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Effects Of Temperature, Pretreatment And Slice Orientation On The Drying Rate And Post Drying Qualities Of Green Plantain (*Musa Paradisiaca*)

O. A. Adeboye, R.A. Iyanda, K.A. Yusuf, A.M. Olaniyan, K.O. Oje

Lower Niger River Basin Development Authority. P.M.B.1529, Ilorin, Kwara state.
Department of Water Resources Development and Management", Indian Institute of Technology, Roorkee, 247667, Uttarakhand, India.
Department of Agricultural and Bio-Environmental Engineering Technology, Auchi Polytechnic, P.M.B 13 Auchi, Edo state, Nigeria
Department of Agricultural and Bioresources Engineering, Federal University, Oye-Ekiti, Nigeria.
Department of Agricultural and Bioresources Engineering, University of Ilorin. P.M.B.1515, Ilorin, Nigeria.
Email: adeboyejide@gmail.com

ABSTRACT: Effects of temperature, pretreatment and slice orientation on the drying rate and quality of mature green plantain (Musa paradisiaca) were studied using an electrically-powered, experimental cabinet dryer. The product was dried from an initial moisture content of 62 % (w.b) to 11.9 % (w.b) with hourly moisture loss and drying rate values measured and calculated. A factorial experiment in a Randomized Complete Block Design (RCBD) involving three levels of temperature (50, 60 and 70 ^{0}C); three levels of pretreatment (blanching, boiling and control), and two levels of slice orientation (round and flat) were used. The results were statistically analysed using SPSS 16.0 and Duncan's New Multiple Range Tests (DNMRT) to determine the level of significance among the treatment factors. Drying occurred in two phases of the falling rate period. Drying rate increased with increase in temperature for all the samples. Control and blanched round slices had the highest drying rate of 8.76 g/hr at 70 ^{0}C. The interaction between slice orientation—temperature was significant on the drying rate. The protein, fat and fibre content decreased with increase in temperature but the ash content increased with increase in temperature. Control flat slices had the highest protein and fibre contents of 4.33 % and 1.29 % respectively at 50 ^{0}C. Boiled round slices had the highest fat content of 4.05 % at 50 ^{0}C. Control round slices had the highest ash content of 2.15 % at 70 ^{0}C. Drying plantain at 70 ^{0}C with round slices for 7 hours with control or blanching pretreatment will be appropriate if energy, time and cost are major factors to be considered.

Keywords : Blanching, Quality, Drying Rate, Moisture Content, Temperature.

1 INTRODUCTION

PLANTAIN (*Musa paradisiaca*) is a perennial tree crop which belongs to the kingdom Plantae and the family Musaceae. It is a staple carbohydrate food commonly grown in the tropical regions of the world and it can be grown in almost all types of soils provided adequate moisture is available. It is attractive to farmers due to the low labour requirement for production compared with cassava, maize, rice and yam (Marriott and Lancaster, 1983). The annual world production of plantain and banana is estimated at 75 million tonnes. In Nigeria, the production is estimated at 2.11 million metric tonnes in 2004. Plantain contains carbohydrate, protein, dietary fibre, vitamins (A, B, C, E and K) and minerals which include potassium, calcium, phosphorus, sodium, iron, zinc, selenium, copper, etc. The African landrace "*Agbagba"* has a moisture content of about 61 % wet basis in the green plant which increases on ripening to about 68 %. This increase is due to the breakdown of carbohydrates during respiration (Adeniji, *et.al*, 2006). Green plantain contains the starch amylase and amylopectin which are replaced by sucrose, fructose and glucose during the ripening stage due to the hydrolysis of the starch (Marriot, *et.al*, 1981). Plantain contains 100 percent utilizable iron and is considered the number one cure for blood and limb poisoning as it reduces venom-caused inflammation and reduces excess moisture in the body. It can be used to treat ulcers, asthma, lung infections and hay fever. As a well-acclaimed diuretic it is extremely effective against kidney and bladder problems (Loeseck, 1950). In Nigeria over 80% of the crop is harvested during the peak period between September and February and there is much wastage during this period because the product does not store for a long period (Ogazi, 1982). This results in seasonal unavailability and limitations on the use by urban populations. Hence the need to develop appropriate preservation methods for this crop. The maintenance of the freshness of fruits and vegetables is one of the most difficult aspects of fruits and vegetables production in the tropics. Physiological deterioration which results during storage due to natural reactions lead to significant loss of nutritional value and in many cases, loss of the whole fruits or vegetable. It also arises from actions of biological or microbiological agents such as insects, rodents and other animals, bacteria, mould, yeast and viruses (William *et al.,* 1991). One of the prime goals of food processing and preservation is to convert perishable foods such as fruits and vegetables into stabilized products that can be stored for extended periods of time to reduce their postharvest losses (Jayaraman and Gupta, 2006). Processing extends the availability of seasonal commodities, retaining their nutritive and aesthetic values, and adds variety to the otherwise monotonous diet. It adds convenience to the products. Madamba, *et al*., (1996) investigated the thin-layer drying characteristics of garlic slices and found that temperature and slice thickness significantly affected the drying rate while relative humidity and airflow rate were insignificant factors during drying. Johnson, *et. al.,* (1998) found out that air temperature had the greatest influence on the drying behaviour. He also explained that one of the primary requirements in using hot-air drying is to understand the phenomena involved in the drying process, to be able to predict drying times, establish the distribution of moisture throughout the solid pieces during drying and the influence of the processing variables such as air temperature and velocity, pretreatment and the size of the pieces on drying behaviour. Kashaninejad, *et. al.,* (2005) reported that increase in drying air temperature decreased the moisture ratio (MR) of pistachio nuts, increased drying rate and decreased drying time.

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2 MATERIALS AND METHODS

2.1 Experimental Equipment

The equipment used for this study is an experimental dryer which was designed and built prior to this study. Other apparatus included an infrared moisture meter (Model AD-4714A), plantain slicer, sensitive weighing balance, grinder (Polymix - PX-MFC90D), stainless steel knife, thermo-hygrometer, and distilled water. As shown in figures 1 and 2, the dryer consists of heating chamber having three electrical heating coils of 1.8 kW each, connected directly to a centrifugal fan of 0.5 hp and drying chamber. The heating coils are connected in series and the whole unit connected to the temperature regulator (0-400°C) which controls the temperature of the heaters. The drying cabinet measures 500 mm long, 500 mm wide and 800 mm high (with external dimension of 560 mm x 560 mm x 860 mm) consisting of three set of trays separated by 150 mm clearance. The drying chamber is double walled insulated with fibre glass with a thickness of 3 mm. The drying trays with an area of 500 mm x 500 mm were made from one inch square pipe with expanded metal having an aperture wide enough to allow free flow of heated air. The heating chamber is trapezoidal in shape with the length of the side touching the drying chamber 600 mm while the opposite side touching the fan is 200 mm. The length of the chamber is 500 mm in order to accommodate the heating elements. To ensure that the hot air touches all the products simultaneously the heating chamber opened directly into the drying chamber. To avoid moisture condensation at the top of the dryer vents were provided with the aid of two galvanized, four inch diameter pipes. This was achieved by drilling holes of about 5 mm diameter for discharge of moisture laden air and for the placement of the thermo-hygrometer probe.

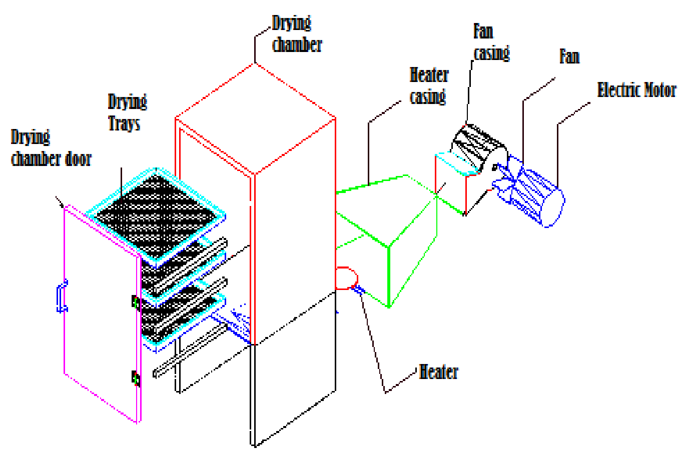

Figure 2: Exploded view of the dryer showing the component parts.

Figure 1: Pictorial front view of the dryer showing the temperature regulator.

2.2 Experimental Procedure

In order to investigate the effects of the processing parameters on the drying rate and post-drying quality attributes of plantain, a 2 × 3 × 3 factorial experiment under randomized complete block design (RCBD) was used. The design included two (2) levels of slice orientation (round and flat), three levels (3) of pre-treatment (control, boiled, and blanched) and three (3) levels of drying temperature (50, 60 and 70 ^{0}C). Each test run was replicated thrice making a total of 54 samples that were individually tested and measured.

2.3 Experimental Procedure

I. Sample Pretreatment

Green, mature, healthy and freshly-harvested plantain bunches (figure 3) which were free from mechanical injuries was purchased from a local farmer within Ilorin metropolis. '*Agbagba'* (false horn) was used for the experiment as it is the most commonly grown variety among farmers in South-West Nigeria. Samples were weighed using a top loading balance — Snowrex Counting Scale (Model SRC 5001, Saint Engineering Ltd., London, UK) with an accuracy of 1 g and range 0 - 5000 g. The fruits were rinsed in clean water at room temperature and cut with the plantain slicer to a thickness of 5 mm. 1000g of the samples were blanched in 2000 mls of boiling water at 90 ^{0}C for three minutes as suggested by Crowther (1979). A second set of the samples were left unpeeled, cut into half and put into 4000 mls of boiling water for five (5) minutes. All samples subjected to hydrothermal treatment (blanching and boiling) were drained, weighed and checked for sample weight and moisture content before drying commenced. A third sample was also prepared which served as the control sample.

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Figure 3: Freshly harvested mature plantain

II. Drying Procedure:

The dryer was pre-heated to a temperature of 40^0C by means of a thermostat while the samples were being prepared to ensure stability of the condition of the drying chamber. After arranging the trays in the dryer, the fan was switched on and set to a velocity of 0.5 m/s using the fan regulator with the speed measured with the anemometer. The initial condition of the environment and the drying chamber were recorded immediately after loading. 100g samples of green plantain were cut into two slice orientations (Round and Flat), pretreated at three levels (Control, Blanched, and Boiled) and dried at three levels of drying temperature (50, 60 and 70°C) with each experiment carried out in triplicates. The drying samples were weighed at 1 hour intervals and drying continued from an initial moisture content of 62% (wb) until the desirable moisture content of 11 % (wb) was reached

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2.4 Output Parameter

I. Drying Rate:

Drying rate is the rate of change in moisture with drying time during the drying process. In this study, drying rate was determined by using equation 1 below:

$$R = \left(\frac{dM}{dt}\right) = \frac{m_i - m_f}{t} \qquad (1)$$

Where;

R is the drying rate (g/hr);

dM is change in mass of green plantain (g);

dt change in time (hrs);

t is the total time of drying (hrs); and

m_i and m_f are the initial and final mass of plantain samples respectively (g).

II. Post-Drying Qualities:

The post-drying qualities of dried plantain were determined at the Biochemistry Laboratory of the Nigerian Stored Products Research Institute (NSPRI), Ilorin, using the AOAC (1990) standards. The post-drying qualities determined were crude protein; crude fat; crude fibre; and ash contents.

2.5 Statistical Analysis

The data obtained from the experiments for drying rate and post-drying qualities were subjected to statistical Analysis of Variance (ANOVA) at 95 % confidence level ($p \le 0.05$) using SPSS software. Further analysis by Duncan's New Multiple Range Test (DNMRT) was used to compare the means among different levels of each experimental factor.

3 RESULTS AND DISCUSSION

Table 1: ANOVA for the Effect of Slice Orientation, Pretreatment and Temperature on the Drying Rate and Quality of Green Plantain

S.V	D.F	S.S	M.S	F	P>F
a. Drying Rate					
Slice orientation (S)	1	0.229	0.229	1.859	0.181
Pre-treatment (P)	2	0.512	0.256	2.074	0.140
Temperature (T)	2	94.223	47.111	381.686*	0.000
S × P	2	0.511	0.256	2.071	0.141
S × T	2	1.928	0.964	7.809*	0.002
P × T	4	0.918	0.229	1.859	0.139
S × P × T	4	0.838	0.210	1.698	0.172
Error	36	4.443	0.123		
Total	53	103.603			
b. Crude Protein Content					
Slice orientation (S)	1	0.487	0.487	107.812*	0.0
Pre-treatment (P)	2	0.698	0.349	77.206*	0.000
Temperature (T)	2	0.608	0.304	67.197*	0.000
S × P	2	0.002	0.001	0.245	0.784
S × T	2	0.079	0.039	8.710*	0.001
P × T	4	0.111	0.028	6.122*	0.001
S × P × T	4	0.318	0.080	17.597*	0.000
Error	36	0.163	0.005		
Total	53	2.465			
c. Crude Fat Content					
Slice orientation (S)	1	0.126	0.126	5.189*	0.029
Pre-treatment (P)	2	3.816	1.908	78.477*	0.000
Temperature (T)	2	2.548	1.274	52.408*	0.000
S × P	2	8.258	4.129	169.832*	0.000
S × T	2	0.106	0.053	2.174	0.128
P × T	4	3.347	0.837	34.414*	0.000
S × P × T	4	1.164	0.291	11.973*	0.000
Error	36	0.875	0.024		
Total	53	20.239			
d. Crude Fibre Content					

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Slice orientation (S)	1	0.957	0.957	66.218*	0.000
Pre-treatment (P)	2	0.041	0.021	1.430	0.253
Temperature (T)	2	0.200	0.100	6.9138*	0.003
S × P	2	0.091	0.045	3.132	0.056
S × T	2	0.112	0.056	3.872*	0.030
P × T	4	0.105	0.026	1.808	0.149
S × P × T	4	0.156	0.039	2.693	0.066
Error	36	0.520	0.014		
Total	53	2.182			
e. Crude Ash Content					
Slice orientation (S)	1	0.055	0.055	2.627	0.114
Pre-treatment (P)	2	1.286	0.643	30.833*	0.000
Temperature (T)	2	0.404	0.202	9.679*	0.000
S × P	2	0.047	0.024	1.127	0.335
S × T	2	0.097	0.097	4.644*	0.016
P × T	4	0.194	0.011	0.510	0.729
S × P × T	4	0.128	0.032	1.531	0.214
Error	36	0.751	0.021		
Total	53	2.906			

*significantly different at $p \leq 0.05$

3.1 ANOVA of Process Variables on Drying Rate and Post-Drying Qualities

The result of the statistical analysis of variance (ANOVA) of the data obtained from the experiment is presented in table 1. From the table, it is evident that only drying temperature was significant on the drying rate and all the post-drying quality parameters; pretreatment and slice orientation had no effect on the drying rate. Pretreatment was significant on the post drying qualities except crude fibre; slice orientation was also significant on all post-drying qualities except crude ash.
Among the two factor interactions, only that between slice orientation (S) and drying temperature (T) was significant on the drying rate and all the post-drying quality parameters except crude fat content. The interaction between slice orientation (S) and pretreatment (P) was only significant for fat content. Lastly, the interaction between pretreatment (P) and drying temperature (T) was significant for protein and fat content alone, all at $p \leq 0.05$. This implies that drying temperature had appreciable effect on the drying rate and post-drying quality attributes of green plantain. Therefore, while drying plantain, drying temperature must be carefully controlled. The three factor interaction was significant only on protein and fat content.

I. Effect of Drying Temperature on Drying Rate and Post-Drying Qualities

The effect of drying temperature on drying rate is shown in figure 4a. The drying rate increased as the drying temperature increased. At 70 ^{0}C, blanched and control samples had slightly higher values than the boiled samples (though not statistically significant). Johnson, *et. al.,* (1998) and Kashaninejad *et. al.,* (2005) also had similar results in their works.
In figure 4b drying temperature significantly affected the protein content of plantain at all pretreatment levels considered. Protein content reduced as the drying temperature increased in all the samples with control having the highest value at all the temperatures used. This trend was also observed by Omodara, *et. al.,* (2011) and Olaniyan, *et.al.,* (2013) who worked on African catfish and okra respectively.Figure 4c shows the effect of drying temperature on crude fat content. The fat content reduced slightly when the temperature increased from 50 ^{0}C to 70 ^{0}C for control and blanched pretreatments whereas for boiled pretreatment it reduced slightly between 50 and 60 ^{0}C and drastically between 60 and 70 ^{0}C. This unusual behaviour was due to the lipid oxidation at high boiling temperatures (Kilic, 2009; Chukwu and Shaba, 2009; Omodara, *et al.,* 2011).
The crude fibre content also reduced as drying temperature increased for all the samples (Figure 4d). At 50 and 60 ^{0}C the crude fibre content of boiled pre-treatment was highest while those of control and blanched were about the same. However, at 70 ^{0}C blanched pre-treatment had the highest value. The wet hydrothermal processing of blanching caused the blanched samples to have higher values than the boiled samples as reported by Arthey and Ashurt (2001) that wet processing such as cooking and blanching may change some fibre properties, for example, the amount of soluble fibre in fruit may increase by partial breakdown of pectin.
The ash content increased as drying temperature increased (Figure 4e). Since ash content indicates the amount of minerals present, increasing the temperature caused the samples to increase in ash content.

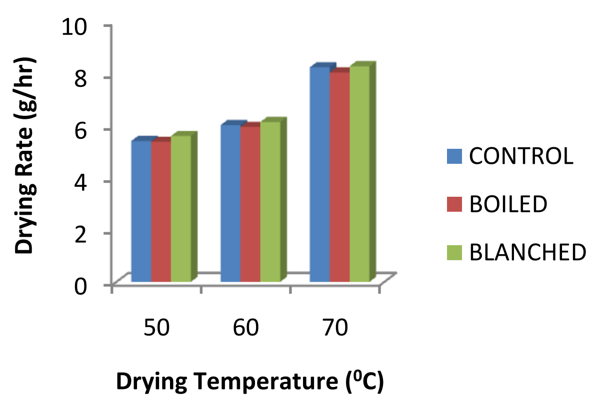

Fig 4a: Effect of temperature on drying rate

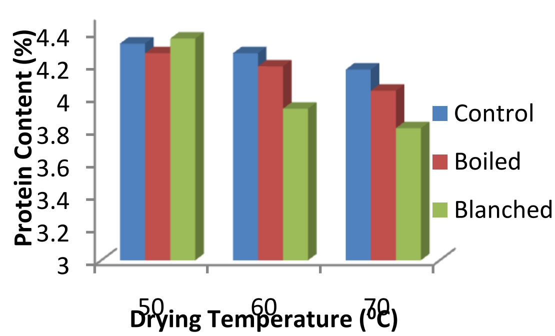

Fig. 4b: Effect of temperature on protein content

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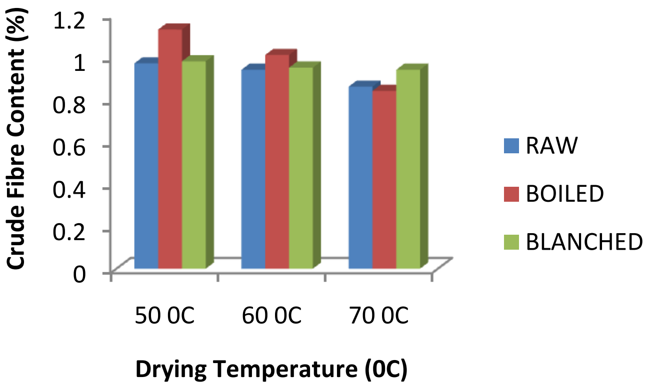

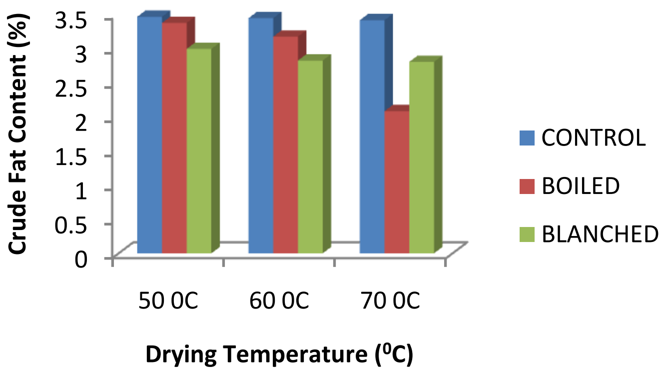

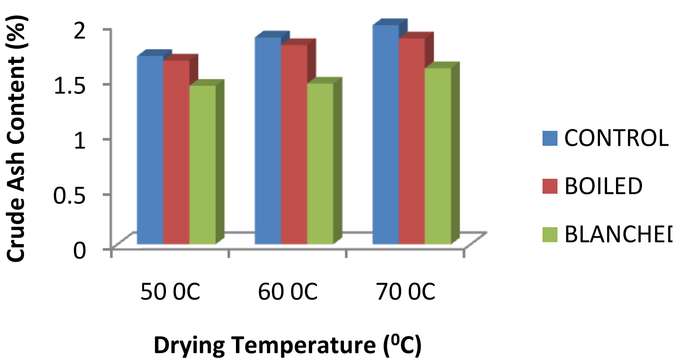

Figure 4e: Effect of temperature on ash content

II. Effects of Pretreatment on Drying Rate and Post Drying Qualities:

Pretreatment had no effect on the drying rate and fibre content of green plantain, although the blanched and control samples dried faster than the boiled sample at 70 ^{0}C. Pretreatment was significant on the protein content. It was also observed that the flat slices had higher values than the round slices and this is due to the higher surface area exposed to the drying front. The effects of pretreatment on the post drying qualities are shown in Figure 5a-c. In Figure 5a, pretreatment can be seen to be significant on the protein content at all the drying temperatures considered. As the temperature increased the protein content reduced. Generally, Control samples had the highest values followed by Boiled and Blanched respectively in descending order. The low value observed in the boiled and blanched samples indicate that blanching and boiling caused green plantain to have less protein content when compared with the control and this confirms earlier works by Adeniji, *et al*, (2006); Baiyeri, *et. al.,* (2011); Amankwah, *et al*., (2011).

Figure 5b shows that the crude fat content reduced generally as the temperature was increased. Boiled samples behaved unusually as the values dropped radically. The high loss of lipid (crude fat) in the boiled sample was due to lipid oxidation at the high boiling temperature. Lipid quality is affected by dehydration. (Kilic, 2009; Chukwu and Shaba, 2009; Omodara, *et al.,* 2011). In Figure 5c, it can be seen that the crude ash content increased for all the pre-treatment methods at the drying temperatures used.

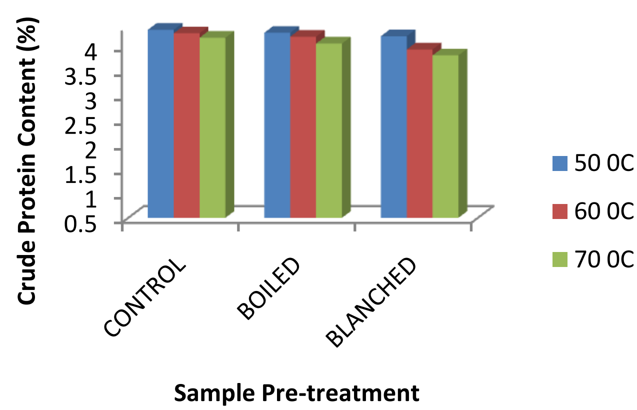

Fig 5a: Effect of Pretreatment on Protein Content

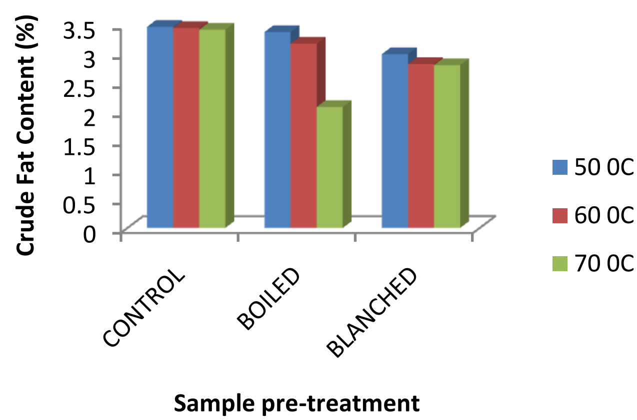

Fig. 5b: Effect of Pretreatment on Fat Content.

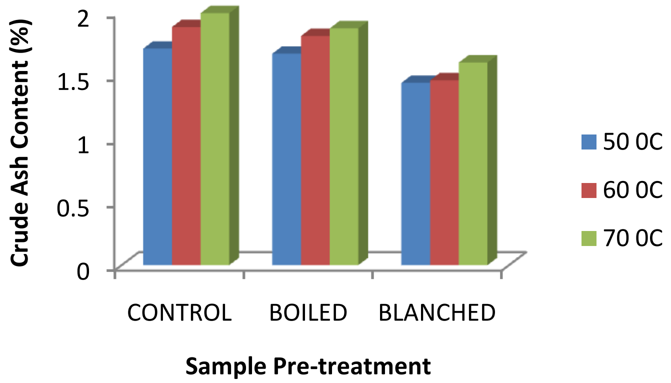

Figure 5c: **Effect of Pre-treatment on ash content**

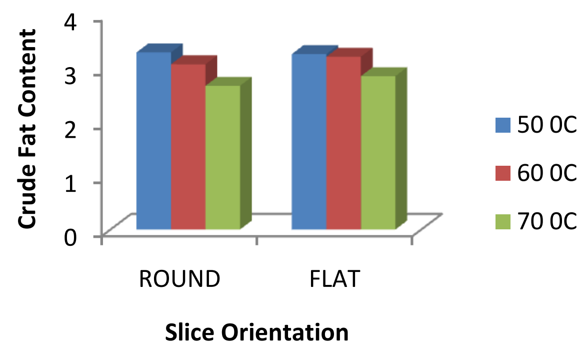

Fig 6b: Effect of Slice Orientation on fat content

III. Effects of Slice Orientation on Drying Rate and Post Drying Qualities

The effects of slice orientation on the drying rate are presented in figures 6 a- c. It can be seen that slice orientation had no effect on the drying rate and ash content of green plantain. Figure 6a shows that slice orientation was significant on the protein content. Flat slices had higher protein content than round slices for all the pretreatments and temperatures used. This is as a result of the higher surface area exposed for drying. Other authors who worked on slice orientation chose cylindrical slices (Taiwo and Adeyemi, 2009) and cubes (Ogazi and Jones, 1990) in their works but this result indicates that flat slices could be used to preserve the protein content. From figure 6b, it is obvious that at 50 ^{0}C, round slices had slightly greater amount of crude fat than flat slices but as the temperature increased, flat slices had higher fat content than the round slices which has been the general behavior of the slices. In figure 6c flat slices had higher crude fibre content than round slices at all the reference temperatures used and pretreatments used. This agrees with Arthey and Ashurt (2001) who stated that wet processing such as cooking and blanching may change some fibre properties, for example, the amount of soluble fibre in fruit may increase by partial breakdown of pectin.

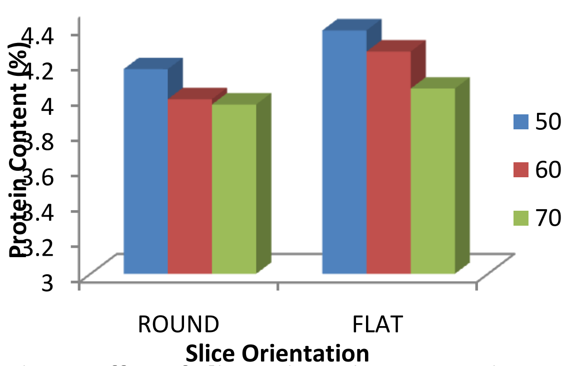

Fig 6a: Effect of Slice Orientation on Protein

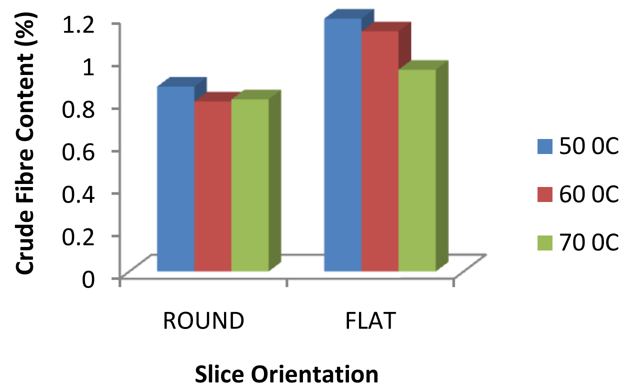

Fig 6c: Effect of Slice Orientation on fibre content

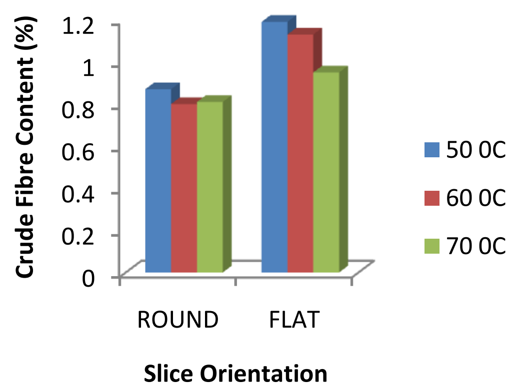

Table 2: Average Drying Rate and Proximate Composition of Green Plantain (*M. paradisiaca*)

Pretreatment	Temp (^{0}C)	Slice Orient	Drying Rate (g/hr)	Protein	Fat	Fibre	Ash
				Proximate Composition (%)			
Control	50	Round	5.49 ± 0.091	4.11 ± 0.021	3.02 ± 0.031	0.69 ± 0.017	1.63 ± 0.062
		Flat	5.33 ± 0.158	4.55 ± 0.044	3.91 ± 0.037	1.25 ± 0.154	1.78 ± 0.020
	60	Round	6.07 ± 0.094	4.26 ± 0.024	2.83 ± 0.181	0.69 ± 0.050	1.81 ± 0.081

Flat 5.97 ± 0.047 4.25 ± 0.039 4.04 ± 0.064 1.19 ± 0.075 1.95 ± 0.020
70 Round 8.76 ± 0.269 4.09 ± 0.133 3.19 ± 0.198 0.82±0.096 2.15 ± 0.137
Flat 7.71 ± 0.311 4.24 ± 0.062 3.62 ± 0.145 0.89±0.070 1.82 ± 0.178

Boiled 50 Round 5.39 ± 0.042 4.26 ± 0.051 4.05 ± 0.237 0.97 ± 0.073 1.62 ± 0.094
Flat 5.36 ± 0.078 4.28 ± 0.028 2.68 ± 0.025 1.29 ± 0.099 1.72 ± 0.217
60 Round 6.03 ± 0.047 3.96 ± 0.084 3.76 ± 0.073 0.88 ± 0.025 1.73 ± 0.057
Flat 5.87 ± 0.170 4.42 ± 0.033 2.59 ± 0.066 1.14 ± 0.121 1.89 ± 0.181
70 Round 8.66 ± 0.137 4.02 ± 0.055 2.28 ± 0.082 0.77 ± 0.026 1.89 ± 0.075
Flat 7.42 ± 0.059 4.07 ± 0.037 1.88 ± 0.043 0.90 ± 0.172 1.85 ± 0.054
Blanched 50 Round 5.49 ± 0.091 4.11 ± 0.062 2.79 ± 0.156 0.94±0.054 1.29 ± 0.128
Flat 5.70 ± 0.224 4.30 ± 0.017 3.20 ± 0.204 1.02 ± 0.159 1.58 ± 0.036
60 Round 6.27 ± 0.189 3.75 ± 0.054 2.63 ± 0.100 0.83 ± 0.048 1.45 ± 0.152
Flat 6.00 ± 0 .082 4.11 ± 0.028 3.00 ± 0.186 1.07 ± 0.033 1.48 ± 0.157
70 Round 8.76 ± 0.137 3.78 ± 0.048 2.55 ± 0.064 0.83 ± 0.056 1.56 ± 0.062
Flat 7.79 ± 0.292 3.84 ± 0.050 3.05 ± 0.049 1.05 ± 0.178 1.63 ± 0.139

*Each value is the mean of triplicates ± standard deviation.

4 Conclusion

Drying temperature increases the drying rate of green plantain and reduces the drying time. Generally, the higher the drying temperature the lower the proximate composition retained. The protein, fat and fibre content of green plantain reduced with increase in drying temperature while the ash content increased with increase in drying temperature. Pretreatment does not have any significant effect on the drying rate of green plantain although blanching increases the drying rate of green plantain. Pretreatment can be used to reduce the time it takes to complete the first phase falling rate period of drying plantain. It affects the crude protein, fat and ash contents but has no effect on the crude fibre content of green plantain. Boiling and drying at 70 ^{0}C significantly reduces the fat content of green plantain. Slice orientation does not significantly affect the drying rate of green plantain. It affects the crude protein and fat contents but does not affect the fibre and ash content. Flat slices had higher proximate composition than the round slices.

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