Investigation of the Effect of Frying Temperature and Time on Thermophysical Properties and Quality Attributes of Deep-Fat Fried Plantain (*Dodo*)

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Suggested title: **Effect of Frying Temperature and Time on Thermophysical and Quality Characteristics of Deep-Fat Fried Plantain**

ABSTRACT

Aims: This study investigated the effect of the processing conditions (frying temperature and time) on the thermophysical properties and quality attributes of deep-fat fried plantain (*Dodo)*.

Study Design:

Place and Duration of Study: Department of Food Science and Engineering, Ladoke Akintola University of Technology (LAUTECH), Ogbomoso, between June 2020 and July 2021.

Methodology: The plantain were deep-fried at various frying temperatures (150 - 190 °C) and time intervals (120-240 sec). The thermophysical properties determined include specific heat, thermal conductivity, thermal diffusivity and density. The quality attributes were moisture content, oil content and colour. Means of the sample triplicates were calculated and data analysed using Analysis of Variance (ANOVA).

Results: The specific heat, thermal conductivity, thermal diffusivity and density of the deep-fat fried plantain ranged from 2.68 to 2.33 kJ/kgK, 0.37 to 0.33 W/mK, 1.12 to 1.36 $x10^{-7}$ m^2/s and 1049.50 to 1257.00 kg/m^3, respectively. While the colour, moisture and fat contents of the deep-fat fried plantain ranged from 0.24 to 0.65 abs, 30.37 to 43.40% and 9.96 to 14.25%, respectively. It was observed that the specific heat, thermal conductivity, thermal diffusivity and moisture content of the deep-fat fried plantain were significantly reduced as frying temperature and time increased. While colour and fat content of the deep-fat fried plantain were found to increase with increased temperature and time of frying.

Conclusion: Outcome of the study resulted in the development of *dodo* with acceptable quality characteristics. Therefore, generated data will be useful in choice of processing conditions for plantain and development of deep-fat fryer.

Keywords: Plantain, frying temperature, frying time, thermophysical properties, quality attributes.

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Comment [D5]: deep-fat fried or deep-fried…?? Use only one term

Comment [D6]: write all the units in standard format throughout the manuscript ex…$kJ.kg^{-1}.K$

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1. INTRODUCTION

Plantain (---) and banana (*Musa spp.*) are important staple crops that contribute to the calories and subsistence economies in Africa [1]. Plantains are native to India and are grown most widely in tropical climates. Plantains grow best in areas with constant warm temperatures and protection from strong winds. Plantain cultivation is attractive to farmers due to low labour requirements for production compared with cassava, maize, rice and yam [2]. In Nigeria, plantain (*Musa paradisiaca*) ranks among the fruits and vegetables as an important staple food [1]. The nutritional composition of plantain is higher than that of banana which makes it stand out as an essential addition to healthy diet (). Plantain is a rich source of carbohydrates, magnesium, dietary fibre, and phosphate. It also rich in potassium, which assists in prevention of hypertension, heart attack and maintain a healthy heart. An excellent source of vitamins A, B_6, and C [2]. Plantain helps maintain healthy skin, vision, and build immune defenses against diseases. It has complex carbohydrates that are released slowly over time, and cooked unripe plantain is a very healthy diet for diabetic patients. High in starch and fibre, extremely low in fat and cholesterol, and a typical average size plantain after cooking contains about 4 to 6 g of fibre, 260 calories and about 0.01 to 0.3 g of fat [1]. Plantain pulp is low in protein containing about 9 g per kg in the fully ripe finger and 4 g per kg in green unripe finger [3]. A higher content of about 72 g per kg is located in the peels, which makes the peel an appropriate feeding stuff for ruminants, especially in ripe form [3]. Plantain comes in different ripening stages, and during this process major biochemical changes occur such as the drastic peel colour changes, increase in peel permeability, softening of the pulp tissues, decrease in starch to sugar ratio, production of volatiles such as flavour and smell [4].

Frying is part of the cooking and processing methods of plantain, it involves the cooking of food in oil or fat, a technique that originated in ancient Egypt around 2500BC [5]. Stir frying, pan frying, shallow frying, and deep frying are all part of the standard frying techniques, but deep frying has been the most common use when frying products like plantain chips, potato chips, fried plantain, etc. Deep-fat frying technique is a cooking method in which plantain is submerged in hot fat e.g. oil [6]. This is normally performed with a deep fryer or chip pan; industrially, a pressure fryer or vacuum fryer may be used. Deep frying is an efficient method of maintaining the product nutritional quality, and reducing the oil deterioration in fried snacks [7]. It also causes a reduction in the boiling points of the oil and the moisture in the foods [7, 8]. Three main factors play a part in the frying process: the food to be fried, the oil used, and the characteristics of the process, especially temperature and frying time [9], and

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these temperature and frying time can be between the range of (136-233 °C) and (0.5-10 min) respectively depending on individual choice, the product ripeness, and the type of product being frying [10]. The advantages of deep-fat-fried products lie in the increased quality of the product with respect to flavour retention, texture, taste and other sensory characteristics, and also preserves and enhances most of the micronutrients present in the plantain [9]. This study therefore investigated the effect of frying temperature and time on the thermophysical properties and product quality attributes of *dodo*.

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2. MATERIALS AND METHODS

2.1 Materials

Fresh and matured plantains (*Musa paradisiacal*) were procured from a local market in Ogbomoso. Other materials (weighing balance, thermometer, venier caliper, sealing machine, tray, knife etc) were obtained in the Food Chemistry and Processing Laboratories, LAUTECH, Ogbomoso.

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2.2 Methods

2.2.1 Determination of Ripening Stages of Plantain

2.2.1.1 Peel and Pulp Method Determination

The peel and pulp colours were determined by visual look to examine the level of ripeness of the plantain. As the plantain undergoes ripening stages, the peel colour changes from green to yellow, and from yellow to black which is the peak of its ripeness, above that, the plantain was considered over-ripped or rotten [11].

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2.2.2 Sample Preparation

The bunch of plantain was weighed, cleaned, peeled, washed, and sliced diagonally into 2 mm thickness and was deep-fried in 5 L of preheated vegetable oil using deep-fat fryer. The plantains were fried at various temperatures (150 - 190 °C) and different time intervals (120 - 240 sec). After frying, the frying oil was allowed to drain off from the plantain, packaged and then stored prior to analyses.

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2.3 Determination of Thermal and Physical Properties

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2.3.1 Specific heat determination

The specific heat of the samples were determined using equation developed by Singh and Heldman [12].

$$C_p = 1.424X_c + 1.549X_p + 1.675X_f + 0.837X_a + 4.187X_w \quad (1)$$

Where C_p is the specific heat in (KJ/kgK) and X are the respective mass fractions of carbohydrate, protein, fat, ash and water present in each sample and obtained from proximate compositions.

2.3.2 Thermal conductivity determination

The thermal conductivities of the samples were determined based on weight fraction of water, protein, carbohydrate, fat and ash components of the samples using the equation stated below [12].

$$k = 0.58X_W + 0.155X_p + 0.25X_c + 0.16X_f + 0.135X_a \quad (2)$$

Where k is the thermal conductivity in (W/mK) and X are the weight fractions of water, protein, carbohydrate, fat and ash components of the samples and obtained from proximate compositions.

2.3.3 Thermal diffusivity determination

This was determined based on weight fraction of water, fat, protein and carbohydrate components of the samples using equation 3 [13]:

$$\alpha = 0.146 \times 10^{-6}\mathrm{X_w} + 0.10 \times 10^{-6}\mathrm{X_f} + 0.075 \times 10^{-6}\mathrm{X_p} + 0.082 \times 10^{-6}\mathrm{X_c} \quad (3)$$

α is the thermal diffusivity in (m^2/s), X is the fraction of the sample components, and the subscripts; *w, f, p,* and *c* represent water, fat, protein and carbohydrate respectively.

2.3.4 Density

Density was determined by placing 20 g of the sample into a measuring cylinder and tapped gently to eliminate air spaces, the resulting volume was recorded [14].

$$\text{Density} = \frac{\text{Mass of sample}}{\text{Volume}} \quad (4)$$

2.4 Quality Attributes Determination

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2.4.1 Moisture and oil contents determination

Moisture and oil contents were determined according to the method of AOAC [15]. The moisture content of deep-fat fried plantain was determined by drying to a constant dry weight in a hot-air oven. The total fat content was determined gravimetrically by Soxhlet extraction method as given by AOAC, [15].

2.4.1 Colour determination

Colour was measured at 520 nm using a Genesis 6 spectometer [12]. The absorbance of each sample infusion was recorded and the colour value was determined.

2.5 Statistical Analysis

All the analyses were performed in triplicates and data obtained were reported as mean ± standard deviation. One-way ANOVA was used to determine the statistical significance of the results. Duncan means comparison test was applied to determine the difference between the mean values at a significant level of *P*=.05 using SPSS version 16.0 (SPSS Inc., Chicago, IL, USA).

3. RESULTS AND DISCUSSION

3.1 Thermophysical Properties of *Dodo*

Discribe all the thermophysical properties in subsections like 3.1.1 specific heat, 3.1.2 thermal conductivity etc

The result of thermal and physical properties of *dodo* at various frying temperatures and time intervals are presented in (Table 1). Frying reduced specific heat of deep-fat fried plantain from 2.68 to 2.33 kJ/kgK (Table 1). The specific heat were significantly influenced by the processing conditions at 95% confidence level. Similar observation on potato at different heat treatments was also reported by Nwanekezi and Ukagu [16]. The specific heat was found to be reducing with increasing frying temperature and time . However, the values fall between the ranges of specific heat of plantain 2.03 to 3.56 kJ/kgK [17]. XXXXX Specific heat is an important parameter in the design of food processing equipment such as fryer. The data obtained will be helpful in choice of heat transfer medium and processing conditions. Deep-fat frying reduced thermal conductivity of plantain from 0.37 to 0.33 W/mK (Table 1). Decrease in the thermal conductivity values were also observed as temperature and time of frying increased (Table 1). Thermal conductivity of 0.49 W/mK was reported for banana [16].

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Thermal conductivity is essential to control or predict processing time and heat reflux. This ensures the efficiency of equipment, enhances economics of the process, and improves product quality.

The density values ranged from 1049.50 to 1257.00 kg/m^3 with decrease observed with increased frying temperature and time (Table 1). Deep-fat frying as a heat treatment influenced the density of plantain at *P*=.05 significant level. It was observed that samples YKK and YNY were significantly the same, while the other samples were significantly different from each other at *p<0.*05. The variation in the density values might have been influenced by the starch polymers' structure that can result in a low density. This implies that lower density results to higher floatation of the samples on top of water and consequently may not be of high quality and may in turn be abnegated by consumers [17]. Similar observation on vacuum fried carrot chips at various frying temperatures and time intervals was also reported by [18]. The quality of a particular fruit can be evaluated by its density. The soluble solid contents and hollowness of plantain and other intact fruits are related to their solid and specific densities.

Thermal diffusivity value of *dodo* ranged from 1.12 to 1.36 x10^{-7}m^2/s (Table 1). It can be observed from the result that thermal diffusivity values decreased with increased frying temperature and time (Table 1). Deep-fat frying as a treatment significantly influenced thermal diffusivity of plantain at 5% of significance. It was noticed that samples YRR and YLL were not significantly different (*p<0.*05) from each other, and also samples YYS, YKK, YNY and YQQ were found to be significantly the same at *P*=.05. Meanwhile, this reduction in thermal diffusivity values might be due to low heat energy transfer or diffusion through the plantain during deep-fat frying process. Thermal diffusivity is a ratio of thermal conductivity, specific heat and density. Since these variables (thermal conductivity, density and specific heat) were significantly affected or influenced at 95% confidence level, this explains the obtained

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Properties	YTY	YRR	YYS	YPP	YKK	YNY	YLL	YQQ	OYY
Cp (kJ/kgK)	2.68±0.03^{a}	2.61±0.06^{ab}	2.59±0.04^{bc}	2.53±0.04^{bcd}	2.53±0.05^{bcd}	2.50±0.07^{cd}	2.48±0.05^{d}	2.36±0.05^{e}	2.33±0.05^{f}
K (W/mK)	0.37±0.00^{a}	0.37±0.00^{b}	0.36±0.00^{c}	0.36±0.00^{d}	0.36±0.00^{d}	0.35±0.00^{e}	0.35±0.00^{f}	0.33±0.00^{g}	0.33±0.00^{h}
ρ (kg/m^{3})	1257.00±57.00^{a}	1087.00±35.50^{cde}	1142.5±3.50^{bcd}	1230.00±84.0^{b}	1156.50±76.50^{c}	1158.00±2.00^{bc}	1065.50±45.5^{e}	1155.00±12.00^{bc}	1049.50±25.5^{e}
α (m^{2}/s)	1.12±0.07^{d}	1.31±0.03^{ab}	1.24±0.03^{bc}	1.16±0.06^{cd}	1.24±0.11^{bc}	1.23±0.03^{bc}	1.33±0.03^{ab}	1.23±0.02^{bc}	1.36±0.06^{a}

Table 1: Thermophysical Properties of Deep-fat Fried Plantain

Values are means of triplicate readings

Superscripts represent ANOVA indicators

Values in the same row with different superscript are significantly different at $p<0.05$

Key: Sample= Frying Temperature (°C): Frying Time (sec)

YTY=150:180, YRR=170:120, YYS=190:180, YPP=170:180, YKK=160:150, YNY=160:210, YLL=180:150, YQQ=170:240, OYY=180:210, C_p= Specific heat (kJ/kgK), K= Thermal conductivity (W/mK), ρ=Density (kg/m^{3}), α= Thermal diffusivity (x 10^{-7}m^{2}/s).

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results. Thermal diffusivity explains the capacity of the material to conduct heat compare to its heat-storing capacity. Therefore, speed of heat diffusion through a material is also very important information in processing-time prediction model.

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3.2 Quality Attributes of *Dodo*

Result of product quality attributes of *dodo* fried at various frying temperatures and time intervals are presented in (Table 2). The colour values ranged from 0.24 to 0.65 abs, with increase observed as temperature and time of frying increased (Table 2). The effects of temperature and time of processing was significant (*P*=.05) on the colour of deep-fried plantain. Though, it was observed that there was no significant difference (*P*=.05) between samples YYS and OYY. Nevertheless, this change in colour might have resulted due to the heating phenomena, that is, the colour increased with increase in frying temperature and time . This is similar to the result obtained by Shyu *et al.* [18] on fried carrot chips at various frying temperatures and time intervals. Most of the products changed their original colours when fried under deep-fat fryer. The moisture content of deep-fat fried plantain was greatly reduced from 43.40 to 30.37% (Table 2), with increased in frying temperature and time. This might be due to diffusion through the plantain during deep-fat frying process. This is in agreement with previous research carried out on potato [17]. The food values of many food products are related to their solid content. The lower the moisture content (higher solid content) of the fruits, the higher is its nutritional value [17]. The percentage fat content of deep-fat fried plantain increased from 9.96 to 14.25% (Table 2). This was observed with increased temperature and time of frying. The fat content was also significantly influenced at (*P*=.05) by the processing conditions as shown in Table 2. Similar observation on deep-fried lotus rhizome chips at different frying temperatures (180°C, 190°C and 200°C) was also reported by Sharma *et al.* [19].

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Comment [D85]: The colour of the deep fried Plantain was found to affect significantly with temperature and time of frying.

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Table 2. Product Quality Attributes of Deep-fat Fried Plantain

Properties	YTY	YRR	YYS	YPP	YKK	YNY	YLL	YQQ	OYY
C (abs)	0.63±0.01^{b}	0.42±0.01^{d}	0.38±0.01^{f}	0.24±0.01^{h}	0.54±0.01^{c}	0.34±0.00^{g}	0.40±0.01^{e}	0.65±0.00^{a}	0.39±0.00^{f}
MC (%)	43.40±0.62^{a}	40.90±0.54^{b}	40.39±0.34^{b}	37.68±0.59^{c}	37.85±0.17^{c}	37.28±0.88^{c}	35.44±0.68^{d}	31.39±0.17^{e}	30.37±0.00^{f}
FC (%)	11.89±0.02^{c}	10.05±0.09^{e}	10.80±0.67^{d}	11.21±0.45^{d}	14.25±0.04^{a}	10.86±0.32^{d}	13.47±0.18^{b}	13.52±0.43^{b}	9.96±0.03^{e}

Values are means of triplicate readings

Superscripts represent ANOVA indicators

Values in the same row with different superscript are significantly different at $p<0.05$

Key: Sample= Frying Temperature (°C): Frying Time (sec)

YTY=150:180, YRR=170:120, YYS=190:180, YPP=170:180, YKK=160:150, YNY=160:210, YLL=180:150, YQQ=170:240, OYY=180:210, C=Colour (abs), MC=Moisture content (%), FC=Fat content (%).

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4. CONCLUSION

Deep-fat frying as a heat treatment deeply influenced the thermophysical properties (specific heat, thermal conductivity, density and thermal diffusivity) and product quality attributes (colour, moisture content and fat content) of *dodo* by the processing conditions at ($p<0.05$) significant level. The specific heat, thermal conductivity, thermal diffusivity and moisture content of *dodo* were significantly reduced as frying temperature and time increased. This might have resulted from low heat energy transfer or diffusion through the plantain during frying process. Meanwhile, the colour and fat content of deep-fat fried plantain were found to increase with increased temperature and time of frying. The outcome of this present study resulted in the development of *dodo* with acceptable quality characteristics. Therefore, generated data will be useful in choice of processing conditions for plantain and development of deep-fat fryer.

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COMPETING INTERESTS DISCLAIMER:

Authors have declared that no competing interests exist. The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

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Comment [D98]: Add more latest references 2017 onwards
Strictly follow journal guidelines to cite references
Support result and discussion part with more references related to the study (potato, banana, sweet potato ect