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The Effect of Soaking Time on Some Selected Engineering Properties of White African Yam Bean

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ABSTRACT

A study on the effect of soaking time on some selected engineering properties of white variety of African yam bean was carried out with a view to providing the much needed data that can aid in the development of an optimized design for some specific process equipment and components such as size reduction, cleaning, sorting and grading machines, controls as well as storage components and facilities. Harvested seeds with minimal processing were procured from the market and subjected to manual cleaning before it was soaked in water at room temperature within the range of 28-32^oC for 0minute, 90minutes, 180minutes, 270minutes, 360minutes, 450minutes and 540minutes and the selected response parameters observed. The results indicated that length, width, thickness, geometric mean diameter, mass, volume, true density and porosity increased non-linearly from 7.63mm to 11.10mm, 6.20mm to 7.29mm, 5.63mm to 7.26mm, 6.43mm to 8.26mm, 0.29g to 0.57g, 0.15cm^3 to 0.32cm^3, 2.24g/cm^3 to 2.45g/cm^3, and 60.30% to 74.10% respectively as soaking time increased; while sphericity and bulk density decreased non-linearly from 0.84 to 0.70 and 0.796g/cm^3 to 0.629g/cm^3 with increased soaking time. Static coefficient of friction on plywood increased non-linearly from 0.517 to 0.836; while angle of repose increased non-linearly also from 17.33^o to 29.67^o. From the results, it is recommended to use an angle of tilt less than 40^o in the design of process components requiring easy movement of products along its surface.

Keywords: *African Yam Bean, Engineering Properties, Process Optimization Procedure, Soaking Time.*

1. INTRODUCTION

African yam bean, *Sphenostylis sternocarpa*, is a leguminous crop grown in West Africa, particularly, in Cameroon, Cote d'lvoire, Ghana, Togo and Nigeria. It is grown as a minor crop in mixed association with yam and cassava. It is used extensively in various dietary preparations and has potential for supplementing the protein requirement of many families throughout the year (Potter and Doyle, 1994).

In Nigeria, African yam bean is cultivated by subsistent farmers for its seeds although there are reports about the use of its tubers as food. The bean is called "odudu" in Igbo, "nsama" in Efik and Ibibio, all of which are local dialects in Nigeria. The ripe pods vary between 120 and 130mm in length and contain 10 to 30 seeds. The smooth hard testa varies in seed size and colour. The colour of the testa varies from whitish and unmarked to various shades of brown, black, and grey with speckling or marbling.

However, despite the huge potentials which the crop presents, the crop has remained largely under-utilized as a result of lack of adequate processing equipment. Modern research efforts suggest that whenever a shift is needed from the traditional methods of cleaning, sorting, and grading; processing; preservation; storage; packaging; and transportation to improved post-harvest methods, the determination of the engineering properties of the biological material involved is often carried out prior to design and simulation studies as well as fabrication and performance evaluation of the machine intended to solve the problem (Princewill and Ogwo, 2014). The determination of the engineering properties of biological materials is often carried out with a view to mitigating the challenges posed by modern design techniques. Process optimization procedure is a design technique utilized in the manufacture of process equipment (Vanderplaats, 2007; Raju et al., 2014). This method allows for the use of relevant input and response parameters. Since the decisions that will be taken during the design stages will ultimately dependent largely on the outcome of the analysis between the most relevant parameters involved, choosing the correct input and response parameters is a very important step in process optimization. An input parameter is one that has the capacity to cause a change in a biological material whereas a response parameter is that whose behaviour alters as a result of the introduction of an input parameter. Soaking is a unit operation utilized in processing, preservation, etc., to cause some targeted alterations such as the yield of certain constituents which are considered to be very important to the process thus, making soaking time a relevant input parameter. Does soaking time influence the engineering properties of white African yam bean? If yes, is it significant? If significant, how does this influence the design of process equipment, machines and operations? Interestingly, these questions follow closely to similar questions asked frequently by curious researchers in their efforts to link several input parameters to some specific response parameters of utmost relevance to process optimization. Accordingly, many authors (Simonyan et al., 2009; Nalbandi et al., 2010; Wandkar et al., 2012; Tavakoli et al., 2009a) have worked and reported on the use of certain key input parameters such as fluctuating the amount of moisture a given biological material can hold under certain specified conditions by way of drying, spraying, soaking in fluid, suspension in humid environment, time of exposure of the material during soaking and suspension, etc, while simultaneously observing the response of the material in terms of its shape and size, true density, bulk density, porosity, hardness, shear strength, tensile strength, compressive strength, specific heat, thermal conductivity, thermal diffusivity, electrical conductivity, reflectance, absorptance and transmittance, etc. Despite the overwhelming importance of the subject to design, process analysis and control, there appears to be a lack of useful data on some of the species of most crops. Consequently, this current research is aimed at providing useful design data by examining the effect of soaking time on some selected engineering properties of white African yam bean.

2. MATERIALS AND METHODS

2.1. Experimental Procedures

The white variety of African yam bean used for this study was obtained at a market (New market) in Aba, Abia State, Nigeria. The seeds, upon returning from the market, were cleaned manually to remove all foreign matter such as dirt, stones, immature and broken seeds. A marked bowl capable of containing enough seeds to meet the various experimental determinations was used to draw random samples of approximately 2.5kg, 2.9kg and 3.8kg from the lot for each replicate at a specified treatment (soaking time).

Experimental determination of the engineering properties of the samples was carried out at the Department of Agricultural and Environmental Engineering Laboratory, Rivers State University of Science and Technology, Nkpolu-Oroworukwo, Port Harcourt, between October 21, 2013 to December 17, 2013.

2.2. Experimental Determinations

A digital vernier caliper with a sensitivity of 0.001mm was used to obtain the length, width and thickness dimensions of each unit seed of 10 seeds sampling. A single seed was placed within the vernier caliper measuring unit and the nob adjusted until the seed is just firmly held before taking its reading. The applied force on the adjustable nob of the vernier caliper was manually controlled in order to minimize damage to the sample due to excessive compressive force. The process was done for three (3) replications and the average result calculated and recorded.
Geometric mean diameter was determined for each seed at specified soaking time from the average measurements of the length, width and thickness with the expression presented by Mohsenin (1980):

$$D_g = (abc)^{\frac{1}{3}}$$

Where D_g is Geometric Mean Diameter, *a* is Length (Major diameter), *b* is Width (Minor diameter), *c* is Thickness (Intermediate diameter). Sphericity was calculated using the expression by Mohsenin (1980):

$$\emptyset = \frac{(abc)^{\frac{1}{3}}}{a}$$

Mass was determined by weighing each unit seed of 10 seeds sampling on an electronic scale with an accuracy of 0.01g. This was done for three (3) replications and the average mass was used. Volume of the seeds was calculated from the expression presented by Mohsenin (1980):

Volume = (sphericity)^3 x volume of circumscribing sphere
Where volume of circumscribing sphere = $\frac{\pi}{6} \times a^3$
True density of seeds was determined by using the mathematical expression suggested by Mohsenin (1980) by dividing the mass of a single African yam bean with the volume of that particular single seed using the following equation:

$$\text{True density} = \frac{\text{Mass of single seed}}{\text{Volume of that particular seed}}$$

The Bulk density was determined using the standard test weight procedure in which bulk seeds were poured from a standard height of 15cm into a standard container (20cmx20cmx10cm) at a constant rate. The surface was then leveled with a hard 30cm meter rule without causing any considerable compaction on the bulk grains. Mathematically:

$$\text{Bulk density} = \frac{\text{Mass of seeds in the box}}{\text{Volume of the box}}$$

This method has been used by (Gebreselassie, 2012; Davies, 2010 and Davies, 2009).
The porosity of the seeds was calculated from the values of the bulk and true densities by using the mathematical equation suggested by Ogunjimi et al (2002) and Ozguven and Vursavus (2005):

$$\varepsilon = 100(1 - \frac{\rho_b}{\rho_s})$$

Where ε is the porosity, ρ_b is the bulk density and ρ_s is the true density.
Static coefficient of friction was determined by using the method described by Vikash et al (2013). The following equation was used to calculate the static coefficient of friction:

$$\text{SCF } (\mu) = \frac{\text{Limiting frictional force}}{\text{Normal reaction}}$$

The angle of repose was measured using a wooden box filled with the seeds and then mounted on a tilting table top as described by Igbeka et al (2006).

3. RESULTS AND DISCUSSION

Scientific equipment with specific measuring capacities was used to obtain observations of some response parameters of white African yam bean. Initially, it was thought that because of the perceived physical appearance of the observed seeds, a number of the response parameters of these seeds would not register significantly over a specified period of soaking time

However, this view was discarded as our findings indicated otherwise, in which soaking time showed a significant effect on most of the selected engineering properties of white African yam bean.Table 1 below shows the results obtained from the analysis

TABLE 1: Some Engineering Properties of Soaked White African Yam Bean

SAMPLE	LENGTH	WIDTH	THICKNESS	GEOMETRIC MEAN DIAMETER	SPHERICITY	MASS	VOLUME	TRUE DENSITY	BULK DENSITY	POROSITY	SCF	ANGLE OF REPOSE
AWT	7.63^{bd}	6.20^{a}	5.63^{b}	6.43^{b}	0.84^{a}	0.29^{b}	0.15^{b}	2.24^{a}	0.796^{a}	60.30^{a}	0.517^{b}	17.33^{b}
BWT	8.13^{bcd}	6.37^{a}	5.98^{ab}	6.70^{ab}	0.77^{g}	0.39^{c}	0.16^{b}	2.27^{a}	0.685^{g}	66.37^{a}	0.628^{c}	22.00^{c}
CWT	10.10^{ac}	6.69^{a}	6.36^{ab}	7.53^{ab}	0.75^{f}	0.48^{d}	0.24^{ab}	2.31^{a}	0.676^{f}	67.83^{a}	0.6597^{d}	24.67^{d}
DWT	10.39^{a}	6.75^{a}	6.45^{ab}	7.59^{ab}	0.73^{e}	0.49^{ad}	0.24^{ab}	2.32^{a}	0.667^{e}	68.83^{a}	0.715^{e}	26.33^{e}
EWT	10.81^{a}	6.83^{a}	6.50^{ab}	7.81^{ab}	0.72^{d}	0.54^{ad}	0.26^{ab}	2.36^{a}	0.657^{d}	69.03^{a}	0.758^{f}	27.67^{ef}
FWT	11.05^{a}	7.18^{a}	6.97^{a}	8.20^{a}	0.71^{c}	0.56^{ad}	0.30^{ab}	2.43^{a}	0.636^{c}	73.87^{a}	0.789^{g}	28.00^{f}
GWT	11.10^{a}	7.29^{a}	7.26^{a}	8.26^{a}	0.70^{b}	0.57^{a}	0.32^{a}	2.45^{a}	0.629^{b}	74.10^{a}	0.836^{a}	29.67^{a}
LSD	2.03	1.299	1.29	1.71	0.0024	0.08	0.15	0.58	0.0014	19.90	0.00135	1.610

Comment: *Samples with different superscript have significant difference.*

Keywords:
AWT - Sample soaked for 0minute
BWT - Sample soaked for 90minutes
CWT - Sample soaked for 180minutes
DWT - Sample soaked for 270minutes
EWT - Sample soaked for 360minutes
FWT - Sample soaked for 450minutes
GWT - Sample soaked for 540minutes

Units:
Length, Width, Thickness and Geometric mean diameter – millimeter (mm)
Mass - gram (g)
Volume - cm^3
True density and bulk density - g/cm^3
Porosity - %
Angle of repose - α^0

3.1. Grain dimensions

Figure 1 shows a combine plot of length, width and thickness against soaking time. The figure reveals that the length, width and thickness increased non-linearly from 7.63mm to 11.10mm, 6.20mm to 7.29mm, and 5.63mm to 7.26mm respectively with increased soaking time. The effect of soaking time on the length and thickness of white African yam beans was statistically significant ($p<0.05$), while on the width, there was no significant difference. The increase in the grain dimensions could be as a result of moisture absorption as soaking time increased thus causing a uniform volumetric expansion of each unit seed. Though the volumetric expansions of the seeds were uniform, their rates of expansion along the length, width and thickness differed. The calculated geometric mean diameter also increased, from 6.43mm to 8.26mm with increasing soaking time (Figure 2).

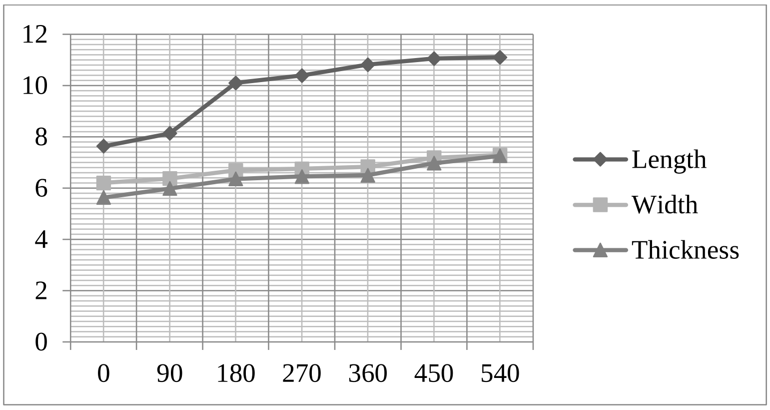

Figure 1: Variation of grain dimensions with soaking time

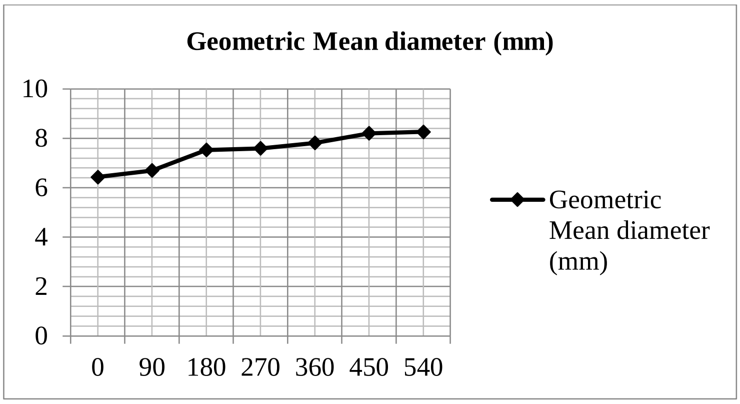

Figure 2: Variation of geometric mean diameter with soaking time

Similar results have been reported by Igbozulike and Aremu (2009) for Garcinia kola seeds, Altuntas and Erkol (2010) for shelled and kernel walnuts, Davies et al (2011) for three varieties of cowpea, Lella et al (2013) for Pistachio nuts, Princewill and Ogwo (2014) for brown-speckled African yam bean, and Ajav and Ogunlade (2014) for Ginger.

3.2. Sphericity

Table 1 shows values of sphericity at different soaking times. As against our earlier belief that increase in the volume of white African yam bean seeds could lead to seeds approaching spheroids, Table 1 indicates otherwise as there was a decrease in sphericity from 0.84 to 0.70 as the soaking time increased. An explanation of this behaviour could be attributed to the non-uniform rates of increase in the grain dimensions thus resulting into an increasing differential between the volume of the seeds and the volume of the smallest circumscribing spheres at the end of each soaking time. This notwithstanding, significant difference was observed amongst the samples ($p<0.05$) and the result is in agreement with previous reports for soybean grains by Tavakoli et al (2009a), Garcinia kola seeds by Igbozulike and Aremu (2009), for *N. lappaceum* seed by Zakariya and Yang (2012), for Brown-speckled African yam bean by Princewill and Ogwo (2014), and Ginger by Ajav and Ogunlade (2014). However, it is in contrast with works published for some grain legume seeds by Altuntas and Demirtola (2007), barley grains by Tavakoli et al (2009b), three varieties of cowpea by Davies et al (2011), and Pistachio nuts by Lella et al (2013).

3.3. Mass

The mass of each unit seed of white African yam bean showed a steady increase from 0.29g to 0.57g as soaking time increased (Table 1). Expectedly, the result confirms the affirmation that biological materials such as white African yam beans are hygroscopic in nature and hence has a tendency to hold water under a given condition as well as being able to adjust to take up more water once the condition changes (Mohsenin, 1980). Initially, only a few water holding sites within the cells are utilized as soaking commenced. Under such circumstance, the seeds have a maximum amount of water it can hold until the condition changes and the water holding sites are being increased. It is this increase in the water holding sites and the ability of the sites to retain the absorbed water within its confinement that gives rise to the increase in mass of each unit seed. At 5% studentised range, the effect of soaking time on mass was found to be significantly different.

This result is in tandem with results of previous works reported by Altuntas and Demirtola (2007), Polat et al (2007), Simonyan et al (2009), Nalbandi et al (2010), Lella et al (2013), Princewill and Ogwo (2014) for some grain legume seeds, Pistachio nuts, Lablab purpureus (L.) sweet seeds, T. L. seeds and wheat kernels, Pistachio nuts, and brown-speckled African yam bean respectively.

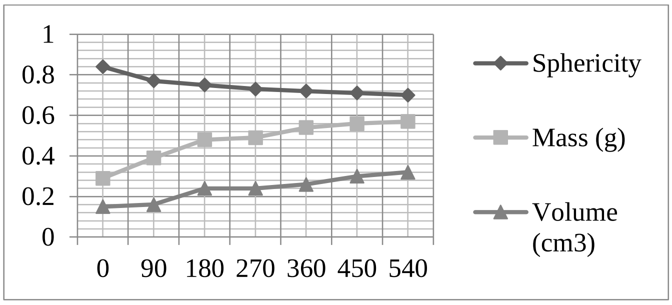

Figure 3: Variation of Sphericity, Mass and Volume with soaking time

3.4. Volume

The increase in volume of each unit seed of white African yam bean from 0.15cm^3 to 0.32cm^3 as soaking time increased appears to be non-linear as shown in Figure 3. However, since the volume of biological materials correlates to the rate at which substances are produced and consumed within the cells (Wikipedia, 2015), a steady and slow rise in the volume of the sampled seeds over a specified period of time indicates that the overall utilization of cell content for cell enlargement is considerably small. This is because much of what is produced within the cell is consumed and the waste that is generated is easily evacuated due to a large surface area of the soaked seeds. Hence, the materials which would have ordinarily supported a tremendous increase in the cell content is heavily consumed after production than accumulated thus leading to a small increase in the volume over time. When compared, it was found that the effect of soaking time on volume was significantly different ($p<0.05$). Simonyan et al (2009) reported a similar result for Lablab purpureus (L.) sweet seeds, Altuntas and Erkol (2010) for shelled and kernel walnuts, Nalbandi et al (2010) for T. L. seeds and wheat kernels, Gharib-Zahedi et al (2010) for black cumin, Lella et al (2013) for Pistachio nuts, Princewill and Ogwo (2014) for brown-speckled African yam bean, and Ajav and Ogunlade (2014) for Ginger.

3.2. True density

As shown in Figure 4, the true density of the seeds varied from 2.24g/cm^3 to 2.45g/cm^3, indicating an increase as the soaking time increased. It was further revealed that during the initial stages of soaking, the increase in the ratio of the mass of single seed to its volume was proportional until after 180mins of soaking. Although the observed proportionality did not exceed beyond this point, an explanation of this behaviour could be attributed to the non-uniform rates of increase in both mass and volume of each unit seed after 180mins of soaking. The effect of soaking time on the true density of the seeds was statistically significant ($p<0.05$).

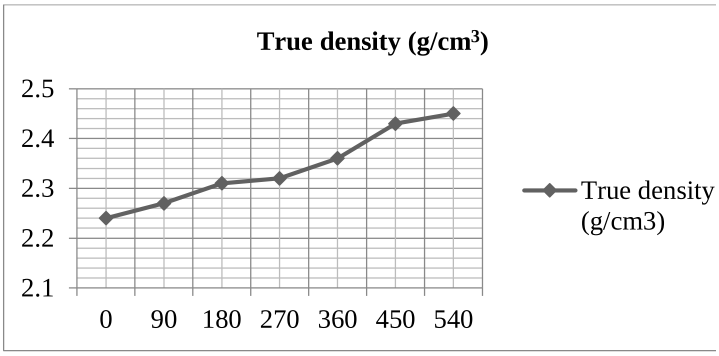

Figure 4: Variation of True density with soaking time

Similar trends were reported for Black cumin seed by Gharib-Zahedi et al (2010), T. L. seeds and wheat kernels by Nalbandi et al (2010), Pistachio nuts by Lella et al (2013), and Brown-speckled African yam bean by Princewill and Ogwo (2014). However, different results were recorded by Zewdu and Solomon (2006) for Tef seed, Igbozulike and Aremu (2009) for Garcinia kola seeds, Davies et al (2011) for three varieties of cowpea, Tavakoli et al (2009b) for barley grains, and Tavakoli et al (2009a) for soybean seed.

3.6. Bulk density

The values of bulk density of white African yam bean samples at different treatments are as shown in Table 1. The table reveals that bulk density decreased from 0.796g/cm^3 to 0.629g/cm^3 as soaking time increased. This means that the numerical value of bulk mass of the seeds is less than the numerical value of bulk volume of the same seeds as soaking time increased thus resulting in a ratio less than 1. Ordinarily, the decrease in the values of bulk densities was unexpected considering the fact that both mass and volume increased as soaking time increased and at such, their ratios ought to have increased likewise. The reason for this decrease is still not very clear. At 5% level, the results were found to be statistically significant. However, some researchers namely: Ajav and Ogunlade (2014), Zewdu and Solomon (2006), Tavakoli et al (2009a), Simonyan et al (2009), Gharib-Zahedi et al (2010), Zakariya and Yang (2012), Princewill and Ogwo (2014), and have reported similar results as moisture content increased for ginger, Tef seed, soybean grains, Lablab purpureus (L.) Sweet seeds, Black cumin seed, *N. lappaceum* seed, and Black-speckled African yam bean respectively; whereas Igbozulike. and Aremu (2009) reported a different result for Garcinia kola seeds Ajav and Ogunlade (2014), Zewdu and Solomon (2006), Tavakoli et al (2009a), Simonyan et al (2009), Gharib-Zahedi et al (2010), Zakariya and Yang (2012), Princewill and Ogwo (2014), and have reported similar results as moisture content increased for ginger, Tef seed, soybean grains, Lablab purpureus (L.) Sweet seeds, Black cumin seed, *N. lappaceum* seed, and Black-speckled African yam bean respectively; whereas Igbozulike and Aremu (2009) reported a different result for Garcinia kola seeds.

3.7. Porosity

A steady increase in the values of porosity from 60.30% to 74.10% as soaking time increased was observed (Figure 6). An explanation for this increase can be linked to differential changes in values of bulk density and true density thus indicating that heat transfer applications such as drying can be carried out more rapidly when the seeds are soaked prior to preservation. The effect of soaking time on the porosity of the seeds was statistically significant ($p<0.05$). Previously reported works for Black cumin seed by Gharib-Zahedi et al (2010), three varieties of Cowpea by Davies et al (2011), Pistachio nut by Polat et al (2007), soybean grains by Tavakoli et al (2009a), and Brown-speckled African yam bean by Princewill and Ogwo (2014) are in agreement with this result. It is, however, in disagreement with those of Ginger by Ajav and Ogunlade (2014), Pistachio nuts by Lella et al (2013), barley grains by Tavakoli et al (2009b), Lablab purpureus (L.) Sweet seeds by Simonyan et al (2009), and shelled and kernel walnuts by Altuntas and Erkol (2010).

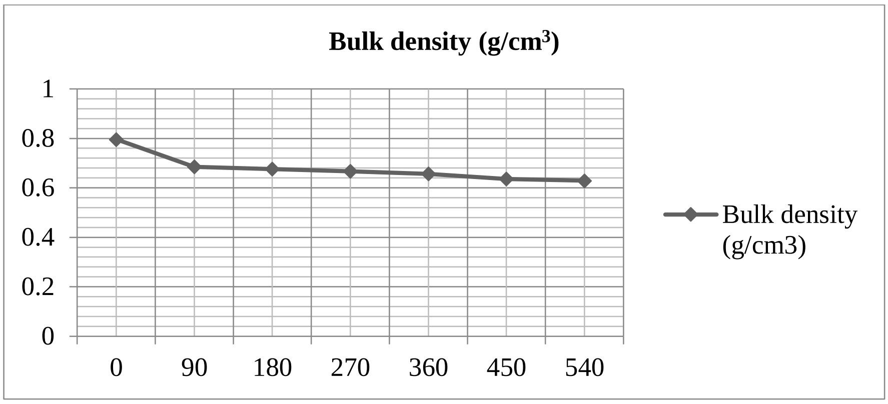

Figure 5: Variation of Bulk density with soaking time

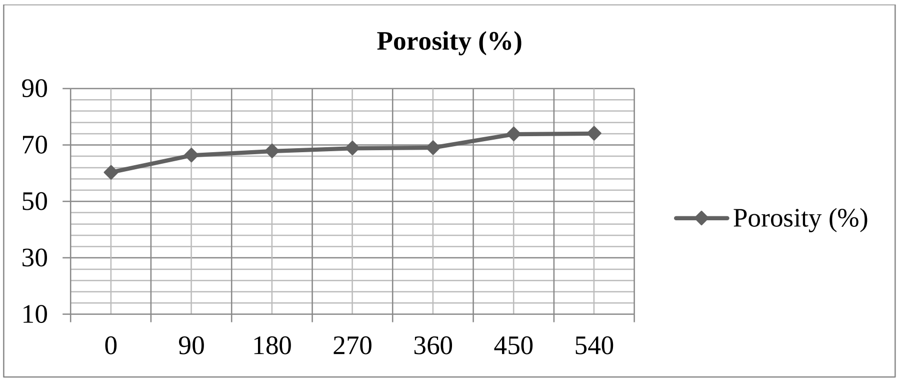

Figure 6: Variation of Porosity with soaking time

3.8. Static coefficient of friction

Figure 7 shows that static coefficient of friction varied nearly directly proportional to soaking time as it increased from 0.517 to 0.836. Like standard engineering materials whose values of static coefficient of friction for dry surfaces often fall below 1(Chowdhury et al., 2012), the range of values of static coefficient of friction given for white African yam bean are no different thus suggesting that soaked white African yam bean would require greater energy to pull it over dry surfaces than unsoaked seeds particularly in handling operations where bulk movement of seeds in conveyors are needed. At 5% studentised range, it was found that the effect of soaking time on static coefficient of friction was significantly different.

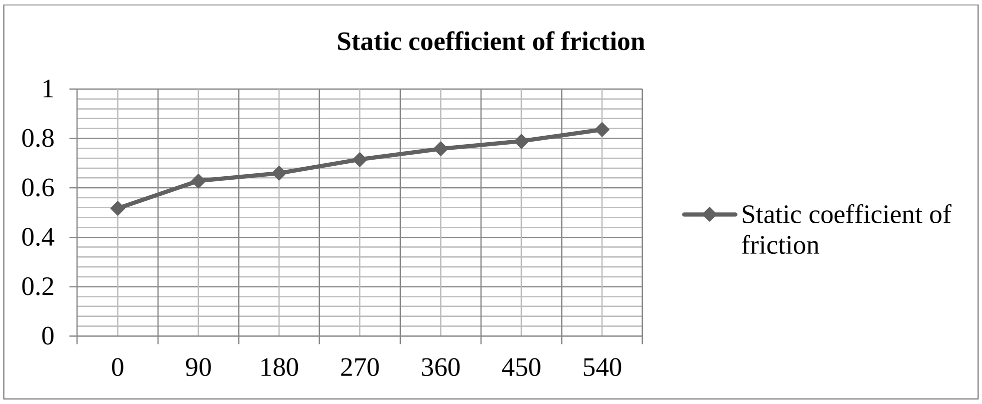

Figure 7: Variation of Static coefficient of friction with soaking time

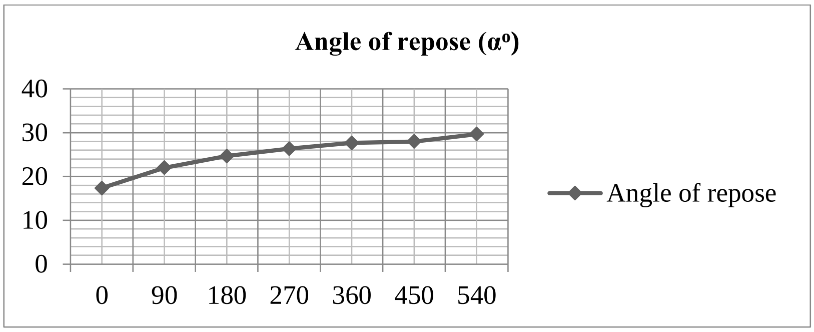

Figure 8: Variation of Angle of Repose with soaking time

Igbozulike and Aremu (2009) reported similar results for Garcinia kola seeds as well as Altuntas and Demirtola (2007) for some grain legume seeds, Tavakoli et al (2009b)for barley grains, , Gharib-Zahedi et al (2010) for Black cumin seed, Princewill and Ogwo (2014) for Brown-speckled African yam bean, and Ajav and Ogunlade (2014) for ginger.

3.9. Angle of repose

As shown in Figure 8, values of angle of repose increased non-linearly from 17.33^o to 29.67^o as the soaking time increased. This implies that the force of attraction between the seeds and the contacting surface increased to such an extent that the asperities of both surfaces were more tightly locked together thus leading to reduced sliding tendencies between the seeds and the contacting surface. Consequently, a higher sliding angle was reached before sliding could occur (Princewill and Ogwo, 2014). At 5% level, the samples were found to be significantly different. This result is similar to those published in several literatures by Zewdu and Solomon (2006) for Tef seed, Igbozulike and Aremu (2009) for Garcinia kola seeds, Davies et al (2011) for three varieties of cowpea, Zakariya and Yang (2012) for *N. lappaceum* seed, Princewill and Ogwo (2014) for Brown-speckled African yam bean, and Ajav and Ogunlade (2014) for ginger.

4. CONCLUSION

Owing to the obvious lack of useful design data that can aid in the complete design and fabrication of some process equipment and controls, this research work concentrated on finding whether soaking time contributed meaningfully to the changes in some of the selected engineering properties of white African yam bean and if so, to find out further whether such a contribution was significant. The study has shown that soaking time significantly influenced the increase in most of the selected engineering properties of white African yam bean except sphericity and bulk density.

5. RECOMMENDATIONS

Compelled by the desire to provide the much needed data for the complete design of equipment, processes and controls for white African yam bean, the following recommendations were made:

1. Studies targeted at establishing the contribution of each of those engineering properties that were significantly influenced as soaking time increased to some physical operations like cleaning, sorting, and grading should be carried out with a view to making process optimization a lot easier.

2. The effect of soaking time on the static coefficient of friction and angle of repose of some other surfaces like mild steel, stainless steel and aluminum should be investigated.

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