Optimization of Deep-Fat Frying of Plantain Chips (*Ipekere*) using Response Surface Methodology

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Abstract

Deep-fat frying of plantain chips (*ipekere*) was investigated with the aim of predicting optimum operating conditions for plantain chips to minimize oil content in order to produce healthy products. The effect of frying temperature and time on moisture content, oil content, breaking force and colour difference of plantain chips was evaluated. Response surface methodology was used to analyze the results of the central composite design of the frying processes for the responses as a result of variation in the levels of frying temperature ($150 - 190^{\circ}$C) and frying time ($2 - 4$ min). Response surface regression analysis shows that responses were significantly ($p<0.05$) correlated with frying temperature and time. Regression model was developed for the investigation of the effect of frying temperature and time on the responses. The polynomial regression models were validated with statistical tool whose values of coefficients of determination (R^2) were 0.995, 0.982, 0.971 and 0.996 for moisture content, oil content, breaking force and colour difference, respectively. The optimum values of moisture content, oil content, breaking force and colour difference were 3.73%, 1.18%, 17.66 N and 65.53, respectively, at frying temperature of 183°C and frying time of 3 min. Therefore, frying conditions had a significant effect on the quality attributes of chips produced from plantain.

Keywords: plantain chips, deep-fat frying, regression models, texture and colour

1. Introduction

Plantain (*Musa* AAB) is one of the most important food crops in the world. It is a major source of carbohydrate, antioxidants and minerals like potassium and calcium and caters for the calorific needs of many people in developing countries (Kanazawa & Sakakibara, 2000; Mohapatra *et al*., 2010). Nigeria is one of the largest plantain producing countries in the world with an estimated production at 2,722,000 metric tons in 2009 and an average consumption level of 190 kg/person/year (FAO, 2011; 2013). In spite of its prominence, the country does not feature among plantain exporting nations because it produces more for local consumption than for export. Plantain consumption has risen greatly in Nigeria in recent years because of the rapidly increasing urbanization and the great demand for easy and convenient foods by the non-farming urban population. Besides being the staple for many people in more humid regions, it is a delicacy and favoured snack for people in other regions. Plantain chips called *Ipekere* in south western part of Nigeria. It can be produced from green and slightly ripen green plantain with yellow patch, and fried to almost bone dry with golden yellow colouration.

Deep-fat frying (DFF) is a multifunctional unit operation of food transformation that can be described as cooking of food by immersion in edible oil or fat at a temperature higher than the boiling point of water (Farkas & Hubbard, 2000). DFF can be considered as a high temperature and a short time process which involves both mass transfer, mainly represented by water loss and oil uptake, and heat transfer (Vitrac *et al*., 2002). It is one of the major value addition processes for plantain which results in products with a unique flavour-texture combination (Mellema, 2003; Pedreschi, 2012). The primary reason for the popularity of DFF foods may be the desirable characteristics like soft, juicy interior as well as thick and crispy outer crust (Garcia *et al*., 2002). Texture, colour and oil content are the main quality parameters of fried products (Hindra & Baik, 2006).

Response surface methodology (RSM) is a useful technique for optimization studies. This is a collection of mathematical and statistical techniques that is useful for modeling and analysis in applications where a response is influenced by several factors (Montgomery, 2005). RSM is important in designing, formulating, developing, and analyzing new scientific studies and products. The most common applications of RSM are in industrial, biological, clinical, social, food, physical and engineering sciences. Optimization is therefore required to ensure rapid processing while maintaining optimum product quality especially in term of the quality characteristics. The quality attributes for frying of food materials may include moisture content, oil content, breaking force and colour parameters while the process parameters to be optimized include frying temperature and time.

Most published studies on plantain over the years have dealt primarily with final product quality and physico-chemical changes in the oil medium during frying (Onyejegbu & Olorunda, 1995; Akubor & Adejo, 2000; Agunbiade *et al*., 2006; Avallone *et al*., 2009). None of these reports have particularly optimized frying conditions to obtain fried plantain chips of acceptable quality attributes. However, there is little or no published work on the use of RSM during DFF of plantain chips to obtain optimum conditions for quality characteristics of plantain. Therefore, the objective of this work was to optimize the DFF conditions with respect to quality attributes like moisture and oil contents, breaking force and colour parameters.

2. Materials and Methods

2.1 Materials

Mature plantain (*Musa paradisiacal* AAB) fruits harvested at green stage were procured from a local farm in Ogbomoso, South West Nigeria. The plantains were identified in the department of Crop and Environmental Protection, LAUTECH, Oyo State, Nigeria.

2.2 Methods

Plantains were washed with clean water, peeled manually and were cut into 2 mm thick slices using a stainless steel knife and a slicer. Refined vegetable oil (Devon King's®) obtained from Ace Supermarket, Ogbomoso was used as the frying medium in the deep-fat frying process.

2.2.1 Experimental Design

Central composite of RSM for a two-variable experimental design was employed (Garcia, 2002). The independent factors considered were frying temperature and time while the dependent factors were moisture content, oil content, breaking force and colour difference (ΔE) (Table 1).

2.2.2 Frying Operation

Frying was carried out in a deep-fat fryer (model MC-DF 1031, Cool Touch deep fryer, General Electric, Hong Kong, China) adapted with temperature controller to maintain the set frying temperature within ±1°C. The fryer was filled with 2.5 L of oil and equipped with a 2 kW electric heater. Plantain slices to oil ratio was kept at 1:10 was used. The oil was preheated prior to frying and discarded after 2 h. Before each frying test, the oil level was checked and replenished as required. Samples were fried at temperatures 150, 160, 170, 180 and 190ºC, for 120, 150, 180, 210 and 240 seconds. After frying, excess oil was removed by shaking the baskets manually and the chips were placed on a rack to cool. Samples were stored in sealed, low density polyethylene bags and kept at room temperature until analyses were performed.

2.3 Quality Characteristics Determination

2.3.1 Moisture content: Five gram was weighed into a pre-weighed moisture dish. The dish plus sample taken was transferred into the oven pre-set at 105°C to dry to a constant weight for 24 hours overnight. At the end of 24 hours, the dish plus sample was removed from the oven and transferred to a desiccator, cooled for 30 min and weighed (AOAC, 2000).

2.3.2 Oil content: Oil content was determined according to method described by AOAC (2000) using soxhlet extraction. Fried samples were ground using a grinder. Five gram of sample was weighed into thimbles for fat extraction in a solvent extractor using petroleum ether. Fat content was determined as the ratio of the mass of extracted fat and dry matter of the sample.

2.3.3 Breaking force: The texture (breaking force) of the chips was determined using a universal testing machine (Testometric AX, model M500, Rochdale, Lancashire, England) equipped with a 50 kN load cell. Fried plantain chips of uniform sizes were selected and then placed on a metal support with jaws at a distance of about 25 mm. They were pressed in the middle with a cylindrical flat end plunger (70 mm diameter) at a speed of 2.5 mm/min. The measurement was recorded by a computer connected directly to the equipment. The breaking force (N) interpreted as crispness was obtained as the peak force from the force – deformation curve (DaSilva & Moreira, 2008).

2.3.4 Colour: Colour parameters lightness ($L*$), redness ($a*$) and yellowness ($b*$) were measured using a colorimeter (Colour Tec-PCM, Hunterdon, NJ) as described by Krokida *et al.* (2001a). The instrument was standardized and the samples were placed in the sample holder. Samples were scanned at different locations to determine ($L*$, $a*$ and $b*$) parameters. Colour difference (ΔE) was calculated according to the equation:

$$\text{Colour difference (Hunter } \Delta E) = [(L - L_{\text{ref}})^2 + (a - a_{\text{ref}})^2 + (b - b_{\text{ref}})^2]^{1/2} \tag{1}$$

Where L_{ref}, a_{ref} and b_{ref} were the L, a and b values of fresh plantain slices which were used as references.

2.4 Statistical analysis

All data were analyzed using the Design-Expert Version 9.0.3 (State-ease software). Regression analysis and analysis of variance (ANOVA) were conducted by fitting the equation to the experimental data to determine the regression coefficients and statistical significance of model terms. The significance of the model terms was assessed by F-ratio at a probability $p<0.05$. Model adequacies were determined using model analysis, lack of fit test and coefficient of determination (R^2).

2.5 Optimization procedure

Numerical optimization was performed using Design Expert software version 9.0.3. Multiple responses were optimized simultaneously through the use of a desirability function that combines all the responses into one measurement. The method finds operating conditions (combination of independent variables) that maximizes the desirability function. The constraints were set to get the value of a variable for an optimum response (a minimum and maximum level must be provided for each variable included). The optimization of the DFF process was aimed at finding the levels of frying temperature and time, which could minimize the moisture content, oil content, breaking force and moderate colour.

3. Results and Discussion

3.1 Estimation of the model parameters for plantain chips (*Ipekere*)

The experimental data and their corresponding responses are shown in Table 1. Multiple regression and correlation analysis are used as tools for assessment of the effects of two or more independent variables on the dependent variables. The coefficients of determination (R^2) for moisture content, oil content, breaking force and colour are, 0.995, 0.982, 0.971 and 0.997, respectively. These values are quite high for response surfaces and indicated that the fitted quadratic models accounted

for more than 95% of the variance in the experimental data, which were found to be highly significant. The only regression coefficients significant at 95% levels according to p-values were selected for developing the models.

3.2 Adequacy test of the models for plantain chips

The fitted models were tested for adequacy and consistency by analysis of variance (ANOVA). The results from the statistical analysis revealed that the F-value for moisture content (38.21), oil content (88.19), breaking force (18.69) and colour difference (129.08) were significant at the 95% confidence level. Analysis of variance for response surface quadratic models of plantain chips is shown in Table 2. The empirical models obtained for the quality characteristics of plantain chips are stated as equations 1 to 4. Quadratic model was found to satisfactorily explain the relationship for moisture content, oil content and breaking force while 2FI model was used to represent the relationship between colour of *ipekere* as affected by frying conditions. The model satisfied lack of fit test. Significant model terms at $p < 0.05$ were frying temperature (X_1), frying time (X_2), second order of frying temperature and time (X_1^2, X_2^2) and interaction of frying temperature and time (X_1X_2). Therefore, the model is appropriate for predicting moisture content, oil content, breaking force and colour as influenced by frying temperature and time.

3.3 Effect of variables on the responses
3.3.1 Moisture content

Equation 2 indicates that at linear level, temperature and time had negative effect on the moisture content. At quadratic level, all the variables had positive effect on the moisture content, while interaction between temperature and time had negative effect. Effect of moisture content with frying temperature and time are shown in Figure 1. Significant interaction suggests that the level of one of the interaction variables can be increased while that of other decreased for constant value of the response. Shyu and Hwang (2001) reported that the unbound water in the fried food can be rapidly removed when the oil temperature reaches the boiling point of water. The effects of frying temperature and time were significant ($p < 0.05$) on the moisture content. Response plot (Fig. 1) revealed that the rate of moisture loss in plantain chips increased by increasing the frying temperature and time. The moisture changes during frying showed the typical progressive decrease with increasing frying time. The result obtained was similar to the findings on French fries and chicken meat respectively (Krokida *et al.*, 2001b; Kassama & Ngadi, 2005).

$$MC = 33.51 - 0.31X_1 - 2.11X_2 + 8.91E - 004X_1^2 + 0.25X_2^2 - 2.73E - 003X_1X_2 \qquad (2)$$

3.3.2 Oil content

As shown in Equation 3, at linear level, temperature and time had negative effect on the oil content. At quadratic level, temperature had negative effect and time had positive effect, while the interaction between temperature and time had positive effect on the oil content. Significant interaction suggests that the level of one of the interaction variables can be increased while that of other decreased for constant value of the response. The relationship of oil content with frying temperature and time are shown in Figure 2. The increased oil absorption during deep frying of plantain may be accredited to changes in porosity and molecular size redistribution. The oil content in fried products needs to be optimized because it affects the texture and appearance of the chips (Dobarganes *et al.*, 2000). The final oil content of the chips is affected by the plantain's physicochemical characteristics and the processing conditions. Moreover, oil content in a product can depend on the frying temperature, time as well as moisture content (Moreira *et al.*, 1997; Sharma *et al.*, 2000; Yagua & Moreira, 2011). The result obtained was similar to the findings of Nantawan *et al.* (2007) who reported increase in fat content at longer frying time.

$$OC = 1.01 + 5.87E - 003X_1 - 0.24X_2 - 2.32E - 005X_1^2 + 9.48E - 003X_2^2 + 9.98E - 004X_1X_2 \qquad (3)$$

3.3.3 Breaking force

Breaking force was used to represent the crispness of fried plantain chips. Frying temperature and time had negative linear effect on the crispness of the chips. At quadratic level, temperature had negative effect and time had a significant positive effect, while interaction between temperature and time had negative effect on the crispness. The interaction effect of temperature and time on crispness is shown in Figure 3. As shown in Eqn. 4, at the two independent variables, second order derivatives and interactions between the variables are significant. Results showed that the effects of temperature were significant ($p < 0.05$) on the crispness of the plantain chips. As temperature of frying increases, the rate of moisture removal becomes faster, thus favouring the frying process. The breaking force of the chips decreases as frying temperature and time increases. Crispness of chips is a vital measure that determines the consumers' acceptance (Setiady *et al.*, 2009). It is the most important textural attribute which denotes freshness and high quality. The peak compression force increased with increasing frying conditions or when the initial plantain moisture content was lower. The result obtained was in agreement with the findings that the hardness of fried chickpea flour-based snack increased at lower moisture content of the pre-fried product (Debnath & Rastogi, 2003).

$$BF = 322.02 - 2.82X_1 - 34.94X_2 + 7.79E - 003X_1^2 + 4.87X_2^2 - 0.02X_1X_2 \qquad (4)$$

3.3.4 Colour

The effect of interaction of temperature and time on colour is shown in Figure 4. As reflected in Eqn. 5, at linear level, temperature had negative effect, time had a significant positive effect on the crispness. At quadratic level, temperature had positive effect and time had negative effect, while interaction between temperature and time had negative effect on the colour. The colour intensity of plantain chips decreased progressively as the frying temperature and time increased (Fig. 4).

This indicates that higher ΔE values will lead to lower colour quality on the surface of plantain chips. It was observed that an increase of temperature led to a significant formation of brown products. The modification in fried plantain colour is mainly due to the effect of temperature on heat-sensitive compounds such as carbohydrates, proteins and vitamins, which cause colour degradation during drying process. The formation of brown compounds in plantain may be related to both enzymatic and essentially non-enzymatic (maillard reaction) reactions (Miranda *et al*., 2009). This result is similar to the findings of Onwuka & Onwuka (2005) that colour changes also indicated more maillard reaction with frying time which utilized the abundant reducing sugars in plantain.

$$\Delta E = -70.18 + 0.78X_1 + 64.40X_2 - 0.39X_1X_2 \qquad (5)$$

3.5 Optimization of the frying process

RSM was used for the optimization of DFF of plantain chips and for understanding the factors affecting the frying process. Based on response surface regression analysis of each model, the models (MC, OC, BF and ΔE) were useful for indicating the direction in which to change variables in order to minimize moisture content, fat content and texture (breaking force) and moderate colour. The desirability lies between 0 and 1; and it represents the closeness of a response to its ideal value. Desirability of the solution was 0.76. Three possible optimum solutions were found with desirability ranging from 0.75 to 0.79. The best of the three conditions was frying at 183.61 ^{o}C for 3.19 min which gave 3.73% MC, 1.18% OC, 17.66 N crispness and 65.53 colour.

4. Conclusion

The RSM was effectively used to investigate the effects of frying temperature and time on the quality characteristics of plantain chips. The optimum values for moisture content, oil content, breaking force and colour from the surface plot was 3.73%, 1.18%, 17.66 N and 65.53, respectively at frying temperature of 183°C and frying time of 3 min. Therefore, temperature and time were determined to have significant effect on the quality attributes of plantain chips. Thus, the optimized frying conditions were able to produce high quality plantain chips.

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Table 1: Experimental design arrangement and responses of *ipekere*

Run	Coded		Actual		Responses			
	x_1	x_2	X_1	X_2	MC (%)	OC (%)	BF (N)	ΔE
1	-1.0	-1.0	190	4	3.67	1.22	21.41	34.56
2	1.0	-1.0	170	4	3.69	1.20	15.97	55.89
3	-1.0	1.0	180	3	3.77	1.20	15.75	51.39
4	1.0	1.0	170	3.5	3.50	1.19	17.78	52.64
5	0.0	1.414	190	2	3.76	1.22	24.90	56.80
6	0.0	-1.414	150	4	4.37	1.14	24.11	66.99
7	1.414	0.0	160	3.5	4.32	1.18	18.59	60.24
8	-1.414	0.0	170	3	3.69	1.20	15.97	55.89
9	0.0	0.0	180	2.5	3.91	1.21	18.88	54.55
10	0.0	0.0	190	3	3.86	1.20	15.67	47.73
11	0.0	0.0	170	3	4.06	1.19	22.40	49.19
12	0.0	0.0	170	2	4.19	1.19	17.78	52.64
13	0.0	0.0	170	3	4.02	1.22	23.01	56.42

Where: X_1 = Frying temperature (^oC), X_2 = Frying time (min), MC= Moisture content (%),
OC = Oil content (%), BF = Breaking force (N), ΔE = Colour difference

Table 2: Analysis of variance for the responses

| Responses	Sources of Variation	DF	Sum of Squares	Mean squares	F-value	R^2
MC	Regression	5	0.650	0.130	38.211	0.995
	Residual	7	0.023	0.003		
	Total	12	0.674			
OC	Regression	5	0.005	0.001	88.194	0.982
	Residual	7	9.013E-05	1.290E-05		
	Total	12	0.005			
BF	Regression	5	125.966	25.193	18.695	0.971
	Residual	7	9.433	1.347		
	Total	12	135.399			
ΔE	Regression	5	660.253	220.084	129.080	0.996
	Residual	7	675.599			
	Total	12	0.650	0.130	38.211	
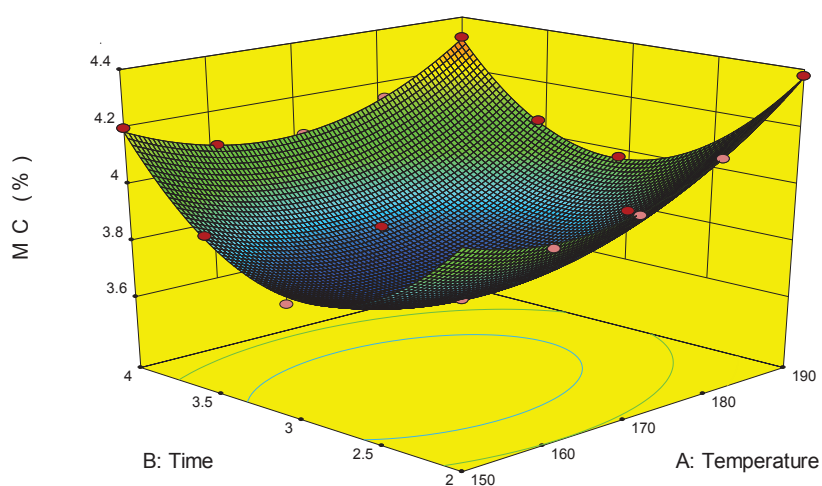
Figure 1: Response surface plot showing the effect of frying temperature and time on moisture content of *ipekere*
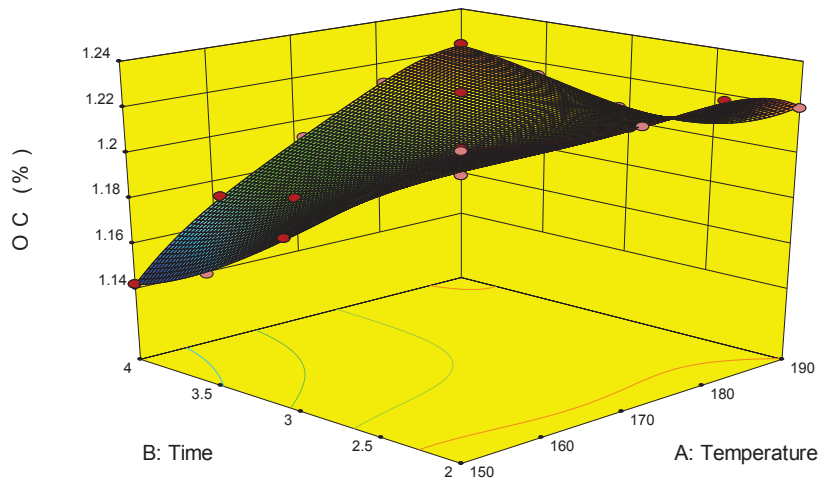
Figure 2: Response surface plot showing the effect of frying temperature and time on oil content of *ipekere*
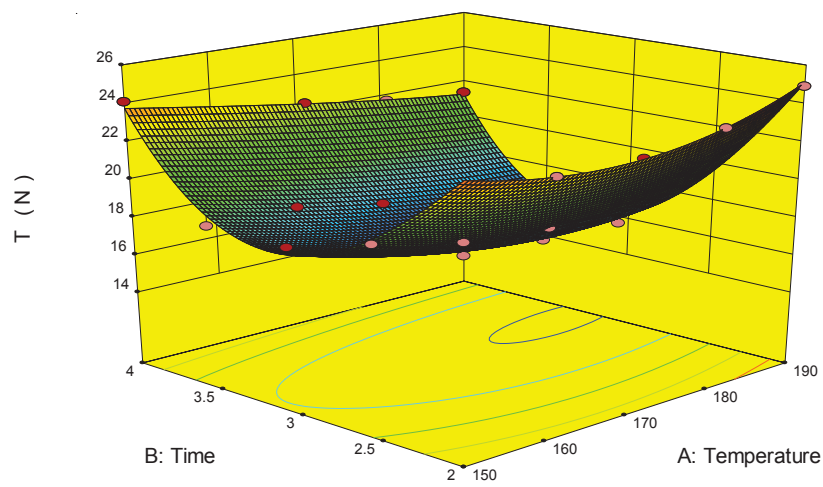

Figure 3: Response surface plot showing the effect of frying temperature and time on breaking   force of *ipekere*
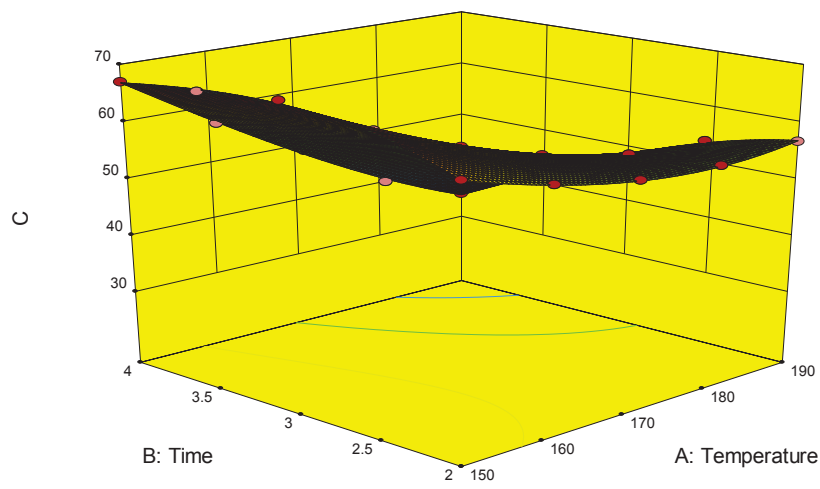
Figure 4: Response surface plot showing the effect of frying temperature and time on colour difference of *ipekere*