



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

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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

This study investigated the effect of the processing conditions (frying temperature and time) on the thermophysical properties and product quality attributes of deep-fat fried plantain (*dodo*). 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 product quality attributes were moisture content, oil content and colour. 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 m²/s and 1049.50 to 1257.00 kg/m³, respectively. The quality attributes of *dodo* varied from 0.24 to 0.65 abs, 30.37 to 43.40% and 9.96 to 14.25% for colour. 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. The colour and fat content of *dodo* were found to increase

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with increased temperature and time of frying. Outcome of the study resulted in the development of dodo with high acceptable quality characteristics. Therefore, generated data will be useful in choice of processing conditions for plantain and development of fryer.

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

1. INTRODUCTION

Plantain (*Musa paradisiaca* AAB) 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 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 [3]. 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. Plantain is an excellent source of vitamins A, B₆, and C [2], helps maintain healthy skin, vision, and build immune defenses against diseases. It has complex carbohydrates that are released slowly over time. Unripe plantain is a very healthy diet for diabetic patients. Plantain is 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 [4]. 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 [4].

Frying is part of the cooking and processing methods of plantain, it involves the cooking of food in oil or fat [5]. Stir frying, pan frying, shallow frying, and deep frying are all part of the standard frying techniques. Deep fat frying has been the most common use when frying products like plantain chips, potato chips, fried plantain, etc. It 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 nutritional quality of the product, 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]. These temperature and frying time can be between the range of 136 to 233 °C and 0.5 to 10 minutes depending on individual choice, the product ripeness, and the type of product being fried [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 most of the micronutrients present in the plantain [11]. This study therefore investigated the effect of frying temperature and time on the thermophysical properties and quality attributes of *dodo*.

2. MATERIALS AND METHODS

2.1 Materials

Fresh and matured plantains were procured from a local market in Ogbomoso. Other materials; weighing balance, thermometer, sealing machine, tray, knife were obtained in the Food Chemistry and Processing Laboratories, LAUTECH, Ogbomoso. All chemicals used for this research were of analytical grade.

2.2 Methods

2.2.1 H 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 (Devon King's®) 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, cool before packaged and then stored prior to analyses.

2.3 Determination of Thermophysical Properties

2.3.1 Specific heat

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

The thermal conductivity (k) 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

Thermal diffusivity (α) were determined based on weight fraction of water, fat, protein and carbohydrate components of the samples using equation 3 [13]:

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

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

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

2.4 Determination of Quality Attributes of Fried Plantain

2.4.1 Moisture content

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.

2.4.2 Fat contents

Fat content was determined gravimetrically by Soxhlet extraction method as given by AOAC, [15].

2.4.3 Colour

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

2.5 Statistical Analysis

Data obtained are means of triplicate determinations and data were subjected to ANOVA and means separated using Duncan multiple range test at $p < 0.05$ using SPSS version 16.

3. RESULTS AND DISCUSSION

3.1 Thermophysical Properties of Fried Plantain

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 was significantly influenced by the processing conditions at 95% confidence level. The specific heat was found to be reduced with increasing temperature and time of frying. However, the values fall between the ranges of specific heat of plantain 2.03 to 3.56 kJ/kgK. Similar observation on potato at different heat treatments was also reported by Nwanekezi and Ukagu [16]. 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

Table 1. Thermophysical properties of deep-fat fried plantain

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 ×10 ⁶ (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

Values are means of triplicate readings

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, Cp= Specific heat (kJ/kgK), K= Thermal conductivity (W/mK), ρ=Density (kg/m³), α= Thermal diffusivity (x 10⁻⁷m²/s)

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

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 (%)

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]. 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 of fried plantain ranged from 1049.50 to 1257.00 kg/m³ with decrease observed with increased frying temperature and time (Table 1). Deep-fat frying as a heat treatment influenced the density of plantain at $p < 0.05$ significant level. 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 Shyu et al. [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 fried plantain ranged from 1.12 to 1.36 x10⁻⁷m²/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 were not significantly different ($p < 0.05$) from each other. 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 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.

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. The increase observed as temperature and time of frying increased (Table 2). The effects of temperature and time of processing was significant ($p < 0.05$) on the colour of deep-fried plantain. 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. 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 influenced by processing conditions as shown in Table 2. Similar observation on deep-fried lotus rhizome chips at different frying temperature was also reported by Sharma et al. [19].

4. CONCLUSION

This study has shown that there was a significant effect of frying temperature and time on the thermophysical properties and quality attributes of *dodo*. The thermophysical properties and moisture content decreased as frying temperature and time increased. This might have resulted from low heat energy transfer or diffusion through the plantain during frying process. The colour and fat content of deep-fat fried plantain were found to increase with increase in temperature and time of frying. The study resulted in the development of *dodo* with acceptable quality attributes.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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