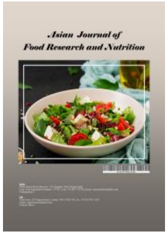

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Effects of Pretreatments on the Physicochemical Properties of Deep Fat Fried Plantain Strips

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Deep-fat frying of plantain strips was investigated with the aim of optimizing the effect of pretreatments with sorbitol and carboxymethyl cellulose to minimize oil uptake. The effect of sorbitol and carboxymethyl cellulose on water retention, oil uptake, crispness, colour and breaking strength of the plantain strips were evaluated. The experiment was Response surface methodology designed as Face centered central composite design (FCCCD). The levels of sorbitol concentration ranged between 0.5 - 2.5% and carboxymethyl cellulose concentration (CMC) 1 - 3%. The plantain was washed, peeled, sliced and blanched at 85^{0}C for 6 minutes. It was immediately immersed in an aqueous solution of CMC mixed with sorbitol, drained and dried at 100^{0}C for 3 minutes. Frying was carried out at 180^{0}C for 4 minutes, cooled and packaged in an air tight polyethylene bag. The dependent variables : water retention, oil uptake, crispness, colour, breaking strength, free fatty acid, peroxide value were in the following ranges 3.02 - 4.95 %, 1.21 - 1.93%, 3.95 - 4.95 Nnm^{-1}, 41.65 - 70.33, 11.76 - 18.08 N, 3.53 - 5.08 mg(KOH)/g and 2.07 - 4.01 meq/kg respectively. The

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optimum values of the dependent variables were 3.95 %, 1.63 %, 4.67 Nnm^{-1}, 17.23 N, 4.23 mg(KOH)/g and 2.87 meq/kg at the concentrations of 1.75 % sorbitol and 1 % CMC with a frying temperature of 180^{0}C for 4 minutes. Therefore, pretreatment had a significant effect ($p<0.05$) on the quality attributes of the deep fat fried plantain strips.

Keywords: Deep fat frying; pretreatments; sunflower oil; plantain strips; optimization.

1. INTRODUCTION

"There is a growing concern amongst consumers about high intakes of oil and saturated fats, and this has led to the investigation into process technologies that minimize the absorption of oils and fats in foods subjected to frying processes. Many methods have been studied to control the final oil content of fried products, including modifications of the surface properties of the materials" [1].

"Food subjected to the frying process undergoes physical and chemical changes. The development of pores is a major structural change, followed by shrinkage. Furthermore, chemical changes form toxic components such as acrylamide, produced by the Millard reaction, which together with other degradation products are absorbed by the food" [2]. "Among the foods that are preferably eaten fried are potatoes and bananas. Banana is a general term embracing a number of species or hybrids in the genus Musa of the family *Musaceae*. The genomic groupings AAA of the subspecies *M. acuminate* and *M. balbisiana* are chiefly eaten raw as table fruit, while some bananas belonging to genomic groupings AAB and ABB (plantain) have to be cooked" [3].

"Plantains are mostly cooked to be consumed at different stages of maturity. When the fruit has reached physiological maturity, but the skin is green, the plantain is starchy and hard and is treated like a vegetable. Unlike ripe fruits with yellow or even black skin, green fruits are preferably consumed cooked by frying, in the form of slices (chips) or thin strips (snacks)" [3].

"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" [4]. "DFF can be considered as a high temperature and a short time process which involves both mass transfers, mainly represented by water loss and oil uptake, and heat transfer" [5]. "Consumers prefer plantains that are cooked by deep fat frying, because this improves the quality characteristics and the sensory properties of color, flavor, texture and palatability" [6]. "The fried products are recognized for their crispy texture, roasted, fried aroma and their pleasant golden to brown color" [7]. "The physical and chemical changes that happen in different types of oils during deep frying have been generally studied by different researchers. However, in lots of researches there were comparison of traditional methods of frying with some new methods, such as microwave drying, osmotic pretreatments etc" [8,9,10]. "Some efforts have been made to improve the frying process by controlling and lowering the final fat content through techniques to reduce the oil content of snacks and plantain chips" [11].

"Pretreatments, such as convective, osmotic and assisted ultrasound dehydration, have been applied with the purpose of reducing the absorption of oil in fried products" [12]. "Osmotic solutions of glucose and salt have been used as a pretreatment for plantain, reducing the oil absorption content by up to 38%" [12]. Garcıa et al. [13] noted that "an edible methylcellulose coating plasticized with sorbitol on potato strips and dough discs caused an oil reduction of 40.6 and 35.2%, respectively". Tavera-Quiroz et al. [14] found that "the addition of sorbitol enhanced the barrier properties of an edible methylcellulose, and reduced the oil uptake by 30 % with respect to uncoated samples during the deep fat-frying". "By combining hydrogen bonds with polymers and reducing polymer interactions, the coatings have better adhesion and flexibility, and reduce the possibility of discontinuity and brittleness" [15]. "Polysaccharide-based films are commonly plasticized with polyols such as sorbitol. The plasticizer of sorbitol could improve the films flexibility and lower tensile strength and higher elongation at break" [14].

"In foods with a high starch content, surface modifications using thermal treatments favor gelatinization and porosity. On the other hand, the absorption of oil has also been studied as a global concentration, where the depth of oil absorption is influenced by the properties of the crust" [16,17]. Primo-Martín et al. [16,17] reported "differences between the properties of crust and crumb, with the crust having a lower degree of starch gelatinization".

"Hydrocolloids with thermal gelation capabilities or thickening properties have been widely studied as edible coatings. Coatings based on cellulose derivatives such as methylcellulose (MC), sodium carboxymethyl cellulose (CMC) and hydroxypropyl methylcellulose (HPMC) have showed a good barrier to the absorption of oil during deep-fat frying" [18,19]. "Hydrocolloids are also used to control retrogradation, syneresis, texture, and overall quality of the final product" [20,21]. "Carboxymethyl cellulose (CMC) is one of the most common hydrocolloids used in food applications. Structurally, it consist of a cellulose backbone of β (1,4)-D-glucose units with carboxymethyl group substituent" [22]. Garcia et al. [13] investigated "the effects of several hydrocolloid materials, including, gellan gum, CMC and pectin". "CMC coating formulations were the most effective, reducing the oil uptake by 35 - 40%, depending on the product" [1]. "Therefore, the use of hydrocolloids as edible coatings can be an alternative to meet the demands of current consumers, and thus be a promising route for obtaining Plantain snack low on calories, but investigations are still insufficient in relation to deep-fat frying while applying coatings in matrices such as plantain, since the surface of the food is important for the absorption of oil" [14].

"Sunflower oil, which contains a high (around 71%) polyunsaturated fatty acid (PUFA) content is a commonly used vegetable oil consumed in Turkey" [23]. "Depending on the frying condition, the oil is subjected to many chemical reactions that result in the formation of various compounds and reduction in its PUFA content" [8,9]. "Several physical (colour, viscosity) and chemical parameters (FFA, PV etc.) are used as indicators of oil quality during deep fat frying. The quality of fried food depends on the quality of the frying oil since the majority of the compounds, deleterious to health, formed in the oil during frying has been shown to be absorbed by the food" [11]. "Sunflower oil is considered as one of the best oils used in frying because of its low smoking point, slight color and taste, low level of saturated fats found in, and its firmness at high cooking degrees, also, it is an excellent oil for household use such as baking preparing, frying, and salads" [24].

"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" [25]. "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 water retention, crispness, oil uptake, breaking strength and colour parameters while the process parameters to be optimized include sorbitol and Carboxymethyl cellulose (CMC)" [25].

Therefore, the aim of this study was to determine the effect of carboxymethyl cellulose mixed with sorbitol on water retention, breaking strength, crispness and colour, its concentration and the frying time in terms of oil uptake for plantain strip samples undergoing deep-fat frying at 180 ^{0}C for 4 minutes.

2. MATERIALS AND METHODS

2.1 Sources of Materials

Matured plantain (*Musa paradisiacal* AAB) fruits were procured from Natural Root and Tuber Research Umudike, Anambra state. Sunflower oil was procured from Eke-Awka market. The CMC and sorbitol were procured from Onitsha main market, Anambra state. At the department's laboratory, the Plantains were washed with portable water, peeled manually and cut into 2 mm thick slices using a stainless-steel knife and a slicer. The raw plantain strips were then placed in a sieve and blanched at 85^{0}C for 6 minutes. The sieve containing the blanched raw plantain strips was immersed immediately into an aqueous solution of CMC (Carboxymethyl cellulose) mixed with sorbitol at different concentrations (Table.1). After which, it was drained and dried in an oven at 100 ^{0}C for 3 minutes in order to reduce surface moisture.

2.2 Frying Operation

Frying was carried out in a deep-fat fryer (model MC-DF 1032, crown star deep fryer, General Electric, Hong Kong, China) adapted with a PID temperature controller to maintain the set frying temperature within ± 1°C. The fryer was filled with 3 L of sunflower oil and equipped with a 2-kW electric heater. Plantain Strips to oil ratio was kept at 1:6. The deep fat fryer was first preheated with sunflower oil 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 a constant temperature of 180 ^{0}C for 4 minutes. After frying, excess oil was removed by shaking the deep fat frier basket manually and the strips were placed on a rack to cool. Samples were stored in sealed, low density polyethylene bags and kept at room temperature (27 ^{0}C) until analyses were performed.

2.3 Experimental Design

Face Centered Central Composite Design of RSM for a two-variable experimental design was employed [26]. The independent factors considered were CMC concentration (Factor A: 1%, 2% and 3%) and sorbitol (Factor B: 0.5%, 1.5% and 2.5%) while the dependent factors were oil uptake, water retention, breaking strength, crispness and colour (Table 1). The ideal predictive regression equation showing the response variables as a function of the independent Variables (Process Variables) is given in equation 3

$$Y = b_0 + b_1A + b_2B + b_{12}AB + b_{11}A^2 + b_{22}B^2 + e \quad (1)$$

Where

Y = Response
b_0 = Intercept
b_{1-22} = Coefficient of A, B, their squares and interactions
A = Concentration of sorbitol (%)
B = Concentration of CMC (%)
e = Estimate error

2.4 Water Retention

Water content (WC) was determined by measuring weight loss of fried products, upon drying in an oven at 110 ^{0}C until constant weight. Relative variation of water retention % (WR) in the coated plantain strip relative to the uncoated plantain strip was calculated using equation 2:

$$WR = \left(\frac{WCcoated}{WCuncoated} - 1 \right) \times 100 \quad 2$$

where:
WC is the water content of the samples
WR is the water content of the samples.

For each coating formulation, results were obtained using all the samples from two different batches.

Table 1. Face centered Central Composite (FCCC) design matrix and the independent variables

Run	Factor A Sorbitol %	Factor B CMC%
1	1.5	2
2	0.5	3
3	0.5	1
4	2.5	3
5	2.5	1
6	0.5	2
7	1.5	1
8	1.5	2
9	1.5	3
10	1.5	2
11	1.5	2
12	1.5	2
13	2.5	2

2.5 Oil Uptake

Lipid content (LC) of fried products was determined on dried samples using a combined technique of successive batch and semi continuous Soxhlet extractions. The first batch extraction was performed with petroleum ether ethylic ether (1:1) followed by a Soxhlet extraction with the same mixture and another Soxhlet extraction with n-hexane. Oil uptake relative variation% (OU) in the coated plantain strip relative to the uncoated plantain strip was calculated using equation 3:

$$Oil\ Uptake = \left(\frac{LCcoated}{LCuncoated} - 1 \right) \times 100 \quad 3$$

where: LC is the lipid content of the samples. For each coating formulation, results were obtained using all the samples from two different batches.

2.6 Crispness

The crispness (breaking force) of the strips was determined using a universal testing machine (model M500, Test metric AX, Rochdale, Lancashire, England) equipped with a 50 kN load cell. Fried plantain strips of uniform sizes were selected and placed on a metal support with jaws at a distance of about 25 mm. Samples 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 [27].

2.7 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. [28]. 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 and were also analyzed in triplicates.

2.8 Statistical Analysis

All data was analyzed using the Design-Expert Version 12. (State-ease software). Regression analysis and analysis of variance (ANOVA) was 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).

2.9 Optimization Procedure

Numerical optimisation was performed using Design Expert software Version 12. Multiple responses were optimised 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 optimisation of the Deep fat frying (DFF) process was aimed at finding the levels of sorbitol and CMC, which could minimize the water retention, oil content, maximize breaking force and crispness with moderate colour.

3. RESULTS AND DISCUSSION

The physicochemical properties of CMC and sorbitol pretreated deep fat fried plantain strips were evaluated using Response surface methodology (RSM) approach.

3.1 Influence of Sorbitol and Carboxymethyl Cellulose Coatings on Water Retention and Oil Uptake of Fried Plantain Strips

3.1.1 Water retention

Table 2 shows the changes in moisture retention and oil uptake of pretreated and non-pretreated deep fat fried plantain strips. With respect to the moisture content, significant differences were found for each concentration of pretreatments $p<0.05$.

The relationship between the concentration of each coating and the moisture content was direct, a fact that is related to the ability to retain water due to the strong interaction of the resulting hydrogen bridges, between groups of molecules of hydrocolloids with the water.

Moisture content of fried coated plantain strips was affected by the coating agents used as pretreatments before frying process as shown in Table 2. All coated samples in this work showed a higher water retention value compared to the control as also reported by Saad et al. [29]. The Water retention of the control (uncoated fried plantain strip) was 2.99 %. This positive effect could be related to the high-water binding capacities of CMC, that prevented the replacement of moisture with oil during the frying process. Moisture loss and oil absorption have inverse relationship as previously reported by Bouaziz et al. [30]. Decrease in moisture loss leads to an increase in oil uptake. Mathilde et al. [31] recorded that sorbitol coated biscuit dough showed a slightly higher water content compared to sucrose, maltitol and its control.

The mathematical model for the moisture content of the water retention is presented in Eq. 4, while Fig. 1 shows its contour graph. Water Retention of plantain strips decreased with an increase in sorbitol and carboxymethyl cellulose concentration. It could be inferred that sorbitol decreased water retention faster than carboxymethyl cellulose since the coefficient of CMC (-0.2967) is higher than that of the concentration of sorbitol (-0.6617).

$$water\ retention = 3.82 - 0.66A - 0.29B \quad (4)$$

Table 2 is the summary of ANOVA and the value of R^2 adj (75.30 %) was high suggesting that the model equation 6 could explain 75.30% of the changes in water retention caused by the application of the coating agents. Coefficient of variation (CV) value of 7.48% indicates that the data is relatively close to the mean, with a low level of dispersion. It is an indicator of the homogeneity of the data.

Fig. 1 shows the interaction effect of Sorbitol and CMC concentrations on water retention. As the concentration of sorbitol increased from 0.94 to 2.31% and the concentration of CMC increased from 1.94 to 2.55%, the water retention of plantain strips decreased from 4.5 to 3%.

3.1.2 Oil uptake

Generally, significant reduction in fat content was noticed in all pretreated samples compared with the non-pretreated sample. The fat content of deep fat fried plantain strip samples are presented in Table 2. The results show that the control sample had significantly (*P*=0.05) higher fat content (3.01%) than the pretreated samples.

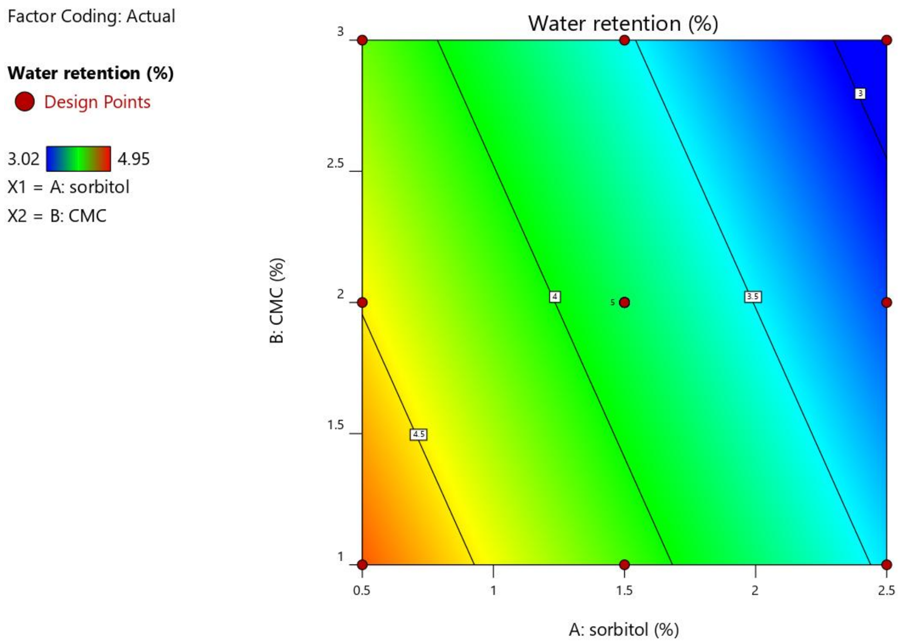

Fig. 1. Contonur of interaction effect of CMC and sorbitol concentration on the water retention of the deep fat fried plantain strips

Table 2. Water retention and oil uptake values of pretreated deep fat fried plantain strips with control

Samples	Sorbitol (%)	CMC (%)	Water retention (%)	Oil uptake (%)
1	1.5	2	4.07 ± 0.01^{def}	1.74 ± 0.04^{f}
2	0.5	3	4.05 ± 0.01^{def}	1.84 ± 0.01^{g}
3	0.5	1	4.95 ± 0.05^{g}	1.93 ± 0.03^{h}
4	2.5	3	3.02 ± 0.01^{ab}	1.21 ± 0.00^{a}
5	2.5	1	3.06 ± 0.02^{b}	1.30 ± 0.00^{b}
6	0.5	2	4.09 ± 0.03^{ef}	1.79 ± 0.02^{g}
7	1.5	1	4.02 ± 0.01^{d}	1.71 ± 0.03^{ef}
8	1.5	2	4.04 ± 0.01^{de}	1.67 ± 0.03^{e}
9	1.5	3	3.18 ± 0.01^{c}	1.55± 0.04^{d}
10	1.5	2	4.07 ± 0.01^{def}	1.75± 0.02^{f}
11	1.5	2	4.09 ± 0.01^{f}	1.69 ± 0.02^{ef}
12	1.5	2	4.04 ± 0.01^{de}	1.67 ± 0.02^{e}
13	2.5	2	3.04 ± 0.01^{b}	1.36 ± 0.02^{c}
CONTROL	-	-	2.99 ± 0.03^{a}	3.01 ± 0.02^{i}

Results are expressed as mean ± standard deviation. Values in the same column bearing different superscript differ significantly (P=0.05)

Similar observations were made by Garcia et al. [13] and Hua et al. [32] for coated potato strips and Bajaj and Singhal [33], Phule and Annapure [34], Karimi and Kenari [35] for other coated products such as chickpea (Cicer ariertinum L.) and green gram (Vigna radiata) splits, and cassava product. The reduced oil uptake in plantain strips, as influenced by the pretreatments can be attributed to their synergized thermo-gelling properties and film-forming characteristics. These hydrocolloids (CMC) usually form an oil-resistant barrier film on the surface of fried products due to changes in surface hydrophilicity.

Sample 4 (2.5% sorbitol and 3% CMC) had the lowest oil uptake (1.21%) that resulted to the highest oil reduction percent (59.80%) compared with the control, and sample 3 (0.5% sorbitol and 1% CMC) had a higher oil uptake (1.93%), that resulted to the lowest oil reduction (35.88%). Samples of 2.5% Sorbitol concentration showed a lower oil uptake value as the concentration of CMC increased compared to other pretreated samples. Samples containing 1.5% sorbitol with a varied concentration of CMC showed oil reduction range of 33.20% - 48.50%, while Samples containing 0.5% sorbitol with varied concentration of CMC also showed an increased oil reduction ranging from 35.88% - 41.86%.

It was observed that samples having 2.5% sorbitol gave a lower oil uptake with lowest water retention. This result is similar to the findings of Jia et al. [36], that french fries pretreated with calcium ion + guar gum + sorbitol had the lowest water content (%) compared to those coated with only guar gum, and calcium ion + guar gum. Sorbitol addition was necessary to maintain coating integrity and improve barrier properties. The most effective coating formulations reported by María et al. [37] were 1% MC and 0.75% sorbitol for dough discs and 1% MC and 0.5% sorbitol for potato strips. For these formulations, oil uptake reduction was 35.2 and 40.6% for dough discs and potato slices, respectively. Similarly, Garmakhany et al. [38] reported that potato chips coated with 1% CMC resulted in 57% fat reduction. This is in agreement with this present finding that 1% CMC pretreated plantain strips had optimum qualities.

The mathematical model for the oil uptake of plantain strips is presented in Eq.5, while Fig. 2 shows its contour graph. The oil uptake of plantain strips decreased as the concentrations of Sorbitol and CMC increased. The Concentration of CMC caused a lower oil uptake than Sorbitol because the coefficient of CMC (-0.0567) is higher than the concentration of sorbitol (-0.2817).

$$Oil\,uptake = 1.69 - 0.28A - 0.06B - 0.09A^2 \quad (5)$$

Table 4 shows the coefficients of regression value of R^2 adj (9.265 %) which indicates variability in the oil uptake of the deep fat fried strips. This indicates 92.65 % variability in the

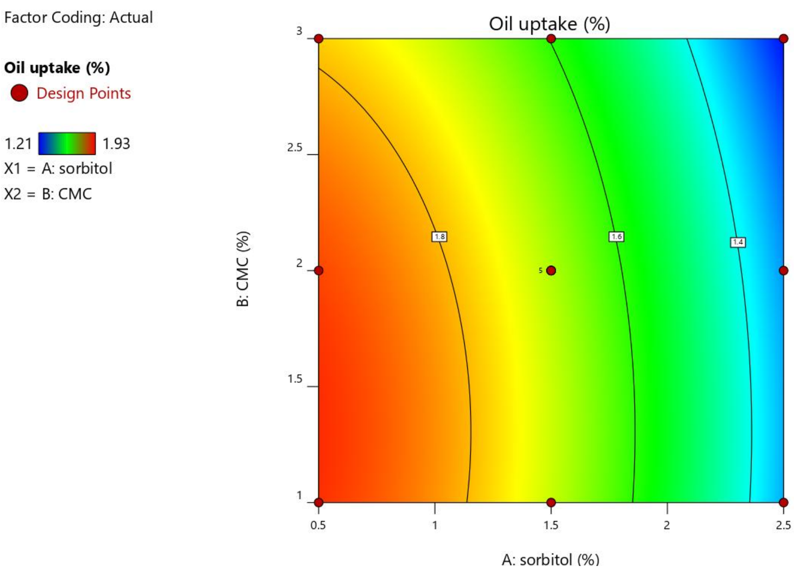

Fig. 2. Contour of interaction effect of CMC and Sorbitol on the oil uptake of the deep fat fried plantain strips

response. When the value of R^2 adj (correlation coefficient) is close to 1, the correlation is better between the experimental and predicted values. A coefficient of variation (CV) value (3.60%) indicates that the data is relatively close to the mean, with a low level of dispersion.

Fig. 2 show the effect of sorbitol and CMC concentrations on the fried plantain strips. As the concentration of sorbitol and CMC increased from 1.14 to 1.85 % , the oil uptake of the deep fat fried plantain strips decreased from 1.8 to 1.4 %. This decrease is desirable and of benefit to both the food industry and consumers because producing a high-quality fried food low in oil content at a considerable cost has been of interest by many researchers. Also, reducing the excessive oil content in fried food could reduce the increasing rate of obesity and related diseases that affects the health and well being of consumers.

3.2 Influence of Sorbitol and CMC Coatings on the Crispness, Breaking Strength and Colour of Deep Fat Fried Plantain Strips

3.2.1 Crispness

The crispness is shown in Table 3. Crispness and crunchiness of food, especially of fried food, also depends on its oil content. Crispness of plantain strips is a vital measure that determines the consumers' acceptance. It is the most important textural attribute which denotes freshness and high quality. Oil uptake does not lead to significant changes in the mechanical properties of crispy cellular food, but the number of acoustic events and the acoustic energy are greatly reduced upon fracture [39]. This effect appears to be due to reflection of sound at the oil-air interface and increases within 20 minutes of frying, resulting in loss of crispness [39].

From Table 3, samples of 1.5% sorbitol with 2% CMC showed no significant difference ($p > 0.05$) as also observed with sample 6 (0.5% sorbitol with 2% CMC) and 8 (1.5% sorbitol with 2% CMC); and sample 4 (2.5% sorbitol with 3% CMC) and 13 (2.5% sorbitol with 2% CMC). Control (non-pretreatted) sample had the highest crispness value of 8.76 Nnm^{-1} as a result of its high moisture loss after deep frying compared to the coated samples. It was observed that all coated samples having high water retention value had high crispness value than coated samples of low water retention. As such, sample coated with 0.5% sorbitol and 1% CMC having the highest water retention of 1.93% resulted in the most crispy of 4.96 Nnm^{-1} and sample coated with 2.5% sorbitol and 3% CMC had the lowest water retention of 3.02% that resulted in the lowest crispness value of 3.96 Nnm^{-1}. This observation is in agreement with Michael et al. [40] who stated that the crispness of fried foods depends on the decreased moisture.

3.2.2 Breaking strength

Table 3 shows the Breaking Strength for the deep fat fried plantain strips (pretreated and non-pretreated). All pretreated samples showed a higher value compared to the non-pretreated (control) sample. When water activity and moisture were reduced, food had become crisp and could not break easily [41]. Also according to Hofsetz and Lopes [41], as the breaking force (hardness) of a plasticized food increases, the crispness decreases. This is due to the fact that plasticized structures does not disintegrate easily, allowing the fried food sample to remain intact and offering more resistance to deformation, which is in agreement with this present research work.

It was observed that the breaking strength of coated and uncoated (control) samples increased as the crispness decreased. The Control (uncoated sample) with the highest crispness of 8.76 Nm^{-1} had lowest breaking strength value of 10.33 N. samples with 1.5% sorbitol and 2% CMC had no significant difference (P=0.05) at a 5% level of significance.

3.2.3 Colour

Colour is an important concern in snack industry as well as consumer acceptance. The result for colour of (coated and uncoated) fried plantain strips are presented in Table 3. Alphabet super-scripted letters (a- m) shows significant difference between samples using Duncan's multiple range test at a level of P=0.05. The golden color corresponds to higher L* and b* values and lower a* values, which is an important quality parameter influencing consumers' choice of French/plantain fries.

The L* value is an important parameter that affects the attractiveness of plantain strips. Lower values reflect pale and "not-fresh" appearance. Increasing value indicates reddish taint and has strong correlation with browning [42]. In terms of lightness (L^*), Coated and

Table 3. Physical properties of pretreated deep fat fried plantain strips with control

Samples	Sorbitol (%)	CMC (%)	Crispness (Nnm^{-1})	Breaking strength (N)	Colour L*	a*	b*
1	1.5	2	4.65 ±0.03^{e}	17.54 ± 0.02^{g}	65.62 ± 0.02^{J}	4.06 ± 0.02^{d}	42.06 ± 0.04^{a}
2	0.5	3	4.54 ± 0.02^{d}	11.83 ± 0.02^{c}	41.65 ± 0.03^{c}	2.92 ± 0.01^{b}	41.06 ± 0.01^{a}
3	0.5	1	4.95 ± 0.04^{h}	11.76 ± 0.04^{b}	40.75 ± 0.04^{b}	3.07 ± 0.03^{i}	41.07 ± 0.03^{a}
4	2.5	3	3.96 ± 0.03^{a}	18.05 ± 0.03^{i}	70.06 ± 0.05^{L}	7.05 ± 0.01^{k}	42.23 ± 0.00^{a}
5	2.5	1	4.01 ± 0.01^{b}	18.75 ± 0.01^{j}	69.08 ± 0.02^{L}	6.43 ± 0.03^{j}	43.03 ± 0.03^{a}
6	0.5	2	4.85 ± 0.04^{g}	11.94 ± 0.02^{d}	41.76 ± 0.05^{d}	2.86 ± 0.03^{b}	41.96 ± 0.01^{a}
7	1.5	1	4.96 ± 0.01^{h}	15.05 ± 0.01^{e}	64.65 ± 0.05^{i}	4.95 ± 0.04^{g}	41.94 ± 0.02^{a}
8	1.5	2	4.81 ± 0.02^{g}	17.44 ± 0.01^{f}	64.65 ± 0.04^{h}	4.09 ± 0.03^{d}	42.08 ± 0.01^{a}
9	1.5	3	4.17 ± 0.02^{c}	17.94 ± 0.04^{h}	68.02 ± 0.01^{k}	4.56 ± 0.01^{e}	42.92 ± 0.02^{a}
10	1.5	2	4.74 ± 0.01^{f}	17.44 ± 0.01^{f}	63.75 ± 0.04^{g}	4.76 ± 0.04^{f}	42.44 ± 0.01^{a}
11	1.5	2	4.71 ± 0.02^{f}	17.44 ±0.06^{f}	63.04 ± 0.01^{f}	4.96 ± 0.04^{g}	42.36 ± 0.03^{a}
12	1.5	2	4.74 ± 0.04^{f}	17.55 ± 0.02^{g}	62.94 ± 0.04^{e}	5.07 ± 0.01^{h}	42.32 ± 0.01^{a}
13	2.5	2	3.95 ± 0.01^{a}	18.05 ± 0.04^{i}	70.33 ± 0.02^{m}	5.34 ± 0.01^{i}	41.87 ± 0.04^{a}
CONTROL	-	-	8.76 ± 0.04^{i}	10.33 ± 0.04^{a}	36.74 ± 0.04^{a}	2.08 ± 0.01^{a}	39.25 ± 6.34 ^{a}

Table 4. Summary of Anova and coefficient estimate of pretreated deep fat fried plantain strips for the terms that showed significant model

Term	Coefficient	Water retention	Oil uptake	Crispness	Breaking strength
Intercept	b_0	3.82	1.69	4.71	17.33
A	b_1	-0.6617	-0.2817	-0.4033	3.33
B	b_2	-0.2967	-0.0567	-0.2083	-
A^2	b_{11}	-	-0.0957	-0.2672	-1.96
B^2	b_{22}	-	-	-	-
R^2 Adj.		0.7530	0.9265	0.8656	0.910
CV (%)		7.48	3.60	3.07	4.86

Table 5. Numeric Optimization solution for the physiochemical composition of pretreated deep fat fried plantain strips

Sorbitol	CMC	Water retention	Oil uptake	Crispness	Breaking strength	Desirability
1.756	1.000	3.952	1.632	4.674	17.239	0.596 (60 %)

uncoated (control) plantain strips were significantly different from each other as indicated with different superscripts of alphabet (Table 3). Fried coated samples had higher redness (a*) value than control indicating brownish taint of fried samples, which agrees with the findings of Kurek et al. [43]. It was observed that Millard reaction was more severe in sample coated strips of 2.5% sorbitol compared to other samples. Redness is a less preferable colour attribute in fried products. Redness (a*) values of the control (uncoated) strips was significantly different from all coated strips. Samples with 1.5% sorbitol and 2% CMC; and 1.5 % sorbitol with 2% CMC; 0.5% sorbitol with 1% CMC and 2.5% sorbitol with 2% CMC showed no colour redness significant difference at a 5% level of significance. Yellowness (b^*) is the most desired colour attribute in fried products. Obtained results show that coating treatments did not significantly alter the yellowness of fried strips. Similar observations were reported by Kizito et al. [44] and Izadi et al. [45] in products coated with different hydrocolloids.

3.2.4 Numeric optimization for the physiochemical composition

Table 5 shows the Numeric Optimization solution of the physiochemical composition of pretreated deep fat fried plantain strips. The main criteria for physiochemical composition were minimum sorbitol, CMC, water retention, oil uptake and maximum crispness and breaking strength. Optimization of the selected process parameters generated the solution with desirability of 0.596% (Table 5). The scale range for desirability values was from 0 - 1, where a value of 0 indicates a fully unwanted response, while a value of 1 indicates a fully desirable response. In this study, the Physicochemical components had a desirability of 0.596 or 60%, where the value was closer to the value of 1, which means higher value for the optimization accuracy. The percentage desirability was high and acceptable. However, desirability of 100% is the most ideal if it could be obtained. It shows that if the selected critical values of 1.756% Sorbitol and 1.000% Carboxymethyl cellulose (CMC) are employed, the production of deep fat fried plantain strips would exhibit a physical composition of 3.952%, 1.632%, 4.674 Nnm^{-1} and 17.239 N for Water retention, Oil uptake, Crispness and Breaking strength respectively, with a lower water retention, oil uptake but an increased crispness and breaking strength of the desirability at approximately 60%.

4. CONCLUSION

In conclusion, this study has shown that pretreating plantain strips with sorbitol and CMC is an effective way for reducing the oil uptake of plantain strips when compared to unpretreated plantain strips. From the responses and results obtained from this research, it can be concluded that the samples differ significantly ($P < 0.05$) in some of the physicochemical properties. The study also shows that the pretreatment on the deep fat fried plantain strip had better oil reduction percent, water retention, breaking strength and colour as compared to the non-pretreated sample (control).

On the results of the optimization, the optimum conditions for pretreated deep fat fried plantain strips were determined to be a concentration of 1% CMC, 1.756% of sorbitol, with a Frying temperature of 180^{0}C and desirability of 60%. Emerging technologies based on edible coatings combined with a process of deep-fat frying, maintain the quality and addressed fried products as a healthier product, because of its lower oil content, as a new alternative for the needs and tastes of consumers.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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