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Optimization of plantain drying process using response surface methodology

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Abstract

Optimization of plantain drying process parameters to obtained high quality product is very vital as improper drying conditions can affect the composition of the plantain flour and thereby increases the risk of running into deterioration of the nutrient contents of the product and loss. Matured unripe plantains were processed by washing, peeling and cut into required size. The samples obtained were analysed in triplicate using different drying oven temperatures (60, 70 and 80^{o}C) and time (187, 242, and 311 minutes) at pulp size of 3 mm by employing Design of experiment (DOE). Statistical analysis and Response surface methodology based on the D-Optimal were carried out. The significant factors on the experimental design response were identified from the analysis of variance. The optimum conditions for the processing of unripe plantain into dry product were obtained by using temperature of 80^{o}C, time of 187 minutes and pulp size of 3 mm which resulted in final carbohydrate content of 87.4%. From these results obtained, the use of response surface methodology in optimizing plantain drying process can be recommended.

Keywords

Oven; Drying; Optimization; Response surface methodology; Plantain drying; Design of experiment; D-Optimal; Moisture content

Introduction

In recent years, much attention has been drawn to the quality of dehydrated food products. Different drying methods have effect on the biochemical and functional properties of dehydrated products [1].

Heat treated plantain flour, can be used for many applications in food processing such as cake, biscuit and wafer flours, beadings, batter flour, coatings; soup, sauces, baby food and thickeners for the industry, it sometimes could be mixed with wheat flour for baking [2; 3]. Heat treated flour was first patented, with the process using a temperature range of 100^{o}C to 115^{o}C for a time of 60 min [4, 5]. Heat treated flour allows high ratio recipes to be developed which generate products with longer shelf life, finer texture, moist crumb and sweeter taste.

The mechanism by which heat treatment improves the flour is not fully understood, but it is known that during the heat treatment process, protein denaturation and partial gelatinization of the starch granules occurs, as well as an increase in batter viscosity [4].

In the production of dried foodstuffs, minimizing drying cost is the most critical factor. However, the conditions which produce minimum costs are likely not to give the desired quality characteristics [6]. It has been reported that many industrial drying processes were found experimentally, but their validity has not been evaluated since. Optimization of the drying operation leads to an improvement in the quality of the dried product and a reduction in the cost of processing as well as optimizing the throughput [6, 7]. This is because the design and optimization of dryers used for food crops is dependent on the thermal and physical properties of the specific crops [6]. The capacity to preserve food is directly related to the level of technological development. The slow progress in upgrading traditional food processing and preservation techniques in West Africa contributes to food and nutrition insecurity in the sub-region [8].

Optimization of the drying operation leads to an improvement in the quality of the dried product, a reduction in the cost of processing as well as optimizing the throughput [9]. This is because the design and optimization of dryers used for food crops is dependent on the thermal and physical properties of the specific crops [10]. An optimization problem requires the determination of the optimal (maximum and minimum) values of a given function called the objective function under a given set of constraints. One of the most widely used optimization techniques is the regression analysis [11].

Therefore, it is important to optimize the process parameters with reference to the physicochemical and quality characteristics of plantain. Also, according to [6], drying temperature and drying time have significant effect on the drying kinetics and quality of the dried product. Therefore, the processing parameters considered in this investigation were the drying temperature and drying time.

The objective of this work is to optimize the parameters of plantain drying process using response surface methodology (RSM).

Material and method

Preparation of plantain samples

A bunch of French horn specie of matured unripe plantain produced by the Faculty of Agriculture, University of Uyo, Uyo, Akwa Ibom State was obtained and used for this study.

The unripe plantain bunch was collected and prepared the same day it was harvested. Plantain flour was produced from the plantain fingers using the traditional method of processing plantain into flour Plantain was immersed in a plastic bowl, washed with potable water to remove dirt and then peeled and sliced into thin thicknesses (3 mm) using a stainless kitchen knife, meter rule, and a cylindrical mould to achieve approximately equal surface area for uniform heat transfer. The thicknesses of sliced samples were measured using a Vernier slide Caliper to confirm the actual thickness of the pulps which were then oven-dried at different temperatures and later ground into flour.

Determination of moisture content

A clean crucible was dried to a constant weight in air oven at 110°C, cooled in a desiccator and Weighed.

Two grams of finely ground sample was accurately weighed into the previously labelled crucible and reweighed. The crucible containing the sample was dried in an oven to constant Weight [12]. The percentage moisture content was calculated thus Eq. (1):

$$\%Moisture\ content = \frac{W_2 - W_3}{W_2 - W_1} X100 \quad (1)$$

Where: W_1 - weight of empty crucible; W_2 - weight of crucible plus sample before drying; W_3 - weight of crucible plus sample after drying.

Determination of ash content by furnace method

The porcelain crucible was dried in an oven at 100°C for 10 min, cooled in a desiccator and Weighed. Two grams of the finely ground sample was placed into a previously weighed porcelain crucible and reweighed; it was first ignited and then transferred into a furnace which was set at 550°C. The sample was left in the furnace for eight hours to ensure proper 'ashing'. The crucible containing the ash was then removed; cooled in a desiccator and weighed [12]. The percentage ash content was calculated as follows Eq. (2):

$$\%Ash\ content = \frac{W_3 - W_1}{W_2 - W_1} X100 \qquad (2)$$

Where: W_1 - weight of empty crucible; W_2 - weight of crucible plus sample before 'ashing'; W_3 - weight of crucible plus sample after 'ashing'.

Determination of crude fibre content

The sample (2 g) was weighed into a round bottom flask, 100 cm3 of 0.25 M sulphuric acid solutions were added and the mixture boiled under reflux for 30 min.

The hot solution was quickly filtered under suction. The insoluble matter was washed several times with hot water until it was acid free. It was quantitatively transferred into the flask and 100 cm^3 of hot 0.31 M Sodium Hydroxide solution was added, the mixture boiled under reflux for 30 min and was filtered under suction.

The residue was then washed with boiling water until it was base free, dried to constant weight in an oven at 100°C, cooled in a desiccator and weighed. The weighed sample was then incinerated in a muffle furnace at 550°C for 2 h, cooled in a desiccator and reweighed [13].

Calculation by Eq. (3) use the loss in weight on incineration (C_1-C_2):

$$\%Crude\ fibre = \frac{(C_1 - C_2)}{Weight\ of\ original\ sample}\ x\ 100 \qquad (3)$$

Where: C_1 - weight of desiccator before heating; C_2 - weight of desiccator after heating

Determination of lipid content using Soxhlet extraction method

A clean, dried 500 cm^3 round bottom flask containing few anti-bumping granules was Weighed with 300 cm^3 petroleum ether (40 - 60°C) for extraction poured into the flask filled with Soxhlet extraction unit. The extractor thimble weighing twenty grams was fixed into the Soxhlet unit. The round bottom flask and a condenser were connected to the Soxhlet extractor and cold water circulation was connected and put on.

The heating mantle was switched on and the heating rate adjusted until the solvent was refluxing at a steady rate. Extraction was carried out for 6 h. The solvent was recovered and the oil dried in an oven set at 70°C for 1 h. The round bottom flask and oil was then Weighed.

The lipid content was calculated thus Eq. (4):

$$\%Lipid = \frac{(Weight\ of\ flask\ and\ extract - weight\ of\ flask)}{Weight\ of\ sample\ extracted}\ x\ 100 \qquad (4)$$

Determination of nitrogen and crude protein content using Kjeldahl method

1 g of the sample was weighed into a standard 250ml Kjeldahl flask containing 1.5 g $CuSO_4$ and 1.5 g of Na_2SO_4 as catalyst and 5ml concentrated H_2SO_4. The Kjeldahl flask was placed on a heating mantle and was heated gently to prevent frothing for some hours until a clear bluish solution was obtained. The digested solution was allowed to cool and transferred to 100 ml standard flask and made up with distilled water. 20 ml portion of the digest was pipetted into a semi micro Kjeldahl distillation apparatus and treated with equal volume of 40% Sodium hydroxide solution. The ammonia evolved was steam distilled into a 100 ml conical flask containing 10ml solution of saturated boric acid to which 2 drops Tashirus indicator (double indicator) had been added.

The tip of the condenser was rinsed with distilled water and then titrated with 0.1 M Hydrochloric acid until a purple-pink end point was observed. The crude protein was obtained by multiplying the %Nitrogen content by a factor of 6.25 [13]. Calculations by Eq. (5):

Crude %Protein = %Nitrogen x factor

$$\%N_2 = \frac{Titre\ value\ x\ 1.4\ x\ 100}{100mg\ x\ 0.1\ x\ 20}\ \text{X}\ 6.25 \qquad (5)$$

Determination of carbohydrate

The carbohydrate was determined by difference i.e. the sum of the percentage moisture, ash, crude lipid, crude protein and crude fibre was subtracted from the total dry matter [14]. Calculation by Eq. (6):

$$\%Carbohydrate = 100 - (\%Moisture + \%Ash + \Pr otein + \%fibre) \quad (6)$$

Oven drying process

Drying experiments were carried out in the oven which was preheated for 90 minutes to reach the steady state set drying air temperature conditions of 60ºC, 70ºC, and 80ºC for the study. The plantain samples with pulp size of 3 mm were placed in the oven (model DHG 9101 S.N) tray. The sliced plantain samples were allowed to dry to attain the time required to reach the recommended microbiologically shelf-stable product of 0.10 (kg water/kg dry matter) [15]. All experiments were carried out in triplicates.

Stages of plantain drying process

Matured plantain bunch was harvested, washed, peeled and cut into required sizes before it was later dried at various oven temperatures as can be seen in Figure 1.

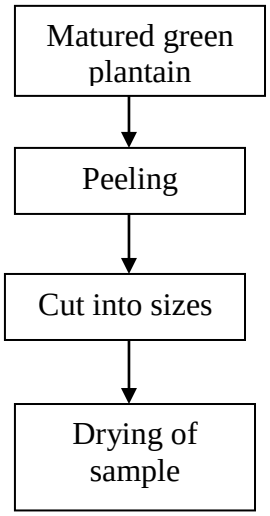

Figure 1. Flow chart for drying of plantain

Data analysis

Response Surface Methodology (RSM) techniques were employed for analysis using Design Expert software. The dependent variable was the carbohydrate content (%) of the flour and the independent variables were the drying temperature (^{0}C) and the drying time (min). According to [16-17], Response Surface Methodology (RSM) is one of the experimental designing methods which can surmount the limitations of conventional methods collectively and has an advantage that it reduces the number of experimental trials needed to evaluate multiple parameters and their interactions.

Analysis of variance (ANOVA) was employed to determine the significance of the relationship between the independent and dependent variables, for which was judged by the coefficient of determination (R-squared and adjusted R-squared) and p-value [18]. The model and its coefficients was considered significant when $p<0.05$ which indicated that the model was statistically significant at α-level of 0.05 [18]. The model was valid when the lack of fit was not significant ($p>0.05$) which indicated a good fit, a low coefficient of variance (C.V. % <10) which meant that the experiments perform was highly reliable, and adequate precision (Adeq Precision > 4) which indicate that the model as fitted was adequate for predicting [6].

Experimental design for optimization of the formulation

D-Optimality was used in the design of the experiment to establish the effect of the process parameters on the response [16].

Results and discussion

The proximate composition of the plantain sample studied at different temperatures of 60, 70 and 80^{o}C were obtained as presented in Table 1.

Table 1. Proximate composition of plantain sample at the different drying temperatures

Nutrient contents (%)	Temperature (^{0}C)		
	Sample A (60^{0}C)	Sample B (70^{0}C)	Sample C (80^{0}C)
Protein	4.75%	3.70%	3.56%
Fibre	8.70%	10.10%	10.34%
Fat	0.89%	0.92%	1.56%

Ash	1.20%	4.60%	5.50%
Carbohydrate	67.85%	68.20%	71.20%

From Table 1, it can be seen that carbohydrate has the highest percent in all the samples and the amount of carbohydrate increases as the temperature increases. Also, the amount of fat, fibre, and ash increases as the temperature increases which is in accordance with the results in literature [19]. On the other hand, the protein and moisture content of the plantain flour decreases with increase in the drying temperatures as shown in the Table 1 above which also agrees with the results in literature [20].

According to [20], increase in the macro nutrients i.e. fat, fibre, ash, and carbohydrate may be attributed to the application of heat. It can be seen that the apparent increase in carbohydrate, ash, fat, and fibre contents of the plantain flour at the different drying temperatures in this study could be as a result of the removal of moisture which tends to increase the amount of the individual nutrients. Application of heat can be both beneficial and detrimental to nutrients. Heat improves the digestibility of food, promotes palatability and also improves the keeping quality of food, making them safe to eat [21]. However heating process may result in nutrients' losses by inducing biochemical and nutritional variation in food composition [21].

Table 2 shows the drying times required to reach the recommended microbiologically shelf-stable product of 0.10 (kg water/kg dry matter).

Table 2. Drying times of samples required to reach shelf-stable

Sample	A	B	C
Temperature (^oC)	60	70	80
Drying time (minutes)	311	242	187

We observed in the Table 2 which is the time it took the moisture content of the dried plantain to reduce to approximately 10% of the initial content were 311, 242 and 187 minutes for 60, 70 and 80^0C respectively. The pulp size of 3 mm was used which is in line with previous researchers who reported that as thickness increases, the diffusion path, becomes longer and vice versa [22, 23, 24].

Optimization of the process parameters with carbohydrate content

The D-Optimal design which was employed to correlate the experimental relationship between the response and the independent variables is seen in Table 3 below.

Table 3. Design of experiment

Ctr. No.	FACTOR 1 A: Temperature (^{0}C)	FACTOR 2 B: Time (min.)	RESPONSE 1 Carbohydrate (%db)
1	60.0	187.0	82.9
2	70.7	187.0	85.7
3	60.0	311.0	83.5
4	60.0	311.0	84.9
5	80.0	244.8	84.3
6	60.0	187.0	82.0
7	80,0	244.8	86.9
8	69.1	255.2	84.7
9	75.2	278.1	82.7
10	80.0	311.0	71.1
11	64.0	223.8	82.0
12	80.0	187.0	84.2
13	60.1	263.9	81.0
14	80.0	311.0	81.1
15	68.5	311.0	84.0
16	80.0	187.0	85.7
17	74.1	223.8	85.6

The G Efficiency = 78.1% indicated that the experimental design was efficient for analysis. The Table 3 shows the results of the dependent variable (carbohydrate) which were obtained at thickness of 3 mm and at the shown drying times and temperatures.

In the Table 4a we have the ANOVA response surface model.

Table 4a. RESPONSE 1 carbohydrate. ANOVA for response surface 2FI model - Analysis of variance table (Partial sum of squares – Type III)

Source	Sum of squares	df	Mean square	F - value	p – value Prob >F	
Block	22.82	1	22.82			
Model	82.62	3	28.87	3.93	0.0363	Significant
A- temperature	0.30	1	0.30	0.041	0.8433	
B- Time	24.61	1	24.61	3.35	0.0920	
AB	61.72	1	61.72	8.41	0.0133	
Residual	88.08	12	7.34			
Lack of fit	32.47	7	4.64	0.42	0.0073	not significant
Pure Error	55.61	5	11.12			
Cor Total	197.52	16				

In table 4b we have the ANOVA response surface 2FI model.

Table 4b. ANOVA for response surface 2FI model

Indicator	Value
R-Square	0.4958
C.V. %	3.26
Adj R-Square	0.3698
Adeq Precision	5.808

From Tables 4a-b, it was observed that the model for carbohydrate content was significant (R-Square = 0.4958 and $p<0.05$). The model terms (x and y) were also significant which implied that the process parameters had significant effects on the carbohydrate content of the plantain flour. Adequate precision measures the signal to noise ratio. A ratio greater than 4 is desirable. Adequate precision = 1.808 greater than 4, indicated that the model as fitted was adequate for predicting and can be used to navigate the design space.

The lack of fit on the other hand was not significant (Prob>F) implying that the model was valid. A low coefficient of variance (C.V. % = 3.26) indicated that the experiments were highly reliable.

Figure 2 above is the three dimensional graph that visualizes the graphical relationship between the various process parameters and the response.

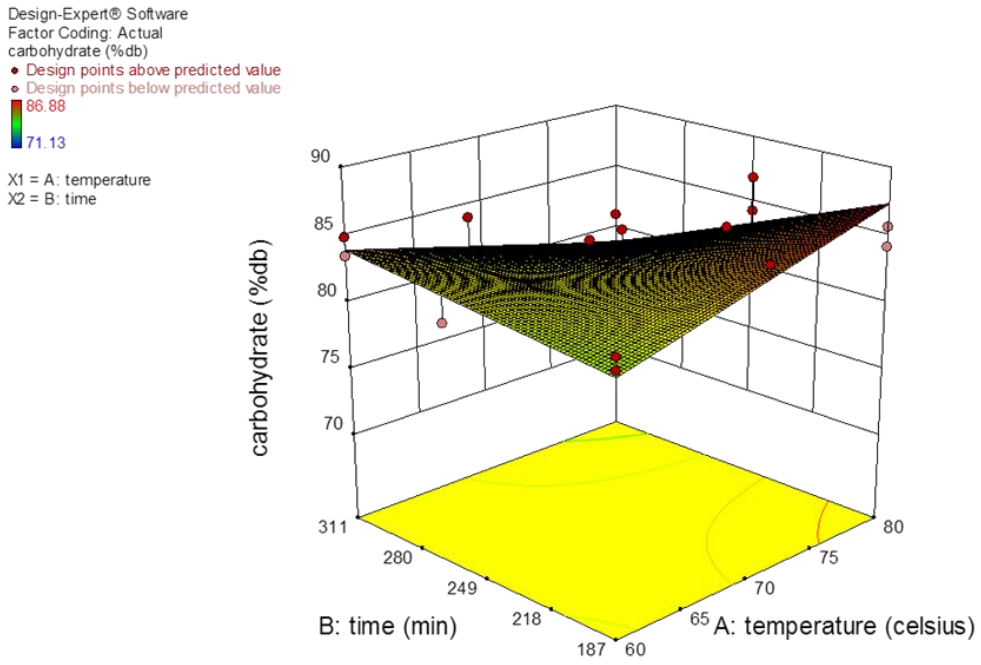

Figure 2. The effect of the process parameter on the response

It entails the level of interaction which existed between the process parameters i.e. B: time and A: temperature and their possible effect on the response. 3D plot of AB interaction

show that 2FIS allow for twisting of the plane, but did not allow for hills and depressions [25].

Validation of the optimum process parameters

Since our main objective here was to maximize the carbohydrate content of the plantain flour and minimize the drying time and temperature, the criteria was to keep "in range" the drying temperature and time while the carbohydrate content was "maximized" in our targeted goal as shown in Table 5.

Table 5. Criteria for optimization of the process parameters (constraint)

Name	Goal	Lower limit	Upper limit
x: Time	Is in range	187 min	311 min
y: Temperature	Is in range	60^{o}C	80^{o}C
z: Carbohydrate	Maximize	71.13	100

From the result in Table 5, it shows the criteria for the process parameters where time (lower limit was 187 min and upper limit was 311 min); Temperature (lower limit was 60^{o}C and upper limit was 80^{o}C) and carbohydrate (lower limit was 71.13 and upper limit was 100).

Table 6. Solution for optimization of the process parameters

Number	Temperature (^{o}C)	Time (min)	Carbohydrate (%)	Desirability
1	80.000	187.000	87.374	0.563
2	79.666	187.000	87.277	0.559
3	80.000	189.033	87.234	0.558
4	80.000	192.790	86.976	0.549
5	74.770	187.000	85.854	0.510
6	60.000	311.000	83.983	0.445

From the optimizations shown in Table 6, it can be seen that the optimum processing parameters for plantain flour were: drying temperature (80^{0}C), drying time (187 min) carbohydrate content (87.374 %), pulp thickness (3 mm).

Conclusion

This study has analysed some nutritional compositions of unripe plantain at different drying temperatures. The plantain sample studied had comparable proximate compositions to

what is reported in the literature. From the proximate analysis, moisture content ranged from 7.84 - 16.60%, ash content from 1.2 - 5.5%, fibre content from 8.70 - 10.34%, fat content from 0.89 - 1.56%, protein content from 3.56 - 4.75%, and carbohydrate content from 67.85 - 71.20%. The dried plantain may find application in food industry due to low moisture content as ingredient for foods that require good shelf life.

Response surface methodology was successfully used to investigate the effects of temperature and time on the final carbohydrate content of the plantain using oven drying method. Response Surface Methodology (RSM) was used to generate the design and optimize the drying conditions for plantain. The generated experimental design was considered to be efficiently applicable when the G Efficiency was greater than 60%. The optimum drying conditions were obtained at temperature of 80^{o}C, time of 187 minutes. The optimum carbohydrate content was 87.4% db. Also, the model and its coefficients were found to be significant through the response analysis.

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