AJFAND ONLINE African Journal of Food, Agriculture, Nutrition and Development
Scholarly, Peer Reviewed
Volume 12 No. 7
December 2012
ISSN 1684 5374
Published by African Scholarly Science Communications Trust

DEVELOPMENT OF FROZEN-FRIED YAM SLICES: OPTIMIZATION OF THE PROCESSING CONDITIONS

Touré Y[1,2,4*], Nindjin C[1,2], Brostaux Y[3], Amani GN[1] and M Sindic[4]

Yetioman Touré

* Corresponding author email: yetiomantiti@yahoo.fr / yetioman.toure@doct.ulg.ac.be

[1]Food Biochemistry laboratory and Technology of the Tropical Products (FBLTTP), University of Abobo-Adjamé, B.P. 801 Abidjan 02, Côte d'Ivoire

[2]Swiss centre of Scientific Research, 01 B.P. 1303 Abidjan 01, Côte d'Ivoire

[3]University of Liège–Gembloux Agro-Bio Tech, Department of Applied Statistics, Computer Science and Mathematics, Avenue de la Faculté 8, 5030 Gembloux, Belgium

[4]University of Liege–Gembloux Agro-Bio Tech, Analysis Quality and Risk Unit, Laboratory of Agro-food Quality and Safety, Passage des Déportés 2, 5030 Gembloux, Belgium

ABSTRACT

The research performed on yam processing mainly concerns the production of crisps and flour. However, its transformation into deep-frozen French fries does not necessitate any other equipment than those used for potatoes. The industrial process of production of frozen French fries traditionally includes a pre-frying step. These steps contribute to the development of color and crispness, and the oil partially absorbed inhibits dehydration during the freezing step. The aim of this study was to optimize frying conditions of deep-frozen fried yam (*Dioscorea cayenensis var* Kponan) slices. The effect of pre-frying time and temperature, final frying time and temperature on the oil uptake, texture, dry matter and colour of the fried yam slices has been studied. Frying conditions optimized with Box-Behnken experimental design were short pre-frying and frying conditions at high temperature characterized by pre-frying temperature at 157-170°C during 5-9s and frying temperature at 181-188°C for 2min 15s-2min 30s; or long pre-frying and frying conditions at low temperature characterized by pre-frying temperature at 150-158°C during 10-15s and frying temperature 170-177°C for 3-3min 15s. An adiabatic system was also developed by means of an insulator in which the core temperature of fried yam slices can be maintained constant at about 55°C after 15min of cooling, facilitating texture measurements at constant temperature. The present results may help in choosing the yam slices frying condition to be applied in order to achieve the desirable fried yam slices quality, required for protection against certain diseases like obesity. These models may also provide guidance as to how to control these quality parameters by altering four key environmental factors, pre-frying temperature and time and, final frying temperature and time. This process can also be commercialized and does not necessitate any other cost for equipment than those used for potatoes French fries and might be an interesting way of added value processing for this highly perishable yam tuber.

Key words: yam slices fried, frying, optimization

INTRODUCTION

The market of potato French fries has increased over recent years in tropical and northern hemisphere countries [1]. Frying process of these western starchy food materials has been extensively studied. However, few investigations on frying behavior of tropical starchy foods like yam tuber have been performed and, worse, no study on deep-frozen yam slices fries has been operated [2]. The researches performed on yam processing mainly concerns the production of crisps and flour. Yams *(Dioscorea species)* are popular in Africa, West Indies and parts of Asia, South and Central America [3]. The annual production of yam is about 37.5 million tons and Nigeria contributes for about 70% of the total world production [4]. Yams are an excellent source of dietary energy for most people in the tropics, but methods of processing, storage and marketing of the crop are poorly developed [5].

Deep-fat frying is an established process of food preparation worldwide. It is a simultaneous heat and mass transfer process where moisture leaves the food in the form of vapor bubbles, while oil is absorbed [6]. It is often selected as a method of choice for creating unique flavors and texture in foods processed and results in modification of the physical, chemical and sensory characteristics of the food [7]. Quantitative information describing oil penetrations into the food, crust and texture development, interactions between water and oil, color parameters among others are required for process optimization. Frying in hot oil at temperatures between 160 and 180°C is critical for ensuring favorable structural and textural properties of the final product [8]; at the same time, there are nutritional concerns related to oil migration into the final product.

The industrial process of production of frozen French fries traditionally includes a pre-frying step. The aim of this step is to develop the color and crispness, and the oil partially absorbed inhibits dehydration during the freezing step [9, 10]. According to Sanz *et al*. [11], the increase in final frying time improved crispness, but it cannot counterbalance a lack of pre-frying, and pre-frying may allow an easier loss of water from the crust during final frying, which will enhance its crispness. Krokida *et al.* [12] have examined the effect of pre-fry drying on frying kinetics and quality of French fries. They indicated that pre-fry drying decreased fat content of French fries and, significantly affected color and structural properties of French fries.

The purpose of this study was to optimize pre-frying and frying conditions of deep-frozen yam slices, by comparing the qualities of fried yam slices with the standard quality (oil content, dry matter, color and texture) of potato French fries.

MATERIALS AND METHODS

Potatoes tubers (*Solanum tuberosum* L.), variety Bintje was purchased from Brussels local supermarket in Belgium, and kept at 10°C prior to processing. These potatoes were used to control the fryer parameters and to standardize frying conditions in the fryer by applying the process of potato deep-frozen French fries before its application on yam. The choice of this potato variety is due to the fact that it is one of the varieties showing techno-functional properties for processing into French fries [13]. Fresh yam tubers from variety Kponan *(Dioscorea cayenensis-rotundata)*, a stable yam product, originating from Africa, was bought in Bruxelles (Belgium) market.

Preparation of potato and yam slices

Potato tubers were cut into cylindrical sticks having a diameter of 1cm and a length of 6cm with a punch. Seventeen French fries sticks were taken for each frying session. As for yam tubers, they were divided in the longitudinal direction into three equal parts (Fig. 1a). The central part was used and the samples (Fig. 1b) were cut in a similar way as the potato French fries sticks. After cutting, each stick was kept in water at room temperature in order to reduce the drying up and oxygen-activated physiological deterioration. The sticks were then washed, drained for 1min and blanched at 80°C for 5min in a double boiler to inactivate enzymes (polyphenol oxidase and peroxidase). This leads to uniform colour after frying and permits to form a layer of gelatinized starch that limits oil absorption and improves texture. The blanched sticks were drained for 1min and dried at 60°C for 5min in a drying oven before pre-frying.

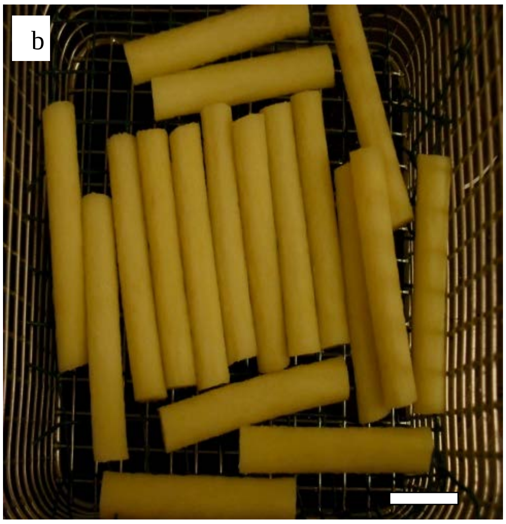

Figure 1: Yam French fries sticks cutting steps. (a): distribution of yam tuber; (b): yam slices cut out. Scale bar: 20mm. Source: Fujifilm ME06

Frying conditions

A deep-fat fryer (Haake N2, Germany, Berlin, Karlsruhe) equipped with an agitator and temperature control about ±2°C, was used. The fryer was filled with 8 liters of oil (Frying oil, 100% vegetable, Buttella, Belgium) and heated with an electrical resistance (effective power 2120W) sub-merged at the bottom of the tank. An agitator shaft fixed to a central and driven by a 100W motor was added to the device. The stirring unit produced a radial flow with aeration-free turbulence. The stirring speed used (150rpm) reduced field temperature heterogeneity in the bath between frying sessions. Dried French fries sticks were introduced under continuous stirring in the fryer. They were pre-fried at 150, 160 and 170°C for 5, 10, and 15s, drained for 30s

Published by African Scholarly Science Communications Trust
Josem Trust Place, Bunyala Road, Upper Hill, Nairobi
P.O. Box 29086-00625 Tel: +254-20-2351785 Fax: +254-20-4444030, Nairobi, KENYA
Email: oniango@iconnect.co.ke OR info@ajfand.net www.ajfand.net

and transferred to an absorbent paper to remove the excess oil on the surface. Pre-frying and frying times and temperatures were chosen on the basis of preliminary experiments. Then, the samples were deep-frozen at –50°C for 20min before frying for 2, 3 and 4min at 170, 180 and 190°C respectively. After frying, French fries were drained (30s) and transferred to an absorbent paper to remove the excess oil on the surface before analysis. In order to minimize variation in the bulk bath temperature during frying, the samples-to-oil weight ratio was kept as low as possible, only 30g of French fries sticks per 8 liters were fried at a time. During pre-frying, frying and blanching time, French fries samples were fixed on stainless steel rods to ensure defined and constant position of sticks in the oil to prevent floatation. Frying oil was changed after every two frying cycles.

Temperature control

Temperature data were recorded every 2 seconds during the experiment using a digital multimeter (Ellab TM9608, US) fitted with thermocouples T-type (Omega, TT-T-30-SLE, US) and a personal computer. During all frying tests, a thermocouple was inserted longitudinally (about 3cm) into the core of French fry, with the help of a needle tip. This permitted us to monitoring the core temperature of the French fries during instrumental texture measurements. These thermocouples were positioned in the center of the oil bath, hung at about half way the level of the oil; this was the point in which the oil temperature represented the average value of those registered in nine different points of the oil bath according to results of preliminary experiments. During pre-frying and frying, a thermocouple was also fixed on the basket edge. Location of the thermocouple inserted in the oil and in the French fries sticks was checked and verified during and after each experiment by visual examination. After removal from the fryer, French fries with incorporated thermocouples were put in a thermal insulator composed of sea sand in a cylindrical metallic plate and put in the drying oven at 75°C for 20h (±1h). At the exit of the drying oven, absorbing paper was spread out over the sand in the plate as well as in the upper case of the insulator. This absorbing paper helps to absorb water produced by condensation in the insulator during the cooling and thus avoiding moisture uptake by the French fries. Monitoring of the oil bath and the core temperature of French fries in the thermal insulator were followed. Two initial French fries core temperatures, 80 and 90°C corresponding to 30-70s after removal from the oil bath were used for the experimentation. Three initial oil temperatures (20, 50 and 100°C) were used to study the stability of oil bath temperature during heating before pre-frying and frying operations. The temperature of 180°C was fixed as the temperature to be reached before experimentations.

Fries yam slices characterization

All analyses were carried out in triplicate. Fat content was determined using the Soxhlet method [14, 15]. Dry matter content was determined by gravimetric method using the modified AOAC standard methods. The samples were dried at 105±4°C for 24h in a convective oven [16]. Texture measurements for the fried yam slices were performed at room temperature (25°C). Cutting test was carried out by measuring the maximum shear force (Fmax expressed in Newton) necessary to cut fried French fries sticks. This test imitates a human front teeth bite [17]. This force was determined as the hardness expressing French fries texture. A Texture Analyzer TA-XT2 (Stable

Micro Systems, Surrey, UK), equipped with a 50kg load cell, a light knife blade probe guillotine (HDP/BSG) and a test speed of 0.5mm/s were used. Fried yam slices core temperature at the measurement time was 55°C. For each frying batch, six fried yam slices were analyzed. Eight fried yam slices were used for each frying test for colour measurements. After frying, the slices were placed on a white plate and the slices surface color was measured using a spectrocolorimeter Hunterlab Miniscan XE (version 3.5, Escolab Nv, Belgium), operating in the CIE L*a*b* colour space [18]. The readings were carried out in duplicate placing the instrument measuring port at both sides of the sticks. In this way, the reflectance of a representative part of the surface was measured. The following measurement conditions were applied: UV 100%; standard illuminant D65 and observer angle 10°. The instrument was calibrated with a white and a black ceramic plate. The color is defined by three orthogonal co-ordinates. L* refers to lightness and ranges from black (L* = 0) to white (L* = 100) while a* (+a* = red; -a* = green) and b* (+b* = yellow; -b = blue) represent coordinates for hue. From these values, chroma (C*) and hue angle (h*) were calculated based on $C^* = (a^{*2} + b^{*2})^{0.5}$ and $h^* = \text{arctangent } b^*/a^*$. While h* (where 0° = red-violet; 90° = yellow; 180° = blue-green; 270°= blue) is useful to quantify the hue expressed by an object, C* is somewhat analogous to colour saturation [19].

Experimental design and statistical analysis

To determine the effect of pre-frying temperature and time, and final frying temperature and time on fried yam slices quality, response surface methodology was applied with a Box-Behnken experimental design [20]. Yam type was taken as a fixed parameter. This design led to studying the effects of four factors (pre-frying temperature (x_1), pre-frying time (x_2), final frying temperature (x_3) and final frying time (x_4)) in a single block of 27 sets of test conditions and 3 central points. The order of the experiments was fully randomized. Three levels were attributed to each factor, coded as −1, 0, +1 (Table 1). Fried yam slices quality such as fat content, texture, dry matter and colour parameter (L*, a*, c*, h*) with target value (Table 2) [21], were considered as responses to evaluate the effect of pre-frying temperature, pre-frying time, frying temperature and frying time. Statistical analysis was performed with the software package R version 2.9.0 [22]. A quadratic polynomial model was defined to fit the response:

$$Y= \beta_0 + \beta_1x_1+ \beta_2x_2+ \beta_3x_3+ \beta_4x_4+ \beta_{11}x_1^2+ \beta_{22}x_2^2+ \beta_{33}x_3^2+ \beta_{44}x_4^2 + \beta_{12}x_1x_2+ \beta_{13}x_1x_3+ \beta_{14}x_1x_4 + \beta_{23}x_2x_3+ \beta_{24}x_2x_4 + \beta_{34}x_3x_4 \quad (1)$$

where Y is the response expressed as fried yam slices quality (fat content, texture, dry matter and colour parameter) and β_0 is a constant coefficient of the model. The regression coefficients (β_1, β_2, β_3 and β_4), (β_{11}, β_{22}, β_{33} and β_{44}) and (β_{12}, β_{13}, β_{14}, β_{23}, $\beta_{24}$and β_{34}) respectively represent linear, quadratic, and interaction effects of the model, estimated by multiple regression analysis. x_1 (Pre-frying temperature), x_2 (pre-frying time), x_3 (frying temperature) and x_4 (frying time) are coded variables ranging from −1 to +1 (table 1). Interpretation of the data was based on the signs (positive or negative effect on the response) and statistical significance of coefficients ($P<0.05$). Interactions between two factors could appear as an antagonistic effect (negative coefficient) or a synergistic effect (positive coefficient). Internal validation of prediction accuracy of the Box-Behnken models was based on statistical evaluation of the following tests: bias index and accuracy factor, and the lack-of-fit test [23].

$$Bias\ factor = 10^{\left[\left(\Sigma \log(\mu_{observed}/\mu_{predicted})/n\right]} \quad (2)$$

$$Accuracy\ factor = 10^{\left[\left(\Sigma | \log(\mu_{observed}/\mu_{predicted})|/n\right]} \quad (3)$$

where $\mu_{observed}$ and $\mu_{predicted}$ are respectively the observed and predicted values and, *n* is the number of observations used in the calculation.

RESULTS

Temperature profiles

The temperature profiles of fried yam slices core and oil bath were monitored during the whole frying test (results not shown). It has been observed that the temperature of oil bath remained constant once 180°C was reached. This indicated that the frying bath used during the study was therefore reliable. At the beginning of frying, the initial oil temperature in the fried yam slices basket rapidly increased during both pre-frying and frying time as a consequence of the fried yam slices immersion, and reached the oil bath temperature in the first five seconds and the first 30 seconds, respectively; surface temperature profile rapidly exceeded the boiling point of water. Only for the longest frying times, at which overcooked products were obtained, was there a high similarity between the temperature behavior of the oil bath and the fried yam slices surface. No decrease of the temperature profile of oil bath occurred during pre-frying or frying. It supposes that the quantity of fried yam slices (17 slices of 90g) introduced in the oil (8 liters) was adequate to maintain a constant temperature during pre-frying and frying, which was necessary for the control of experimental conditions. Fig. 2 shows the temperature profile of fried yam slices core during cooling in the thermal insulator versus time. There were no differences between these initial core temperature curves. At the beginning of cooling, both the initial core temperature of fried yam slices rapidly decreased and reached 60°C after 10min. The core temperature of fried yam slices remained relatively constant at 55±3°C during at least 25min after 15min of cooling. The thermal insulator thus made it possible to stabilize the fried yam slices core temperature at about 55°C after 15min of cooling for texture measurement.

AJFAND ONLINE Scholarly, Peer Reviewed
African Journal of Food, Agriculture, Nutrition and Development
Volume 12 No. 7
December 2012
ISSN 1684 5374
Published by African Scholarly Science Communications Trust

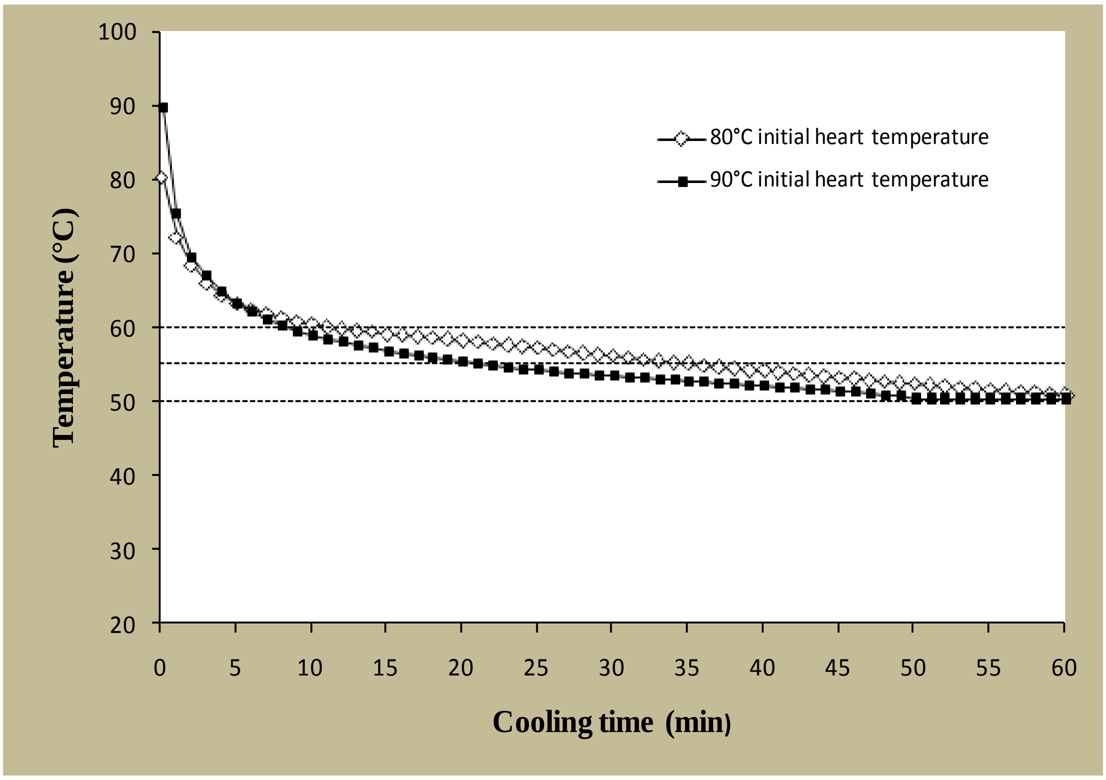

Figure 2: French fries core temperature behavior during cooling in the thermal insulator

Effects of pre-frying and final frying conditions on fried yam slices quality

The experimental values obtained for the fried yam slices quality parameters under the various conditions tested are shown columns 6 (MG), 8 (Fmax), 10 (MS), 12 (h*), 14 (a*), 16 (C*) and 18 (L*) in Table 2. It was possible to achieve the desirable quality target values of fried yam slices when the frying temperature 180°C was applied for 2 or 4min and high pre-frying temperature with short time or low temperature with long time. At higher frying temperature and short time or lower frying temperature and long time, these target values were sometimes reached (see observed value in E2, E14, E21, and E27).

Modeling the effects

The results of the multiple regression analysis from which the model coefficients were derived are listed in (Table 3). The higher the absolute value of a linear coefficient (β_1, β_2, β_3 or β_4), the greater the influence of the corresponding factor on the predicted quality values [24], considering the chosen range of the parameter. With oil content, the applied pre-frying temperature had the greatest effect, followed by the final frying time, then final frying temperature and finally the pre-frying time. For this model, the coefficients β_1 (pre-frying temperature), β_{14} (effect of the interaction between pre-frying temperature and final frying time), and β_{23} (effect of the interaction between pre-frying time and final frying temperature) appeared significant ($P<0.05$). In texture model, fried yam slices texture was more significantly affected by the effect of interaction between pre-frying temperature and frying time (coefficient β_{14}) and the

AJFAND ONLINE Scholarly, Peer Reviewed
Volume 12 No. 7
December 2012
ISSN 1684 5374
African Journal of Food, Agriculture, Nutrition and Development
Published by ASSCAT African Scholarly Science Communications Trust

effect of interaction between pre-frying time and frying temperature (β_{23}) (P<0.01). With dry matter, only the final frying time had the greatest effect and appeared highly significant (coefficients β_4) (P<0.01). In all colour parameters models, the applied final frying temperature had the greatest effect, followed by the final frying time (except for C*), then pre-frying temperature and finally the pre-frying time. For these models, the highly significant (P<0.01) coefficients were β_3 (final frying temperature), β_4 (final frying) and the other significant (P<0.05) were β_{11} (quadratic effect of pre-frying temperature), β_{22} (quadratic effect of pre-frying time for L* and C*), β_{33} (quadratic effect of final frying temperature only for C*), β_{14} (effect of the interaction between pre-frying temperature and final frying time) (effect of the interaction between pre-frying temperature and final frying time), β_{24} (effect of the interaction between pre-frying time and final frying time for L*) and, β_{34} (effect of the interaction between final frying temperature and final frying time for L*). In redness and chroma models, all significant coefficients have positive effects except the linear β_2 has negative effect, while they have negative effect hue angle and lightness models except the linear β_2 and quadratic β_4 have positive effects for lightness.

DISCUSSION

Modeling

In the oil content model, all coefficients except the linear β_3 had negative effect. Due to positive interactions between pre-frying temperature and frying time, and pre-frying time and frying temperature, pre-frying and frying times were less important at higher temperatures. The process could thus be shortened at higher temperatures, without high oil absorption. Pedreschi and Moyano [25] reported similar results for fried potato slices. In texture model, fried yam slices texture was more significantly affected by the effect of interaction between pre-frying temperature and frying time (coefficient β_{14}) and the effect of interaction between pre-frying time and frying temperature (β_{23}) (P<0.01). Other significant effects (P<0.05) were those of the quadratic effect of pre-frying time (coefficient β_{22}) and effect of interaction between final frying temperature an final frying time (β_{34}) and, all coefficients except the linear β_4 have negative effects. With dry matter, only the final frying time had the greatest effect and appeared highly significant (coefficients β_4) (P<0.01). For the defined conditions of frying, dry matter variation would be due to the frying time. Besides, it needs to be mentioned that the previous blanching, drying treatments and yam tuber history could also influence the final dry matter content of yam fries as in the case of potatoes French fries [26]. In all colour parameters models, the applied final frying temperature had the greatest effect, followed by the final frying time (except for C*), then pre-frying temperature and finally the pre-frying time. Sobukola [2] observed a similar result for colour parameters. The average predicted values obtained with these fried yam slices quality parameters models under various conditions are summarized in Table 2, columns 7 (MG), 9 (Fmax), 11 (MS), 13 (h*), 15 (a*), 17 (C*) and 19 (L*). With all quality parameters studied, differences were slight between the predicted and observed values. All models predict values close to target values when “high frying temperature/short time” or “low frying temperature/long time” were applied.

Statistical validation of the models

The tests used to validate our predictive models are listed in Table 4. The lack of fit F test is insignificant for all established models (except oil content and C*), suggesting that quadratic models adequately approximate the true surfaces. The significant lack of fit for oil content and C* is mainly due to the high repeatability of the oil content measurement and therefore does not affect the quality of their model predictions. For each model, the R^2 (coefficient of determination) was calculated. This coefficient, ranging from zero to one, represents the part of the response variation that is attributable to variations of the factors studied in the model and their interactions. The closer the R^2 value is to one the higher the predictive power of the model. In this case, the values for all fried yam slices quality parameters are higher than 70% except for dry mater and oil content. This means that fewer than 30% (except oil content and oil content) of the total response variation remained unexplained by the model. Thus, the fit between the quadratic model and the experimental data is good. Bias index and accuracy factors were calculated for all fried yam slices quality parameters. Perfect agreement between predictions and observations will lead to the bias factor of one. However, a bias factor less than one indicates a "fail-dangerous" model. For accuracy factors, the larger the value, the less accurate the average estimate, while a value of one indicates that there is perfect agreement between all predicted and observed value [23]. The bias index was close to one for all models. This result implies that, for this experiment, all models are good predictors fried yam slices quality. The accuracy factors are close to one for all and show that the prediction differs from the observation by fewer than 15%.

Optimization process

The optimum processing conditions of fried yam slices were obtained using optimization tool in R. The data and the target value of oil content, dry matter, texture and color parameters were set in the program. For each observed value, the model was used to predict the experimental response areas of the target values of the optimization value concerned. These specific optimization areas were then combined to determine joint optimization areas by crossing, allowing to meet optimization target values of several combined values. To determine the frying parameters range satisfying the various outlined target values, the values grid covering the entire range observed in these four factors has been previously generated:

- Pre-frying temperature of 150 to 170°C in steps of 1°C
- Pre-frying time of 5 to15 sec in steps of 1 sec
- Final frying temperature of 170 to 190°C in steps of 1°C
- Final frying time of 2 to 4 min in step of 15 s

For each combination of frying parameters thus produced, the values predicted by the response surface models were generated. These estimated values were then compared to the target values provided for each observed value to accept or reject the frying conditions. The target values of each variable were then combined to determine a subset of frying parameters satisfying all of them. The sub-assembly thus formed being empty, the target values were removed one by one, in ascending order of priority (starting by the lightness L*). The assembly formed by all the target values except the lightness target values was not empty, and thus had been retained.

The second stage of optimization was to retain the frying combination parameters which not only meet the target values set, but lead to values closest to the optimum values for the observed values. The weighted distance between the value predicted by the model and the optimal target value of the values was calculated, with a decreasing weight according to priority of this variable (from seven for fat, one for clarity). The average distance from all targets was then calculated for each frying parameters combination. The closest 5% combinations to the global optimum (with the lowest overall distance from this optimum) were retained. The results showed two groups of optimal frying conditions: short pre-frying and frying conditions at high temperatures and long pre-frying and frying conditions at low temperatures. The frying conditions at high temperatures were characterized by pre-frying temperature 157-170°C for 5-9s and frying temperature 181-188°C for 2min 15s-2min 30s. For the frying conditions at low temperature, they are characterized by pre-frying temperature 150-158°C for 10-15s and frying temperature 170-177°C for 3-3min 15s. These results are in agreement with authors who have reported that an increase in oil temperature decreased the frying times and enhanced properties of deep fried products [2, 27]. Pedreschi *et al.* [28] reported that the use of low temperature of frying (under 160°C) reduces the concentration of acrylamide produced, but quality characteristics of the product like texture, color and oil content are negatively affected. For Fiselier *et al.* [29] and Romani *et al.* [30], the optimal frying temperature and time are influenced by the product to oil ratio and the fryer equipment. Baumann and Escher [8] found that oil temperatures between 160 and 180°C are critical for ensuring favorable structural and textural properties of the final product and this temperature is used with a frying time between 4 and 5min [2].

CONCLUSIONS

The best parameters derived by the models in the study were short pre-frying and frying conditions at high temperature characterized by pre-frying temperature at 157-170°C during 5-9s and frying temperature at 181-188°C for 2 min 15s - 2 min 30s; or long pre-frying and frying conditions at low temperature characterized by pre-frying temperature at 150-158°C during 10-15s and frying temperature 170-177°C for 3 min 15s. This study also allowed for the finalization of an adiabatic system by means of an insulator in which the core temperature of fried yam slices can be maintained constant at about 55°C after 15 min of cooling for texture measurement, facilitating texture measurements.

ACKNOWLEDGEMENTS

This research was financially supported by AUF grant (University Agency from French Speaking countries) and IFAD/IITA (International Fund for the Agricultural Development / International Institute for Tropical Agriculture). Authors are grateful to Mrs. Lynn Doran and Nicolas Mabon for assistance with English.

AJFAND ONLINE Scholarly, Peer Reviewed
African Journal of Food, Agriculture, Nutrition and Development
Volume 12 No. 7
December 2012
ISSN 1684 5374
Published by African Scholarly Science Communications Trust

Table 1: Coded values of independent variables attributed to each factor parameters of frying conditions

	Codes		
Variables	-1	0	+1
x_1 (°C)	150	160	170
x_2 (s)	5	10	15
x_3 (°C)	170	180	190
x_4 (min)	2	3	4

x_1: Pre-frying temperature; x_2: Pre-frying time;

x_3: Frying temperature; x_4: Frying time

AJFAND ONLINE Scholarly, Peer Reviewed
Volume 12 No. 7
December 2012
ISSN 1684 5374
African Journal of Food, Agriculture, Nutrition and Development
Published by African Scholarly Science Communications Trust

Table 2: Experimental, predicted and target values of fried yam slices

Experiments Standard order	x_1	x_2	x_3	x_4	Oil content (MG, g. kg^{-1} db) values		Texture (Fmax, N) values		Dry matter (MS, g. kg^{-1} wb) values		Colour parameters: Hue angle (h*) values		Colour parameters: Redness (a*)		Colour parameters: Chroma (C*) values		Colour parameters: Lighness (L*) values	
					MG.observed	MG.predicted	Fmax.observed	Fmax.predicted	MS.observed	MS.predicted	h*.observed	h*.predicted	a*.observed	a*.predicted	c*.observed	c*.predicted	L*.observed	L*.predicted
E1	1	0	-1	0	178±15	168	8±1.1	9.17	617±06	598	88.3	85.3	1.0±0.5	2.9	33.5	35.6	77.5±1.2	76.7
E2	-1	0	0	-1	123±02	152	5.2±2.3	6.60	538±17	547	89.6	85.6	2±0.2	2.5	32.6	34.0	79.9±0.9	77.2
E3	1	1	0	0	17±07	163	7.2±1.3	6.60	553±17	598	80.1	81.8	7.4±1.0	6.8	43.0	41.5	71.2±0.5	71.0
E4	0	0	0	0	168±05	147	9.6±2.1	9.01	647±00	598	85.7	85.5	2.7±0.5	2.5	36.3	34.9	76.2±1.5	76.8
E5	-1	0	-1	0	166±03	138	9.9±2.6	9.78	563±17	598	86.4	88.3	2.3±0.5	0.1	35.7	32.8	80.5±0.6	80.8
E6	1	0	0	1	236±03	208	7.60	7.42	558±34	648	74.7	76.0	12.3±0.8	10.6	46.5	46.9	64.6±1.6	66.2
E7	0	1	0	-1	126±06	135	5.7±1.4	6.19	496±24	547	89.8	88.7	0.1±0.1	0.9	29.4	31.0	80.6±0.3	80.9
E8	-1	1	0	0	139±07	133	8.2±1.4	7.21	534±10	598	83.0	84.9	4.8±0.5	4.0	39.9	38.6	73.3±1.2	75.1
E9	-1	0	0	1	112±03	112	12.3±1.2	12.03	593±26	648	86.2	84.2	2.4±0.5	3.4	36.8	37.8	77.2±0.8	76.4
E10	0	1	0	1	182±06	161	7.03±2.2	7.62	76±15	648	82.2	82.3	5.9±0.8	6.2	43.3	44.3	69.9±2.2	69.3
E11	0	0	0	0	163±07	147	10.6±1.5	9.01	601±03	598	88.1	85.5	1.2±0.4	2.5	36.1	34.9	80.7±0.7	76.8
E12	-1	-1	0	0	127±06	131	8.4±1.8	8.56	624±31	598	84.0	84.9	4±0.4	4.8	37.6	39.0	75.7±1.6	74.5
E13	0	0	1	-1	141±02	128	9.8±1.7	9.45	534±00	547	86.9	85.3	1.8±0.2	0.9	34.2	34.7	76.1±0.8	78.7
E14	0	-1	0	-1	107±13	133	8.9±1.0	7.53	551±30	547	86.6	88.7	2±0.3	1.6	33.9	34.6	76.6±0.9	75.6
E15	-1	0	1	0	151±01	126	6.7±0.7	8.85	579±11	598	80.0	81.4	7.3±0.5	5.8	42.0	42.4	70.2±1.1	72.8
E16	0	-1	0	1	128±03	159	9.5±1.3	8.97	673±23	648	84.3	82.3	4.1±0.4	7.0	41.3	41.4	75.3±0.9	73.4
E17	1	0	1	0	142±08	156	8.3±1;7	8.23	611±07	598	81.8	78.3	6.4±0.9	8.6	44.8	45.3	71.4±1.1	68.7
E18	0	0	-1	1	118±17	166	13.1±1.5	11.82	632±16	648	86.9	85.7	1.9±0.6	0.6	35.8	35.1	78.2±1.5	79.8
E19	0	1	1	0	135±02	168	5.4±2.0	4.34	746±22	598	82.2	82.0	6.20±.9	6.4	45.7	44.2	72±1.4	71.1
E20	0	0	-1	-1	151±09	140	9.6±0.4	7.13	557±14	547	89.2	92.2	2±0.1	1.3	30.1	28.4	79.3±0.7	81.9
E21	0	1	-1	0	102±06	128	7.9±2.1	9.47	641±14	598	89.0	89.0	0.6±0.2	0.7	32.9	34.5	79.5±1.0	79.1
E22	0	0	0	0	166±18	147	9.1±3.6	9.01	62±12	598	87.2	85.5	1.7±0.3	2.5	35.5	34.9	79±0.7	76.8
E23	0	-1	1	0	126±03	114	10.6±1;6	9.88	663±07	598	78.6	82.0	9.1±1.1	7.1	45.9	44.6	69.6±1.6	70.5
E24	0	0	1	1	145±11	154	6.8±2.3	7.63	621±02	648	77.3	78.8	10.3±1.6	9.7	46.7	48.2	65.4±2.4	67.0
E25	0	-1	-1	0	196±02	177	4.7±1.4	6.62	469±11	598	88.6	89.0	0.8±0.7	1.5	33.4	34.9	77.9±1.1	78.5
E26	1	-1	0	0	155±03	161	7.4±1.8	7.94	602±05	598	77.5	81.8	9.6±1.2	7.6	44.4	41.9	67.8±2.1	70.4
E27	1	0	0	-1	115±01	116	8.5±2.7	9.98	554±07	547	88.3	87.6	0.9±0.1	0.9	29.7	30.6	79.5±0.4	79.2
Taget values					The possible smallest		08-13N		550-620		85-90		(-2) - (+8)		<91		60-70	

A Box-Behnken experimental design was applied with four controlled factors: x_1: Pre-frying temperature; x_2: Pre-frying time; x_3: Frying temperature; $x_{4:}$ Frying time; Ei: experiment standard order.

Published by African Scholarly Science Communications Trust
Josem Trust Place, Bunyala Road, Upper Hill, Nairobi
P.O. Box 29086-00625 Tel: +254-20-2351785 Fax: +254-20-4444030, Nairobi, KENYA
Email: oniango@iconnect.co.ke OR info@ajfand.net www.ajfand.net

AJFAND ONLINE Scholarly, Peer Reviewed
African Journal of Food, Agriculture, Nutrition and Development
Volume 12 No. 7
December 2012
ISSN 1684 5374
Published by African Scholarly Science Communications Trust

Table 3: Significance of the coefficients used in the Box and Behnken (1960) experimental design adopted for estimating fried yam slices quality, obtained after multiple regression analysis (x_1: Pre-frying temperature; x_2: Pre-frying time; x_3: Frying temperature; x_4: Frying time)

		Oil content (MG, g.kg^{-1} db)	Texture (Fmax, N)	Dry matter (MS, g.kg^{-1} wb)	Colour parameter			
					Hue angle (h*)	Redness (a*)	Chroma (C*)	Lighness (L*)
Response mean	β_0	14.7 **	9.01**	59.77**	85.51**	2.49**	34.86**	76.83**
x_1	β_1	1.48*	-0.31 ^{NS}	~	-1.54*	1.42*	1.44*	-2.07*
x_2	β_2	0.13^{NS}	-0.67 ^{NS}	~	~	-0.38 ^{NS}	-0.19 ^{NS}	0.3 ^{NS}
x_3	β_3	-0.59 ^{NS}	-0.47 ^{NS}	~	-3.47**	2.84**	4.83**	-4.02**
x_4	β_4	1.32 ^{NS}	0.72 ^{NS}	5.06**	-3.23**	2.66**	5.04**	-3.45**
x_1^2	β_{11}	~	~	~	-2.18*	1.88*	2.45*	-2.09*
x_2^2	β_{22}	~	-1.43*	~	~	1.43 ^{NS}	2.97*	2.01*
x_3^2	β_{33}	~	~	~	~	~	1.72*	~
x_1x_4	β_{14}	3.3*	-2.00**	~	-2.55*	2.2*	3.15*	-3.05*
x_2x_3	β_{23}	2.56*	-2.1**	~	~	~	~	~
x_2x_4	β_{24}	~	~	~	~	~	1.63 ^{NS}	-2.35*
x_3x_4	β_{34}	~	-1.63*	~	~	1.75 ^{NS}	1.7 ^{NS}	-2.4*

~ Coefficient = 0

* Significant to the predictive regression model (P< 0.05).

** Highly significant to the predictive regression model (P< 0.01).

wb is weight in wet basis and db is weight in dry basis.

AJFAND ONLINE Scholarly, Peer Reviewed
African Journal of Food, Agriculture, Nutrition and Development
Volume 12 No. 7
December 2012
ISSN 1684 5374
Published by African Scholarly Science Communications Trust

Table 4: ANOVA of quadratic response surface models for fried yam slices parameters

	Oil content (MG, g.kg^{-1} db)	Texture (Fmax, N)	Dry matter (MS, g.kg^{-1} wb)	Colour parameter			
				Hue angle (h*)	Redness (a*)	Chroma (C*)	Lighness (L*)
R^2	0.51	0.68	0.27	0.75	0.83	0.94	0.86
F Ratio	101.56	3.51	0.48	3.01	5.62	21.32	0.93
p value	0.00	0.24	0.50	0.06	0.16	0.05	0.63
Bias indice	1.009	1.009	1.004	1.000	1.010	1.001	1.000
Accuracy indice	1.127	1.125	1.070	1.021	1.678	1.034	1.020

REFERENCES

1. **Vitrac O, Dufour D, Trystram G and WAL Raoult** Deep-fat frying of cassava: influence of raw material properties on chip quality. *J Sci Food Agric* 2000; **8**:227-236.

2. **Sobukola OP** Influence of some processing parameters on quality attributes and sorption kinetics of fried yam crisp. *J Food Sci and Technol* 2007; **43**:1233-1238.

3. **Coursey DG** Yams. In: handbooks of Tropical Foods; H.T Chan, ed. by Marcel Dekler, New York 1983; 550-601.

4. **FAO.** World crop production statistics, Food and Agriculture Organization of the United Nation Statistical database online service 2002, 2006; http:/www.appsl.fao.org.

5. **Ihekoronye AI and PO Ngoddy** Integrated Food science and Technology for the tropics. *Mac Pub, Lond and Bas* 1985; 236–282.

6. **Lui-ping F, Min Z, Gong-nian X, Jin-cai S and T Qian** The optimization of vacuum frying to dehydrate carrot chips. *Inter J Food Sci* 2005; **40**:911-919.

7. **Patterson SP, Phillips RD, Mcwatters KH, Hung YC and MS Chinnan** Fat reduction affects quality of akara (fried cowpea paste). *Inter J Food Sci* 2004; **39**:681-693.

8. **Baumann B and F Escher** Mass and heat transfer during deep-fat frying of potato slices. I: rate of drying and oil uptake. *Leb-Wis und-Tech* 1995; **28**:395-405.

9. **Van BK** Batter and coating systems. *Food Ing and Anal Inter* 2001; **23**:26-28.

10. **Priva R, Singhal RS and PR Kulkarni** Carboxymethylcellulose and hydroxypropylmethylcellulose as additives in reduction of oil content in batter based deep fat fried boondis. *Carb Pol* 1996; **29**:333-335.

11. **Sanz T, Primo-Martın C and VT van** Characterization of crispness of French fries by fracture and acoustic measurements, effect of pre-frying and final frying times. *Food Res Int* 2007; **40**:63-70.

12. **Krokida MK, Oreopoulou V and Maroulis ZB and D Marinos-Kouris** Effect of pre-drying on quality of French fries. *J Food Eng* 2001; **49**:347-354.

13. **INA PG.** La pomme de terre. *A Fargue* 2003; 32 p.

14. **Moreira RG, Castell-Perez M and MA Barrufet** Deep-fat frying: Fundamentals and applications. *Gaithersburg, MD: Aspen Publ* 1999; 350 p.

15. **CCE.** Directive 98/64/CE de la commission du 3 septembre 1998 portant fixation des méthodes d'analyses communautaires pour la détermination des

acides aminés, des matières grasses brutes et de l'olaquinox dans les aliments des animaux. *J Off Com Eur* 1998; 14-28.

16. **AOAC**. Official methods of analysis ed. by Ccunniff P, 16th edition. AOAC International, Arlington, VA, USA; 1995.

17. **Vincent JFV, Jeronimidis G, Kahn AA and H Luyten** The wedge fracture test: A new method for measurement of food texture. *J Tex Stu* 1991; **22**:45-57.

18. **CIE.** Principales régissant la photométrie, Pavillon de Breteuil, F-92310 Sèvres1983; 32 p.

19. **McGuire RG** Reporting of objective colour measurements. *Hort Sci* 1992; **27**:1254-1255.

20. **Box GEP and DW Behnken** Some new three level design for study of quantitative variables. *Technometerics* 1960; **2**:455-476.

21. **Lisinska G and G Golubowska** Structural changes of potato tissue during French fries production. *Food Chem* 2005; **93**:681-687.

22. **R Development Core Team.** R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria; 2009 http://www.R-project.org. Accessed date 2009.09.13.

23. **Ross T** Indices for performance evaluation of predictive models in food microbiology. *J App Bact* 1996; **81**:50-08.

24. **Box GEP and NR Draper** Least squares for response surface work. Empirical Model Building and Response Surfaces. John Wiley, New York 1987; 34-103.

25. **Pedreschi F and P Moyano** Oil uptake and texture development in fried potato slices. *J Food Eng* 2005; **70**:557-563.

26. **Delpeuch F and S Trèche** Potentialités nutritionnelles de l'igname *Discorea dumeterum* au Cameroun. *Cah LAO* 1979; **2**:27-51.

27. **Rossell BJ** Factors affecting the quality of frying oils and fats: Improving quality. Cambridge, UK: *CRC Press* 2001; 115-336.

28. **Pedreschi F, Kaack K and K Granby** Acrylamide content and color development in fried potato strips. *Food Res Int* 2006; **39**:40-46.

29. **Fiselier K, Bazzocco D, Gama-Baumagartner F and K Grob** Influence of the frying temperature on acrylamide formation in French fries. *Eur Food Res and Tech* 2006; **222**:414-419.

30 **Romani S, Bacchiocca M, Rocculi P and MD Rosa** Influence of frying conditions on acrylamide content, other quality characteristics of French fries. *J Food Comp and Anal* 2009; **22**:582-588.