carrot	70	0.6	180	0.5717	0.5709	0.139934
Treated carrot	70	0.4	180	0.3492	0.3473	0.544101

IV. CONCLUSION

Response surface analysis was effectively used to determine the effect of temperature, drying time and slice thickness on moisture content. The result of the experiment showed that increase in drying temperature resulted in decreasing the values of composition except carbohydrate. Experimental drying curves showed only a falling drying rate period. Exponential model is adequate to describe the relationship between the moisture content and time of drying..The rate constants deduced from the linear models of ln(moisture ratio) versus time were adequate for the determination of the effective diffusivity constants.The page model was described as the best model for drying characteristics of the foodstuff samples within 60ºC-80ºC. At this optimum condition, the predicted response for moisture content was 0.5709gwater/gsolid and 0.3473gwater/gsolid for untreated and treated carrot.

REFERENCES

[1]. Akipnar, E.K. & Toraman S., (2013) Estimation of the Moisture Diffusivity and Activation Energy in thin Layer Drying of Ginger Slices. International Journal of Nutrition and Food Energy. 7(66), 415 - 418.

[2]. Doymas, I. (2004). Convective Air Drying Characteristics of Thin Layer Carrots. Journal of Food Engineering, 61:359 – 364.

[3]. Adegunwa, M.O., Alamu E.O & Omitogun L.A. (2011). Effects of processing on nutritional content of yam and cocoyam tubers. Journal of Applied Biosciences 46: 3086-3092

[4]. Ajala, A.S., Ajala, F.A., & Tunde-Akintunde, T.Y.(2012). Study on Drying Kinetics of fermented Corn Grain. Food Science and Quality Management 5,10-17

[5]. Akpinar, E.K. & Bicer, Y., (2008). Mathematical modelling of thin layer drying process of long green pepper in solar layer and under open sun. Energy Conversion and Management., 49(6): 1367-1375

[6]. AOAC (2004). Association of Official Analytical Chemistry. Official Method of Analysis 14th ed. Washington D.C.

[7]. Babalis, S.J, & Belessiotis VG (2004). Influence of drying conditions on the drying constants and moisture diffusivity during the thin-layer drying of figs. Journal of Food Engineering; 65: 449–458.

[8]. Bakal, S.B., Sharma G.P., Sonawane S.P., & Verma R.C.,(2011). Kinetics of potato drying using fluidized bed drying doi: 10.1007/s13197-011-0328-x

[9]. Carlos, J. & Dias S, (2014) Nutritional And Health Benefits Of Carrots And Their Seed Extracts. Food and Nutrition Sciences 5:2147-2156

[10]. Chau, C.F., Chen C.H., & Lee M.H (2004). Comparism Of The Characteristics Of Functional Properties And In Vitro Hypoglycaemic Effects Of Various Carrot Insoluble Fiber-Rich Fractions. Labensmittel-Wissenshaff And Technologies, 37,155-160

[11]. Corřea P.C.,Oliveira, G.H.H, Oliveira, P.L.R.,Botelho F.M. & Goneli A.L.D.(2011). Thermodynamics properties of drying process and water absorption of rice grains. Cyta-Journal of Food.15(2),204-210

[12]. Dimente, L.M. & Munro P.A., (1993). Mathematical Modelling of Convection Drying of Green Table Olives. Biosystems Engineering, 98:47-53.

[13]. Erenturk, S. & Erenturk, K.. (2007). Comparison of genetic algorithm and neutral network approaches for the drying process of carrot. Journal of food Engineering 78: 905-91

[14]. Falade , K.O & Soladami, O.J (2010). Modelling of air drying of fresh and blanched sweet potato. International Journal of food science and technology, 45, 278-288.

[15]. Falade, K.O., Olurin, T.O, Ike, E.A., & Aworh O.C. (2007). Effect of pretreatment and temperature in air-drying of Dioscorea alata and Dioscorea rotundata slices. Journal of Food Engineering, 80: 1002-1010

[16]. Fellows, P.J., (2000). Food Processing Technology (principles and practice) Second Edition. H. Head published Limited England.18-27.

[17]. Gatea, A. A. (2011). Design and construction of a solar drying system, a cylindrical section and analysis of the performance of the thermal drying system. African Journal of Agricultural Research, 6, 343–351

[18]. Gornicki, K.& Kaleta A. (2007): Drying curve modelling of blanched carrot cubes under natural convection condition. Journal of Food Engineering, 82: 160–170.

[19]. Goyal, R.K., Kingsley A.R.P., Manikatan M.R., & Ilyas S.M., (2007). Mathematical Modelling of Thin-Layer Drying Kinetics of Plum in a Tunnel Dryer. Journal of Food Engineering, 76: 176 – 180

[20]. Goyalde, N. A., Melo, E. C., Rocha, R. P., Goneli, A. L. D., & Araújo, F. L. (2009). Mathematical modelling of the drying kinetics of sugarcane slices. Revista Brasileira de Produtos Agroindustriais, Campina Grande, 11, 117–121.

[21]. Gupta, M. K., Sehgal, V. K., & Arora, S. (2011). Optimization of drying process parameters for cauliflower drying. Journal of Food Science and Technology, 50, 62–69.

[22]. Gurlek, G., Ozbalta, N., & Gungor, A. (2009). Solar tunnel drying characteristics and mathematical modelling of tomato. Journal of Thermal Science and Technology, 29, 15–23.

[23]. Gurlek, G., Ozbalta, N., & Gungor, A. (2009). Solar tunnel drying characteristics and mathematical modelling of tomato. Journal of Thermal Science and Technology, 29, 15–23.

[24]. Hassini, L., Azzouz, S., Peczalski, R., & Belghith A. (2007). Estimation of potato moisture diffusivity from convective drying kinetics with correction of shrinkage. Journal of Food Engineering, 79, 47-56.

[25]. Henderson, S.M, & Pabis S. (1961). Grain drying theory I. Temperature effect on drying coefficient. Journal of Agricultural Engineering Research; 6: 169-174.

[26]. Jideani, V.A. & Mpotokwana S.M (2009). Modelling of Water Absorption of Blotswana Bambers varieties using peleg`s equation. Journal of Food Engineering 92, 182-188.

[27]. Kelbaliev, G. I., & Manafov, M. P. (2009). Mass transfer in the process of drying of porous materials. Journal of Engineering Physics and Thermophysics, 82, 991–999.

[28]. Lui, Q., & Bakker-Arkema, F.W (1997). Stochastic modelling of grain drying. Part 2: Model development. Journal of Agricultural Engineering Research; 66: 275–280.

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

[30]. Mulualem, T., Mekbib F., Hussein S., & Gebre, E. (2018). Analysis of Biochemical Composition of Yam (dioscorea spp) landraces from Southwest. Ethopia Agrotechnology.7:1-8

[31]. Nazghelichi T., Aghbashlo M., & Kianmehr M.H., (2011) Optimization of an Artificial Neural Network Topology using Coupled Response Surface Methodology and Genetic Algorithm for Fluided Bed Drying. Computer and Electronic in Agriculture, 75 (1): 84 – 91.

[32]. Oforkansi, B.C,& Oduola, M.K.(2016). Mathematical model of thin-layer drying process in a plantain sample. International Journal of Engineering Research.5(5),364-366.

[33]. Oforkansi, B.C,& Oduola, M.K.(2016). Mathematical model of thin-layer drying process in a plantain sample. International

Journal of Engineering Research.5(5),364-366.
[34]. Onwude D.I., Janius R.B., Nawi N.,& Abdan k (2016) Modelling the thin-layer drying of fruits and vegetables. A Review. Compr. Rev. Food Science. Food Safety 15, 599-618.
[35]. Prakash, S., Jha, S.K. & Datta, N. (2004). Performance Evaluation of Blanched Carrots Dried by three different driers. Journal of Food Engineering 62: 305-313.
[36]. Sacilik, K., & Elicin A.K., (2006). The Thin Layer Drying Characteristics of Organic Apple slices. Journal of Food Engineering,73: 281-289
[37]. Sanni, L.O. (2015). Drying for wealth, Food Security and Nation Building FUNAAB Inauguarl Lecture Series No.49 Pp 17-30.
[38]. Senadeera W., Bhandan, B.R., Young G., & Wijesingle B.(2005) Modelling Dimensional Shrinkage of Shaped Foods in Fluidized Bed Drying. Journal Food Processing and Preservation 29:109-119.
[39]. Sing,K., Dhongade H., Sing N. & Kashyap P. (2010). Hypolipidemic Activity Of Ethanolic Extract Of Daucus Carota Linn On Isoproterenol-Induced Myocardial Infaraction. Bangladeh. Journal Of Pharmacology 3, 74-79
[40]. Varnalis, A.I., Brennan J.G., Macdougall D. B., & Gilmour S.G., (2004). Optimization of High Temperature Puffing of Potato Cubes using response Surface Methodology. Journal of Food Engineering 61 (1): 153 – 163.
[41]. Wani A.A., Kaur D., Ahmed I. & Sogi D.S., (2008). Extraction Optimization of Watermelon Seed Protein using Response Surface Methodology. LWT – Food Science and Technology: 41 (8): 1514 – 1520.
[42]. Wong, K., & Cheung, P. C. (2001). Influence of drying treatment on three Sargassum species. Journal of Applied Phycology, 13, 43–50.
[43]. Yaldiz, O, Ertekin, C, & Uzun, H.I (2001). Mathematical modeling of thin layer solar drying of sultana grapes. Energy – An International Journal; 26(5): 457–465.
[44]. Zhang Q.A., Song, Y., Wang X., Zhao, W.Q. & Fan X.H (2016). Mathematical Modelling of Debittered Apricot Kernels During Thin-layer. Cyta.-Journal of Food 14, 509-517.