American Journal of Science and Technology
2017; 4(5): 74-79
http://www.aascit.org/journal/ajst
ISSN: 2375-3846

American Association for Science and Technology

Drying Characteristics and Thermal Properties of Two Local Varieties of Unripe Plantain

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Citation
Arinola Stephen Olanrewaju, Jeje Olumuyiwa Abidemi. Drying Characteristics and Thermal Properties of Two Local Varieties of Unripe Plantain. *American Journal of Science and Technology.* Vol. 4, No. 5, 2017, pp. 74-79.

Keywords
Plantain,
Drying Characteristics,
Proximate Composition,
Thermal Properties

Received: April 10, 2017
Accepted: September 19, 2017
Published: October 17, 2017

Abstract
The drying characteristics, proximate composition and thermal properties of two local varieties of plantain were evaluated in this study. Unripe plantains of two local varieties (*bambam* and *agbagba*) were dried using hot air oven, tray dryer and fluidized bed dryer at 70°C with weight lost being measured at interval of 20 minutes (hot air oven and fluidized bed dryer) and 60 minutes (tray dryer). The resulting six samples of unripe plantain were subjected to proximate analysis and some thermal properties were also determined. The result showed that the use of fluidized bed dryer gave the highest drying rate and the lowest drying time for the two varieties with *bambam* having the shortest drying time of 120 minutes. The drying methods affected the proximate compositions of the two varieties significantly especially protein, fat, ash & moisture; generally for each drying method used, *bambam* variety had higher protein content than *agbagba* variety. The result also showed that the ranges of thermal properties for *bambam* and *agbagba* unripe plantain samples were: specific heat capacity 1.641 kJ/kg°C – 1.699 kJ/kg°C and 1.631 kJ/kg°C – 1.821 kJ/kg°C; thermal conductivity 0.255 W/m°C – 0.262 W/m°C and 0.253 W/m°C – 0.260 W/m°C; thermal diffusivity 0.192 m^2/s – 0.205 m^2/s and 0.169 m^2/s – 0.190 m^2/s respectively. *Agbagba* sample dried with tray dryer had the highest bulk density of 0.840 g/ml while *bambam* sample dried with fluidized bed dryer had the lowest bulk density of 0.760 g/ml.

1. Introduction

Plantain (*Musa paradisiaca*) is an important component of food security in the tropical world and also provides income to the farming community through local and international trade. It is a staple food for rural and urban consumers in the Central and West Africa, plantain along with bananas provides 60 million people with 25% of their calories [1, 2]. One of the reasons that plantain and banana are popular is because they are one of the cheapest foods to produce; the cost of production of one kilogram of plantain for example is less than that of most other staples including sweet potato, rice, maize and yam [3]. There is a very wide range of plantain cultivars, each adapted to a specific eco-region and selected for specific eating or cooking qualities [4]. In Nigeria for example there are several local varieties of plantain spread across the southern part of the country. Plantain is essentially a starchy food crops with little quantity of other basic nutrients, however it is rich in mineral nutrients especially potassium. The ripe plantain, apart from it being boiled and eaten as a main meal, can also be used in preparing a number of snacks. Recently unripe plantain have been processed into flour and such flour has been considered as having commercial potential on its own or as ingredient for other foods such as baby weaning food; the flour is also used as part of composite flour in the production of bakery products [5, 6]. In recent time unripe plantain flour has been recommended as a good diet for diabetic patients, this may be because of its low glycemic response when consumed and its free radical scavenging activity in diabetics [7].

Drying technology has been used as a method of food processing and preservation in developing economics. Drying methods ranging from the simple sun drying method to methods employing a forced draft of conditioned air all depends on removal of water. However careful analysis of the various processes, mechanism and parameter such as heat and mass transfer, thermal properties (specific heat capacity, thermal conductivity, thermal diffusivity), drying characteristic of the food product is needed for the design of an appropriate drying equipment [8]. Ajiboye [9] reported that different food products respond to drying in different ways and have different isotherm curves. The drying behavior, shrinkage and moisture distribution within cylindrical pieces of plantain of various thickness and with different air temperature have been studied by Johnson *et. al.* [10]. Consumer demand has increased for products that preserve their original characteristics as much as possible, this invariably means developing processing operations, drying inclusive, that have reduced negative effect on the nutritional characteristics of foods. Pacheco-Delahaye *et. al.* [11] reported that double drum dryer, freeze dryer, microwave oven and tray chamber have significant effect on the physical characteristics, proximate, rheological and functional properties of unripe plantain flour. Effect of drying methods on the chemical, pasting and functional properties of unripe plantain had also been evaluated [12]. However to the best of our knowledge, there is little or no information on the drying characteristics and thermal properties of local varieties of plantain commonly consumed in the south western states of Nigeria. The focus of this research was to evaluate the effect of drying methods on the drying characteristics and proximate composition of two local varieties of plantain; as well as to provide data on some thermal properties of these varieties of plantain.

2. Materials and Methods

2.1. Sample Collection and Preparation

Matured unripe plantains of two local varieties (*Bambam & Agbagba*) used in this work, which were obtained from a rural market in Ado-Ekiti, Ekiti State, Nigeria, were processed separately. Plantains from each varieties were washed with clean water, peeled into sodium metabisulphite solution (100ppm) using stainless kitchen knife and then sliced into a cylindrical shape of about 3mm thickness. The slices were drained using plastic sieve and then divided into three equal batches of the same quantity. First batch of the slices of the two varieties of plantain were dried in hot air oven (Model DHG 9030A) at 70°C with the weight being measured at interval of 20 minutes until a constant weight was obtained. Second batch was dried in the fluidized bed dryer (Armfield Fluid Bed Dryer MARK II) at 70°C & air velocity of 3.65 m/s with weight being measured at interval of 20 minutes until a constant weight was obtained, the third batch was dried in tray dryer (Armfield Tray Dryer UOP8) at 70°C and a blower speed of 1.5 m/s, with weight being measured at the interval of 60 minutes until a constant weight was obtained. The weight difference at 20 minutes interval while drying in tray dryer was found to be negligible hence the time interval was increased to 60 minutes. The six dried unripe plantain samples were milled into flour using hammer mill, packaged in polythene bags, sealed and then stored in air tight containers with appropriate labeling.

2.2. Proximate Analysis

The six samples of unripe plantain flour were subjected to proximate analysis using standard methods described by Association of Analytical Chemists (AOAC) [13].

2.3. Drying Curve

Drying curve was obtained by plotting the change in moisture content of each sample during drying against time.

2.4. Determination of Thermal Properties and Bulk Density

The specific heat capacities of the samples were determined from the expression developed by Choi and Okos [14]

Specific heat capacity (kJ/kg°C) = $1.547M_c + 1.711M_p + 1.929M_f + 0.908M_a + 4.180M_m$

Thermal conductivities of the samples were obtained using the model equation developed by Sweat [15]

Thermal conductivity (W/M°C) = $0.25M_c + 0.155M_p + 0.16M_f + 0.135 M_a + 0.58M_m$

Where M_c, M_p, M_f, M_a & M_m are the respective mass fractions of carbohydrate, protein, fat, ash and moisture present in each sample.

Thermal diffusivity of the samples were evaluated using the expression below

Thermal diffusivity (m^2/s) = K/PC_P

Where K, P & C_P are thermal conductivity, bulk density and specific heat capacity of each sample respectively.

The bulk densities of the various samples were also evaluated using the method described by Onwuka [16].

2.5. Statistical Analysis

The difference in experimental data was tested for statistical significance $p \leq 0.05$ by Statistical Analysis of Variance (ANOVA) using SPSS version 17.0 software package (Statistical Package for Social Scientist, Michigan, USA).

3. Results and Discussion

3.1. Drying Rate

The drying curves which indicates rate of change in moisture content during drying for the two varieties of plantain are shown in figures 1, 2 and 3. Drying time of 3 hours 20 minutes and 4 hours 40 minutes (hot air oven); 2 hours and 2 hours 20minutes (fluidized bed dryer); 10 hours (for both varieties)(tray dryer) at 70°C were necessary to dry *bambam* and *agbagba* respectively to a constant weight. The drying curve gives an indication of the moment at which the process of drying should be stopped when the required moisture content has been reached and thus obtaining a good quality product. As it is expected the moisture contents of all the samples decreased as drying time increased. Generally, samples of *agbagba* had the highest drying time irrespective of the drying methods used; this is probably due to the higher percentage of fat in the samples which could lower the drying rate. The drying rate which is the quantity of moisture evaporated per unit time indicated that, irrespective of the varieties and drying methods, there was a higher rate of initial moisture loss and this rate decreased as the drying time increased. This observation was as a result of the state of water in the food sample, free water is easily removed whereas the strongly bound water is difficult to remove by drying [17]. It is known that the vapourization enthalpy of bound water which is sorbed by the hydrophilic and polar groups of food components is higher than that of free water [18]. It was observed that the use of fluidized bed dryer gave highest drying rate and lowest drying time for the two varieties with *bambam* having the shortest drying time of 120 minutes. This was due to the fact that fluidized bed dryer involves the use of hot air stream which disperse the food materials and keep it suspended in the drying chamber thereby enhancing removal of moisture and preventing the food materials from caking or sticking together as it may occur when other drying methods are used. Tray dryer gave the lowest drying rate and the highest drying time for the two varieties amidst the three methods of drying employed in this study. The two plantain varieties exhibited different drying characteristics and this may be due to the difference in their proximate composition. It is known that the rate of removal of water from food materials depend among other factors on, properties of food materials, initial moisture content, drying temperature, air velocity, surface area of food material exposed to drying medium and types of dryer.

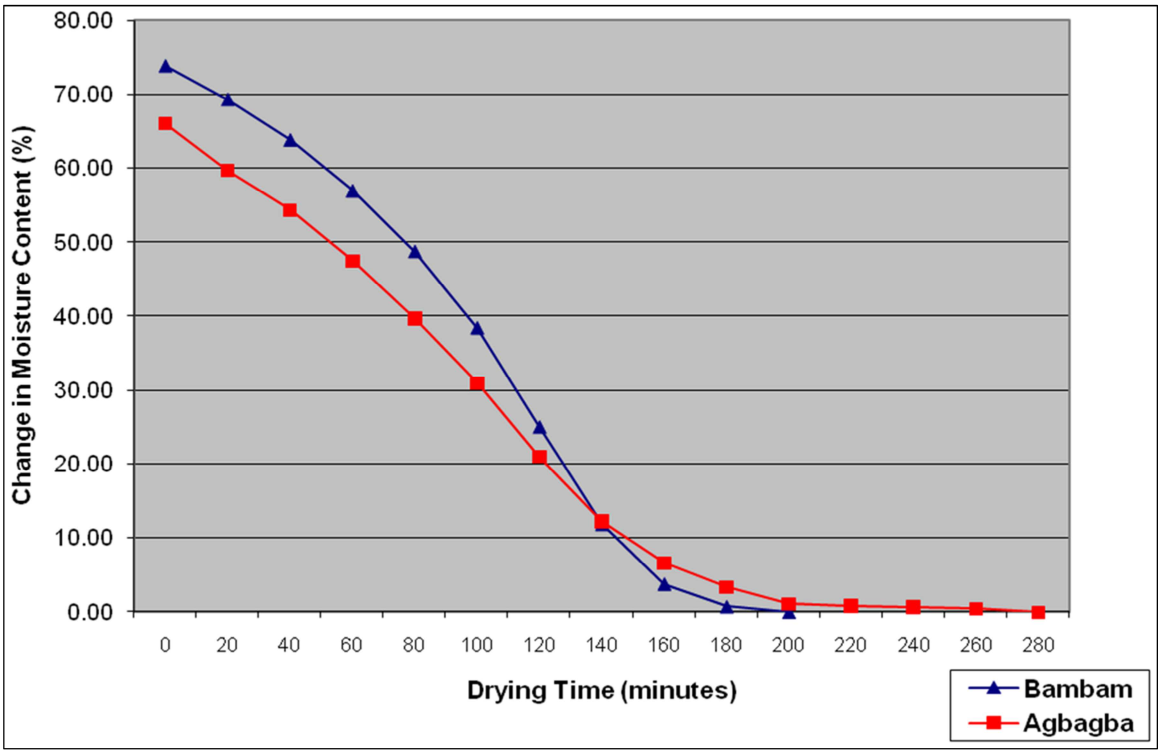

Figure 1. *Drying curve of Unripe Bambam and Agbagba Plantains Using Hot Air Oven.*

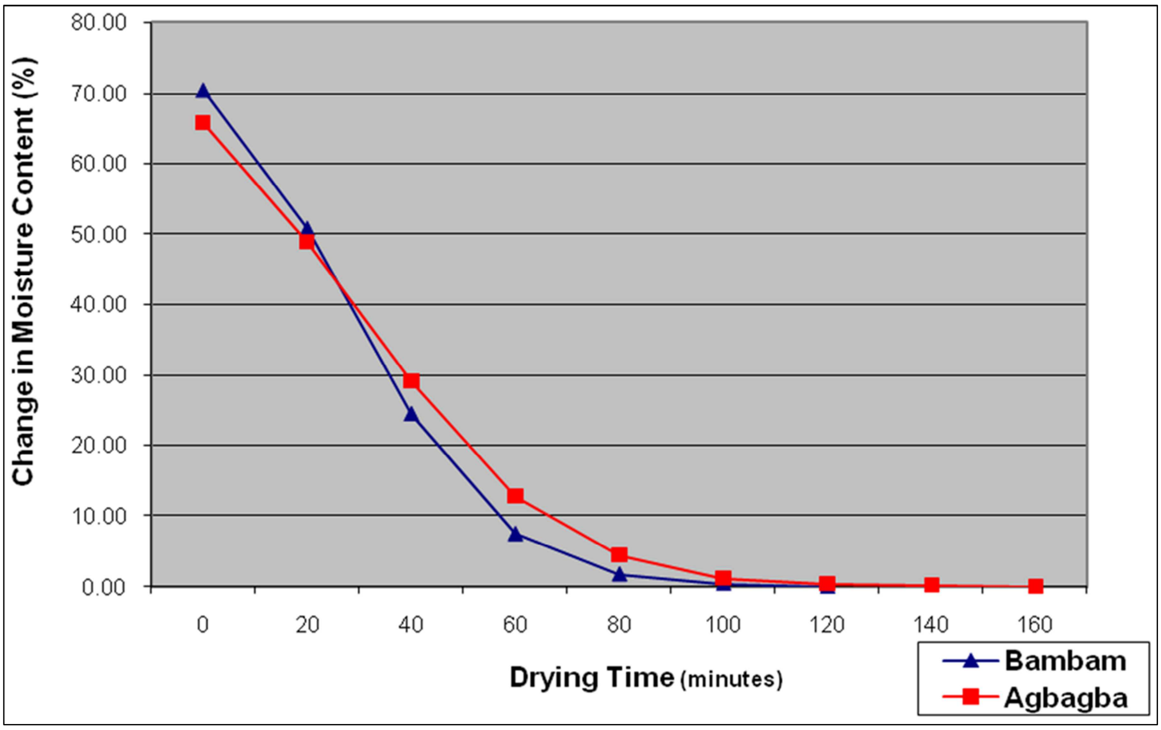

Figure 2. *Drying Curve of Unripe Bambam and Agbagba Plantains Using Fluidized Bed Dryer.*

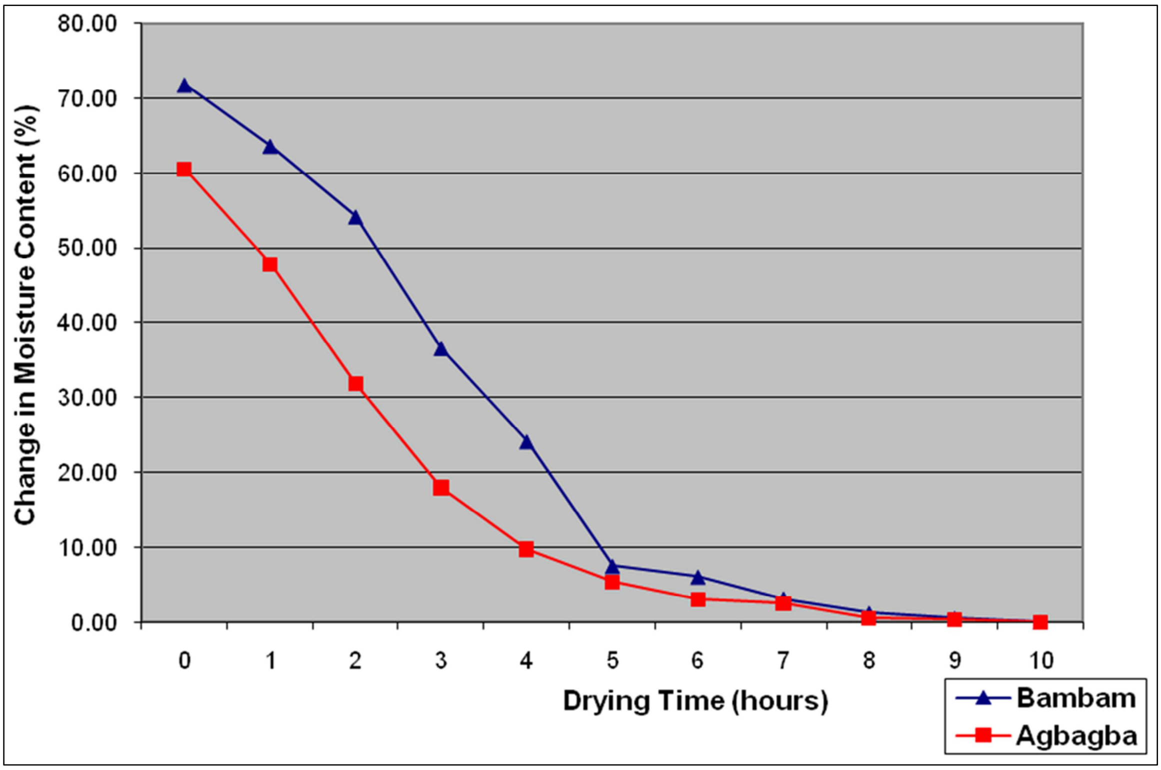

Figure 3. *Drying Curve of Unripe Bambam and Agbagba Plantains Using Tray Dryer.*

3.2. Proximate Composition

The proximate compositions of the samples are presented in Table 1. The moisture contents of *bambam* samples were significantly higher than that of *agbagba* samples especially for those samples dried in hot air oven and fluidized bed dryer. Moisture content is very important in food storage as it dictates the shelf stability of foods, the lower the moisture contents the better the shelf stability of such food. Therefore *agbagba* samples dried in hot air oven and fluidized bed dryer is expected to have higher shelf stability than *bambam* samples. The range of moisture contents reported in this work (3.24% – 6.16%) was comparable to 2.36% – 11.75% reported by Pacheco-Delahaye *et. al.* [11] for unripe plantain dried in different kinds of dryers. The protein contents of all the six samples were significantly different (p≤0.05). Samples dried in fluidized bed dryer had the lowest protein content while those dried in hot air oven had the highest; this seems to suggest that fluidized bed dryer affected the protein content of the samples negatively. Generally *bambam* had higher protein content than *agbagba* irrespective of the drying methods used. Samples of *agbagba* dried in hot air oven and fluidized bed dryer had higher fat contents than samples of *bambam*. The range of ash contents (which is a reflection of mineral composition) for *bambam* samples was 3.17% - 3.80% while that of *agbagba* samples was 3.11% - 3.91%. The crude fibre of all the samples was not affected by the method of drying and there was no significant difference (p≤0.05) between the crude fibre contents of the two varieties of plantain. Gwanfogbe *et. al.* [19] had reported that fibre content of plantain was not affected by the method of heat treatment.

Table 1. *Proximate Composition of Unripe Bambam and Agbagba Plantains.*

Sample	Moisture (%)	Protein (%)	Fat (%)	Ash (%)	Crude Fibre (%)	Carbohydrate (%)
Oven Dried *Bambam*	6.16 ± 0.10^{a}	4.87 ± 0.03^{a}	0.50 ± 0.02^{f}	3.26 ± 0.04^{c}	0.05 ± 0.01^{a}	85.17 ± 0.30^{d}
Oven Dried *Agbagba*	3.24 ± 0.03^{e}	3.82 ± 0.03^{b}	1.15 ± 0.02^{b}	3.11 ± 0.01^{e}	0.04 ± 0.01^{a}	88.64 ± 0.20^{a}
Fluidised Dried *Bambam*	4.13 ± 0.02^{c}	3.13 ± 0.01^{e}	0.89 ± 0.02^{d}	3.80 ± 0.04^{b}	0.04 ± 0.01^{a}	88.01 ± 0.10^{b}
Fluidised Dried *Agbagba*	3.48 ± 0.04^{d}	3.07 ± 0.03^{f}	1.53 ± 0.02^{a}	3.14 ± 0.01^{de}	0.04 ± 0.01^{a}	88.74 ± 0.25^{a}
Tray Dried *Bambam*	4.09 ± 0.03^{c}	3.77 ± 0.02^{c}	0.99 ± 0.01^{c}	3.17 ± 0.03^{d}	0.04 ± 0.01^{a}	87.93 ± 0.12^{b}
Tray Dried *Agbagba*	5.43 ± 0.05^{b}	3.21 ± 0.02^{d}	0.68 ± 0.01^{e}	3.91 ± 0.01^{a}	0.05 ± 0.01^{a}	86.72 ± 0.20^{c}

Means of triplicate determination ± standard deviation
Values in the same column with different superscript are significantly different (p≤0.05)

3.3. Thermal Properties

The thermal properties of the six samples are presented in Table 2. From the results it can be observed that there were significant differences (p≤0.05) in the thermal properties of the two varieties of plantain. To a greater extent the specific heat capacities of *agbagba* samples were higher than that of *bambam* samples; since specific heat capacity is the amount of heat energy required to raise a unit mass of a material by 1°C, the result suggests that *agbagba* will require more heat energy than *bambam* during drying. Thermal diffusivity is indicative of the rate at which a material will undergo a change in temperature [17]. Generally, *bambam* had higher thermal diffusivity than *agbagba*; *bambam* dried in fluidized bed dryer exhibited the highest thermal diffusivity of 0.205 m^2/s and it would therefore be expected that in a given thermal environment this sample will undergo temperature change at a faster rate than the other samples. The result of thermal diffusivity corroborates that of drying time and this shows that thermal diffusivity had negative correlation with drying time. Sample with high thermal diffusivity is expected to have low drying time; therefore *bambam* samples with higher thermal diffusivity than *agbagba* samples had lower drying time. The thermal conductivity of *bambam* and *agbagba* samples dried in hot air oven and tray dryer respectively were significantly different (p≤0.05), however there was no significant difference (p≤0.05) in the thermal conductivity of the two varieties dried in fluidized bed dryer; the thermal conductivity of the samples ranged from 0.253 W/m°C to 0.262 W/m°C. *Agbagba* samples had higher bulk density than bambam samples irrespective of the drying methods used; while *agbagba* sample dried in tray dryer had the highest bulk density of 0.840 g/ml, *bambam* sample dried in fluidized bed dryer had the lowest (0.760 g/ml). Bulk density is known to have implication in the packaging and transportation of food materials; higher bulk density products are known to exhibit better packaging properties than those with low bulk density [12]. This suggests that *agbagba* samples may offer better packaging and transportation advantages.

Table 2. *Thermal Properties and Bulk Density of Unripe Bambam and Agbagba Plantains.*

Sample	Specific Heat Capacity (kJ/kg°C)	Thermal Conductivity (W/m°C)	Thermal Diffusivity (m^2/s)	Bulk Density (g/ml)
Oven Dried Bambam	1.699 ± 0.003^{b}	0.262 ± 0.002^{a}	0.193 ± 0.001^{b}	0.800 ± 0.004^{d}
Oven Dried Agbagba	1.821 ± 0.002^{a}	0.253 ± 0.002^{b}	0.169 ± 0.002^{d}	0.820 ± 0.003^{b}
Fluidised Dried Bambam	1.641 ± 0.001^{d}	0.255 ± 0.002^{b}	0.205 ± 0.004^{a}	0.760 ± 0.003^{e}
Fluidised Dried Agbagba	1.631 ± 0.002^{e}	0.254 ± 0.001^{b}	0.190 ± 0.001^{b}	0.820 ± 0.002^{b}
Tray Dried Bambam	1.644 ± 0.003^{d}	0.256 ± 0.002^{b}	0.192 ± 0.001^{b}	0.810 ± 0.001^{c}
Tray Dried Agbagba	1.673 ± 0.002^{c}	0.260 ± 0.001^{a}	0.185 ± 0.002^{c}	0.840 ± 0.001^{a}

Means of triplicate determination ± standard deviation
Values in the same column with different superscript are significantly different (P≤0.05)

4. Conclusion

Drying methods had significant influence on the drying characteristics, proximate composition and thermal properties of the two varieties of plantain. The drying rate, specific heat capacity and thermal conductivity are functions of the chemical composition of the varieties. Generally, drying of plantain with fluidized bed dryer gave better results in terms of drying characteristics and thermal properties when compared with other drying methods employed in this study.

The two varieties differed in their response to the same drying method; *bambam* variety generally had better thermal properties than *agbagba.*

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