1 Introduction

Cardaba banana, a dwarf banana is a cultivar classified within the Saba subgroup (Porcher 1998; Sequeira 1998; Dela et al. 2008). Although this banana variety can be eaten raw, it is mainly used for cooking. It is rated high amidst other banana species by the Philippine cuisine. A triploid (ABB) hybrid of the seeded banana *Musa balbisiana* and *Musa acuminate* (Porcher and Barlow 2002). The traditional method of sun drying has been used extensively but the drying process is somehow inadequate and dried products exhibit some undesirable changes that lower the quality of the final product (Maskan 2000).

Cardaba is a predominant banana variety in Nigeria, but most of its production goes to waste because few people consume it, either raw or fried. The fruit ripens quickly, which also increases its propensity to become waste. Therefore, producing flour from the matured banana variety will help reduce, if not eliminate, its wastage.

Pre-drying treatments such as blanching have contributed to the improvement of the product quality in terms of colour, texture and vitamin retention, the transfer of mass and heat as well (Mazza 1983; Nieto et al. 1998; Kaymak-Ertein 2002; Taiwo et al. 2002a). Drying is a complex process that is accompanied by physical and structural changes to the produce. There is a continuous change in dimensions of differently shaped food particulates during drying as a result of water removal and internal collapse of the particulates (Senadeera et al. 2005).

The functional properties are the intrinsic physicochemical characteristics that affect the behaviour of a food ingredient in food systems during processing, manufacturing, storage and preparation. Such functional properties include water holding, oil binding, emulsification, foam capacity, gelation, whipping capacity, viscosity and others.
The functional properties of flours play an important role in the manufacturing of bakery products (Asif-UL-Alam et al. 2014). Rehydration is defined as the process of reintroducing water to dried foods to reach similar water levels as in their initial state (Vega-Galvez et al. 2009). Factors such as the chemical composition of the dried food, method and conditions of drying, the solvent medium, temperature among others affects rehydration (Taiwo and Adeyemi 2009). Dearth information on the physico-chemical properties of Cardaba banana that could assist in the drying and rehydrating processes of this produce led to the development of the present study. Therefore, we examined the effect of processing variables on the drying kinetics of Cardaba banana slices in comparison to regular plantain. Additionally, we determined the physico-chemical and rehydration properties of the flours produced from Cardaba banana and regular plantain.

2 Materials

Matured unripe banana (Musa cardaba) and matured unripe regular plantain fruits were sourced from the Teaching and Research Farm of OAU, Ile-Ife, Nigeria. All chemicals used were of analytical grade and were obtained from Sigma Chemicals Company, U.S.A.

2.1 Preparation of Cardaba Banana and Plantain Flour

Banana flour was prepared by the modified method described in Oluwalana et al. (2011). Cardaba banana and regular plantain were harvested manually and peeled with a knife. The peeled fingers were then cut into 5 mm thick discs using a knife and a Vernier caliper. The fruits (plantain and Cardaba) were separately treated. The sliced samples were immersed directly in water at 60°C for 10 min for blanching. Samples were drained, gently cleaned with blotting paper to remove the adhering surface water, then weighed on electronic laboratory scales. The unblanched portion was used as control.

The blanched and unblanched portions were divided into three portions; sun-dried: thinly spread on a tray and placed under the sun to dry for 3 days (at 27 ± 2°C); oven dried (UNISCOPE SM9053, England) at 50°C and; oven dried (UNISCOPE SM9053, England) at 70°C. The dried samples were milled into flour using a hammer mill. The flour was then sieved using a mesh aperture of 500 μm diameter. The sieved flour samples were packed inside a polyethylene bag, labeled and stored for analyses.

2.2 Measured Variables

The measured variables before, during and after drying were weight and diameter.

2.3 Drying Kinetics

The weight and thickness of each sample were monitored hourly until it was dry to calculate the drying curves of the sample’s mass (g) against time (h) and the drying rate curves by the method of (Johnson et al. 1998).

\[
\text{Drying rate} = \frac{\text{change in moisture content}}{\text{change in time}}
\]

(1)

% Moisture content (d.b) = \( \left( \frac{W - W_s}{W_s} \right) \times 100 \)

(2a)

% Moisture content (w.b) = \( \left( \frac{W - W_s}{W} \right) \times 100 \)

(2b)

Where: d.b = dry basis; w.b = wet basis; W = weight of dried solid + moisture (g) and \( W_s \) = weight of dried solid (g).

The Weibull model was used to replicate the drying kinetics. This equation has been successfully applied to describe kinetics of chemical, enzymatic and microbiological degradation processes as well as in the drying process (Marabi et al. 2003; Uribe et al. 2009), using the moisture ratio (MR) as the dependent variable is the moisture ratio (Equation 3).

\[
MR = \frac{X_{wt} - X_{we}}{X_{wo} - X_{we}}
\]

(3)

Where \( X_{wo}, X_w, \) and \( X_{we} \) are the initial, at a real time, and at equilibrium moisture content, respectively (Kg water/Kg dried matter).

2.4 Rehydration capacity (RC)

A modified method of (Taiwo et al. 2002a) was employed. Glass beakers with water in a 1:30 (w/v) ratio were used to hold the dried samples at room temperature, 45°C, 60°C, 75°C and 90°C for 4 hours. Equations described by Levi et al. (1998) were used to analyze the rehydrated data.

\[
\text{RC at time } t (\%) = \left( \frac{M_t}{M_i} \right) \times 100
\]

(4)

Where; RC = Rehydration capacity; \( M_t \) = rehydrated weight at time (t) and \( M_i \) = sample weight before drying.
2.5 Bulk density

The method of Okezie and Bello (1988) was used to determine the bulk density. Samples were placed in 10-ml graduated cylinder, then gently tapped 50 times on a laboratory bench to level the sample to the 10 ml mark. Bulk density was then calculated as weight of sample per unit volume of sample (g/ml).

\[
\text{Bulk density} = \frac{\text{Weight of sample (g)}}{\text{Volume of sample after tapping (ml)}} \quad (5)
\]

2.6 pH

The pH was obtained was by making a 10% w/v suspension of the sample in distilled water. The suspension was thoroughly mixed, and the pH was measured with a Hannachecker pH meter (Model HI1270).

2.7 Water absorption capacity (WAC)

The AACC [1995] method was used to determine the WAC at room temperature. A dispersion of the sample was performed by adding 2.0 g of sample to 20 ml distilled water then mixed for 30 seconds at 10-min intervals using a glass rod. After mixing for 5 minutes, the dispersion was centrifuged (Bosch TDL-5) at 4000 \( \times \) g for 20 minutes. The supernatant was decanted carefully, whilst the infranatant in the centrifuged tubes was left to drain at a 45º angle for 10 minutes, then weighed. The water absorption capacity was expressed as percentage increase of the sample weight.

\[
\text{Water absorption capacity (\%)} = \left( \frac{W_2 - W_1}{W_1} \right) \times 100 \quad (6)
\]

Where; \( w_1 = \) weight of tube + sample before centrifuging and decanting \\
\( w_2 = \) weight of tube + sample after centrifuging and decanting \\
\( w_3 = \) weight of sample

2.8 Oil absorption capacity (OAC)

The modified centrifugal method described by Beuchat (1997) was used in determining the OAC by taking 1.0 g of sample and mixing it with 10 ml of pure Goya oil for 60 seconds. After the separation, the separated oil was decanted, centrifuged then left in tubes at a 45º angle for 10 min to drain. The samples were then weighed and the OAC was calculated as percentage increase of the sample weight.

\[
\text{Oil absorption capacity (\%)} = \left( \frac{W_3 - W_2}{W_1} \right) \times 100 \quad (7)
\]

Where: \( W_1 = \) weight of tube + sample after centrifuging and decanting; \( W_2 = \) weight of tube + sample before centrifuging; \( W_3 = \) weight of sample

2.9 Dimensional changes (shrinkage)

The thickness and the diameter of the samples were measured before and after drying using a steel Vernier caliper. Shrinkage was expressed as the percentage change in thickness and diameter (Barat et al. 2001; Kabiru et al. 2013).

\[
S = \frac{d_o - d_f}{d_o} \times 100 \quad (8)
\]

Where; \( S = \) percentage shrinkage; \( d_o = \) initial diameter of the sample and \( d_f = \) diameter after time (t) of drying

2.10 Determination of swelling power

The swelling power was determined as described in Takashi and Sieb (1988). One gram of each sample was gently mixed into a 5-ml centrifuge tube with 10 ml of distilled water. The slurry was then heated in a water bath (SW 22 Julabo) at 100°C for 15 minutes. The slurry was gently stirred during heating to prevent flour clumping. Once heated, the paste was centrifuged at 3000 rpm for 10 minutes, then the supernatant was decanted, and the sediment was measured. The moisture content of the sediment gel was used to determine the dry matter content of the gel.

\[
\text{Swelling power} = \frac{\text{Weight of wet mass sediment}}{\text{weight of dry matter in gel}} \quad (9)
\]

2.11 Determination of dispersibility

Dispersibility of the flour samples was determined using the method described by (Kulkarni et al. 1991). Water was added to a 100-ml measuring cylinder to make up a volume of 100 ml of sample. The sample was stirred then left to rest for 3 hours. The supernatant was discarded, and the sediment’s volume was measured. The sediment’s weight was subtracted from 100 and the difference was reported as percentage dispersibility.

\[
\% \text{Dispersibility} = 100 - \text{volume of settled particle} \quad (10)
\]
2.12 Statistical Analysis

The physico-chemical properties calculated in this research were subjected to a One Way Analysis of Variance (ANOVA) at 5% level of significance using SPSS 20.0 for Windows. Duncan Multiple Range Tests were used to find significant differences among means at the confidence level.

Ethical approval: The conducted research is not related to either human or animals use.

3 Results and discussion

3.1 Drying kinetics

The drying curves on wet and dry basis obtained from drying of Cardaba banana and plantain slices are shown in Figure 1. All curves sloped down from left to right indicating that weight reduced as time increased in all three drying temperatures (sun, 50°C and 70°C). Sample mass of both Cardaba and plantain achieved equilibrium (i.e. there was no change in weight) after 6, 12, and 14 hours for samples that were sun-dried, oven-dried at 70°C, and oven-dried at 50°C- respectively.

Moisture removal was temperature dependent: drying time is shorter, and dehydration is faster as temperature increases. Moisture loss was faster and higher in blanched samples than in the unblanched samples, similarly to what was reported by Taiwo and Adeyemi (2009) for blanched plantain and banana slices. This could have happened because blanching increased permeability of cell walls, thus favoring faster water migration to the surface for easier dehydration. The result suggests that blanching influences faster and higher moisture removal from materials.

The drying rate curves for all the samples are presented

Figure 1: Percentage moisture content of blanched and unblanched cardaba and plantain on:
a) wet basis dried at 70°C; b) dry basis dried at 70°C; c) wet basis dried at 50°C; d) dry basis dried at 50°C; e) wet basis sun-dried; f) dry basis sun-dried
The drying rate decreased as moisture decreased under all drying conditions. As drying begins, unbound water or free moisture can easily evaporate from the product's surface, which causes a higher drying rate at the onset of the drying process. The reduced drying rate found in the present study was caused by the product through evaporation after free water had been removed. This led to decreased a drying rate toward the equilibrium moisture content (Kabiru et al. 2013).

Table 1 shows the polynomial regression equations of the drying rate curves. The R-squared ($R^2$) values ranged from 0.9293 to 0.9889, suggesting a good fit between moisture content and time. Unblanched samples had $R^2$ values ranging from 0.9332 to 0.9889 while $R^2$ values for

**Figure 2:** Drying rate curves for:

a: Unblanched cardaba banana oven-dried at 70°C; b: Unblanched plantain oven-dried at 70°C; c: Blanched cardaba banana oven-dried at 70°C; d: Blanched plantain oven-dried at 70°C; e: Unblanched cardaba banana oven-dried at 50°C; f: Unblanched plantain oven-dried at 50°C; g: Blanched cardaba banana oven-dried at 50°C; h: Blanched plantain oven-dried at 50°C; i: Unblanched cardaba banana sun-dried; j: Unblanched plantain sun-dried; k: Blanched cardaba banana sun-dried; l: Blanched plantain sun-dried
the blanched samples varied from 0.9293 to 0.9874. The oven-dried at 50°C samples had the highest $R^2$ (0.9615 to 0.9889), sun-dried samples had higher $R^2$ (0.9332 to 0.9874) while those oven-dried at 70°C had the least $R^2$ (0.9293 to 0.9806). Plantain slices had $R^2$ values ranging from 0.9293 to 0.9889 while Cardaba banana slices had $R^2$ values ranging from 0.9604 to 0.9874.

### Table 1: Polynomial Regression Equation for the Drying Rate Curves of Cardaba banana and Plantain Slices

<table>
<thead>
<tr>
<th>Sample</th>
<th>Regression Equation</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>UHC</td>
<td>$Y = 0.0049x^2 + 0.1319x$</td>
<td>0.9604</td>
</tr>
<tr>
<td>UHP</td>
<td>$Y = -0.1387x^2 + 0.5913x$</td>
<td>0.9628</td>
</tr>
<tr>
<td>BHC</td>
<td>$Y = 0.0585x^2 + 0.2133x$</td>
<td>0.9806</td>
</tr>
<tr>
<td>BHP</td>
<td>$Y = -0.0921x^2 + 0.5025x$</td>
<td>0.9293</td>
</tr>
<tr>
<td>ULC</td>
<td>$Y = 0.0255x^2 + 0.1397x$</td>
<td>0.9615</td>
</tr>
<tr>
<td>ULP</td>
<td>$Y = 0.0209x^2 + 0.2566x$</td>
<td>0.9889</td>
</tr>
<tr>
<td>BLC</td>
<td>$Y = -0.0386x^2 + 0.3084x$</td>
<td>0.9846</td>
</tr>
<tr>
<td>BLU</td>
<td>$Y = -0.0201x^2 + 0.2937x$</td>
<td>0.9823</td>
</tr>
<tr>
<td>USC</td>
<td>$Y = 0.0132x^2 + 0.1815x$</td>
<td>0.9549</td>
</tr>
<tr>
<td>USP</td>
<td>$Y = 0.0372x^2 + 0.1566x$</td>
<td>0.9332</td>
</tr>
<tr>
<td>BSC</td>
<td>$Y = -0.1082x^2 + 0.4570x$</td>
<td>0.9874</td>
</tr>
<tr>
<td>BSP</td>
<td>$Y = -0.0788x^2 + 0.4322x$</td>
<td>0.9648</td>
</tr>
</tbody>
</table>

Y: Rate (Kg water/h)  
x: Moisture (Kg water/Kg dried solid)  
UHC: Unblanched Cardaba at 70°C;  
BHC: Blanched Cardaba at 70°C;  
UHP: Unblanched Plantain at 70°C;  
BHP: Blanched Plantain at 70°C;  
ULC: Unblanched Cardaba at 50°C;  
BLC: Blanched Cardaba at 50°C;  
ULP: Unblanched Plantain at 50°C;  
BLP: Blanched Plantain at 50°C;  
USC: Unblanched Cardaba sun-dried;  
BSC: Blanched Cardaba sun-dried;  
USP: Unblanched Plantain sun-dried;  
BSP: Blanched Plantain sun-dried

### Table 2: Drying Kinetics Parameters of Cardaba Banana and Plantain

<table>
<thead>
<tr>
<th>Sample</th>
<th>$X_{cw}$</th>
<th>$X_{ew}$</th>
<th>$X_{wo}$</th>
<th>$M_r$</th>
<th>$R_c$</th>
</tr>
</thead>
<tbody>
<tr>
<td>UHC</td>
<td>2.571</td>
<td>0.184</td>
<td>2.571</td>
<td>1.000</td>
<td>0.734</td>
</tr>
<tr>
<td>UHP</td>
<td>1.121</td>
<td>0.077</td>
<td>1.518</td>
<td>0.724</td>
<td>0.537</td>
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<tr>
<td>BHC</td>
<td>2.305</td>
<td>0.131</td>
<td>2.690</td>
<td>0.840</td>
<td>0.900</td>
</tr>
<tr>
<td>BHP</td>
<td>1.299</td>
<td>0.157</td>
<td>1.701</td>
<td>0.739</td>
<td>0.548</td>
</tr>
<tr>
<td>ULC</td>
<td>2.432</td>
<td>0.336</td>
<td>2.774</td>
<td>0.859</td>
<td>0.544</td>
</tr>
<tr>
<td>ULP</td>
<td>1.152</td>
<td>0.067</td>
<td>1.326</td>
<td>0.861</td>
<td>0.355</td>
</tr>
<tr>
<td>BLC</td>
<td>2.621</td>
<td>0.162</td>
<td>3.000</td>
<td>0.866</td>
<td>0.561</td>
</tr>
<tr>
<td>BLP</td>
<td>1.561</td>
<td>0.105</td>
<td>1.652</td>
<td>0.941</td>
<td>0.428</td>
</tr>
<tr>
<td>USC</td>
<td>1.385</td>
<td>0.030</td>
<td>1.710</td>
<td>0.806</td>
<td>0.313</td>
</tr>
<tr>
<td>USP</td>
<td>1.417</td>
<td>0.250</td>
<td>1.778</td>
<td>0.763</td>
<td>0.354</td>
</tr>
<tr>
<td>BSC</td>
<td>1.500</td>
<td>0.071</td>
<td>1.976</td>
<td>0.750</td>
<td>0.449</td>
</tr>
<tr>
<td>BSP</td>
<td>0.962</td>
<td>0.053</td>
<td>1.392</td>
<td>0.678</td>
<td>0.400</td>
</tr>
</tbody>
</table>

$X_{cw}$ – Critical moisture content, $X_{ew}$ – Equilibrium moisture content; $X_{wo}$ – Initial moisture content, $R_c$ – Drying rate and $M_r$ – Moisture ratio;  
UHC: Unblanched Cardaba at 70°C;  
BHC: Blanched Cardaba at 70°C;  
UHP: Unblanched Plantain at 70°C;  
BHP: Blanched Plantain at 70°C;  
ULC: Unblanched Cardaba at 50°C;  
BLC: Blanched Cardaba at 50°C;  
ULP: Unblanched Plantain at 50°C;  
BLP: Blanched Plantain at 50°C;  
USC: Unblanched Cardaba sun-dried;  
BSC: Blanched Cardaba sun-dried;  
USP: Unblanched Plantain sun-dried;  
BSP: Blanched Plantain sun-dried

### 3.2 Drying parameters of Cardaba banana and plantain

Samples oven-dried at 70°C had the highest equilibrium moisture content and critical moisture content. Equilibrium and critical moisture contents of the samples oven-dried at 50°C were higher than those of sun-dried samples. Sun-dried samples had the lowest equilibrium and critical moisture contents (Table 2). As the moisture content of a product approaches the equilibrium, drying rate tends toward zero. Kabiru et al. (2013) reported that an increment in drying air temperature was accompanied by a reduction in the time that it took for the produce to reach the equilibrium moisture content. They reported that equilibrium moisture content was reached at 6.5, 5.5 and 4 hours for mango samples dried at 60°C, 70°C and 80°C respectively.

Cardaba banana samples had higher equilibrium moisture content than plantain samples. Therefore, Cardaba banana seemed to dry faster than plantain slices because of their higher equilibrium moisture contents. Critical moisture content is the moisture content at which the drying rate begins to slow down (under constant drying conditions) in equilibrium with air of 58-65% relative humidity. There was a significant (p < 0.05) difference in the moisture ratio of all the samples (Table 2), and Cardaba banana samples had the lowest critical moisture content compared to plantain samples.
3.3 Effect of processing on shrinkage of samples

Changes in height (thickness) are shown in Figure 3 and changes in diameter of Cardaba banana and plantain samples are shown in Figure 4. Shrinkage in both Cardaba banana and plantain samples ranged from 4.00 to 60.00% in thickness. Shrinkage in diameter for Cardaba banana samples ranged from 36.67 to 53.33% while shrinkage in diameter for plantain samples ranged from 32.50 to 47.50%. Change in thickness for both Cardaba banana and plantain samples varied with processing treatments (blanching and drying temperature). It was observed for all samples that reduction in height (thickness) was faster in Cardaba banana samples than in plantain samples.

Blanched samples exhibited higher changes in the product’s thickness (Cardaba banana and plantain) than the unblanched samples. Reduction of pectic substances by blanching have been attributed to the greater change

![Figure 3: Percentage change in thickness for:](image)
a) Unblanched cardaba banana slices; b) Blanched cardaba banana slices; c) Unblanched plantain slices; d) Blanched plantain slices

![Figure 4: Shrinkage in diameter at different drying temperatures for cardaba banana and plantain slices](image)
U.C: Unblanched cardaba banana; U.P: Unblanched plantain
B.C: Blanched cardaba banana; B.P: Blanched plantain
in thickness (Plat et al. 1991). The cells and intercellular spaces of fresh tissue shows a net-like pattern loosely arranged but in blanched sample, there is cell wall degradation and broken membranes with formation of vesicles. Probably the rupture of cell membrane during blanching resulted in partial gelatinization of the starch granules (Yadav et al. 2006).

Samples sundried had the lowest shrinkage in diameter (32.50 to 42.80%), samples that were oven-dried at 50°C ranged from 35.00 to 50.00% in diameter while those oven-dried at 70°C had the highest shrinkage in diameter (40.00 to 53.33%). Therefore, shrinkage increases as temperature rises. The following are the percentage of shrinkage in thickness: 4.00 to 40.00% for sundried samples; 10.00 to 60.00% for samples that were oven-dried at 50°C and 10.00 to 50.00% for samples that were oven-dried at 70°C. Sample thickness reduced with time and drying temperature had a significant (p < 0.05) effect on percent change in thickness.

Thickness reduced faster in the samples at the three drying temperatures (sun, 50°C and 70°C). At higher temperature the evaporation of moisture from the surface was faster hence the outer layer of the materials became rigid and the final volume stabilized early in the drying period. As drying proceeded, the tissues split and ruptured internally, forming an open structure. The interior finally dried and shrunk with further drying and the internal stresses pulled the tissues apart. The dried material contained numerous holes (Guizani et al. 2008). Overall shrinkage affected sample’s thickness more than its diameter. These results are supported by the findings of Senadeera et al. (2005), who reported that both the rate of dimensional shrinkage and maximum dimensional shrinkage can be affected by drying temperature.

3.4 Rehydration Capacity (RC) of Cardaba Banana and Plantain Slices

Figures 5 and 6 shows the rehydration capacities of plantain and Cardaba banana slices respectively at room temperature, 45°C, 70°C and 90°C. RC values of Cardaba banana samples ranged from 100 to 160% while plantain slices RC values ranged from 100 to 190%. The extent of damage to the cells and structure determines the extent of rehydration (Guizani et al. 2008). It is probable that Cardaba banana exhibited irreversible cellular rupture and dislocation, which resulted in loss of integrity, thence the formation of a dense structure of collapsed and greatly shrunken capillaries. This caused a reduction of the hydrophilic properties, which was obvious in the inability of the samples to absorb enough water for full rehydration (Guizani et al. 2008).

Blanched slices had RC values ranging from 100 to 175% while unblanched slices had RC values ranging from 100 to 190%. Unblanched samples had higher RC values than the blanched samples, which could be attributed to the water absorption capacity (WAC) of both blanched and unblanched samples (Table 3). Taiwo and Adeyemi (2009) reported that blanched samples exhibit broken membranes with formation of vesicles, plasmalemma breakage as well as some cell wall degradation leading to reduced water uptake.

The physicochemical basis for the structural deformation of blanched samples was the loss of turgor pressure in the cell resulting from loss from selective semi permeability of the cytoplasm membranes. Mayor and Sereno (2004); Nueman (1972) suggested other factors were responsible for the water uptake such as starch crystallinity, protein denaturation and hydrogen bonding of the macromolecules.

There was a significant (p < 0.05) difference in the rehydration capacity of samples at the different drying temperatures. The rehydration capacity of samples increased with higher drying temperatures. Taiwo and Adeyemi (2009) reported that the drying temperatures from 50 to 80°C did not influence the RC of banana significantly (p < 0.05), but RC values increased as temperatures increased.

Rehydration capacity increased with higher temperatures (90°C > 75°C > 45°C > room temperature). The higher the temperature of the rehydrating medium, the higher the rehydration capacity. High rehydrating temperature promotes faster water diffusion as cell membranes in the product swell and plasticize within due to lower viscosity of the medium, thus increasing the product’s rate of water uptake (Lazarides and Mavroudis 1996; Oleiveira et al. 1999). According to Vega-Galvez et al. (2009) air-drying temperature is the main factor affecting the rehydration capacity. The compactness of the tissue structure is affected by different drying methods, where the fibers become more disrupted and result in a coherent structure that has hardly any spaces between the fibers (Dewi et al. 2011).
Studies on the drying kinetics and rehydration capacities of cardaba banana compared to plantain slices

Irreversible physico-chemical changes resulted in the product. Therefore, rehydration can be considered as an indirect measure of the damage to the material caused by pre-drying treatments (Vega-Galvez et al. 2010) or during drying (Lewicki 1998).

Factors affecting the degree of rehydration include: processing conditions, sample preparation, sample composition and the extent of the structural and chemical disruption induced by drying (Singh et al. 2006). Investigations revealed that quicker and total rehydration is achievable from samples that are dried at shorter drying time with higher drying temperature. Hereby, minimal shrinkage will be experienced, thus allowing for well-defined intercellular voids to promote an increased rehydrating rate (Haas et al. 1974; Singh et al. 2006). The lower rehydration values are evidence of inadequate product shrinkage by prolonged drying that resulted in irreversible physico-chemical changes resulted in the product. Therefore, rehydration can be considered as an indirect measure of the damage to the material caused by pre-drying treatments (Vega-Galvez et al. 2010) or during drying (Lewicki 1998).

Figure 5: Rehydration capacity of:
a. Cardaba slices rehydrated at room temperature; b. Cardaba slices rehydrated at 45°C; c. Cardaba slices rehydrated at 75°C; d. Cardaba slices rehydrated at 90°C; e. Blanched plantain rehydrated at 90°C; f. Unblanched cardaba rehydrated at 90°C
3.5 Functional and Physico-chemical Properties of Cardaba Banana and Plantain Flours

3.5.1 Bulk Density

The bulk density of Cardaba banana flour samples ranged from 0.52 g/ml to 0.65 g/ml and from 0.56 g/ml to 0.73 g/ml in plantain flour samples (Table 3). The bulk densities for Cardaba banana and plantain flour samples ranged between 0.52 to 0.73 g/ml. These results are within those ranges found by Chandra and Samsher (2013), who reported bulk densities of 0.762 g/cm³ for wheat flour, 0.914 g/cm³ for rice flour, 0.776 g/cm³ for green gram flour and 0.720 g/cm³ for potato flour.

The bulk density of flour samples were: 0.53 and 0.62 g/ml (oven-dried at 70ºC), 0.52 to 0.59 g/ml (oven-dried at 50ºC) and 0.65 to 0.73 g/ml (sun-dried). Unblanched flour samples were lower in bulk density (0.52 to 0.70 g/ml) than the blanched flour samples (0.53 to 0.73 g/ml) for...
both Cardaba banana and plantain. The results of the bulk densities agree with those reported by Tagogoe (1994) and Fagbemi (1999) and that heat treatment or blanching before drying increases bulk density. The results suggest that Cardaba banana flour samples had lower bulk densities compared to plantain flour samples. A product’s bulk density defines the type of packaging or container in which the product will be commercialised, since it is the product’s density that determines its texture or mouth feel, but also the amount and strength of the packaging material (Wilhem et al. 2004).

### 3.6 Oil Absorption

The oil absorption capacity (OAC) of Cardaba banana flour samples was higher (76.47 to 98.83%) than plantain flour samples (66.20 to 90.67%). The higher oil absorption capacity observed in Cardaba flour samples suggest the presence of greater lipophilic constituents this variety than in plantain flour samples: therefore, Cardaba flour may be more suitable for sausage, soup and cake recipes in which the oil ability of flours is an important factor (Aremu et al. 2006).

OAC of unblanched flour samples ranged from 73.83 to 98.83% while OAC of blanched flour samples ranged from 66.20 to 90.07%. Blanching reduced oil absorption capacities of flour samples by 0.09 to 17.76%. Consequently, unblanched flour samples have higher oil absorption capacity than the blanched flour samples. This might be the result of reduced protein content through blanching, that would otherwise increase the flour’s capacity to absorb oil (Arisa et al. 2013). Boniace and Gladys (2011) reported OAC values for sorghum flours that ranged from 1.33 to 2.34 g/g, where untreated sorghum had the lowest value, whereas lime cooked from sorghum flour had the highest OAC value.

According to Chandra and Samsher (2013), the oil binding capacity of food protein depends on intrinsic factors of the product, such as amino acid composition, protein conformation and surface polarity or hydrophobicity. The quantity of OAC observed in blanched flour samples may be related to the quantity of protein content in the flour samples. Higher protein improved oil absorption capacity, hence OAC reduces as protein content decreases (El Nasri and El Tinay 2007).

Sun dried samples had OAC values ranging between 74.57 and 98.83%, OAC of flour from samples oven-dried at 50°C ranged between 77.90 and 84.57% and OAC of flour from samples oven-dried at 70°C ranged between 66.20 to 85.40%. It was also observed that the lower the drying temperature the higher the oil absorption capacity. Slow drying affects rate of hardening which may affect the sites available for binding. Flour from sun-dried samples have

### Table 3: Functional and physico-chemical properties of cardaba banana and plantain flour

<table>
<thead>
<tr>
<th>Sample</th>
<th>B/D (g/ml)</th>
<th>O/A (%)</th>
<th>W/A (%)</th>
<th>pH</th>
<th>S/P (g/g)</th>
<th>Disper (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>UHC</td>
<td>0.53±0.40</td>
<td>85.4±2.05</td>
<td>132.0±6.96</td>
<td>4.93±0.12</td>
<td>5.85±0.03</td>
<td>56.0±0.52</td>
</tr>
<tr>
<td>UHP</td>
<td>0.59±0.36</td>
<td>73.8±1.10</td>
<td>105.8±1.21</td>
<td>5.87±0.01</td>
<td>5.44±0.01</td>
<td>79.9±0.23</td>
</tr>
<tr>
<td>BHC</td>
<td>0.57±0.55</td>
<td>76.4±0.31</td>
<td>117.0±7.25</td>
<td>4.84±0.01</td>
<td>5.50±0.01</td>
<td>69.5±0.62</td>
</tr>
<tr>
<td>BHP</td>
<td>0.62±0.40</td>
<td>66.2±0.79</td>
<td>98.9±0.44</td>
<td>5.74±0.06</td>
<td>5.07±0.01</td>
<td>81.0±0.73</td>
</tr>
<tr>
<td>ULC</td>
<td>0.52±0.26</td>
<td>84.5±8.13</td>
<td>109.1±3.54</td>
<td>5.76±0.01</td>
<td>6.36±0.00</td>
<td>72.5±0.46</td>
</tr>
<tr>
<td>ULP</td>
<td>0.56±0.15</td>
<td>77.9±7.34</td>
<td>97.9±6.68</td>
<td>6.13±0.02</td>
<td>5.65±0.01</td>
<td>78.7±0.46</td>
</tr>
<tr>
<td>BLC</td>
<td>0.53±0.29</td>
<td>83.0±5.01</td>
<td>98.1±9.36</td>
<td>5.71±0.02</td>
<td>5.93±0.01</td>
<td>74.0±0.67</td>
</tr>
<tr>
<td>BLK</td>
<td>0.59±0.21</td>
<td>77.9±5.50</td>
<td>94.0±2.17</td>
<td>6.05±0.04</td>
<td>4.88±0.01</td>
<td>79.4±0.57</td>
</tr>
<tr>
<td>USC</td>
<td>0.65±0.15</td>
<td>98.8±3.07</td>
<td>99.8±1.78</td>
<td>6.12±0.01</td>
<td>4.69±0.08</td>
<td>69.5±10.65</td>
</tr>
<tr>
<td>USP</td>
<td>0.70±0.06</td>
<td>90.6±1.96</td>
<td>93.6±3.01</td>
<td>6.56±0.01</td>
<td>4.50±0.04</td>
<td>69.8±0.29</td>
</tr>
<tr>
<td>BSC</td>
<td>0.66±0.10</td>
<td>90.0±5.90</td>
<td>87.5±5.33</td>
<td>6.03±0.01</td>
<td>4.42±0.35</td>
<td>74.0±0.57</td>
</tr>
<tr>
<td>BSP</td>
<td>0.73±0.23</td>
<td>74.5±7.31</td>
<td>86.1±10.8</td>
<td>6.34±0.01</td>
<td>4.15±0.32</td>
<td>74.7±0.20</td>
</tr>
<tr>
<td>USC</td>
<td>0.65±0.15</td>
<td>98.8±3.07</td>
<td>99.8±1.78</td>
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</tr>
<tr>
<td>BSC</td>
<td>0.66±0.10</td>
<td>90.0±5.90</td>
<td>87.5±5.33</td>
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<td>4.42±0.35</td>
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<td>6.34±0.01</td>
<td>4.15±0.32</td>
<td>74.7±0.20</td>
</tr>
</tbody>
</table>

Values reported are means ± standard deviation of triplicate determinations. Mean values with different superscripts within same column are significantly (p < 0.05) different.

UHC: Unblanched Cardaba at 70°C; UHP: Unblanched Plantain at 70°C; BHC: Blanched Cardaba at 70°C; BHP: Blanched Plantain at 70°C; ULC: Unblanched Cardaba at 50°C; ULP: Unblanched Plantain at 50°C; BLC: Blanched Cardaba at 50°C; BLP: Blanched Plantain at 50°C; USC: Unblanched Sun-dried Cardaba; USP: Unblanched Sun-dried Plantain; BSC: Blanched Sun-dried Cardaba; BSP: Blanched Sun-dried Plantain

BD: Bulk Density, OA: Oil Absorption, WA: Water Absorption, SP: Swelling Power and Disper: Dispersibility
depicted the greatest oil absorption capacity; flour from samples oven-dried at 50°C were greater while flour from samples oven-dried at 70°C have the least oil absorption capacity. Oil absorption capacity is lower than those recorded by (Chandra and Samsher 2013) (124 to 168%) for wheat, rice potato and green gram flours.

The oil absorption capacity of Cardaba banana flour samples was greater than that of plantain flour samples, which indicates that Cardaba banana flour can be used in foods that require good oil absorption. Additionally, Cardaba banana flour could be better at retaining flavor than plantain flour.

### 3.7 Water absorption

Water absorption capacity represents the ability of a product to associate with water where water is limited (Singh 2001). The WAC of Cardaba banana flour samples is 0.20 to 13.86% greater than that of plantain flour samples. The higher WAC of Cardaba banana flour samples might indicate this product’s higher fiber content. This result suggests that Cardaba banana Flour can be used in foods due to the flour’s greater capacity of absorbing water, which could improve structure binding, enhance flavor retention, improve mouth feel and reduce moisture and fat losses of food products (Sreeerama et al. 2008).

WAC values of unblanched flour samples were higher (93.63 to 132.03%) than WAC of blanched flour samples (86.13 to 117.03%). Water absorption capacity reduced with blanching for both Cardaba banana flour samples and plantain flour samples. It is possible that some thin cell membranes were ruptured during blanching, thus facilitating partial gelatinization of starch granules. Prolonged hot air drying might have further gelatinized the starch granules by inhibiting amylases which resulted in decreased water binding capacity during rehydration (Yadav et al. 2006).

Water absorption capacity of flour from samples ranged as follows: 98.90 to 132.03% (oven-dried at 70°C), 94.00 to 109.13% (oven-dried at 50°C), and 86.13 to 99.83% (sun-dried). Increasing drying temperature increased the product’s water absorption capacity which may be attributed to the amount of moisture loss during drying as seen in the moisture content results.

Water absorption capacities for Cardaba and plantain flour samples ranged from 86.13% to 132.03% and were lower than those reported by Adelekan et al. (2013) for yam flour enriched with pumpkin seeds (128.42 to 167.75%) and by Chandra and Samsher (2013) for wheat, potato, rice and green gram flours (140 to 752%). However, our results were higher than those reported by Abioye et al. (2011) for soy plantain mixes (80.05 to 86.50%). Viscous foods like soups and gravies consider WAC critically. Hence these flours might be useful as functional ingredients in soups, gravies and baked products (Akinyede et al. 2005).

Water absorption/binding capacity is essential for flour and isolates in dough and baking production (Okezie and Bello 1988; Giami 1993).

### 3.8 pH

The results show higher pH values at lower drying temperatures. The highest pH values were detected in the flour produced from sun-dried samples of both Cardaba banana and plantain (6.03 to 6.56), whereas pH values of flour from samples that were oven-dried at 50°C (5.76 to 6.13) were higher than the pH of flour from oven-dried at 70°C samples (4.84 to 5.87). The pH values found in the present study are similar to those reported for soy plantain mixes (5.08 to 5.75: Abioye et al. 2011) and plantain flour (6.12 to 6.29: Arisa et al. 2013).

Lower drying temperatures increase pH values of the final product. Plantain flour samples had higher pH values than Cardaba banana flour samples, in both blanched and unblanched treatments. The pH values of plantain flour samples ranged between 5.74 and 6.56, Cardaba banana flour samples had pH values from 4.84 to 6.12. Such pH values fall within the acidic range and influence the storage capacity of these flours, which improves with lower (or more acidic) pH values. pH is an important factor for flour commercialization since it influences the product’s functional properties (Gbadamosi et al. 2012).

pH values reduced with blanching for both (Cardaba banana and plantain) flour samples irrespective of the drying temperature (sun, 50°C and 70°C). The flour pH range of unblanched samples (4.93 to 6.56) was higher than that of blanched samples (4.84 to 6.34). However, Arisa et al. (2013) reported higher pH values for blanched samples (6.29 and 6.25) than the unblanched sample (6.12). The low flour pH values of blanched samples suggest that this product may have a longer shelf life compared to the flour produced from unblanched samples.

### 3.9 Swelling Power

There was significant (p < 0.05) difference in the swelling power (SP) of the flour samples. The swelling power of Cardaba banana flour samples ranged between 4.42 and 6.36 g/g, while the swelling power of plantain flour...
samples ranged between 4.15 and 5.65 g/g. SP of flour from unblanched samples was higher (4.50 to 6.36 g/g) than the SP of flour from blanched samples (4.15 to 5.93 g/g). Unblanched flour samples of both Cardaba banana and plantain swelled more than the blanched flour samples (Cardaba banana and plantain). These results agree with those found by Arisa et al. (2013) who reported 48.89% and 39.49% SP for unblanched and blanched plantain samples, respectively. Blanching causes the structure of the flour to become firmer, thus reducing its capacity to absorb water compared to the unblanched flour (Guizani et al. 2008).

Temperature of drying affected the swelling power of Cardaba banana and plantain flour samples. SP values of flours ranged from 4.88 to 6.36 g/g SP for oven-dried at 50°C samples, 5.07 to 5.85 g/g for oven-dried at 70°C samples and between 4.15 to 4.69 g/g for sun-dried samples. It was observed that flour from oven-dried samples had higher SP than flour from sun-dried samples.

Swelling power is an indication of the absorption index of the granules during heating (Loos et al. 1981). The swelling capacity of flours depend on size of particles, produce variety, processing methods and unit operations that are employed (Chandra and Samsher 2013). The results of the present study suggest that Cardaba banana flour could have smaller particle sizes and structure for water uptake than plantain flour, which influenced water absorption capacity of Cardaba banana flour (Table 3).

### 3.10 Dispersibility

Dispersibility measures the ability of materials to form dispersions, in which one substance is suspended in a second material (IFIS 2005). It is often determined for dried foods or ingredients such as powders to illustrate how well they can be rehydrated. Plantain flour samples had higher dispersibility values (69.89 to 81.07%) than Cardaba banana flour samples (56.01 to 74.08%). Dispersibility of the plantain flour samples was higher than that of the Cardaba banana flour samples, which may be due to the fact that Cardaba banana flour has higher water absorption capacity and, therefore can rehydrate better than plantain flour samples (Table 3).

The dispersibility of flour from unblanched samples ranged between 56.01% and 79.98% and between 69.55 to 81.07% for blanched sample flour. The flour dispersibility index from blanched samples (Cardaba banana and plantain flour) had higher dispersibility than those from unblanched samples. The dispersibility indices found in this research ranged from: 56.01 to 81.07% for oven-dried at 70°C, 72.51 to 79.49% for oven-dried at 50°C samples, and 69.59 to 74.79% for sun-dried samples. Therefore, higher drying temperature increased the dispersibility indices of all samples.

There was a significant (p < 0.05) difference in the dispersibility values of all the flour samples. The values ranged between 56.01% to 81.07% and were higher than those calculated by Malomo et al. (2012) for yam-soy flour (52.50 to 60.50%), also higher than those found by Edema et al. (2005) for maize soybean flour (32.70 to 34.93%). High dispersibility values are important for pastry manufacturing since it gives a finer consistency to the dough during mixing (Adebowale et al. 2008).

### 4 Conclusion

Plantain flour was higher than Cardaba banana flour in bulk density values and drying temperature and had an effect; sun-dried samples > 70°C > 50°C and blanching increased the bulk densities of samples. Oil and water absorption capacities and swelling power were higher in Cardaba banana flour than in plantain flour but the swelling power and absorption capacities of flour reduced with blanching. Cardaba banana flour had pH and dispersibility values lower than plantain flour and blanching reduced pH and dispersibility values.

Cardaba banana slices dried faster than plantain slices and blanching reduced drying time. The higher the temperature of drying the shorter the drying time. The percentage shrinkage was higher in Cardaba banana slices than in plantain slices. Drying temperature affected shrinkage and blanching increased percentage shrinkage. The higher the drying temperature the higher the rehydration capacity. Rehydration capacity was dependent on the rehydration temperature: 90°C >75°C >45°C >RT, it reduced with blanching and plantain slices had rehydration capacity higher than Cardaba banana slices for most conditions.

Conflict of interest: Authors state no conflict of interest.

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