OPTIMIZATION OF PROCESSING PARAMETERS AND QUALITY ATTRIBUTES OF FRIED COCOYAM CHIPS

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ABSTRACT

The influence of frying temperature and time on the quality characteristics of deep-fat fried cocoyam chips was investigated using Central Composite Design (CCD) in Response Surface Methodology (RSM) consisting oftwo independent variables (frying temperature and time). The dependent variables were moisture content, oil content, colour, texture and shrinkage. The cocoyam tubers were cut into uniform slice of 3 mm thickness and fried at different temperature(150 – 190 ^oC) and time (5 – 9 minutes). Frying conditions significantly influenced all dependent variables at $p<0.05$. Coefficients of determination (R^2) of the models ranged from 0.891 to 0.998 which indicated that the variables were adequately fitted to the regression equation and could highly predict the quality attributes of deep fried cocoyam chips. The optimum conditions werefrying temperature of 190 $^oC$and frying time of 7.59 minutes. This gave 7.85% moisture content, 11.59% oil content, 63.81 colour, 5.32 N crispness and 13.14% shrinkage.

Keywords: cocoyam, deep-frying, moisture loss, oil uptake, texture

INTRODUCTION

Cocoyam (*Colocasiaesculenta)* is one of the tuber crops used mainly for human food. Nigeria is the world's largest producer of cocoyam with an average production of 5,068,000 million tonnes which accounts for about 37% of total world output of cocoyam (FAO, 2007). It is a well-known food plant that has a long history of cultivation. Its corms are an important source of starch. Like many plants of the *Araceae*family, the cocoyam grows from the fleshy corm (tuber) that can be boiled, baked or mashed into a meal. The cormels are used for human consumption while the corms serve as planting material. The corms supply easily digestible starch and are known to contain substantial amounts of protein, vitamin C, thiamine, riboflavin and niacin (Niba, 2003). Despite being rich in starch, tropical root and tuber crops have remained underutilized, though starch from these crops could be used in different industrial applications (Wickramasinghe*et al*., 2009).

Deep-fat frying is a process of cooking foods by totally immersing them in edible oils and fats at elevated temperature to induce fast dehydration (Patterson *et al.,* 2004). It is a simultaneous heat and mass transfer process where moisture leaves the food in the form of vapour bubbles, while oil is absorbed simultaneously. It is often selected as a method of choice for creating unique flavour and texture in processed foods and results in modification of the physical, chemical and sensory characteristics of the food (Patterson *et al.,* 2004). One of the most important quality changes during the process is the amount of oil retained inside the product, which is incompatible with current health trends. Several studies have shown that oil is mainly retained in the crust region which mostly penetrates during the post-frying cooling period.

Response Surface Methodology (RSM) is a powerful mathematical model with a collection of statistical techniques wherein interactions between multiple process variables can be identified with fewer experimental trials (Bas *et al*., 2007). There are various advantages in using statistical methodologies in terms of rapid and reliable short listing of process conditions. Thus, RSM experimental design is an efficient approach to deal with a large number of variables.Optimization is a method used to improve the performance of a system which gives a high yield at low costs. It is a fundamental and frequently applied task for most engineering activities.

Information abounds on fried tuber crops like yam, potatoes and cocoyam (Sobukola, 2007; Troncoso*et al*., 2009; Akinlua*et al*., 2013). However, optimization of frying conditions in term of frying temperature and time on the quality characteristicsof cocoyam chips has not been done. Therefore, the objective of this study was to optimize frying conditions (temperature and time) for quality characteristics of cocoyam chips using RSM.

MATERIALS AND METHODS

Preparation of Samples

Fresh cocoyam tubers (*Colocasiaesculenta*)purchased from a local market in Sabo, Ogbomoso, Oyo State, wereused for the investigation. Tubers were washed, peeled manually and sliced into 3 mm thickness using a stainless steel knife. The slices were rinsed immediately to remove surface starch.

Experimental Design

The RSM used in the present study is a Central Composite Design (CCD) involving two different factors. The two independent variables investigated in this experiment were frying temperature and frying time and the codes of those variables were X_1 and X_2, respectively while the dependent variables were moisture content, oil content, colour, shrinkage and breaking force of fried cocoyam chips. Each independent variable had five levels which were -1.414, -1, 0, +1, and +1.414.Nine experimental combinations were generated and last treatment was repeated four times.

Deep-Frying Process

Frying process was carried out in deep-fat fryer of a commercial type (model MC-DF 1031, Cool Touch deep fryer, General Electric, Hong Kong, China). The fryer was filled with 1.5 L of oil and equipped with a 2 kW electric heater. Frying temperatureswere 150, 160, 170, 180 and 190°C while5, 6, 7, 8and 9min were frying times. The slices obtained were deep fried in heated vegetable oil in a regulated deep fryer until light crispy texture and unique aroma were developed.

Analytical Procedures

Moisture content

Moisture content was determined using the AOAC (2005) method in which 5 g of each of the samples was weighed into a moisture dish and dried in hot air at 105 ºC for 1 hour. It was then cooled in desiccators, weighed and returned into the oven and the process was repeated until a constant weight was obtained.

Oil content

AOAC (2005) standard procedure and Soxhlet method were used for fat extraction and analysis. The dried samples were ground using Sumeet electric grinder. Approximately 5.0 g of each ground sample was used for fat extraction. The fat was extracted using petroleum ether in a Soxhlet extractor (SER 148, VelpScientifica, Usmate, Italy). The fat content was obtained on dry weight bases for each cocoyam chip sample as the ratio of mass of oil extracted to mass of dried samples.

Colour

The colour(colour difference) of cocoyam chips was measured with a colorimeter (Colour Tec-PCM, Hunterdon, NJ) and expressed as Hunter L (lightness), a (redness) and b (yellowness) values. Colour difference (Hunter ΔE) was calculated using Eq. (1) (Hunt 1991):

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

Where L_{ref}, a_{ref} and b_{ref}were the L, a, and b values of fresh cocoyam slices, respectively.

Texture

Breaking force measurement of the chips was performed at room temperature (30±2 °C) by employing puncture test, with slight modifications (Segniniet *al.,* 1999). The measurements was performed by using a computer assisted TA-XT Plus Texture Analyzer (Stable Micro Systems, UK) with a 5 kg load cell. Fried cocoyam chips were mounted individually on a three point support, at a distance maintained at 15mm with punch diameter and cross-head speed of 2mm and 60mm/min, respectively. Each sample was compressed at a constant deformation rate of 10 mm/min., and readings were made using data logger. The highest value achieved upon fracturing the sample in the plot was used as the resistance to breakage (Force, N). The data obtained from texture profile analysis was used to determine the crispness values. Crispness was expressed as the force at significant break in the first bite.

Shrinkage

Shrinkage was determined by measuring the sample dimension before and after frying with a venier caliper. Measurements were made at different places on each sample. Shrinkage was expressed as the percentage change in thickness and diameter (Kawas and Moreira, 2001).

$$S = \frac{d_o - d_t}{d_o} \times 100$$

Where d_o = Initial diameter of the sample and d_t= diameter of the sample after frying at time (t)

Statistical Analysis

Data were analyzed using Design Expert version 6.0.10 software package to generate regression equations and analysis of variance which was determined at 5% level of significance. Suitability of the models was determined by coefficients of determination (R^2) and lack of fit test.

RESULTS AND DISCUSSION

Moisture content

The experimental design and corresponding quality characteristics values of cocoyam chips are presented in Table 1. Moisture content values ranged from 7.76 to7.89% (Table 1). The moisture content of cocoyam chips was significantly affected ($p<0.05$) by frying temperature and time. Moisture loss was found to increase as the temperature increased from 150 to 190 ºC with an earlier rapid fall when the products were fried. The influence of frying temperature and time on the moisture contents of the sliced cocoyam during deep-fat frying is shown as Fig. 1. The moisture loss during frying of the cocoyam slice was similar to the falling rate period of drying in tortilla chips (Moreira *et al*., 1997).Linear model was appropriate for the responses;(Eq. 3) expressed functional relationship between moisture content and the independent variables. Lack of fit test for the model was non-significant at p<0.05. All the model terms were significant (p<0.05). The accuracy of the model was checked by the determination of correlation coefficient, R^2 value of 0.939.

$$MC = +7.83 + 7.59E-003X_1 + 6.50E-002X_2 \quad (3)$$

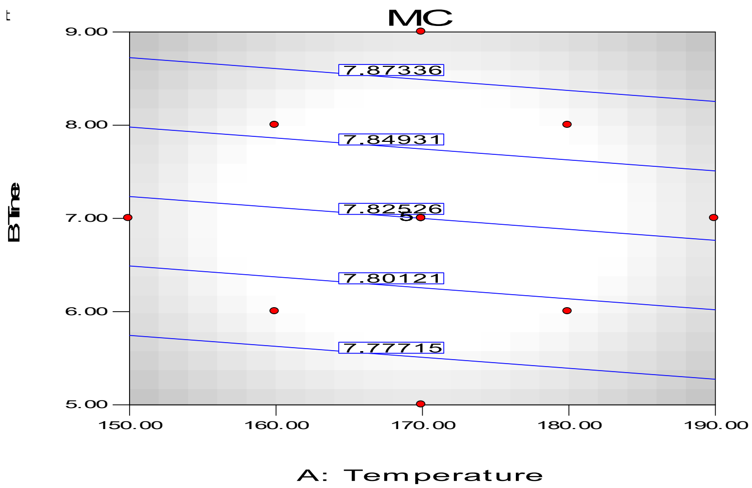

Figure 1: Contour plot of moisture content against frying temperature and time

Table 1: The experimental design and obtained values of the responses

Exp.	Coded value		Actual value		Responses				
Run	x_1	x_2	X_1	X_2	MC (%)	OC (%)	ΔE	C (N)	S (%)
1	-1	-1	160	6	7.78	11.74	56.35	27.87	12.51
2	1	-1	180	6	7.79	11.61	77.67	36.73	19.55
3	0	0	170	7	7.84	11.64	81.09	22.82	15.62
4	-1	1	160	8	7.85	11.8	82.81	27.65	17.71
5	0	0	170	7	7.83	11.65	80.99	21.07	15.67
6	1	1	180	8	7.86	11.68	70.53	10.32	12.95
7	0	1.414	170	9	7.89	11.77	72.78	23.59	14.98
8	0	0	170	7	7.83	11.71	78.08	21.07	15.68
9	0	-1.414	170	5	7.76	11.64	53.46	49.27	16.38
10	1.414	0	190	7	7.83	11.58	72.59	15.21	16.82
11	0	0	170	7	7.80	11.64	80.99	21.07	15.61
12	-1.414	0	150	7	7.81	11.83	63.55	24.63	14.53
13	0	0	170	7	7.82	11.71	78.08	23.50	15.67

Where; X_1 =Frying temperature (°C), X_2 = Frying time (min), MC = Moisture content (%),OC = Oil content (%), ΔE = Colour difference, C = Crispness (N), S = Shrinkage

Oil content

The fat content obtained during deep-fat frying of cocoyam chips ranged from 11.58 to 11.83% (Table 1). The effect of frying temperature and time on the oil content of cocoyam chips was significant at p<0.05. The fat contents of the cocoyam chips increased asfrying temperature and time increases. This increase in fat content coincided with the period of moisture evaporation from the cocoyam chips. When the chips were placed in hot oil, the free water was rapidly lost in form of bubbles. The final oil content of the chips is a function of time and the remaining moisture within the product, which increases with decreasing temperature (Garayo and Moreira, 2002). Figure 2 shows the contour plot of oil content as affected by frying temperature and time. The model equation showed a linear relationship (Eq. 4). The results show that the model is significant based on high F-value and lack of fit test for the model was non-significant at p<0.05.All the model terms were significant (p<0.05). The model accuracy was checked by the determination of correlation coefficient, R^2 value of 0.891.

$$OC = +11.69 - 0.12X_1 + 0.068X_2$$

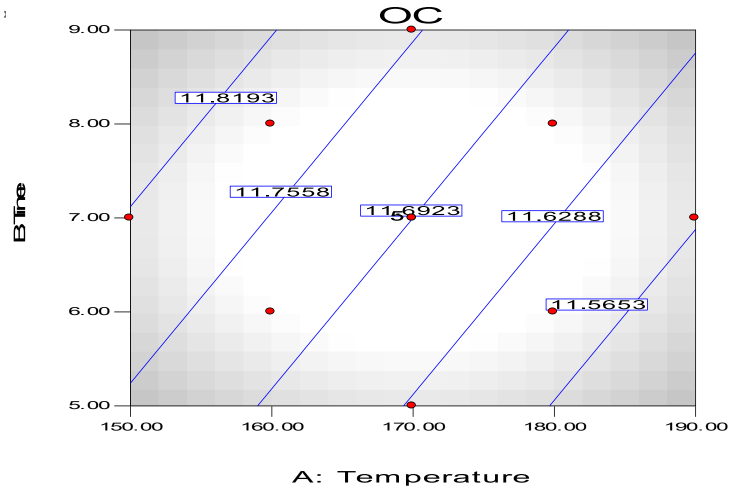

Figure 2: Contour plot of oil content against frying temperature and time

Colour

The colourdifference (ΔE)of fried cocoyam ranged from 53.46 to 82.81 (Table 1).The ΔEof cocoyam chips increased gradually as the frying temperature and time increased. The changes in the colour of cocoyam chips is as a result of the Maillard reaction, which depends on the content of reducing sugars and amino acids or proteins at the surface, as well as temperature and time of frying (Krokida*et al.,* 2001). The model showed a quadratic relationship (Eq. 5). The relationship between the independent variables and colour intensity of cocoyam chips is shown as Fig. 4. Lack of fit test for the model was non-significant at $p<0.05$. All the model terms were significant ($p<0.05$). The accuracy of the model was checked by R^2 value of 0.988.

$$\Delta E = +79.60 + 4.52X_1 + 9.66X_2 - 11.83X_1^2 - 16.79X_2^2 - 33.60X_1X_2 \quad (5)$$

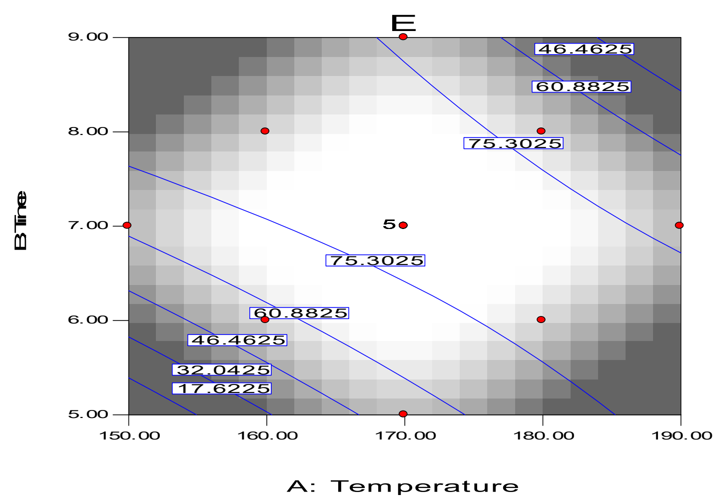

Figure 3: Contour plot of colour difference against frying temperature and time

Texture

The crispnessof cocoyam chips ranged between 10.32 and 49.27 N. As shown in Table 1, the breaking force of cocoyam chips was significantly ($p<0.05$) affected by frying temperature (X_1) and frying time (X_2). Crispness increased as frying time increased due to crust development (Moyano and Pedreschi, 2006). Crispness of chips is a very important factor that determines the consumers' acceptance (Setiady*et al.*, 2009). The peak compression force increased with increasing frying conditions. The result agreed with findings of Debnath*et al.* (2003) who reported that the hardness of fried chickpea flour-based snack increased at the lower moisture content of the pre-fried product.For cocoyam chips, a very crispy texture was expected since crispness was an indicator of freshness and high quality. The influence of frying temperature and time on the crispness of cocoyam chips is shown as Fig. 4. The quadratic model was appropriate for the crispness of cocoyam chips (Eq. 6). The model is significant based on high F-value, lack of fit test for the model was non-significant at $p>0.05$. All the model terms were significant ($p<0.05$). The model accuracy was checked by the R^2 value of 0.993.

$$C = +22.07 - 4.55X_1 - 13.00X_2 - 1.95X_1^2 + 14.57X_2^2 - 26.19X_1X_2 \quad (6)$$

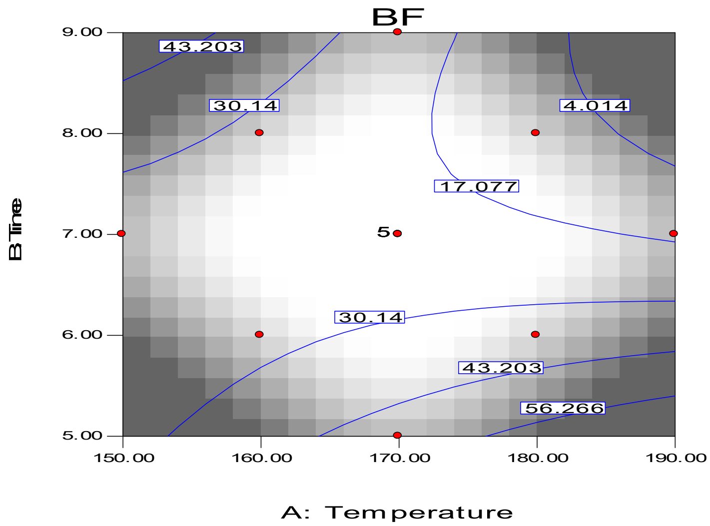

Figure 4: Contour plot of breaking force against frying temperature and time

Shrinkage

The shrinkage value ranged between 12.51 and 19.55 (Table 1). The degree of shrinkage was significantly ($p<0.05$) affected by the frying temperature and time. The relationship between diameter shrinkage and moisture loss during frying has been reported in the literature(Caixeta*et al*., 2002; Tran *et al*., 2007). However, the higher oil temperature caused the cocoyam chips surface to become rigid more rapidly and resulted in more resistance to the shrinkage (Garayo and Moreira, 2002). Contour plot of shrinkage of cocoyam chips is shown as Fig. 5. The appropriate model for the shrinkage is 2FI (Eq. 7). The model is significant based on high F -value, lack of fit test for the model was non-significant at $p>0.05$. All the model terms were significant at $p<0.05$. The model accuracy was checked by the R^2 value of 0.999.

$$S = +15.67 + 1.15X_1 - 0.70X_2 - 11.81X_1X_2 \quad (7)$$

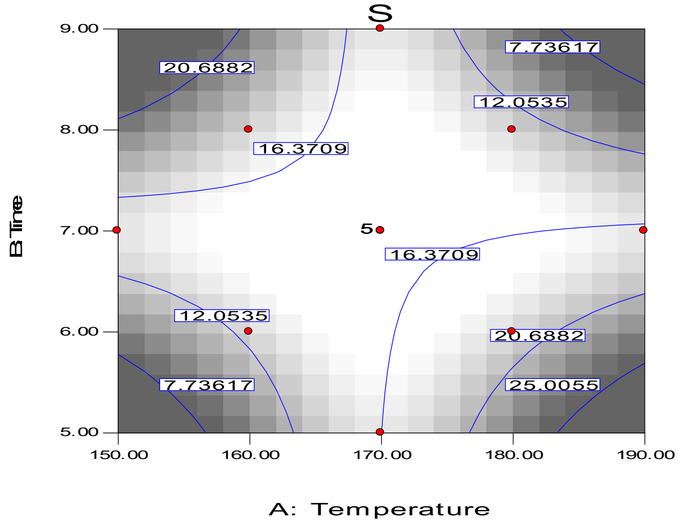

Figure 5: Contour plot of shrinkage against frying temperature and time

Optimization

The optimization of the deep-fat frying 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. The optimum conditions obtained were frying temperature of 190 °C and frying time of 7.59 min when the moisture content, fat content,colour difference, crispness and shrinkage were 7.85%, 11.59%, 63.81, 5.32 N and 13.14%, respectively.

CONCLUSION

The quality characteristics of sliced cocoyam were influenced by frying temperature and time. The results obtained showed that moisture content, oil content, colour, crispness and shrinkage of cocoyam chips were significantly affected ($p<0.05$) by frying temperature and time. The optimal quality of fried cocoyam chips should possess a low moisture content, oil content and crispness as well as acceptable colour.

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