EFFECTS OF FRYING PARAMETERS ON SOME PHYSICAL PROPERTIES OF FRIED SWEET POTATO (*IPOMEA BATATAS*)

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ABSTRACT

The effects of frying parameters (temperature; 130-170°C and time; 2-10 mins) on moisture content, oil content, bulk density and breaking force of fried sweet potato were determined using response surface methodology (RSM). Sweet potato tubers sliced into a uniform thickness (3.0 mm) were fried with sunflower oil using a commercial deep fat fryer. The results from the research showed that frying time had significant ($p<0.05$) effect on moisture content and bulk density. Also, the interaction of temperature and frying time showed significant effect ($p<0.1$) on bulk density. The quadratic term of time had significant ($p<0.1$) effect on the oil content, while the quadratic term of temperature had significant ($p<0.05$) effect on the breaking force of the sweet potato chip. The results further showed that increase in frying temperature and time led to decrease in moisture content, bulk density and breaking force. While increase in frying temperature and time brought about increase in oil content. The optimization developed from this work showed that frying temperature of 145°C and frying time of 6 min would produce sweet potato of high quality in terms of low breaking force, bulk density, moisture and oil content.

KEYWORDS: Sweet potato, frying, moisture content, oil content, bulk density, breaking force.

1. INTRODUCTION

Sweet potato (*Ipomoea batatas)* is a perennial herbaceous dicotyledonous species of the morning glory family Convolvulaceae that is cropped as an annual in many countries (Oates, 2003). Most of the world production is concentrated in 15 countries which account for almost 97% of total world output (Scott, 1992). China is the largest producer of sweet potato in the world (FAO, 2010; Oates, 2003; Jiang et al., 1995). It is the fifth most important crop in the developing countries after rice, wheat, maize and cassava (Oates, 2003). Sanni et al. 2009 stated that Nigeria has the highest production of sweet potato in Africa with 24%, followed by Uganda (23%), Tanzania (8%) and Madagascar (5%) and the rest of the Africa having 29%. Sweet potato (*Ipomea batatas*) is a high-energy crop that is also rich in beta carotene, vitamins and dietary fibres. Several varieties of sweet potato contain higher levels of minerals and proteins than other vegetable (Woolfe, 1992). Utilization of sweet potato includes boiled sweet potato eaten with soup, sweet potato fufu, sweet potato starch, sweet potato noodles, sweet potato snacks, chips and sweet potato flour. Mutungamiri et al. (2001) also demonstrated sweet potato can be processed into jam. Other products that can be derived from sweet potato include juice and ketchup. Sweet potatoes are highly perishables and are not normally stored for any length of time (Fasina, 2006).

Frying is the immersion of a food product into a heated edible oil to achieve a good quality in terms of crispiness, flavour, colour and storability (Hubbard and Farkas, 1999). It is a complex process that involves high temperature, removal of moisture from food product, heat and mass transfer, and micro-structural changes both to the surface and body of the chips (Bouchon *et al.,* 2001). Frying is a very turbulent process that involves the movement of small bubbles particles over the boundary layer of the product surface (Farinu and Baik, 2008). During frying, heat is transferred by convection from the surrounding oil to the surface of the food and by conduction within the solid food. The four stages involved in frying are initial heating, surface boiling, falling rate and bubble endpoint (Farkas *et al.,* 1996).

According to Montgomery (2005), Response Surface Methodology (RSM) makes use of mathematical and statistical techniques for the modelling and analyzing of problems in which a response of interest is influenced by several variables with the aim of optimizing this response. Several works have been carried out on the frying of foods (Yamsaengsung and Moreira, 2002; 2002; Taiwo and Baik, 2002; Moyano and Pedreschi, 2006). The objective of this work is to investigate the effects of processing conditions on the physical properties (moisture content, oil content, bulk density and breaking force) of fried sweet potato using response surface methodology.

2. MATERIALS AND METHODS

The sweet potatoes of local variety (shaba) was purchased from a local market in Uyo, Nigeria. Sweet potato of similar sizes was selected for the experiments. The sweet potato tubers were sliced using a manual slicer (Mothers Choice, Ltd, Texas) to obtain a uniform thickness (2.7mm-3.2mm). The prepared samples were rinsed for 1 min in distilled water to loosen material adhering to the surface; the samples were gently blotted out with towel to remove surface water.

2.1 Experimental Design

The experimental design is based on a three-level factorial design for two variable case as developed by Design Expert 9 (www.startease.com). The two independent variables were frying temperature (130-150^{o}C) and frying time (2-10 mins). Each of these independent variables has three levels. These levels were based on recommendations in literature and trial experiments. The total number of experiments carried out was 13 including five (5) replicates as shown in Table 1.

2.2 The Frying Process

The experiments were performed using a deep fat fryer (MC-DR1030, 3L, Master Chef, China). The deep fat fryer consists of a heating element and a basket. The frying process began by heating oil to the desired temperature, followed by loading the electric fryer with the 12 slices of sweet potatoes per sampling time, using oil-product ratio of 6:1 as recommended by (AOCS Press, 1995). Each experiment was carried out and analyzed according to the experimental design (Table1). After the frying procedure of each batch, the electric fryer was turned off, the basket was lifted out of the oil, and was left to drain oil from fried food. The fried food products were left to cool for 5 minutes, after which they were taken for further analysis.

2.3 Determination of Moisture Content

Moisture content was determined using the Oven dryer (Genlab thermal, MINO/50, Cheshore). Two slices of the sample were weighed and placed in a moisture dish. The sample was heated at 105^{0}C in the oven dryer to constant mass, the sample was cooled at room temperature for 5minutes inside the desiccators and weighed. The amount of weight loss is the moisture contents expressed on wet basis and calculated using formula:

$$\text{Weight loss} = \frac{(initial\ weight\ of\ sample - final\ weight\ of\ sample)}{Initial\ weight\ of\ sample} X\ 100\% \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Table1: Experimental Design and Data for Fried Sweet Potato

Run	Temperature A	Time B	Moisture content	Oil content	Breaking force	Bulk density
	^{0}C	Min	%	%	N	g/cm3
1	170	2	15.73	9.53	0.026	0.688
2	150	6	26.05	16.52	0.03	1.042
3	150	6	12.5	13.65	0.02	0.805
4	150	10	2.87	10.7	0.025	0.547

5	150	6	3.46	6.23	0.02	1.115
6	150	2	21.9	2.91	0.03	1.063
7	150	6	6.94	10.74	0.026	0.869
8	130	2	41.1	13.15	0.043	1.1926
9	130	10	9.05	8.54	0.03	0.598
10	170	10	2.98	8.91	0.02	0.684
11	130	6	15.37	16.97	0.05	0.857
12	170	6	12.3	12.47	0.05	0.882
13	150	6	4.01	15.5	0.02	0.684

2.4 Determination of Oil Content.

This was done using Soxhlet extraction with petroleum ether gravimetrically (AOAC, 1995), available in the food engineering laboratory. The oil content was expressed as:

Oil content = $\frac{weight\ of\ oil}{weight\ of\ sample}\ X100\% \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(2)$

2.5 Determination of Bulk Density

Bulk density was determined by the procedure and formula as described by Irtwange and Igbeka, (2002). Twelve samples put inside the beaker were weighed using the electronic balance. The beaker was weighed separately and the weight was subtracted from the initial weight (samples + beaker) to obtain weight of sample. The inner diameter (radius) r and height h of the beaker were measured to calculate the volume V=[illegible]. The bulk density was then calculated using:

$$\rho = \frac{W}{V} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Where ρ is the bulk density g/cm^3, W is the weight of sample (g) and V is the volume of sample (Cm^3).

2.6 Determination of Breaking Force (Crispness)

The texture of the fried sweet potatoes was analysed using the Rig apparatus, the constant force N exerted by the apparatus per unit length is 1.0 N/m, samples were inserted into the cracking space and the height was read from the metre rule, the knobs were adjusted to crack the sample, the point where the sample cracks (i.e. gives the crack sound) was also read from the metre rule, the difference was multiplied by the force exerted by the Rig apparatus, the calculated value was recorded as the breaking force for the sample. It is calculated using formula;

Breaking force (N) = (Initial Height – Final Height) × Constant force *N/m*………………………… (4)

2.7 Statistical Analysis

The experiment process was repeated in triplicates for each experiment and the mean values recorded as obtained data. The experimental data obtained were subjected to ANOVA and regression analysis by the statistical software, Design Expert 9 (Stat Ease. Inc, Minneapolis, MN). A second order polynomial equation was used to express the responses as follows:

$$Y = \beta_0 + \text{[illegible]} + \sum_{j=0}^{2} \beta_{ii} x_{i}^{2} + \sum_{i=1}^{1} \sum_{j=i+1}^{2} \beta_{ij} X_i X_j \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5)$$

Where Y is the response, β_0 is the constant coefficient, β_i is the linear coefficient, β_{ii} is the quadratic coefficient. β_{ij} an interaction coefficient and X_i and X_j are the coded values of the independent variables.

3. RESULTS AND DISCUSSION

Table 1 shows the experimental data for fried sweet potato and Table 2 shows the ANOVA and coefficient estimates of the responses.

3.1 Effect of Temperature and Time on Moisture Content

As shown in table 2, frying time had significant ($p<0.05$) effect on the moisture content of the fried sweet potato, while the other terms showed no significant effect on the moisture content. However, it is shown in table 2 that the coefficient estimates of linear terms of temperature and time had a negative effect on the moisture content while the coefficient estimates of quadratic terms of temperature and time and interaction of temperature and time had a positive effect on the moisture content. Figure 1 shows the response surface plot for moisture content where moisture content decreased as frying temperature and time increased.

Table 2: Result of ANOVA and Estimated Coefficient of the Responses

Response	Intercept	A	B	AB	A^2	B^2
Moisture content	10.3731	-5.75167	-10.6383*	4.825	4.00914	2.55914
p-value		0.1078	0.0113*	0.2472	0.4123	0.5953
oil content	12.3852	-1.29167	0.426667	0.9975	2.6919	-5.2231**
p-value		0.4480	0.7983	0.6279	0.2932	0.0633**
Breaking force	0.0265862	-0.0045	-0.004	0.00175	0.014948*	0.007551
p-value		0.2606	0.3127	0.7091	0.0282*	0.2062
Bulk density	0.900359	-0.0656	-0.185767*	0.14765**	-0.0242552	0.088755
p-value		0.3192	0.0189*	0.0894**	0.7957	0.3578

A = temperature, B = time
*$p<0.05$
**$p< 0.1$

Higher frying temperature and longer time would result in a product with lower moisture content because during frying there is transfer of heat from the oil to the surface of the product by convection and then from the surface to the center of the product by conduction. This causes an increase in temperature until the boiling temperature is attained and water starts evaporating (Moreira et al., 1999). This shows that at higher frying time and temperature there is decrease in moisture content and vice versa. These results are in agreement with those reported by Krokida *et al.*, (2000); Mariscal and Bouchon, (2008).
The model equation for moisture content is given as:

Moisture content (%) = +355.02142 - 3.65631 *Temperature-13.62581 *Time +0.060312 *Temperature * Time +0.010023 * Temperature^2+0.15995* Time^2……………………….. (6)

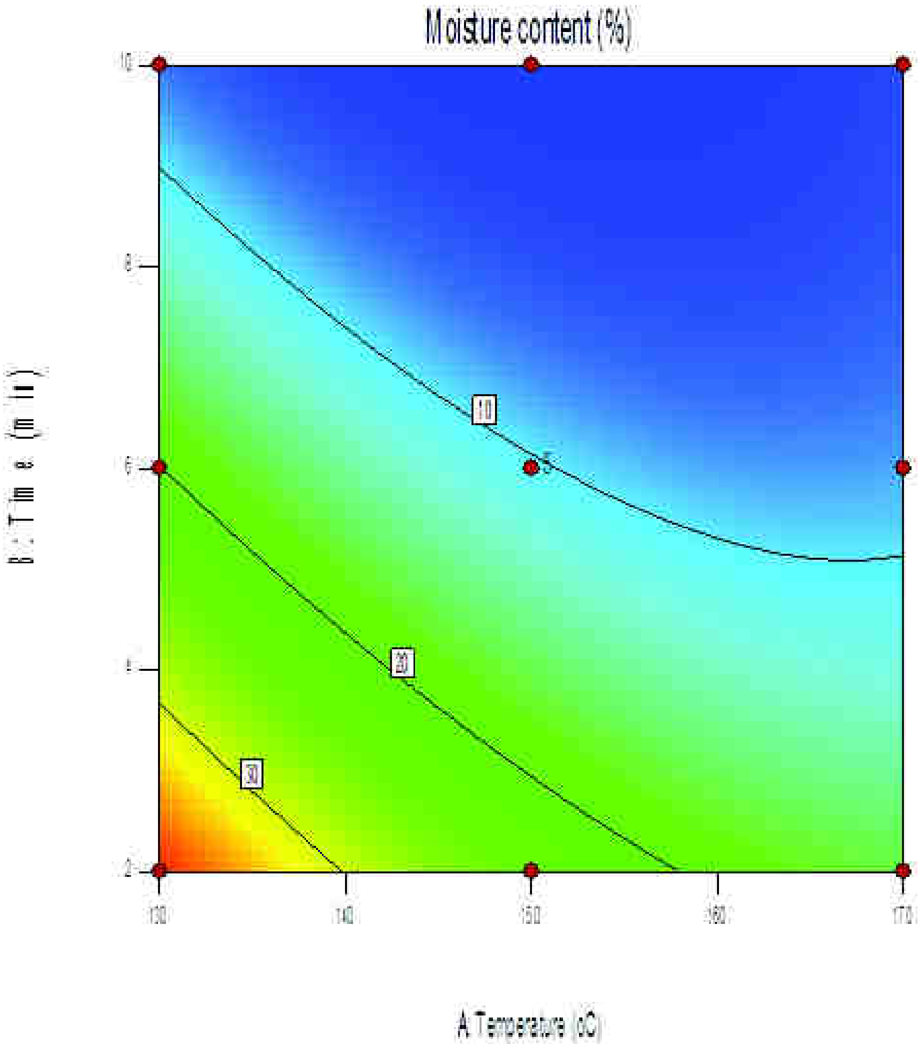

Figure 1: Response surface (Contour) plot for moisture content

3.2 Effect of Frying Temperature and Time on Oil Content

Table 2 shows that only the quadratic term of time had significant ($p<0.1$) effect on oil content while the other terms had no significant ($p>0.1$) effect on oil content. However, the coefficient estimate of linear term of temperature and quadratic term of time had a negative effect on the oil content, while the other terms had a positive effect on the oil content. Oil adsorption is an important aspect in the area of deep fat frying which has been examined by several researchers. Studies show that most of the oil penetrates the product during cooling when the product is removed from the fryer (Moreira et al., 1997; Ufheil & Escher, 1996; Moreira & Barrufat, 1998). At lower temperatures we have higher oil content and at higher temperatures we have lower oil content. Figure 2 shows that the oil content increased as the frying temperature and time increased (Krokida et al., 2000). It has been confirmed that there is a relationship between the moisture content and oil content of fried foods. During frying, moisture leaves the sweet potato through the capillaries inside sweet potato tuber.

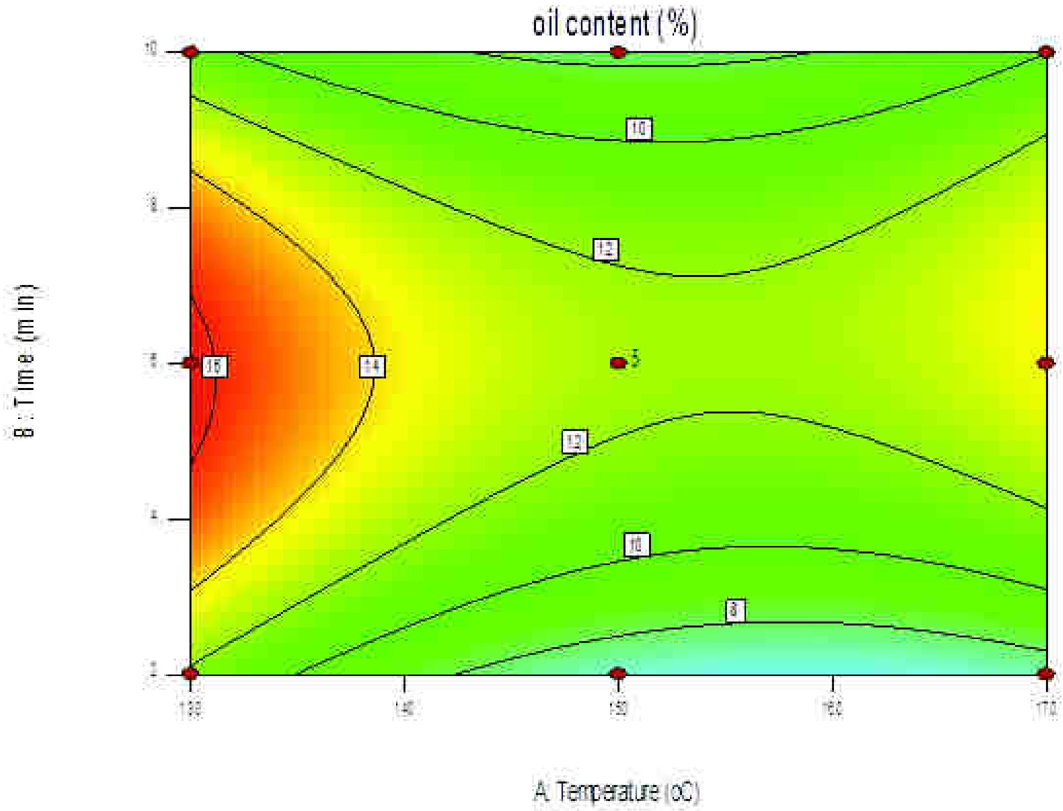

Figure 2: Response surface (contour) plot for oil content.

The oil goes in to occupy the space left by the moisture in the sample. In other words, as the moisture content decreases the oil content increases (Rima-Brncic *et al*., 2004).
The model equation for oil content is given as:

Oil content (%) =+172.32175-2.15832* Temperature+2.15368* Time +0.012469 *Temperature*Time +6.72974E-003* Temperature^2-0.32644* Time^2…………………… (7)

3.3 Effects of Frying Temperature and Time on Bulk Density

It is observed in table 2 that frying time had significant ($p<0.05$) effect on the bulk density of the fried sweet potato. The interaction of temperature and time also had significant ($p<0.1$) effect on the bulk density of the sweet potato. The coefficient estimates of linear terms of temperature and time and quadratic term of temperature had negative effects on bulk density while the other terms had positive effect on bulk density. Figure 3 shows the response surface plot as affected by temperature and time. This result indicates that increase in frying temperature and frying time brought about decrease in bulk density. The decrease in bulk density was as a result of water vaporization, air pore development and oil uptake (Krokida *et al.,* 2000).

The model equation for bulk density is given as:

Bulk density (g/cm^3) = +1.76802+3.83763E-003* Temperature-0.25672* Time+1.84563E-003* Temperature * Time-6.06379E-005* Temperature^2-5.54720E-003* Time^2……………… (8)

3.4 Effect of Frying Temperature and Time on Breaking Force (Crispiness)

Table 2 shows that only the quadratic term of temperature had significant ($p<0.05$) effect on the breaking force of fried sweet potato. The coefficient estimate of linear terms of temperature and time had negative effects on the breaking force while the quadratic and interaction terms of temperature and time had positive effects on the breaking force. Figure 4 shows the response surface plot as affected by temperature and time.

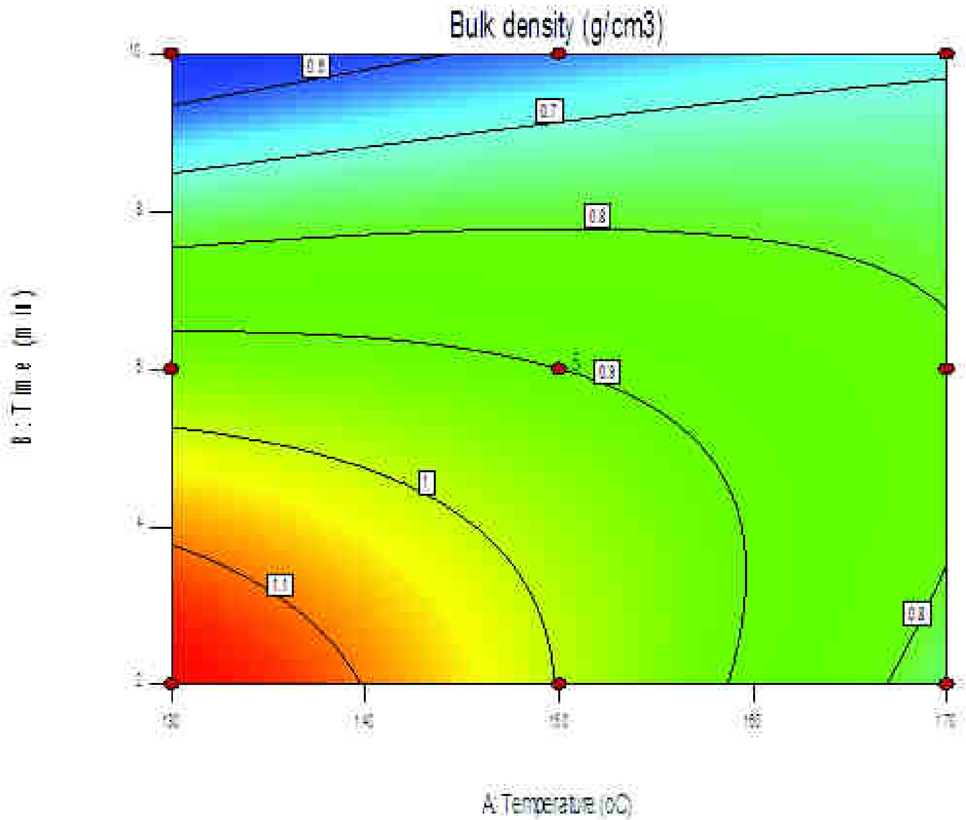

Figure 3: Response surface (contour) plot for bulk density.

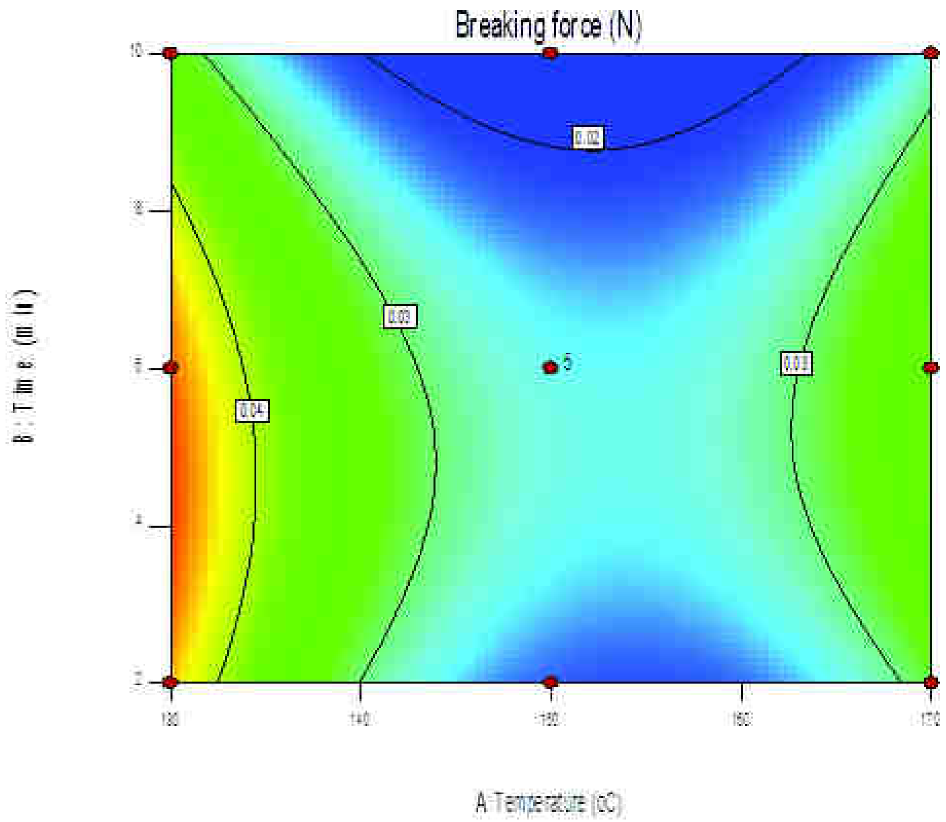

Figure 4: Response surface (contour) plot for breaking force.

The result indicates that breaking force

The result indicates that breaking force decreased as frying time and temperature increased. This is a desirable quality in fried sweet potato because lower breaking force corresponds to higher crispness (Shyu and Hwang, 2001). This is due to decrease in moisture contents as a result of increase in frying temperature.

The model equation for breaking force is given as:

Breaking force (N) = +0.90987-0.011567* Temperature+1. 38254E-003* Time+2.18750E-005* Temperature * Time+3.73707E-005* Temperature^2-4.71983E-004* Time^2……………… (9)

3.5 Optimization of Frying Processes of Sweet Potato

Response Surface Methodology (RSM) was used to generate the optimized values of the frying process variables (temperature and time) based on minimized moisture content, oil content, bulk density and breaking force. Therefore, the optimized values are 145^{o}C and 6 min for temperature and time, respectively. The implication of this is that to produce the fried sweet potato of good quality, the frying temperature should be set at 145^{o}C for frying time of 6 min.

4. CONCLUSION

The various effects of the frying process (temperature and time) had been investigated on the independent variables (moisture content, oil Content, bulk density and breaking force). Frying time was found to have significant effect on the responses in most cases. Response surface methodology had been employed in this work to evaluate and optimize the frying process of sweet potato. The optimized values (temperature of 145^{o}C and time of 6 min) were adequate to produce high quality sweet potato chips.

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