EFFECT OF OSMOTIC DEHYDRATION ON THE DRYING KINETICS OF YELLOW CASSAVA ROOT (*MANIHOT ESCULENTA CRANTZ*)

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ABSTRACT

The effect of osmotic dehydration on the drying kinetics of yellow cassava (*Manihot esculenta Crantz*) was evaluated. Cassava chips of average diameter and thickness of 29.59 mm and 5.64 mm, respectively were immersed in varying concentration of NaCl (10, 20, 30 % w/v) at different temperature (30, 60, 70°C) and different process time (30, 60, 90 min). The pretreated chips were then dried in an oven dryer at temperature of 105°C. The optimization of the processing parameters (concentration, temperature and time) was carried out for maximum water loss and weight reduction and minimum solid gain using response surface methodology. The optimized results were 51.40 °C for temperature, 16.70% for concentration and 90 minutes for time to give the values of water loss, solid gain and weight reduction as 11.88 (g/100g fresh sample), 2.72 (g/100g fresh sample) and 9.16 (g/100g fresh sample), respectively. The thin layer drying kinetics of both the osmodehydrated and untreated (control) yellow cassava root also were investigated by using an oven dryer operated at 105°C. The results showed that the drying time for the osmodehydrated sample was shorter than that of the untreated sample. The experimental drying data were fitted to five well known drying models: the Page, Wang, and Singh, Two-term exponential, Newton and Logarithmic models. Among the five models considered, the Logarithmic model was found to best describe the drying kinetics of both the treated and untreated yellow cassava chips. This work shows that pretreating yellow cassava with osmotic dehydration can enhance the drying rate of the product.

KEYWORDS: Yellow cassava root, drying, optimization, moisture content, drying kinetics.

1. INTRODUCTION

Cassava is a major staple food in the tropical developing countries (Bokanga, 2000). It is very rich in carbohydrate and contains other nutrients like calcium and essential minerals. Yellow cassava is an improved variety that contains high carotenoid content which is a precursor for Vitamin A (Iglesias *et al.,* 1997). Yellow cassava variety was discovered at Amazon region in South America, and was later developed by International Centre for Agriculture in Colombia (Hillocks, 2002). The yellow cassava variety was introduced to Africa by International Institute for Tropical Agriculture, Nigeria (Chavez *et al*., 2005). The vitamin A content in the yellow cassava variety helps to promote good eye sight, high immunity, anti-oxidant and anti-inflammation activities in the body (Krinsky, 1994). The colour of the crop ranges from deep yellow to slightly orange (Akinwale *et al*., 2010). Yellow cassava is also consumed the same way as white cassava in form of garri, fufu, flour and chips (Duah *et al*., 2016).

Yellow cassava just like the white cassava is very susceptible to spoilage after harvest. Therefore, there is need to subject it to drying in order to increase the shelf life of the yellow cassava. However, convective drying has been found to have adverse effects on dried agricultural products, which include, loss of nutrients, loss of texture, loss of colour and structure disruption (Sehrawat *et al*., 2016; Fernandes *et al*, 2008). Also convective drying has been reported to be energy and cost intensive (Chen *et al*., 2016; Paengkanya *et al*., 2015). In order to address these problems, osmotic dehydration pretreatment has been applied prior to convective drying of foods like banana (Chaguri *et al*., 2017), carrot (Singh, *et al*., 2007), water melon (Barbosa *et al*., 2013), mango (Alakali *et al*., 2006) and apple (Sereno *et al*., 2001). Osmotic dehydration is the partial removal of water from an agricultural product when immersed in a concentration solution (Tortoe, 2010). This phenomenon is based on the difference in the osmotic pressure between the solution inside the crop product and the external osmotic solution, which leads to removal of water from the product and uptake of solutes from the solution into the products (Oladejo and Ma, 2016; Ali *et al*., 2010). Osmotic dehydration is usually used as a pretreatment prior to drying because of its numerous advantages, which include low cost of operation, ease of operation, ecofriendly, retention of nutrients and preservation of texture and colour of the product.

In order to achieve a highly acceptable product and to come up with efficient process operations, there is need to optimize the process parameters (temperature, time and concentration) during osmotic dehydration of yellow cassava. The data of the optimized (best) process parameters can easily be used by the food industries for the osmotic dehydration, thus, saving cost and time involved in the drying of yellow cassava.

The goal of optimization is to achieve the best process factors that will give the specified and desired results (Oladejo and Ma, 2016). Response surface methodology (RSM) has been applied for the optimization of process parameters involved in the processing of agricultural products like sweet potato (Oladejo and Ma, 2016), carrot (Singh *et al*., 2010), peach (Yadav *et al*., 2012) and potato (Eren and Kaymak-ertkin, 2007).

The knowledge of the drying kinetics of agricultural products is useful in the process optimization, control and design of agricultural equipment (Alakali *et al*., 2006). Several authors have worked on the drying kinetics of some agricultural products like tomato (Sacilik *et al*., 2006), yam (Sobukola *et al*., 2008), carrot (Doymaz, 2004) and okra (Sobukola, 2009).

Therefore, the objectives of this work were to optimize the process parameters of osmotic dehydration of yellow cassava and to investigate the effects of osmotic dehydration on the drying kinetics of yellow cassava roots using the optimized values.

2. MATERIALS AND METHODS

2.1 Materials

Freshly harvested yellow cassava roots were obtained from a local farm in Uyo, Akwa Ibom state. Cleaning and peeling were done manually using knife. The roots were sliced into an average diameter of 29.59mm and 5mm thickness, and each slice having a weight of 4g. Food grade salt (NaCl) was used as osmotic agent for the experiment. Each of the salt concentrations (10, 20 and 30% w/v) was prepared with distilled water and made up to 300mL volume inside a volumetric flask to serve as the osmotic solution for each experimental run according to a previous experiment (Oladejo, 2020). Three slices of cassava were put inside the osmotic solution contained in a 500 ml beaker which was placed in a water bath at specified temperature (30, 50 and 70 ^{o}C) and was kept constant throughout the process duration by the aid of thermostat in the water bath. Agitation was supplied to the osmotic solution by means of a stirrer. At the end of each experimental run, the yellow cassava slices were removed from the solution, drained and blotted with absorbent paper. The osmodehydrated samples were further subjected to drying in an oven dryer at 70 ^{o}C until the mass remained constant.

2.2 Experimental Design

The experiments were conducted according to Box-Behnken Design using software Design Expert version 7 (Stat Ease. Inc., Minneapolis, MN, USA). This consisted of three factors at three levels each, which made up to 17 experimental runs with replication at five centres as shown in Table 1. The software was also used to optimize the process parameters for maximum water loss and weight reduction, and minimum solid gain.

The experimental data were fitted to second order polynomial model as shown:

$$Y = \beta_0 + \sum_{i=1}^{3} \beta_i X_i + \sum_{i=1}^{3} \beta_{ii} X^2{}_i + \sum_{i=1}^{2} \sum_{j=i+1}^{3} \beta_{ij} X_i X_j + \varepsilon \qquad 1$$

where, Y is the response variable, that is, Y_1 = water loss g/100 g of fresh cassava root chip, Y_2 = solute gain g/100 g of fresh cassava root chip, Y_3 = weight reduction g/100 g of fresh cassava root chip; the values of X_i (i= 1–3) represent the uncoded independent variables (X_1 = solution concentration, X_2 = process duration, X_3 = process temperature), and β_0 is the constant coefficient also known as the intercept, β_i, β_{ii}, β_{ij} (i and j = 3) are the linear, quadratic and cross-product regression coefficients, respectively, and ε is the error term.

Model fitness was based on the analysis of variance (ANOVA) at 5% significance level, R-squared, adjusted R-squared and lack of fit should not be significant (p>0.05).

2.3 Determination of Water Loss, Weight Reduction and Solid Gain

In order to account for initial weight differences between the samples, water loss (WL), solid gain (SG) and weight reduction (WR) were calculated according to the following equations (Ozen et al., 2002):

$$Water\ loss\ (WL) = \frac{(W_O - W_t) + (S_t - S_O) \times 100}{W_O} \qquad 2$$

$$Solid\ gain\ (SG) = \frac{(S_t - S_O) \times 100}{W_O} \qquad 3$$

$$Weight\ reduction\ (WR) = WL - SG \qquad 4$$

where, W_o and W_t are the initial weight of yellow cassava and final weight of yellow cassava after osmotic dehydration at time t (g); S_o and S_t are the initial and final dry matter (g/kg).

Table 1: Experimental design and values of response variables

Runs	Temperature °C	Time mins	Concentration % w/v	Water loss %	Solid gain%	Weight reduction %
1	50	60	20	4.12233	1.236230	2.88609
2	30	30	20	3.80655	0.247942	3.55861
3	70	30	20	7.13327	0.993413	6.13986
4	50	60	20	9.19534	0.496895	8.69844
5	70	60	30	5.21834	1.657830	3.56051
6	50	90	10	16.5148	5.809320	10.7055
7	30	60	10	8.03591	0.413393	7.62252
8	70	60	10	5.25069	0.666884	0.58381
9	50	60	20	8.01256	0.412556	7.60000
10	50	30	30	5.06708	0.996090	4.07099
11	50	30	10	6.27128	0.987467	5.28380
12	70	90	20	9.29934	0.998781	8.30056
13	30	60	30	5.89541	1.250000	4.64544
14	50	60	20	9.22739	1.910330	7.31706
15	50	60	20	8.50723	1.239070	7.26816
16	30	90	20	6.21818	0.902345	5.31584
17	50	90	30	7.16154	0.416879	6.74466

2.4 Determination of Drying Kinetics

Fresh sliced cassava samples were osmodehydrated using the optimized process parameters obtained in the above experiments. The drying kinetics was then conducted for the osmodehydrated and untreated samples. Drying experiments were carried out in a vacuum oven (Genlab oven, Model: Mino/50, Serial No: 13C280) at 105 °C. Moisture contents were determined according to the method of AOAC (2000). Fresh and osmodehydrated samples had average initial moisture content of 67.25% (wet basis) and 61% (wet basis), respectively. Sample weight was measured using a weighing balance. During drying, weighing at intervals of 30min were done until the dynamic equilibrium between the sample moisture content and drying air humidity was reached, when the sample weight became constant.

The moisture ratio (MR) is given as (Abano and Amoah, 2015):

$$MR = \frac{X_S - X_e}{X_O - X_e} \quad 5$$

Where; X_S is the average moisture content at time t, (kg H_2O per kg dry matter); X_e is the equilibrium moisture content, (kg H_2O per kg dry matter); X_O is the initial moisture content (kg H_2O per kg dry matter). Due to long drying period, equation 5 becomes:

$$MR = \frac{X_S}{X_O} \quad 6$$

The experimental drying data were fitted to five well known drying models: the Page, Wang, and Singh, Two-term exponential, Newton and Logarithmic models (Table 2). These models were validated using R-Squared (R^2), reduced chi-square (χ_c^2), mean biased error (MBE) and root mean square error (RMSE) as given below:

Reduced Chi-square (χ_c^2)

$$(\chi_c^2) = \frac{\sum_{i=1}^{\hat{N}} (MR_{exp} - MR_{pre})}{\hat{N} - Z} \quad 7$$

Mean bias error (MBE)

$$MBE = \frac{1}{\hat{N}} \sum_{i=1}^{\hat{N}} (MR_{exp} - MR_{pre}) \quad 8$$

Root mean square error (RMSE)

$$RMSE = [\frac{1}{\hat{N}} \sum_{i=1}^{\hat{N}} (MR_{exp} - MR_{pre})^2]^{1/2} \quad 9$$

Where; MR_{exp} is the experimental values, MR_{pre} is the predicted values, $\hat{N}$ is the number of observations, Z is the number of constants and χ_c^2 is the Chi-square. Therefore, the best model was chosen as one with the highest R^2; and the least χ_c^2, MBE and RMSE values.

Table 2: Thin-layer models used for mathematical determination of drying kinetics of yellow cassava chips

S/No	Model	Equation	References
1	Newton	$MR = \exp(-kt)$	Mujumdar and Menon (1995)
2	Logarithmic	$MR = a \exp(-kt)+c$	Yagcioglu, et al., (1999)
3	Two Term Exponential	$MR=a\exp(-kt)+(1-a)\exp(-kat)$	Sharaf-Eideen, et al., (1980)
4	Page	$MR = \exp(-kt^n)$	Diamante and Munro (1993)
5	Wang and Singh	$MR = 1+at+bt^2$	Wang and Singh (1978)

Where; a, b, c, k and n are the empirical constants in the drying models

3. RESULTS AND DISCUSSION

The experimental values for water loss, weight reduction and solid gain are shown in Table 1. The results of analysis of variance (ANOVA) for fitting the second order polynomial models to experimental data are shown in Table 3. For water loss, time was the most significant factor. The quadratic interactions showed no significant effects among factors, meaning that water loss, solid gain and weight reduction had a linear function of temperature, salt concentration and immersion time. The interaction between immersion time and concentration had significant effect on solid gain.

As shown in Figure 1A, there was an increase in water loss with the interaction between concentration and process time. The effect was same for the interaction between temperature and process time (Fig.1B). That is, increase in temperature yielded a significant outflow of water from the membrane of the cassava with prolonged soaking time. The increase in water loss due to increase in concentration of osmotic solution might be attributed to the difference in osmotic

Table 3: Analysis of variance (ANOVA) and regression analysis for water loss, solid gain and weight reduction

		Water loss		Solid gain		Weight reduction	
Source	**Df**	**Sum of squares**	**P-value**	**Sum of squares**	**P-value**	**Sum of Squares**	**P-value**
Model	9	92.2000	0.2910	16.1300	0.3720	39.5400	0.5683
A: Temperature	1	1.8000	0.6984	0.2800	0.6642	0.2600	0.8240
B: Concentration	1	20.2600	0.1244	1.5800	0.3193	10.5200	0.1853
C: Time	1	35.7700	0.0535	3.0000	0.1830	18.0400	0.0958
A*B	1	1.1100	0.6949	5.96E-03	0.9494	0.9500	0.6715
A*C	1	0.0150	0.9634	0.1100	0.7900	0.0410	0.9298
B*C	1	16.6000	0.1581	7.2900	0.0548	1.8900	0.5535
A^2	1	15.6200	0.1692	1.8600	0.2832	6.7000	0.2793
B^2	1	0.1900	0.8701	1.5300	0.3270	0.6400	0.7283
C^2	1	2.2300	0.5808	0.6400	0.5160	0.4800	0.7636
Residual	7	46.5500		9.6300		34.1300	
Lack of fit	3	28.4900	0.2424	8.1100	0.0443	14.0900	0.5011
Pure error	4	18.0500		1.5800		20.0400	
Total	16	138.7500		25.7600		73.6600	
R-Squared	0.6645			0.6261		0.5367	

gradient between the osmotic solution and the solid food material as well as tissue modification which increases the permeability of water through the tissue of the food material according to a study by Alakali *et al*. (2006). But the interaction between temperature and concentration yielded a decline in water loss (Fig.1C). According to Tortoe (2010), there is deposit of solutes on the surface of the food tissue as the concentration increases, which forms barrier layer and eventually hinders the dewatering process of the food tissue.

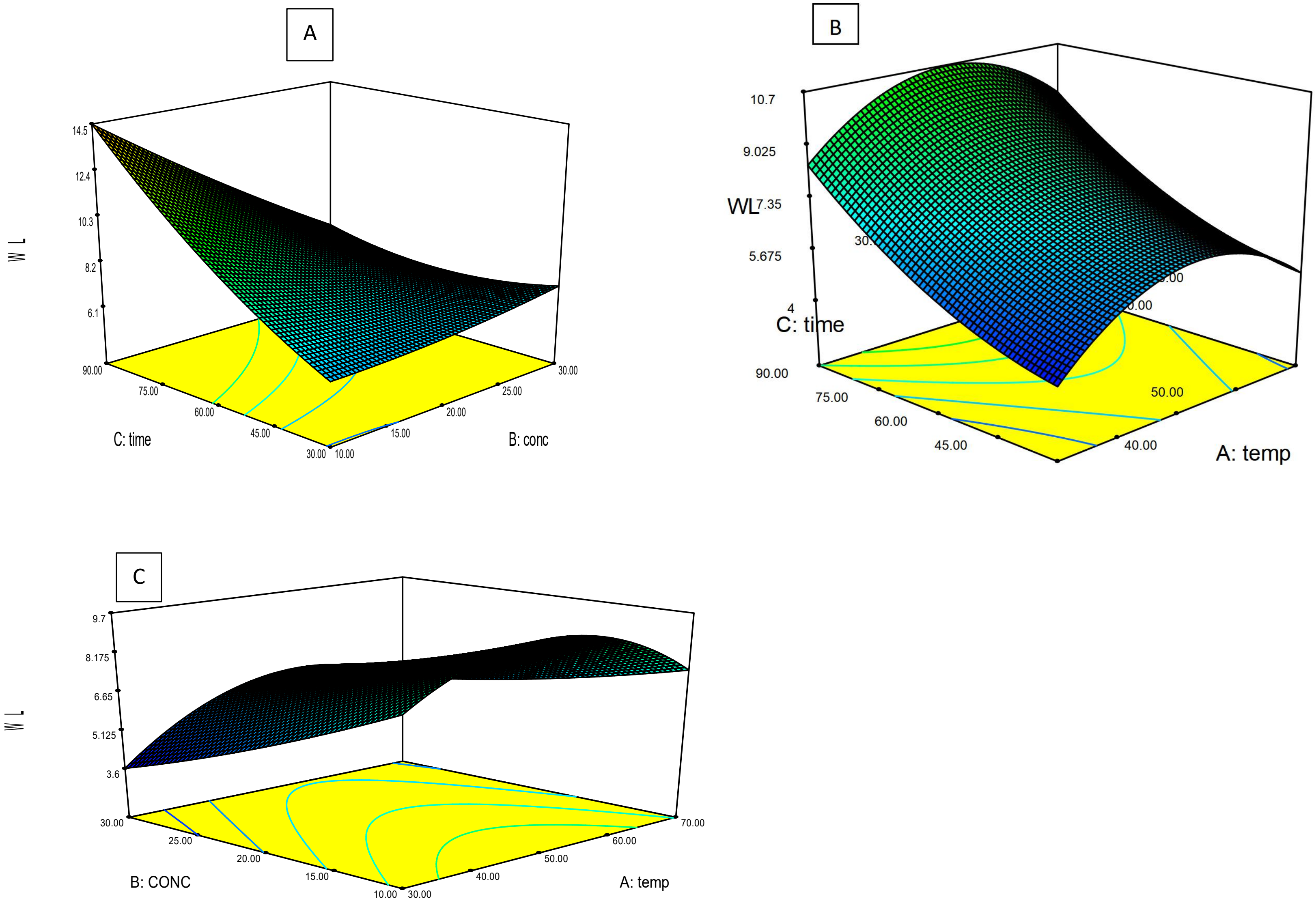

A
W L
14.5
12.4
10.3
8.2
6.1
90.00
75.00
60.00
45.00
30.00
10.00
15.00
20.00
25.00
30.00
C: time
B: conc
B
WL
10.7
9.025
7.35
5.675
4
C: time
90.00
75.00
60.00
45.00
40.00
50.00
A: temp
C
W L
9.7
8.175
6.65
5.125
3.6
30.00
25.00
20.00
15.00
10.00
30.00
40.00
50.00
60.00
70.00
B: CONC
A: temp

Figure 1: (A) Influence of salt concentration and time on water loss (B) Influence of temperature and time on water loss (C) Influence of temperature and salt concentration on water loss

From Figure 2A, it can be inferred that increase in temperature led to increase in solid gain while increase in salt concentration led to decrease in solid gain. Similar observation was reported by Yadav *et al* (2012). The decline in solid gain as the salt concentration increased could be due to the fact that the resistance between the interface of osmotic solution and the yellow cassava slices was weakened by the high viscosity of the osmotic solution. But Figure 2B showed that increase in process temperature and time led to increase in solid gain. Similarly, the interaction between concentration and time also led to increase in solid gain (Figure 2C). This could be an advantage if the organoleptic properties of the product were to be improved as reported by Lewicki and Lenart (2015).

Figure 3A showed that the interaction between temperature and concentration led to decrease in weight reduction just as it was also observed for water loss. However, interactions between temperature and time; and time and concentration led to an increase in weight reduction. These results were in agreement with studies by Raoult-Wack *et al*. (1992); Lewicki and Lenart (2015); Shi and Maguer (2000).

3.1 Optimization

Optimum condition for osmotic dehydration of cassava was determined to obtain maximum water loss and weight reduction, and minimum solid gain. Numerical optimization was applied using the statistical software by Design Expert version 7 (statease Inc). In this study, temperature, processing time and salt concentration were set in the range of 30–70 ^{o}C, 30–90 min and 10–30 % w/v, respectively. By applying desirability function method, solutions were obtained for the optimum covering the criteria. Desirability of 65% was picked which gave 51.40 ^{o}C for temperature, 90 min for time, and 16.70 % for salt concentrations. At this point, water loss, solid gain and weight reduction were calculated as 11.88 (g/100 g fresh sample), 2.72 (g/100 g fresh sample) and 9.16 (g/100 g fresh sample) respectively.

3.2 Drying Kinetics

The drying of control (untreated) cassava started at relatively moisture content (67.25 % w.b) whereas the drying of osmodehydrated cassava began at relatively lower moisture content (61 % w.b.) due to moisture removal and solute gain during osmotic dehydration. As shown in Figure 4, it took 3h (180 min) for osmodehydrated sample to attain equilibrium moisture content compared to the untreated sample which took about 4h 30 min (270 min) to attain steady moisture content. This shows that osmotic dehydration enhances the rate of mass transfer during drying, thereby reducing the drying time. This is because during osmotic dehydration the cell wall and the internal structure of yellow cassava became weakened and pores were created (Aminzadeh *et al*., 2010).This weakened structure and pores enhanced the movement of water (diffusion) from the cassava during drying. This indicates that osmotic dehydration has an effect on drying kinetic. Similar observations were reported by Alakali *et al.* (2006), Ali *et al.* (2010) and Aminzadeh *et al*.(2010). The final moisture content after drying for the untreated and osmodehydrated yellow cassava were 0.76 and 0.7% db, respectively. This low moisture content of the dried yellow cassava could be a good indicator for safe storage since very low moisture content inhibits the growth of microorganism.

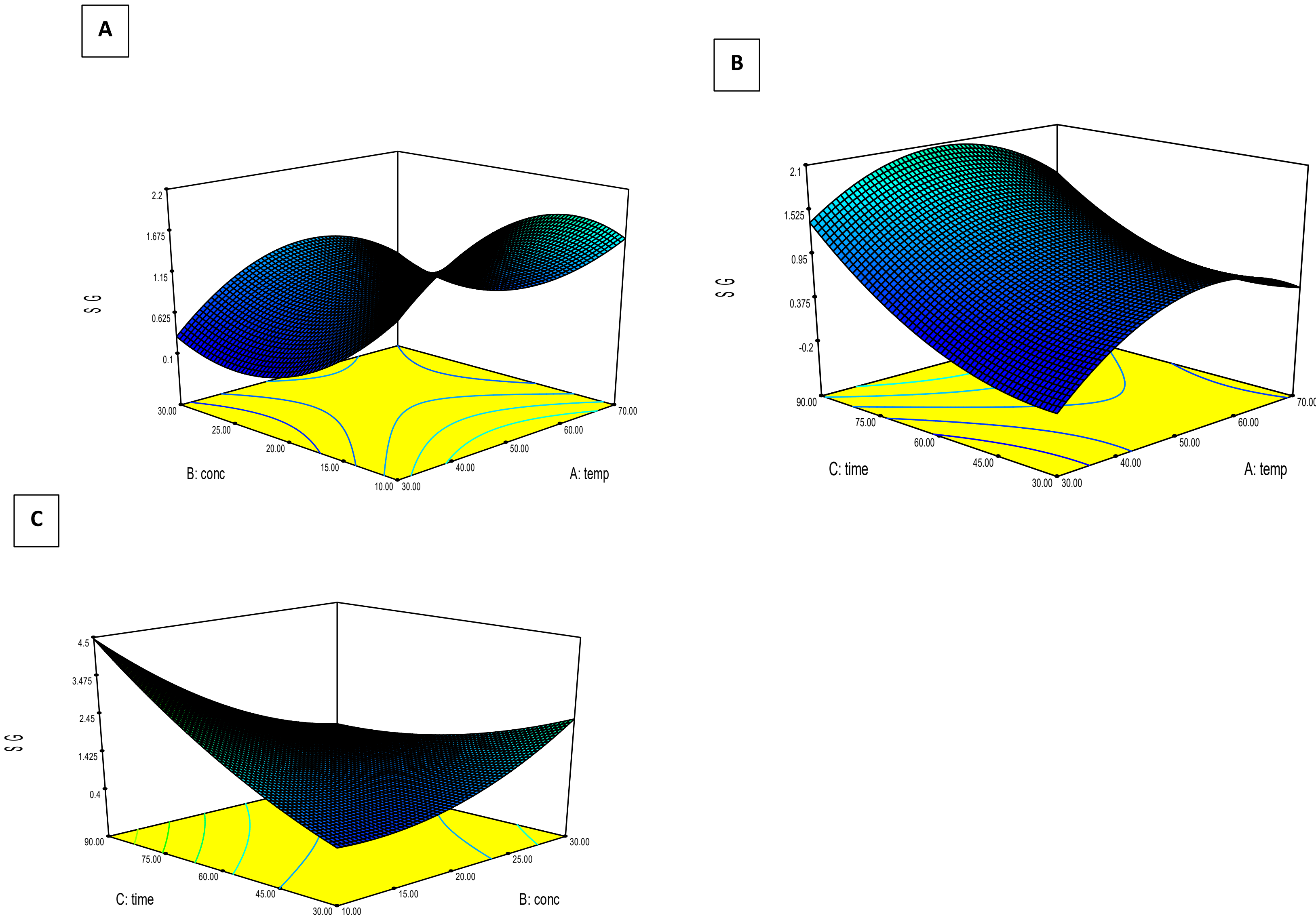
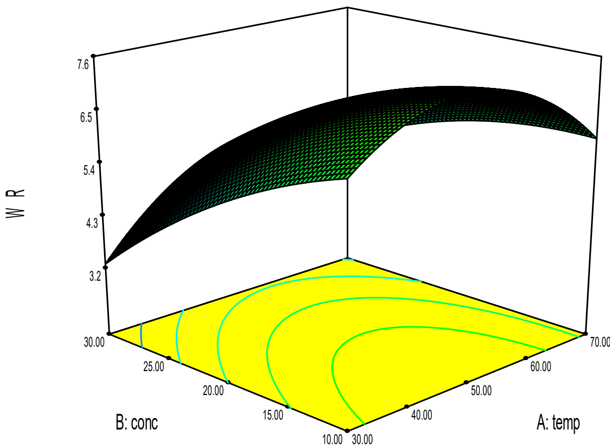
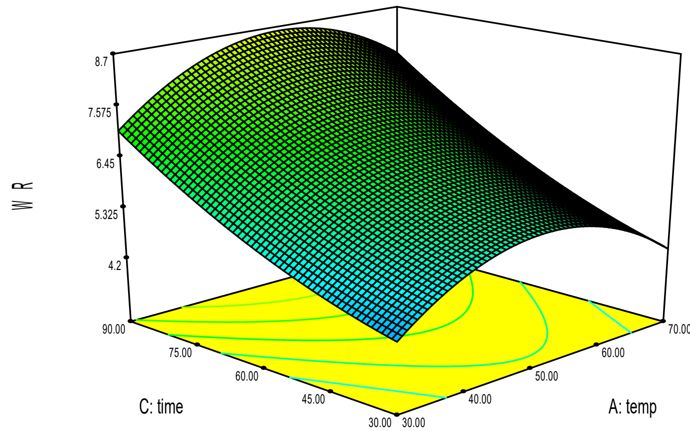


Figure 2: (A) Influence of temperature and salt concentration on solid gain (B) Influence of temperature and time on solid gain (C) Influence of salt concentration and time on solid gain

A


W R
7.6
6.5
5.4
4.3
3.2
B: conc
30.00
25.00
20.00
15.00
10.00
A: temp
30.00
40.00
50.00
60.00
70.00

B


W R
8.7
7.575
6.45
5.325
4.2
C: time
90.00
75.00
60.00
45.00
30.00
A: temp
30.00
40.00
50.00
60.00
70.00

C

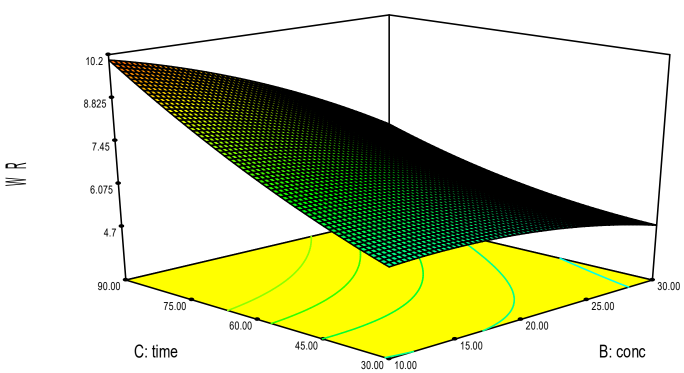

W R
10.2
8.825
7.45
6.075
4.7
C: time
90.00
75.00
60.00
45.00
30.00
B: conc
10.00
15.00
20.00
25.00
30.00

Figure 3: (A) Influence of temperature and salt concentration on weight reduction (B) Influence of temperature and time on weight reduction (C) Influence of salt concentration and time on weight reduction

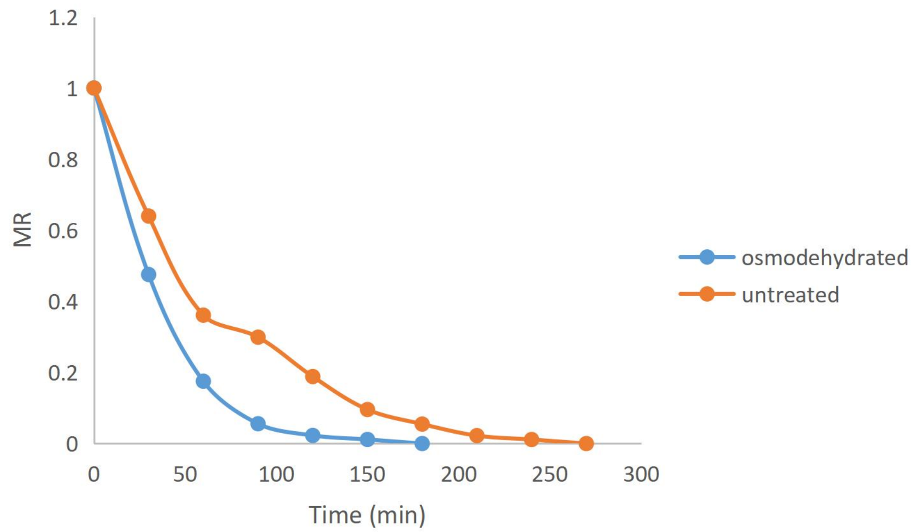


Figure 4: The moisture ratio of osmodehydrated and untreated yellow cassava sample

3.3 Validity of Empirical Models for Convective Drying

The summary of goodness of fits of the thin layer models (Newton, Logarithmic, Two-term exponential, Wang and Singh, and Page) applied to the osmodehydrated and untreated yellow cassava chips is shown in Table 4.

The primary criterion for selecting the best equation to describe the drying curve was highest R^2, the least (χ_c^2), MBE and RMSE. Table 4 showed that Logarithmic model gave the highest value of R^2 for both osmodehydrated and control samples. Furthermore, Logarithmic model had the least values of RMSE for both osmodehydrated and untreated samples, and the values of (χ_c^2) and MBE were at zeros. These are the features of a good fit. Therefore, Logarithmic model fitted best for the prediction of thin layer drying of both osmodehydrated and untreated yellow cassava chips in oven drying. The use of Logarithmic model for the prediction of thin layer oven drying of various food products have been reported for banana and stone apple slices (Doymaz, 2010; Rayaguru and Routray, 2012).

Figure 5 (a) and (b) showed the relationship between the experimental and predicted moisture ratio. The figures confirmed the accuracy of the choice of Logarithmic model as the most suitable for the untreated and osmodehydrated yellow cassava.

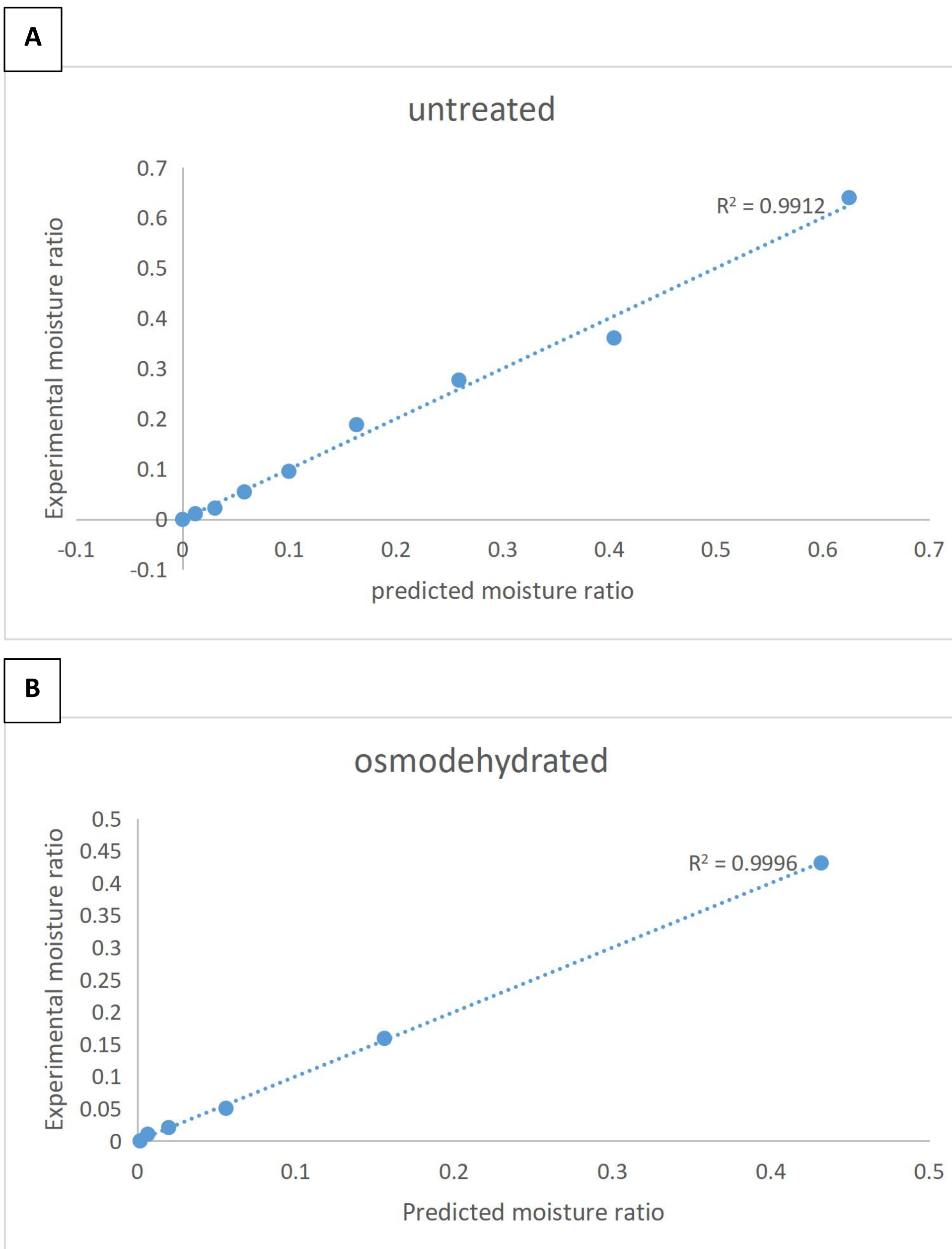


Figure 5: Experimental moisture ratio versus predicted moisture ratio for (a) untreated samples

Model Name	Model Equation	Osmodehyrated Sample			Untreated Sample		
		Values of Constants	Parameters	Values	Values of Constants	Parameters	Values
Newton	MR= exp(-kt)		χ_c^2	-0.0044		χ_c^2	-0.0039
		k = 0.03	MBE	-0.0037	k = 0.015	MBE	-0.0035
			RMSE	0.0126		RMSE	0.0207
			R^2	0.9930		R^2	0.9890
Logarithmic	MR= aexp(-kt) + c		χ_c^2	0.0000		χ_c^2	0.0000
		a=1.193	MBE	0.0000	a= 0.982	MBE	0.0000
		k= 0.034	RMSE	0.0031	k= 0.014	RMSE	0.0188
		c =-0.001	R^2	1.0000	c =-0.023	R^2	0.9910
Two-term exponential	MR= aexp(-kt) + (1- a) exp (-kat)		χ_c^2	-0.1559		χ_c^2	0.0599
			MBE	-0.1039		MBE	0.0466
		a= -2.442	RMSE	0.2690	a= -2.427	RMSE	0.1110
		k= -0.001	R^2	NA	k= -0.0004	R^2	NA
Wang and Singh	MR= 1+ at + bt^2		χ_c^2	0.0191		χ_c^2	0.0066
			MBE	0.0127		MBE	0.0051
		a= -0.017	RMSE	0.0556	a= -0.010	RMSE	0.0336
		b= 6.33×10^{-5}	R^2	0.6980	b= 2.36×10^{-5}	R^2	0.8930
Page	MR= exp(-kt^n)		χ_c^2	-0.0045		χ_c^2	-0.0040
			MBE	-0.0030		MBE	-0.0031
		k= 0.029	RMSE	0.0048	k= 0.015	RMSE	0.0207
		n= 1.00	R^2	0.9920	n= 1.004		0.9890

(b) osmodehydrated samples

Table 4: Summary of goodness of fit parameters by different models for the osmodehyrated and untreated samples

Note: χ_c^2 = reduced Chi square, MBE = mean bias error, RMSE = root mean square error, R^2 = coefficient of determination and NA= not available; a, b, c, k and n are the empirical constants in the drying models

4. CONCLUSION

The optimized results for the osmotic dehydration were 51.40 °C for temperature, 16.70% for concentration and 90 minutes for time to give the values of water loss, solid gain and weight reduction as 11.88 (g/100g fresh sample), 2.72 (g/100g fresh sample) and 9.16 (g/100g fresh sample), respectively. The drying time of osmodehydrated sample was shorter than that of untreated sample by 33.33%.

Logarithmic model was most suitable in describing the drying curve of both the osmodehydrated and untreated yellow cassava root chips under the considered experimental conditions.

Therefore, osmotic dehydration is a good pretreatment method that can be applied to the drying of yellow cassava in order to improve the drying rate.

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