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Optimization of Osmotic Dehydration of Plantain Using Low-calorie Sweetener

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ABSTRACT

Plantain is a major staple food to more than 14 million people in sub-Sahara Africa. It is principally consumed in the boiled, fried, roasted and pounded paste (fufu) forms. The processing into flour has increased in recent years, though the agro-industrial development of its processing is embryonic. Osmotic dehydration (OD) is an important pretreatment in the flour production process because it enhances the nutritional and sensory quality of the flour. However, osmotic pretreatment of plantain usually uses sucrose as osmotic agent which might contribute to raise the glycemic index of the food hence prevalence of diseases like diabetes. Thus, this study was aimed at optimizing the osmotic dehydration process of unripe plantain fruits (´False Horn´ cultivar) using the commonly consumed low-calorie sweetener; Sussli. The effect of four independent variables; temperature of solution (X_1), solution concentration (X_2), plantain slice thickness (X_3) and contact time (X_4) on moisture loss (WL), solids gain (SG), weight reduction (WR), and potassium loss (PL) was evaluated. A sample to solution ratio of 1:20 was used. The Face Centered Central Composite Design (FCCD) experimental design was used. Response Surface methodology (RSM) was also used to determine the optimum condition. The results showed that the optimal conditions of osmotic dehydration for plantain were temperature (30°C), concentration (50 %), slice thickness (8.6 mm) and contact time (60 min) with optimal responses as 19.25 %, 3.21 %, 15.63 % and 1.11 mg/100g for WL, SG, WR and PL, respectively. In this light, the results of the current study can be used in osmotic dehydration process of plantain using the low-calorie sweetener, Sussli.

Keywords

Plantain, Low caloric sweetener, Osmotic dehydration, optimization, Response Surface Methodology

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Introduction

Plantain (*Musa paradisiaca*) is an important food crop in the world especially in Central and West Africa. Africa is one of the top producers of plantain and contributes about 33 million metric tons to global annual production with Ghana, Nigeria, Cameroon, Rwanda, Uganda and Democratic Republic of Congo being the main producing countries (FAO STAT, 2018). Cameroon, which is the fourth largest plantain producer in West and Central

Africa, produces 4.43million tons annually (Lescot, 2017). Main forms of consumption are boiled, fried (chips or dodo), roasted, plantain paste (*ntuba* in Cameroon and *fufu* in Nigeria and Ghana) (Tchango *et al.,* 1999; Ngoh *et al.,* 2005). Most of what is produced is not usually consumed and a huge proportion ends up as waste due to post harvest losses. In Cameroon, the losses are estimated at 20 to 40% (Agri-stat, 2017). This has prompted the processing of plantain into flour in recent years, though the agro-industrial development of plantain processing is embryonic. The most important method widely practiced for preservation of fruits and vegetables is drying (Fadimu *et al.,* 2018; Chavan *et al.,* 2010). Conventional air-drying is a simultaneous heat and mass transfer process, accompanied by phase change and is a high cost process. A pre-treatment, such as osmotic dehydration, can be used in order to reduce the initial water content, reducing total processing and air-drying time and energy requirement which is a major concern in the drying process (Phisut, 2012). The two major mass transfers occurring are the water outflow from the product and the solute inflow from the solution to product concurrently. There are also natural solutes (such as minerals, organic acids, pigments, and flavor) leaching from the product to the solution during the immersion process (Tortoe, 2009). All these mass transfer exchanges might affect the final quality of food product. Thus, it is important to identify the optimum operating conditions to increase the water loss and minimize solute gain and produce a desirable quality product. Osmotic dehydration is considered to be an important technological tool for the development of new derived products from fruits, which add value to such products (Torreggiani and Gianni Bertolo, 2001).

The osmotic dehydration of ripe plantain using sucrose as the osmotic agent has been reported by several researchers (Durvesh and Samsher, 2015; Gallegos-Marin *et al.,* 2016; Loa *et al.,* 2017; Chavan *et al.,* 2010; Haque *et al.,* 2020). The resulting product may not be good for consumption for people with certain ailment especially diabetics because the use of sucrose coupled with the high sugar content of ripe plantain (10.42%) (Adewole and Duruji, 2010) may contribute in raising glycemic index of the product and blood sugar level of concerned. There is increasing interest in designing new low-calorie and minimally processed foods, the replacement of sucrose in traditional processed products and the study of osmotic dehydration with the use of sucrose alternatives. Several low-calorie sweeteners or artificial sweeteners are used today in zero sugar soda drinks or snack foods (Kapadiya and Aparnathi, 2017) and other food products in the market because of the expected health benefits. Calorific values of low-calorie sugars are within the range (0–2.6 kcal/g), compared to sucrose with a calorific value of 4 kcal/g (Washburn and Nedra, 2017; Helen Turner, 2017). The glycemic index for sucrose is 65-80.0 compared to 0-1 for most low-calorie sugars (Redmer, 2014). Because low calorie sugars or alternative sweeteners are recommended to people with life threatening ailments such as diabetics, overweight etc., we hypothesized that it could be used as an osmotic dehydrating agent to give products of low sugar content and consequently low glycemic index. The aim of this study was to determine optimum conditions for the osmotic dehydration process using the low-calorie sugar in view of production of plantain flour.

Materials and Methods

Raw Materials

Fresh matured and unripe plantain fruits (*Musa paradisiaca* L.) of the False horn variety were bought from a local farmer and transported to the food technology laboratory at National Polytechnic University Institute (NPUI) Bamenda. The plantain sample was kept under laboratory temperature (25- 27 °C) and used within 24 h for the experiments. The low-calorie sweetener (Sussli) was purchased from the New Life Super Market at the commercial Avenue, Bamenda, Cameroon

Preparation of Sample

The osmotic solutions of concentrations (25, 37.5 and 50 %) were prepared by dissolving required quantities of low-calorie sweetener in distilled water (w/v). The plantain fruits (False horn variety) were washed in clean water to remove the dirt particles, hand peeled and sliced into different thickness using a stainless-steel knife and the thickness was measured with the aid of vernier caliper. The initial moisture content and dry matter of unripe plantain slices were determined by drying in an electro-thermal oven (Model DHG Search Tech Instruments) at 105 ^{o}C for 24 h**.**

Experimental Design

The factors and their ranges for the osmotic dehydrating process are shown in table 1.Four independent variables; temperature of solution (X_1), solution concentration (X_2), plantain slice thickness (X_3) and contact time (X_4) were selected and used in the study. The osmotic dehydration (OD) experiments were conducted using Face Centered Central Composite Design (FCCD). The experimental design included 27 experiments comprising of 16 factorials, 8-star point and 3 center point runs (Table 2).

A sample to solution ratio of 1:20 was used throughout all the experiments. The original values of all variables in terms of coded and actual units are shown in table 1. All these variables were closely controlled and the responses; water loss, solid gain, weight reduction and potassium loss were accurately measured during experiment carried out in triplicate.

Experimental Procedure

Osmotic dehydration of the plantain slices was carried out in a batch system. The responses were evaluated for the various combinations of slice thickness, sugar concentration, temperature, and contact time following the experimental design (table 2). The 200 mL glass beaker containing the osmotic solution and plantain slices was placed inside an incubator using a sample to solution ratio of 1:20. After completion of contact time as defined by experimental design, samples were withdrawn from the solution, quickly rinsed using distilled water, gently blotted with tissue paper to remove adhering solution. The osmotic dehydrated samples were dried in an electro-thermal oven (Model DHG Search Tech Instruments) at 105 °C till constant weight to determine the moisture and dry matter content. The water loss (WL) and solid gain (SG) were determined using a mass balance method as given by Zhelyazkov *et al.,* (2020) (Eqn.1 and 2) while the weight reduction (% WR) was determined using the Eqn.3employed by Suresh Kumar and Devi (2011). The initial and final potassium content of the samples was determined by Flame photometric method (Mohamed, 2021) and the difference was recorded as potassium lose during OD (Eqn. 4). Experiments were run in triplicates and the data are given as mean of these results.

$$WL\ (\%) = \frac{WiXi - WfXf}{Wi}\ x100 \quad \textbf{...Eqn. 1}$$

$$SG\ (\%) = \frac{WfXstf - WiXsti}{Wi}\ x100 \quad \textbf{...Eqn. 2}$$

Where W_i and W_f are respectively the initial and final mass of samples in grams for a given run; X_i and X_f are initial and final moisture content for a given run. Xst_i and Xst_f are the initial and final solid content for a given run.

$$WR\ (\%) = \frac{Wi - Wf}{Wi}\ x\ 100 \quad \textbf{...Eqn. 3}$$

Where W_i and W_f are respectively the initial and final weights of samples in grams for a given run.

$$PL\ (\%) = \frac{Pi - Pf}{Pi}\ x\ 100 \quad \textbf{...Eqn. 4}$$

Where PL (%) is the percentage loss in potassium, and P_i and P_f are respectively the initial and final potassium contents of samples in milligram for a given run.

Statistical Analysis

Response surface methodology was used to determine the relative contributions of X_1, X_2, X_3 and X_4 to various responses under study: water loss (WL), solid gain (SG), weight reduction and potassium lose in plantain slices. The second order polynomial response surface model was fitted to each of the response variables (Y_i).

$$Y_i = \beta_0 + \beta_1\chi_1 + \beta_2\chi_2 + \beta_3\chi_3 + \beta_4\chi_4 + \beta_{11}\chi_1^2 + \beta_{12}\chi_1\chi_2 + \beta_{13}\chi_1\chi_3 + \beta_{14}\chi_1\chi_4 + \beta_2\chi_2^2 + \beta_{23}\chi_2\chi_3 + \beta_{24}\chi_2\chi_4 + \beta_{33}\chi_3^2 + \beta_{34}\chi_{13}\chi_4 + \beta_{44}\chi_4^2 \textbf{...Eqn.5}$$

The coefficients of the model were determined through regression analysis on JMP software. This software generates R^2 values, RMSE, significant F and plots of actual and predicted values for each response studied. Analysis of variance was conducted to examine statistical significance of the model terms.

Optimization

Numerical optimization technique was used for simultaneous optimization of the various responses. The possible goals for responses were maximized for WL and WR and minimized for PL and SG. In order to search a possible solution, the goals were combined into an overall composite function, D(x), called the desirability function which is defined as:

$$D(x) = (Y_1 x Y_2 \ldots\ldots Y_n)^{1/n} \quad \textbf{...Eqn.6}$$

Where Yi (i=1, 2...n) are the responses and n is the total number of responses in the measure.

Results and Discussion

The results of the experiments as defined by conditions suggested by Response Surface Methodology (RSM) are given in Table 3.

Model Validation

Model constants and R^2 values from multiple regression tests carried out on the experimental results of the responses (WL, SG, WR and PL) as quadratic functions of the temperature of osmotic solution, solution concentration, thickness of plantain slices and contact time are shown in Table 4. The coefficient of determination (R^2) measures the goodness of fit of the model.

The high values of R^2 (>0.80) obtained for response variables suggested that the developed model for WL, SG, WR and PL adequately explained 97.62, 98.38, 84.86 and 88.15% of the variation of experimental data respectively. Generally, a model can be considered reasonably reproducible if its coefficient of variance (CV) is not greater than 10 % (Agarry and Owabor, 2012). Hence, the low CV values (7.82 for WL, 5.66 for SG, 1.77 for WR and 6.99 for PL) obtained in this work indicates a high precision and reliability of the data generated. In addition, the RMSE values obtained for all the responses were less than 4% which further confirmed the ability of the developed equations to describe the experimental data.

Effect of process factors on water loss (WL)

The WL during OD process of plantain slices varied from 5.09 to 29.92% (Table 3). Apart from thickness all other linear terms temperature, concentration and contact time had significant effects (P<0.05) on the WL. Considering the *p* values in table 4, the contact time was the most significant variable that affected WL. Close to this was the temperature (X_1), concentration (X_2), the interaction effect of temperature/time (X_1X_4) and concentration/time (X_2X_4). The quadratic effects of concentration (X_2X_2), time (X_4X_4) and temperature (X_1X_1) did not have a significant effect on WL. Thus, Eqn.7 shows WL for the osmotic dehydration process.

$$WL = 15.26+3.71X_1+2.65X_2-0.59X_3+5.42X_4+0.062X_1X_2\ 0.33X_1X_3\ +0.74X_2X_3\ +1.82X_1X_4\ +1.42X_2X_4.-0.60X_3X_4+2.09X_1X_1+1.302X_2X_2-2.70X_3X_3-2.24X_4X_4$$
…Eqn.7

Temperature and time had positive signs which imply increase in these terms enhanced WL. Increase temperature during osmotic dehydration has been reported to promote WL in some foods as reported by Dash *et al.,* (2021) and Suresh Kumar and Devi (2011).

This finding is contrary to that of Gallegos-Marin *et al.,* (2016) studying structural property changes that occur during osmotic drying of plantain (*Musa paradisiaca*) and Sereno *et al.,* (2001) on apple. Gallegos-Marin *et al.,* (2016) explained that untreated starch granules are insoluble in cold water and have a highly organized structure, however, when these are heated, a slow water absorption process begins in the amorphous area, which are less organized and more accessible. As the temperature increases, more water is retained, and the starch granules swell and increase in volume. Starch swelling in inter-mycelium amorphous areas, due to water absorption, reduces water outlet. The authors reported that process temperatures above 40ºC showed a significant reduction in moisture lose (WL),

Fig.1 shows the interaction effect of temperature and contact time on WL which rather had a positive effect (promoting water loss) on WL. At lower temperatures irrespective of the contact time, water loss during the process was generally constant increasing only slightly. However, as temperatures increased above 35°C, there was a drastic increase in the quantity of water loss from the plantains. Sereno *et al.,* (2001) explained that the impregnation of the food sample with the solute combined with temperature induced changes in permeability properties of the cell membrane that brought about changes in diffusion flow which may explain the observed increase in water loss observed in our work. Fig.2 shows the significant interaction effect of contact time with the concentration of the osmotic solution on water loss. At all concentrations, water loss increased steadily with time up to about 45-50 min where it became more pronounced. Increase concentration of osmotic solution and time positively influenced WL during OD process. Several other authors working with sucrose solution (Yuan *et al.,* 2018) in Lettuce; Coimbra *et al.,* (2022) in Sapodilla (*Achras zapota* L.); and Salimi and Hoseinnia (2020) in coconut; Rigi *et al.,* (2019) on Turnip Slices, Haque *et al.,* (2020) on plantain reported a linear relation between concentration of sucrose solution and WL. They hypothesized that the use of higher concentrations of sucrose led to higher osmotic pressure gradients, resulting to water loss over of the osmotic treatment period.

Effect of process factors on Solid gain (SG)

Table 3 showed that the solid gain ranges from 0.66 to 55.30%, indicating that the difference between the maximum and minimum value of the solid gain was 54.64% during osmotic dehydration (OD) process under the different conditions. The *p* value and β coefficients in Table 4 indicate that temperature (X_1) was the most significant factor ($p<0.05$) that affected solute gain during the osmotic dehydration process of the plantain slices. Also, the linear terms of all the factors significantly affected ($p<0.05$) the SG during the OD process. The equation for SG during the OD process is therefore given by Equation 8. Amongst the linear terms, temperature and contact time have positive coefficients indicating that increase in these parameters promoted solute gain during the OD process. The temperature effect observed here corroborates with the findings of Yadav *et al.,* (2011) and Dash *et al.,* (2021).

$$SG=23.74+11.14X_1+1.58X_2-1.87X_3+9.69X_4+2.12X_1X_2-1.78X_1X_3+0.38X_2X_3+9.16X_1X_4+0.87X_2X_4+1.18X_3X_4-5.24X_1X_1+0.87X_2X_2-0.43X_3X_3-4.84X_4X_4 \quad \textbf{...Eqn.8}$$

Increased concentration with corresponding increase in SG has been reported for plantain slices (Haque *et al.,* 2020) and other fruits and vegetables (Chandra and Kumari, 2015) using sucrose solutions. In this study, it was observed that increase concentration had no significant effect on SG (table 4). This can be attributed to the increase in the viscosity of the OD medium with an increased concentration of low calorie. This reduces mobility and hence uptake of sugar molecules. As illustrated in fig. 3, the simultaneous increase in temperature and concentration facilitated solute gain (SG). Rigi *et al.,* (2019) and Haque *et al.,* (2020) observed similar phenomenon of increased SG with a concurrent temperature/concentration increase.

The researchers explained that **i**ncreased temperature of the osmotic solution results in reduction of solution viscosity, permits easy penetration of sugar into plant tissues hence raising the solids gain**.** Figure 4illustrates the interaction effect of temperature and thickness on solute gain. Worth noting is the fact that at very low slice thickness (5-6 mm) and at higher temperature (35 -40 °C) there is a significantly high SG during the OD process of the plantain. On the other hand, simultaneous increase in slice thickness and temperature lead to SG dropped. Given that one of the goals was to minimize SG, this implies plantain slices above 7 mm dehydrated at high temperature will be proper combination. Fig.5 illustrates the interaction effect of temperature and time (X_1X_4). Increase contact time led to increased SG as indicated by the positive coefficient of the term. This is in agreement with the observation made for the osmotic dehydration of okra (Agarry and Owabor, 2012), plantain (Haque *et al.,* 2020) and pineapple slices (Suresh Kumar and Devi, 2011) in sucrose solutions.

It can be observed from Fig.5 that increases in temperature led to small increase in SG for duration between 20 to 35 min. But above 35 min, uptake of solute by slice increased greatly. In this present study, the simultaneous increased temperature with contact time permitted high solute uptake compensating largely for the losses resulting from leaching thereby leading to the observed increase in SG.

Effect of process factors on weight reduction (WR)

Results in table 3 showed that the WR of OD plantain slices ranged from 2.08 - 28.74% for the different runs. Analysis of variance was carried out for weight reduction and is shown in Table 4. From the model coefficients (β) and p-values presented in Table 4, contact time and temperature were the only two linear independent variables that significantly affected weight reduction during osmotic dehydration process of the plantain slices. From the P-value and magnitude of the coefficient (β), the contact time of the process was the most influential factor on WR among the variables. The second influential parameter was temperature followed by temperature/time interaction (X_1X_4) and the least being the interaction effect of thickness and time (X_3X_4). All the quadratic term had no significant effect on WR. Eqn.9 represents WR during osmotic dehydration of plantain slices using low calorie sugar solution.

$$WR = 8.01 + 2.35X_1 + 1.19X_2 + 1.07X_3 + 4.89X_4 - 1.66X_1X_2 + 1.96X_1X_3 - 0.54X_2X_3 + 2.42X_1X_4 + 0.92X_2X_4 + 2.26X_3X_4 - 0.06X_1X_1 + 1.03X_2X_2 + 2.34X_3X_3 - 1.85X_4X_4 \quad \textbf{...Eqn. 9}$$

The positive coefficients of time and temperature indicate that long contact time and high temperature during the OD process promote high percentage WR. Similar findings were made by Salimi and Hoseinnia (2020) on the optimization of osmotic drying of coconut by response surface methodology preceded by microwave treatment.

Table.1 Process variables and their levels for experimental design

Variables	Names	Units	Levels		
			-1	0	+1
X1	Temperature	°C	30	35	40
X2	Concentration	%	25	37.5	50
X3	Slice thickness	mm	5	7.5	10
X4	Contact time	min	20	40	60

Table.2 Treatment combinations for osmotic dehydration

	Factors							
	Coded values				**Real values**			
Runs	**X1**	**X2**	**X3**	**X4**	**X_1 (°C)**	**X_2 (%)**	**X_3 (mm)**	**X_4 (min)**
1	-1	0	0	0	30.0	37.5	7.5	30.0
2	-1	1	-1	1	30.0	50.0	5.0	30.0
3	-1	-1	1	1	30.0	25.0	10.0	30.0
4	1	-1	-1	1	40.0	25.0	5.0	40.0
5	0	0	0	0	35.0	37.5	7.5	35.0
6	0	0	0	0	35.0	37.5	7.5	35.0
7	1	1	-1	1	40.0	50.0	5.0	40.0
8	1	-1	-1	-1	40.0	25.0	5.0	40.0
9	-1	-1	-1	1	30.0	25.0	5.0	30.0
10	1	-1	1	1	40.0	25.0	10.0	40.0
11	-1	-1	-1	-1	30.0	25.0	5.0	30.0
12	-1	1	-1	-1	30.0	50.0	5.0	30.0
13	1	1	1	1	40.0	50.0	10.0	40.0
14	-1	1	1	-1	30.0	50.0	10.0	30.0
15	0	0	0	-1	35.0	37.5	7.5	35.0
16	0	0	1	0	35.0	37.5	10.0	35.0
17	0	0	-1	0	35.0	37.5	5.0	35.0
18	0	-1	0	0	35.0	25.0	7.5	35.0
19	0	0	0	1	35.0	37.5	7.5	35.0
20	1	-1	1	-1	40.0	25.0	10.0	40.0
21	1	0	0	0	40.0	37.5	7.5	40.0
22	0	1	0	0	35.0	50.0	7.5	35.0
23	0	0	0	0	35.0	37.5	7.5	35.0
24	-1	-1	1	-1	30.0	25.0	10.0	30.0
25	-1	1	1	1	30.0	50.0	10.0	30.0
26	1	1	1	-1	40.0	50.0	10.0	40.0
27	1	1	-1	-1	40.0	50.0	5.0	40.0

Table.3 Centre Composite Design of process variables and values of response for osmotic dehydrated plantain slice

	Factors				Response			
	X_1 (°C)	X_2 (%)	X_3 (mm)	X_4 (min)	WL (%)	SG (%)	WR (%)	PL (mg/100g)
1	30.0	37.5	7.5	40.0	12.73	6.19	6.56	0.65
2	30.0	50.0	5.0	60.0	17.25	2.19	15.06	0.91
3	30.0	25.0	10.0	60.0	9.95	4.49	5.46	1.02
4	40.0	25.0	5.0	60.0	21.84	30.69	8.85	7.88
5	35.0	37.5	7.5	40.0	13.64	21.18	7.54	1.78
6	35.0	37.5	7.5	40.0	15.66	23.40	7.74	1.79
7	40.0	50.0	5.0	60.0	29.92	43.99	14.07	10.65
8	40.0	25.0	5.0	20.0	9.98	3.05	6.95	1.07
9	30.0	25.0	5.0	60.0	9.73	3.81	5.95	2.22
10	40.0	25.0	10.0	60.0	16.88	45.62	28.74	3.21
11	30.0	25.0	5.0	20.0	5.09	3.01	2.08	0.77
12	30.0	50.0	5.0	20.0	7.65	0.66	6.99	1.42
13	40.0	50.0	10.0	60.0	28.72	55.30	26.58	7.91
14	30.0	50.0	10.0	20.0	9.77	3.88	5.89	0.57
15	35.0	37.5	7.5	20.0	6.35	10.48	4.13	0.55
16	35.0	37.5	10.0	40.0	8.57	20.90	8.59	1.51
17	35.0	37.5	5.0	40.0	16.81	26.80	12.44	4.01
18	35.0	25.0	7.5	40.0	16.18	25.40	10.63	3.45
19	35.0	37.5	7.5	60.0	19.95	28.40	8.51	6.11
20	40.0	25.0	10.0	20.0	8.48	4.80	3.68	1.83
21	40.0	37.5	7.5	40.0	22.22	31.89	9.67	2.65
22	35.0	50.0	7.5	40.0	17.20	24.90	7.77	5.23
23	35.0	37.5	7.5	40.0	15.68	23.40	7.80	2.01
24	30.0	25.0	10.0	20.0	4.25	2.42	1.85	1.54
25	30.0	50.0	10.0	60.0	17.21	4.50	12.78	1.35
26	40.0	50.0	10.0	20.0	13.1	11.10	2.23	1.55
27	40.0	50.0	5.0	20.0	9.29	5.15	4.15	6.10

WL: water loss, SG: Solid gain, WR: Weight reduction and PL: Potassium loss

Table.4 ANOVA table of each response showing the linear, quadratic and interaction terms

		WL		SG		WR		PL	
	Df	Coef.	P-value	Coef.	P-value	Coef.	P-value	Coef.	P-value
Model	14	15.256	<.0001	23.738	<.0001	8.012	<.0001	2.527	0.0001
X_1	1	3.711	<.0001	11.136	<.0001	2.350	0.0181	1.800	<.0001
X_2	1	2.652	0.0003	1.577	0.0576	1.185	0.1931	0.706	0.0315
X_3	1	-0.591	0.2885	-1.870	0.0284	1.070	0.2369	-0.808	0.0165
X_4	1	5.416	<.0001	9.691	<.0001	4.892	0.0001	1.437	0.0003
X1*X2	1	0.062	0.9145	2.118	0.021	-1.661	0.0935	0.845	0.0177
X1*X3	1	-0.332	0.5672	-1.770	0.046	1.957	0.0529	-0.648	0.057
X2*X3	1	0.736	0.2166	0.376	0.6451	-0.543	0.5623	-0.210	0.5077
X1*X4	1	1.821	0.0072	9.155	<.0001	2.424	0.0208	1.119	0.0034
X2*X4	1	1.418	0.0272	0.866	0.2981	0.924	0.3305	0.129	0.6829
X3*X4	1	-0.598	0.3098	1.181	0.1638	2.259	0.0290	-0.269	0.3993
X1*X1	1	2.087	0.1637	-5.237	0.0217	-0.056	0.9807	-1.210	0.1407
X2*X2	1	1.302	0.3728	0.873	0.6683	1.029	0.659	1.480	0.0777
X3*X3	1	-2.698	0.0793	-0.427	0.8333	2.344	0.323	-0.100	0.8984
X4*X4	1	-2.238	0.1377	-4.837	0.0314	-1.851	0.4314	0.470	0.5515
R^2			0.945		0.980		0.850		0.901
R^2 Adj			0.882		0.957		0.675		0.785
CV (%)			7.82		5.66		1.77		6.99
RMSE			2.256		3.186		3.646		1.23
SIG F-Value			<0.0001		0.0001		0.0046		0.0005

WL= water loss (%), SG= solid gain (%), WR= Weight reduction (%), PL= Potassium lose (mg/100g). *Parameters with significant effect.

Figure.1 Combined effect of temperature and contact time on percentage water loses during osmotic dehydration of plantain at constant concentration and thickness.

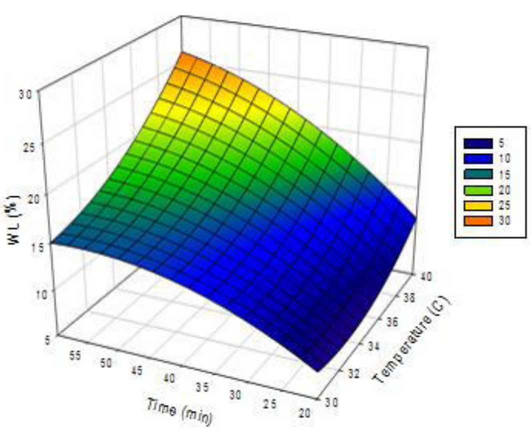


Figure.2 Effect of Concentration and contact time interaction on percentage water loss during osmotic dehydration of plantain at constant temperature and thickness

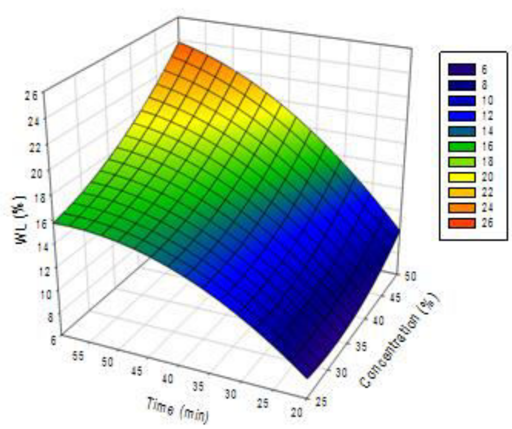


Figure.3 Effect of temperature and concentration interaction on solid gain during osmotic dehydration of plantain at constant time and slice thickness.

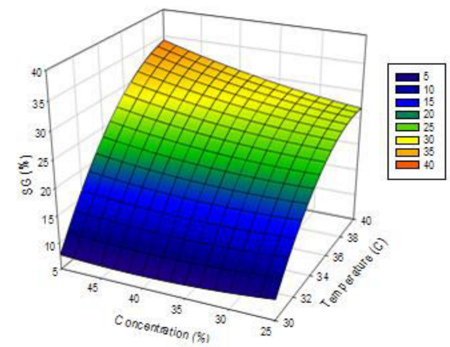


Figure.4 Effect of temperature and slice thickness interaction on solid gain during OD of plantain at constant concentration and time

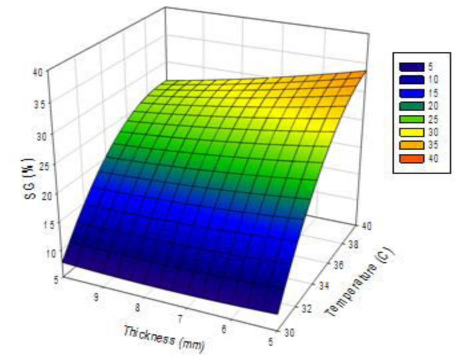


Figure.5 Effect of temperature and contact time on solid gain at constant solution concentration and thickness

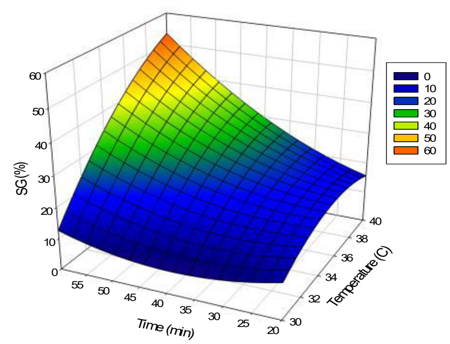


Figure.6 Interaction effect of temperature and contact time on Weight reduction at constant concentration and thickness

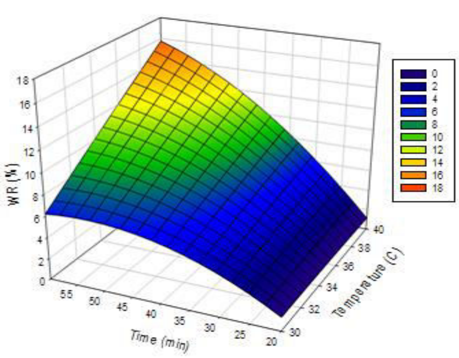


Figure.7 Interaction effect of slice thickness and contact time on Weight reduction at constant temperature and concentration

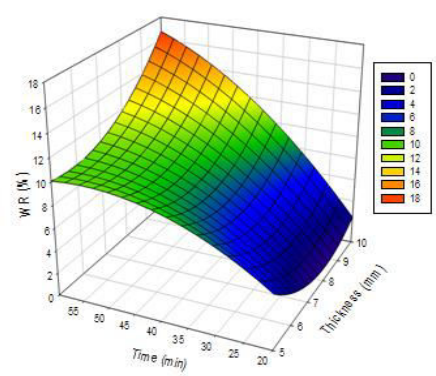


Figure.8 Interaction effect of temperature and concentration on potassium lose during OD process of plantain slices at constant time and thickness

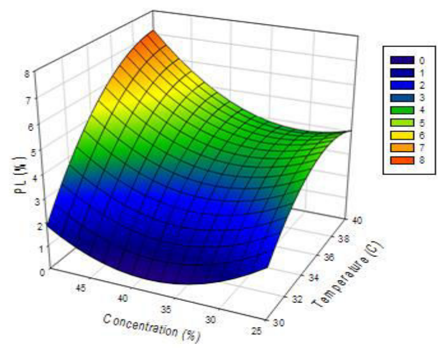
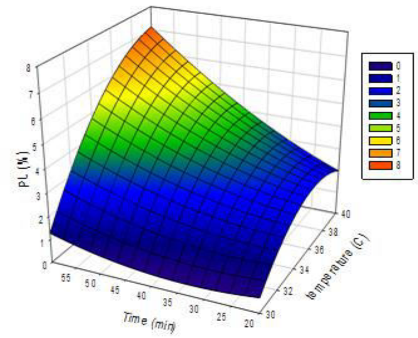


Figure.9 Interaction effect of temperature and contact time on potassium lose at constant time and concentration



The interaction terms of temperature/time and thickness/time all had positive effects on WR of slices. Fig.6 depicts the graphical presentation of the interaction between temperature and time (X_1X_4) in which increase in temperature and time increased percentage weight reduction.

According to Salimi and Hoseinnia (2020), weight reduction (WR) during OD process is a function of the relative amounts of water loss (WL) and solute gain (SG), thus, whichever phenomenon prevails affects WR the most. Prevalence of WL over SG eventually leads to higher percentage WR during OD processes which translates greater dehydration efficiency (WL/SG).

On the other hand, low WL/SG as a result of high SG reduces WR. At all combinations of time and temperature weight loss increased as these parameters increased; with the rate of weight loss becoming very significant after 45 min. The concurrent temperature and time increase could have likely induced structural changes in plantain which favored WL reflected in high WR.

In addition, fig.7 shows the significant interaction effect between plantain slice thickness and time on WR during the OD experiments. The interaction between these two parameters resulted in increased WR. Analysis of fig.7 revealed that at time interval 20- 40 min there was a steady rise in WR (2-8%) even as the slice thickness varied from 5-10 mm. Further increase in contact time (>45 min) witnessed greater increase in WR with thickness variation from 5-10 mm.

Effect of process factor on potassium loss

Results in Table 3 showed that the potassium losses in plantain slices ranged from 0.55 -10.65 mg/100g for the different experimental runs of the OD process. Considering the P-value and β of ANOVA presented in Table 4, temperature was the most influential factor followed by time, the interaction effect of temperature/time (X1X4), concentration and the interaction effect of temperature/concentration (X1X2) in decreasing order. Eqn.10 represents the loss of potassium during the OD of plantain slices.

$$PL = 2.53 + 1.80X_1 + 0.71X_2 - 0.82X_3 + 1.44X_4 + 0.85X_1X_2 - 0.65X_1X_3 - 0.21X_2X_3 + 1.12X_1X_4 + 0.13X_2X_4 - 0.27X_3X_4 - 1.21X_1X_1 + 1.48X_2X_2 - 0.100X_3X_3 + 0.47X_4X_4 \quad \textbf{...Eqn. 10}$$

Normally, leaching of a mineral is associated with steeping or soaking especially for very long periods. Fig.8 illustrates the combined effect temperature and concentration on potassium loses in course of OD of plantain slices in solution. The graph shows that the potassium concentration in the OD medium increased steadily with an increase in temperature. This lose was more pronounced at higher solution concentrations. Normally, high solution concentrations create higher diffusion flow. However, the viscosity of the medium is also known to increase which minimizes this flow. But augmenting the temperature of the dehydrating solution could have contributed immensely in reducing the viscosity as well as also increase the solubility of potassium. These factors could have contributed greatly in easing the flow through the pores of the plantain slice facilitating leaching. Thus, to achieve minimal PL from the plantain slices during OD process low temperatures (30-35°C) and low concentration should be employed.

A plot to visualize the interaction between temperature and time on potassium lose during the osmotic dehydration process of the plantain slice is shown in fig.9. The figure shows that potassium loses increases with concurrent increase of osmotic solution temperature and contact time with plantain slices.

In addition to reducing viscosity and increasing solubility, temperature increase may disrupt membrane integrity and increase permeability. Combined with prolonged time, this favors leakage of important substances like potassium to the surrounding medium. Given the importance of this mineral in nutrition and the fight against some non-communicable disease such as hypertension and diabetes, appropriate control of temperature and concentration during OD is thus critical to minimize the loss and maximize retention.

Optimization of the osmotic dehydration process

According to different studies on osmotic dehydration of fruits and vegetables, this study aimed to maximize WL and WR and minimize SG and PL parameters. The process parameters were optimized to get the desired output. The optimization of process variables was done using STATGRAPHICS version XVII.II following numerical methods (Seth *et al.,* 2018). The optimized value for temperature, solute concentration, slice thickness and contact time was found to be 30.0˚C, 50%, 8.6mm and 60min respectively. The predicted response values for the optimized condition were WL 17.16%, SG 3.47%, WR 12.52% and PL 0.89mg/100g.

The optimization process of the osmotic dehydration of plantain using low calorie sweetener showed that the temperature and contact time were the only two parameters that significantly affected all responses. Solution concentration had significant effects only on WL and PL while slice thickness significantly affected SG and PL.

Using numerical optimization technique, the optimum conditions for osmotic dehydration of the false horn plantain were obtained as; temperature (30°C), concentration (50%), slice thickness (8.6 mm) and contact time (60 min) with optimal responses as 19.25%, 3.21%, 15.63% and 1.11mg/100g for WL, SG, WR and PL, respectively. In this light, the results of the current study can be used in osmotic dehydration process of plantain.

Author Contribution

Lobe Elias Eyembe: Investigation, formal analysis, writing—original draft. Divine Bup Nde: Validation, methodology, writing—reviewing. Sonchieu Jean:—Formal analysis, writing—review and editing.

Data Availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethical Approval Not applicable.

Consent to Participate Not applicable.

Consent to Publish Not applicable.

Conflict of Interest The authors declare no competing interests.

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