Parboiling duration effects on physical properties of African breadfruit seed

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Abstract: Parboiling is a pre-dehulling operation and, the effect on the physical properties of African breadfruit seed (*var. africana*) was investigated. Freshly extracted seeds were parboiled for 0 (control), 5, 10, 15, and 20 min, and their physical properties determined. It was observed that parboiling time had a significant effect ($p<0.05$) on all the physical properties of African bread fruit seeds investigated. The moisture content of the seed ranged from 32.92% ± 0.23% to 50.78% ± 0.19% (w.b.) as the parboiling time increased. Generally, it was observed that the mean values observed for the physical dimensions (axial dimensions, mean diameters, sphericity, aspect ratio and surface area) increased from 0 to 10 min. Parboiling time after which the mean values were observed to generally decrease. The thousand seed weight ranged from 299.87 ± 1.16 to 334.69 ± 3.55 g as the parboiling time increased from 0 to 20 min. The observed value for the true and bulk densities ranged from 1041.58 ± 7.55 to 1304.38 ± 23.23 kg m^{-3} and from 626.55 ± 4.21 to 642.90 ± 2.68 kg m^{-3}, respectively. As the parboiling time increased, the true density was observed to increase while the bulk density decreased. No definite trend was observed for the angle of repose and the static coefficient of friction. The filling angle of repose ranged from 33.19° ± 0.38° to 42.00° ± 2.65°, while the funneling angle of repose ranged from 44.34±0.79 to 51.92±3.52°.

Keywords: African breadfruit, parboiling time, physical properties, frictional properties, seed properties.

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1 Introduction

African breadfruit (*Treculia africana*) is an important tropical African tree crop, widely distributed among the coastal countries of West Africa particularly in the southern rain forest zones (Enibe et al., 2013; Etoamaihe and Ndubueze, 2010; Fasasi et al., 2003; Omobuwajo et al., 1999). The trees bear fruits that vary in size but are generally spherical, large, rough textured, green when juvenile and greenish-yellow when ripe, pulpy and covered with soft structure (Baiyeri and Mbah, 2006). The fruit contains spherical shaped seeds at various depths within the fleshy fruit. A mature seed of the crop is made up of an outer covering, the hull and the inner edible endosperm. The hull is brown in colour but changes to dark brown after sometime in the natural environment due to oxidation during fermentation (Etoamaihe and Ndubueze, 2010). It is coated with a sticky substance which must be washed off prior to dehulling. The seed is usually eaten after boiling, frying or making porridge out of it. The seed is a rich source of vegetable oil (11.3%), protein (17%) and carbohydrates (40%) as well as several minerals and vitamins (Etoamaihe and Ndubueze, 2010; Makinde et al., 1985). The fleshy pulp has been used as fodder while the wood of the tree crop has potential use in the paper industry.

The physical properties of seeds and grains are important in the food industry and are useful in farming, harvesting, storage, and in processing such as drying,

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freezing and boiling, etc. It is important to have an accurate estimation of shape, size, volume, density, specific gravity, surface area, and other properties of agricultural material, either as a bulk or individual seed, which may be considered as designing parameters for food processing equipment (Dobrzański and Stępniewski, 2013). This is important in the design of processing machines for African breadfruit seed from seed to food. Food products during processing operations are subjected to different thermal processes such as pasteurization, sterilization, evaporation, parboiling, baking and drying which impact on their physical properties prior to the actually processing of the material (Naji et al 2012; Yeoh et al., 2011; Ogunsina and Bamgboye, 2007; Oliveira et al., 2005). Such changes in the properties of the biomaterials subjected to pre-processing conditioning are often not considered in the design of processing machines.

Processing African breadfruit seed into its kernel is generally a time consuming and labour intensive operation. Prior to dehulling of the seeds, they are usually parboiled with the aim of loosening the adhering testa from the kernel, and for easy removal of the hull together with the testa. Although a number of African breadfruit dehulling machines have been designed and developed with varying efficiencies, little or no consideration is given to the effect of pre-dehulling conditioning on the physical properties of the seed (Enibe et al., 2013; Etoamaihe and Ndubueze, 2010). The same observation was reported by (Ogunsina and Bamgboye (2007) for cashew nuts. Although the effects of heat treatment on the behaviour of some food materials during handling and processing have been studied (Naji et al., 2012; Özcan and Bozkurt, 2015; Elmastry et al., 2006; Irtwange, 2006; Akinoso et al., 2006; Srikaeo et al., 2005), there is no published data on the effect of parboiling on the physical properties of African bread fruit seed. Understanding the effect of such thermal treatment on the physical properties of African breadfruit seed will assist in improving the design and efficiencies of dehulling machines. The objective of the study was to investigate the effect of parboiling time on the physical properties the African breadfruit seeds.

2 Materials and methods

2.1 Sample preparation

About 8 kg of African breadfruit seeds, *var. africana,* freshly extracted from the pulp head was obtained from farmers' market at Ogbede, in Enugu state, southeastern Nigeria. Extraneous materials such as leaves and leaf stalks were manually removed from the bulk. The heat treatment investigated in this study was the parboiling of African breadfruit seed which is usually carried out prior to dehulling. In preparing the experimental samples, about 5 kg of the seeds were divided into five portions; the first four portions were parboiled for 5, 10, 15, and 20 minutes, while the last portion served as control for the experiment. After parboiling the seeds for the specified time, they were poured into a sieve, allowed to cool for 1 minute and for the surface water to evaporate prior to the determination of the physical properties. Parboiling of each of the experimental samples was done in a pot of 23 cm diameter and 38 cm height using about 4155.23 cm^3 of water. The water was brought to boiling point (100°C) before the seed samples were poured into the pot for parboiling.

2.2 Equipments used

The following equipments were used in the study: moisture dishes made of heavy gauge aluminum; desiccators, Air oven (Gallenkamp); digital weighing balance (Mettler Toledo JL620-GLA01), and a SKOLE digital caliper measuring to an accuracy of 0.01 mm.

2.3 Moisture content

Moisture content determination was carried out following (ASAE, 2003). The moisture content (w.b.) for the control and parboiled African breadfruit seed samples was calculated by dividing the loss in weight due to oven drying by the initial weight of the sample.

$$m = \frac{100W_m}{W_i} \tag{1}$$

Where, m = moisture content, wet basis (%), W_m = moisture loss (g), W_i = initial weight of test sample (g).

2.4 Physical properties

The following physical properties – principal dimensions, arithmetic and geometric mean diameters, sphericity, aspect ratio, surface area, thousand seed weight (TSW), true density, bulk density, porosity, angles of repose, and coefficient of static friction - were determined for the experimental samples using standard methods (Ogunsina and Bamgboye, 2007; Mohsenin, 1978).

I. Principal dimensions, sphericity, aspect ratio and surface area

For each of the experimental samples 100 seeds were randomly picked and the principal axes, i.e. a – length, b – width, and c – thickness measured. The width and thickness were measured perpendicular to the major axis (Ogunsina and Bamgboye, 2007). The length (major diameter) was the highest dimension of the biggest surface of the seed; the thickness (minor diameter) was the shortest dimension of the smallest surface of the seed, while the width (intermediate diameter) was the shortest dimension of the biggest surface of the seed (Milani et al., 2007). The arithmetic mean diameter, D_a, geometric mean diameter, D_{gm}, sphericity (S_p) and the aspect ratio (R_a) were calculated as follows: (Mohsenin, 1978; Tabatabaeefar, 2003).

$$D_a = \frac{a+b+c}{3} \quad (2)$$

$$D_{gm} = (abc)^{1/3} \quad (3)$$

$$S_p = \frac{(abc)^{1/3}}{a}\ 100\% \quad (4)$$

$$R_a = \frac{b}{a}\ 100\ \% \quad (5)$$

Where a – length (mm), b – width (mm), and c – thickness (mm).

The surface area (S, mm^2) of seeds was calculated using the following equation (McCabe et al., 1986):

$$S = \pi \mathrm{D_g}^2 \quad (6)$$

II. TSW, densities and porosity

An electronic digital balance (Mettler Toledo JL620-GLA01) was used to determine the one thousand (1000) seed weight by weighing a sample size of 250 seeds randomly selected, and multiplied by 4 (Sharma et al., 1985; Vilche et al., 2003). The true density (ρ_t) of the seed samples was determined using the water displacement method. A seed of known mass was dropped inside a known volume of water in a measuring cylinder; the ratio of the mass of the seed to the volume of water displaced due to the immersed seed gave the true density of the seed.

To determine the bulk density, a cylindrical container of known weight and volume was filled with African breadfruit seeds and weighed. The weight of the seeds was calculated by the difference between the weight of the empty cylinder and the weight after it was filled with seeds. The ratio of the weight of the seeds to the volume of the cylindrical container was used as the bulk density (ρ_b). The porosity of the experimental samples was calculated from the values obtained for true and bulk density; the porosity (p) of each sample was calculated as follows (Mohsenin, 1978):

III. Angle of repose

The filling angle of repose is the angle with the horizontal at which the material will stand when piled. This was determined by using the procedure described in (ASAE, 2003). A topless and bottomless cylinder of 15 cm diameter and 25 cm height was placed at the centre of a raised circular plate having a diameter of 35 cm and was filled with seeds. The cylinder was raised slowly until the seeds formed a cone on the circular plate. The height and the diameter of the cone were measured and the filling angle of repose (Θ_f) was calculated using the following equation (Razavi et al., 2007):

$$\theta_f = Arc \tan\ (2H/D) \quad (8)$$

Where, H is the height of the cone and D is the diameter of the cone.

The funneling angle of repose was determined using a fiberglass box of 20 × 20 × 20 cm, having a removable front panel. The box was filled with the sample, and then the front panel was quickly removed allowing the seeds to flow and assume a natural slope (Joshi et al., 1993). The funneling angle of repose (Θ_U) was calculated from the measurement of the depth of the free surface of the sample at the centre, using the following equation (Paksoy and Aydin, 2004):

$$\theta_U = Arc \tan\ (2H/X) \quad (9)$$

IV. Coefficient of static friction

The static coefficient of friction of the seed samples was determined on three test surfaces namely, plywood, rubber and aluminum sheet. A fibre glass box of 150 mm length, 100 mm width and 40 mm height without base and lid was filled with the experimental samples and placed on an adjustable tilting plate (Milani et al., 2007). The box containing the seed sample was slightly raised (5-10 mm) so as not to touch the surface of the tilting plate surface. The tilting plate was gradually raised using a screw device until the box just started to slide down and the angle of tilt (α) was read and recorded from a graduated scale. The static coefficient of friction (μ_s) was then calculated using the equation:

$$\mu_s = \tan \alpha \tag{10}$$

2.5 Statistical analysis

The experiment was set up as a completely randomized design (CRD) and the data obtained were subjected to analysis of variance using GenStat Discovery edition 4 (VSN International). Fisher's Least Significant Difference (FLSD) was used to separate the means that were significantly different from each other at 5 % significance level (p<0.05).

3 Results and discussions

The effect of parboiling time ranging from 0 (control) to 20 minutes, on the physical properties of the African breadfruit seed is discussed below.

3.1 Moisture content and physical dimensions

The moisture content and the mean value of the dimensions of African breadfruit seeds parboiled for 0 to 20 minutes are shown in Table 1.

Table 1 Mean value and standard deviation of some physical properties of African breadfruit seed as influenced by the parboiling time

Seed property	Parboiling time, minutes					FLSD
	0 (control)	5	10	15	20	
m, %	32.92±0.23^{a}	47.37±0.19^{b}	50.44±0.33^{c}	50.78±0.19^{c}	49.76±0.42^{c}	0.44
L, mm	11.87±2.06^{a}	12.17±0.58^{b}	12.00±0.88^{a}	12.41±1.33^{c}	11.88±0.78^{a}	0.34
W, mm	7.20±0.47^{a}	7.19±0.54^{a}	7.47±0.46^{b}	6.99±0.88^{c}	6.92±0.73^{c}	0.18
T, mm	6.13±0.86^{a}	6.10±0.60^{a}	6.56±0.55^{b}	6.36±0.66^{c}	6.26±0.75^{a,c}	0.19
D_a, mm	8.40±0.75^{a}	8.49±0.39^{a,b}	8.68±0.49^{c}	8.59±0.61^{b,c}	8.35±0.40^{a}	0.15
D_g, mm	8.03±0.55^{a}	8.12±0.43^{a,c}	8.37±0.48^{b}	8.18±0.57^{c}	7.99±0.46^{a}	0.14
S_p, %	68.46±6.70^{a}	66.81±3.76^{b}	69.97±3.96^{c}	66.24±5.63^{b}	67.55±5.63^{a,b}	1.45
R_a, %	61.59±7.79^{a}	59.33±5.06^{b}	62.55±4.96^{a}	56.96±9.00^{c}	58.58±8.07^{b,c}	2.00
S, mm^2	202.90±28.58^{a}	207.81±22.10^{a,b}	221.01±25.64^{c}	211.02±28.34^{b}	201.07±22.79^{a}	7.13

Note: m - Seed moisture content (w.b.), L – Length, W – Width, T – Thickness, D_a – Arithmetic mean diameter, D_g – Geometric mean diameter, S_p – Sphericity, R_a – Aspect ratio, S – Surface area, FLSD – Fisher's least significant difference. Mean values in the same row with different letters are significantly different at 5% significant level (p<0.05). Data recorded were mean values of 100 replicates except for the moisture content having 4 replicates.

It was observed that the moisture content of the seeds increased from 32.92% ± 0.23% to 50.78% ± 0.19% (w.b.) as the parboiling time increased from 0 to 15 minutes. At 20 minutes parboiling time, the moisture content was observed to drop to 49.76 ± 0.42. This could be attributed to the loss in the structural components of the seed at higher parboiling time as the seeds were observed to split open and texturally softer compared to the seeds of previous boiling time. Similar results were reported by (Mariod et al., 2012) for safflower seed when boiled for 40 min. and by Kita and Figiel (2007) for roasted walnut. Statistically, the moisture content of the control seed sample was significantly different (p<0.05) from the moisture content of the parboiled African breadfruit seeds (Table 1). The moisture content of the seeds at 10, 15 and 20 minutes parboiling time were not significantly different (p>0.05) from one another but were significantly different (p<0.05) from the moisture content determined at 5 minutes parboiling time. This suggests that at higher parboiling duration, the effect becomes non significant on the seed moisture content.

The axial dimensions, mean diameters (arithmetic and geometric), sphericity, aspect ratio and surface area were observed to be vary with parboiling time, but no definite trend was observed (Table 1). The length, width and thickness ranged from 11.87 ± 2.06 to 12.41 ± 1.33 mm, 7.19 ± 0.54 to 7.47 ± 0.46 mm, and 6.10 ± 0.60 to 6.56 ± 0.55 mm, respectively. For the length, the lowest mean value was observed for the raw seed while the maximum was observed at the 15 min parboiling time. The length of the seed parboiled for 0, 10 and 20 minutes were not significantly different (p>0.05) but were all significantly different (p<0.05) from those parboiled for 5 and 15 minutes (Table 1). Akinoso and El-Alawa (2013) reported a significant effect of cooking time on the length of Locust bean seed. For the width, the lowest and highest mean values were observed at the 20 and 10 min parboiling time, respectively, while the highest and lowest values of 6.10 ± 0.60 mm and 6.56 ± 0.55 mm were observed for the thickness at the 5 and 10 min parboiling times, respectively. The mean value obtained at the 10 min parboiling time for the width and thickness were both significantly different from other values ($p<0.05$). The arithmetic and geometric mean diameters ranged from 8.35 ± 0.40 to 8.68 ± 0.49 mm and 7.99 ± 0.46 to 8.37 ± 0.48 mm, respectively. For the mean diameters, the highest mean values were recorded at the 10 min. parboiling time and the lowest was recorded at the 20 min parboiling time. The sphericity, aspect ratio and surface area ranged from 66.24% ± 5.63% to 69.97% ± 3.96%, 56.96% ± 9.00% to 62.55% ± 4.96%, and 201.07 ± 22.79 to 221.01 ± 25.64 mm^2, respectively. The mean value for the sphericity and surface area at the 10 min parboiling time was significantly different ($p<0.05$) from other values. The significant effect of the parboiling time on the physical dimensions of the seed could be attributed to the moisture absorption capability of the seed (Akinoso and El-Alawa, 2013).

Generally, it was observed that the mean values observed for the physical dimensions (axial dimensions, mean diameters, sphericity, aspect ratio and surface area) increased from the 0 to 10 minutes parboiling time after which the mean values were observed to generally decrease. Furthermore, no significant difference ($p>0.05$) was observed between the physical dimensions of the seeds parboiled for 0 and 20 minutes except for the width and aspect ratio. This could be attributed to the loss in the seed structural materials as the seed becomes textually softer in the boiling water at higher parboiling time above 10 minutes. The maximum mean value for the width, thickness, mean diameters, sphericity, aspect ratio and the surface area was observed at the 10 minutes parboiling time while the maximum for the moisture content of the hull, kernel and the length of the seed was observed at the 15 minutes parboiling time (Table 1).

3.2 TSW, densities and porosity

The TSW recorded as the seeds were parboiled from 0 to 20 minutes ranged from 299.87 ± 1.16 to 334.69 ± 3.55 g as shown in Table 2.

Table 2 Mean value and standard deviation of TSW, true and bulk densities, and porosity of African breadfruit seed as influenced by the parboiling time

Seed property	African breadfruit seed parboiled for different times, minutes					FLSD
	0 (control)	5	10	15	20	
TSW, g	299.87±1.16 ^{a}	324.35±6.24 ^{b}	334.69±3.55 ^{c}	306.75±5.38 ^{a}	314.78±5.19 ^{d}	7.03
ρ_t, kg m^{-3}	1216.93±2.82 ^{a}	1262.34±0.72 ^{a,b}	1304.38±23.23^b	1257.83±90.62 ^{a,b}	1041.58±7.55 ^{c}	63.29
ρ_b, kg m^{-3}	642.90±2.68 ^{a}	642.88±0.56 ^{a}	632.87±0.96 ^{b}	626.55±4.21 ^{c}	641.76±4.77 ^{a}	4.72
P, %	47.17±0.10 ^{a}	49.07±0.03 ^{a,b}	51.47±0.79 ^{b}	49.99±3.72 ^{b}	38.38±0.66 ^{c}	2.61

Note: TSW - Thousand seed weight, ρ_t – True density, ρ_b – Bulk density, P – Porosity, FLSD – Fisher's least significant difference. Mean values in the same row with different letters are significantly different at 5% significant level ($p<0.05$). Data recorded were mean values of 4 replicates.

The highest mean value of 334.69 ± 3.55 g was recorded at the 10 min parboiling time while the lowest mean value of 299.87 ± 1.16 g was recorded at 0 min parboiling time. The increase in the TSW could be attributed to the gain in moisture as the seeds were parboiled in water. This was reflected in the moisture content of the seeds as was shown in Table 1. Although the mean value of 306.75 ± 5.38 g recorded at the 15 min parboiling time was numerically higher than that of 299.87 ± 1.16 g recorded for the control seed sample, the two values were not significantly different ($p>0.05$) (Table 2). The observed value for the true and bulk densities ranged from 1041.58 ± 7.55 to 1304.38 ± 23.23 kg m^{-3} and from 626.55 ± 4.21 to 642.90 ± 2.68 kg m^{-3}, respectively. The true density was observed to have increased from the 0 to 10 min parboiling time after which a decrease was observed. This suggests that as the seed was parboiled from 0 to 10 min, the increase in the volume of the seed was less than the corresponding increase in the mass of the seed due to moisture addition.

And from the 15 minutes parboiling time, the increase in the mass of the seed was less that the corresponding increase in the volume due to expansion and splitting of the seed.

While the bulk density was observed to have decreased from 642.90 ± 2.68 to 626.55 ± 4.21 kg m^{-3}, from 0 – 15 min parboiling time and increased to 641.76 ± 4.77 at the 20 min parboiling time, the observed mean values at the 0, 5 and 20 min. parboiling times were not significantly different from one another ($p>0.05$). This could interpret to mean that in the bulky state, the expansion in the volume of the seed in a container of a known volume is more than the corresponding increase in the mass due to moisture addition as the seed is parboiled. This was reflected in the porosity (38.38% ± 0.66% to 51.47% ± 0.79%) which was observed to have increased as the seed was parboiled. The significant decrease ($p<0.05$) in the porosity of the seed at the 20 min parboiling time was as a result of the texturally softer nature of the seed.

3.3 Angles of repose and static coefficient of friction

The mean values observed for the angle of repose and the static coefficient of friction as the African breadfruit seeds were parboiled for 0 to 20 minutes are shown in Table3.

Table 3 Mean value and standard deviation of the angles of repose and static coefficient of African breadfruit seed as influenced by the parboiling time

Parboiling time, min	Seed properties					FLSD
	Angle of repose, º		Static coefficient of friction			
	Filling	Funneling	Plywood	Plastic	Aluminum	
0	36.01±1.25^{a}	44.34±0.79^{a}	0.65±0.02^{a}	0.55±0.02^{a}	0.59±0.02^{a,b}	2.25
5	33.19±0.3^{b}	50.17±0.23^{b}	0.64±0.0^{a}	0.53±0.02^{a}	0.58±0.01^{b}	2.45
10	35.37±1.53^{a,b}	50.96±0.24^{b}	0.56±0.02^{a}	0.48±0.01^{a}	0.50±0.01^{c}	0.03
15	33.80±0.22^{a,b}	47.20±0.20^{c}	0.66±0.02^{a}	0.54±0.02^{a}	0.65±0.01^{d}	0.03
20	42.00±2.65^{c}	51.92±3.52^{b}	0.66±0.02^{a}	0.45±0.03^{a}	0.62±0.04^{a,d}	0.03

Note: FLSD – Fisher's least significant difference; Mean values in the same column with different letters are significantly different at 5% significant level ($p<0.05$). Data recorded were mean values of 4 replicates.

No definite trend was observed for the angles of repose and the static coefficient of friction. The filling angle of repose ranged from 33.19º ± 0.38º to 42.00º ± 2.65º, with the highest value recorded at the 20 min parboiling time being significantly different ($p<0.05$) from others. Numerically, the highest value of 51.92º ± 3.52º was recorded for the funneling angle of repose at the 20 min parboiling time; however, this value was not significantly different from the values of 50.17º ± 0.23º and 50.96º ± 0.24º obtained at 5 and 10 min parboiling time, respectively. The highest mean value recorded at the 20 min parboiling time could be due to the softened state of the seeds which made it difficult for them to slide over each other. The static coefficient of friction on plywood, plastic and aluminum surfaces ranged from 0.56 ± 0.02 to 0.66 ± 0.02, 0.48 ± 0.01 to 0.55 ± 0.02, and 0.50 ± 0.01 to 0.65 ± 0.01, respectively. The static coefficient of friction on plywood and Aluminum surfaces at the 10 min. parboiling time reported to as 0.56 ± 0.02 and 0.50 ± 0.01 respectively, were significantly different ($p<0.05$) from other mean values. The physical properties of cashew nuts were found to be affected by pre-shelling treatment of roasting and steam boiling (Ogunsina and Bamgboye, 2007).

4 Conclusions

The effect of heat treatment on the physical properties of African breadfruit *var. africana* parboiled for 0, 5, 10, 15 and 20 min was investigated. It was concluded that the physical properties of African breadfruit were significantly affected by pre-dehulling treatment of parboiling and the moisture content of the seeds increased as the parboiling time increased with the highest moisture content recorded at the 15 min parboiling time. The mean values recorded for the width, thickness, mean diameters, sphericity, aspect ratio, surface area, TSW, true density and the porosity increased up to the 10 min parboiling time after which they were observed to decrease. The bulk density decreased with increasing parboiling time up to the 15 min parboiling time. Parboiling the seed beyond 10 min resulted in the seeds splitting open which significantly affected the angle of repose and coefficient of static friction of the seeds.

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