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Influence of Parboiling Temperature and Time on the Mechanical Properties of African Breadfruit *(Treculia africana)* Seeds

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Abstract: Mechanization is panacea to the drudgery inherent in the parboiling for dehulling of ABF. The influence of parboiling temperature and time on some mechanical properties of ABF was investigated. Parboiling was accomplished by using a thermostat fitted water bath. At temperature range of 60°C, 80°C, and 100°C for parboiling time of 10 min., 20 min., 30 min and 40 min. The compression test was performed using the Instron testing machine. Values determined from the Instron testing machine was used to compute the mechanical properties using standard mathematical models. Results revealed that the mechanical properties of ABF were significantly ($p \leq 0.05$) affected by parboiling temperature and time. Increasing parboiling temperature and time reduced some of the mechanical properties such that the deformation reduced from 9.007 N±0.113 mm at ambient condition to 5.942 mm±0.061 mm at 60°C of 20 min of parboiling and 1.507 mm±0.049 mm at 100°C of 40 min of Parboiling. The compressive force reduced from 135.366 N±0.00 N at ambient condition to 4.476 N±0.035 N at 100°C of 40 min of Parboiling. Stiffness reduced from 14.723 N/mm±0.055 N/mm at ambient condition to 3.320 N/mm±0.008 N/mm at 100°C of 40 min of Parboiling. Compressive stress reduced from 1.310 N/mm^2±0.044 N/mm^2 at ambient condition to 0.908 N/mm^2±0.006 N/mm^2 at 100°C of 40 min of Parboiling. The modulus of elasticity also reduced from 1.188 N/mm^2±0.015 N/mm^2 at ambient condition to 0.487 N/mm^2±0.001 N/mm^2 at 100°C of 40 min of Parboiling. However, parboiling temperature and time increased the seeds diameter increased from 16.227 mm±0.456 mm at ambient condition to 19.673 mm±0.065 mm at 100°C of 40 min of Parboiling. Compressive strain of the ABF also increased from 1.096 mm/mm±0.044 mm/mm at ambient condition to 1.870 mm/mm±0.162 mm/mm at 100°C of 40 min of Parboiling. These findings can now be integrated into designing processes and mechanical systems for parboiling and dehulling ABF.

Keywords: Parboiling, Mechanical Properties, Temperature, Time, African Breadfruit Seeds

1. Introduction

African Breadfruit (*Treculiaafricana*) is a tropical grain leguminous plant that belongs to the mulberry family called moraceae found in Africa and West indies [1, 2]. African breadfruit can be found in Senegal, Southern Sudan, Angola, Central Mazambique, Sao Tome and Principe. It is largely found around the humid forest of West Africa, central Africa and in Jamaica as well as in the derived savanna regions. In West Africa, it is widely grown and consumed in the southern part of Nigeria and in Ghana [1, 3]. In the South Eastern States of Nigeria, ABF are ranked as the first most populous cash crops commonly consumed and of great economic importance [3]. It has various tribal names in Nigeria because of it prolific nature such as ‘ukwa’ by the Igbo tribe, ‘bere foo foo’ by the

Yorubatribe, 'ediang' by the Efik and Ibibio tribe, 'ize' by the Benins, and 'bafufuta' by the Hausas. [4, 3].

The picture of the ABF is presented in Figure 1. The seeds are oblong in shape, much like the shape of rice seeds but can be about 3 to 5 times bigger than rice seed. It has a heard cover called hull, an inner thin layer (membrane) called the seed coat. The cotyledon known as the kernel which encloses the embryo is the edible part. The hull is brown in color which changes to black due to oxidation during fermentation and parboiling [5, 6]. The nutrient composition of ABF includes carbohydrate, protein and fat. Under favorable farming season, a tree of ABF can produce about 0. 12 Ton to 0. 20 Ton of the seeds. It is an income earning tree crop for many in the region [7]. Farmers and sellers of African breadfruit seeds in the South-Easter and South-South regions of Nigeria as reported by [3] sell for 28 kg of undehulled fresh seeds for sales NGN 500.00 while the same quantity for perboiled dehulled seeds can be sold as much as NGN 850.00

Figure 1. *African Breadfruit (Treculia Africana) Seeds.*

The African Breadfruit seeds are highly nutritious but underutilised crop, which can be eaten as cooked, either fresh or dried meal, roasting or be made into flour for further applications [8]. The mineral composition also includes; calcium phosphorous iron, carotene, vitamin c, thiamin, riboflavin [9]. Each seed of African breadfruit contains about 14-17% crude protein [10, 11], 35-60% carbohydrate, 2.5% crude fiber. It is also a good source of vitamins and minerals. The amino acid composition has also been highlighted to further buttress its nutritional potentials [12].

The objective of parboiling ABF is to ease dehulling and significantly enhance the texture. Parboiling is a form of seed cleaning process by which the texture, appearance, and culinary properties of the seed grains are improved upon by removing fibrous coloured- tough coat (hull) which usually contain poisonous bitter tannin [13]. Parboiling also enhances the ease of digestion and effective utilization of the nutrient compositions of the cotyledons, dehulling also reduces the cooking time. Moreover, hulls of grains generally contributes very little value to the food hence are usually discarded [14].

As a way to improve the dehulling process and reducing the inherent drudgery, a mechanical dehulling process for ABF was developed [15] which involved soaking in hot water at 80°C for 15 min. This was followed by quick steaming for 15 min in a steam chamber. The hot water soaking and steaming brought the moisture content of the seeds within 17-24%, followed by a one hour conditioning of the seeds, bringing the seeds to a final moisture content of 7-10% before dehulling in the polished chamber of a commercial rice milling machine which utilizes abrasive principle. The operation was associated with attrition losses (splitting). This line of operations is cumbersome, expensive and may contribute to high production cost.

The duration of cooking Nera Seeds or African locust beans *(Parkiabiglobosa*) seeds resulted in swelling, dilation of hulls and cotyledons which brought about enhanced efficient dehulling operation [16]. The effects of cooking temperature and time was also linked with water uptake of the seeds which generated increase in seed mass, enlargement of seed diameter causing volume expansion and subsequently variations in true and bulk densities.

ABF are rounded and surrounded by elastic hull. To effectively describe the failure of agricultural seeds compressed between parallel plates, some simplifying assumptions needs to be taken into consideration such as; the compressibility of the cotyledon is very slow such that the volume is constant, agricultural seeds hull thickness are thin that the geometrical calculation is insignificant, the seeds compressed between parallel plates are circular in initial phase of deformation and deforms further into barrel of parabolic shape as compression continues [17]. Using the assumption of constant volume, makes it possible to determine the changes on surface area describing the sphericity of the ABF been compressed. As compression of agricultural seeds increases the inner pressure leads to seed coat tension, which builds up till it ruptures and crack which can be deduced from the force-deformation curve [17].

Due to the complex structure of most agricultural food materials, the determination of some mechanical properties such as the modulus of elasticity presents serious challenges. However, many researchers have determined the modulus of elasticity of some agricultural seeds from force - deformation curves, based on Hertz theory by applying small loading rate in short times [18]. In determining the characteristics of Rapeseeds and Sunflower seeds under compression loading the force-deformation curves was used to determine parameters as deformation and deformation energy which result revealed an increasing function and serration effect [19].

The study conducted on *Jatrophacurcas L.* seeds revealed that there are 3 stages of increasing function of the force - deformation curve dependency, which contributes to the complexity of determining some mechanical properties of agricultural seeds [20]; Stage 1 which is a linear function between the force and deformation and this is the stage where oil release from seeds starts. Stage 2 is the area under the curve, where oil recovery from the seeds is at maximum. Stage 3 describes the stage of energy utilization efficiency in relation to seed oil recovery.

The interaction effects of heating temperatures and time on the deformation energy of sunflower seeds significantly increased the deformation energy during compressive loading [18]. The elastic modulus of pea pod, at loading rate of 5 mm/min and moisture content of 18% (wb) was studied [21].

The report revealed that the elastic modulus of pea pod decreased with the increasing moisture content. In another report, [22] determined the elastic modulus of red bean grains as a function of moisture content and loading rate. The report revealed that the Young's modulus of pea pod decreased from 253.26 Mpa with 3% moisture content to 93.06 Mpa with 15% moisture content. In other hand, the Young's modulus increased as loading rate increased from 3 to 15 mm/min.

The compressive force required to achieve the desired seed coat rupture of African nutmeg decreases as moisture level increases. The compressive force values varied from 56.6N to 33.0N from moisture content level of 8.0% and 20.7%, respectively [23]. It was also reported that the loading orientation influences the response of African nutmeg to deformation [24]. The report also stated that seed coat rupture needed a lower force at high moisture content to conserve energy. According to him, in order to maintain product quality and avoid excessive kernel breakage as to appeal to consumers, the moisture content level for African nutmeg should be at 11.2% to 14.0% (db). This corresponded to compressive force range of 53.82N to 41.55N.

The findings of [25] showed that the rupture force of Nosrat and Kabir varieties of barley grains decreases as the percentage moisture content increased. They attributed the reason for this inverse relationship to the fact that increase in moisture content of these barley grains results to the grain softening. The study of some physical properties of Feba bean *(viciafeba. L)* grains was conducted and the report stated that the rupture force of Feba bean has an inverse relationship with increased moisture content [26].

In a similar vein, the required fracture force of wheat grain was also reported to show an inverse relationship with moisture content increment [27]. The effect of temperature and storage time significantly influenced the mechanical properties and moisture content of the pistachio nut. This is in such a way that the mechanical properties such as hardness, fracture force, and firmness as well as the moisture content increased with the duration of storage. The mechanical properties and moisture contents were observed to reduce with increasing roasting temperature [28]. It was generally concluded that the mechanical and deformation characteristics of agricultural seeds vary extensively as much as their bioengineering properties during processing [29].

It is important to reveal some mechanical properties of the parboiled seeds relevant to mechanical dehulling. Moreover, information on the elastic characteristics of ABF dependent on parboiling time and temperature is essential for an optimum design of boilers and dehulling systems for ABF to ease the drudgery inherent in these unit operations. Very few research works have been carried out on the mechanical properties of African Breadfruit and specifically dealing with the influence of parboiling temperature and time on the mechanical properties of African Breadfruit. This research is not only aimed at presenting the relevant information to take care of the above stated conditions but also to generates data describing the parboiling suitability conditions of African bread fruit for optimum dehulling. Specifically this research revealed the influence of Parboiling temperature and time on the mechanical properties of African bread.

2. Materials and Methods

2.1. Samples Preparation

Bulk quantities of ABF *(Treculia Africana*) (Decnes) were obtained from six major markets in South-South and South-East geographical regions of Nigeria. The bulk quantity seeds were sorted manually to remove unwanted materials and defected seeds, to ensure that sorted samples were only healthy seeds. Sorted seeds were washed in a washing bath under a clear running tap water trice, allowed to drain off capillary water by placing them in a big basin with wire mesh base. Thereafter some fresh seeds samples were separated into parts and tied in cellophane bags and kept for treatments. Others were parboiled and separated into parts and tied in cellophane bags and kept for treatments as well. Figure 1 shows the picture of sorted, washed and clear undehulled ABF.

2.2. Parboiling of Samples

One hundred grams of seeds in 30 cl of distilled water were parboiled for each test. Parboiling in distilled water was accomplished by using a thermostat fitted water bath. Parameters for the raw samples were determined, before investigating the effect of parboiling temperature and time. Parboiling was carried out at 60°C, 80°C, and 100°C for 10min., 20min., 30min. and 40min.

2.3. Determination of Compressive Force, Deformation and Seed Diameter

The compression tests were conducted in conformity with ASAE standard 5368.4 (R2008) [30].

The test procedures are:

i. The diameters of the specimen was measured and recorded.

ii. A flat plate compression test was selected, and installed into the Universal testing machine Instron 6022 for quasi-static tests.

iii. The specimen was placed in the testing machine under the compression tool, in directions along the longitudinal (split axis).

iv. The machine was started and the compression test was run at a slow speed of 2.8 mm/min to allow for compression for a reasonable period of time before failure.

v. The complete force-deformation curve and seed diameter through the point of rupture was recorded. Three replications of the complete test performed.

vi. Values for force deformation and seed diameter to bioyield and ruptured point which was indicated by a sudden drop in force was read directly from the curve and recorded.

2.4. Calculation of the Mechanical Properties

The determinations of the compressive force requires to compress African bread fruit seeds was done using the Instron testing machine. The compression tests were conducted in conformity with ASAE standard [30]. The computerized print out of the Instron Universal testing machine (Model 4400, Instron Limited England) was read off and the required force, deformation and seed diameter were recorded. These values were used for the calculation of the modulus of elasticity of the parboiled ABF. Using the Hertzian equation for contact stress and deformation for a sphere surface as was used by [31]. The expression for Young's Modulus (Ey) and Compression stress (σ_f) for horizontal loading geometry are:

$$Ey = 0.955\left[\frac{F(1-\mu^2)}{D^{1.5}d^{0.5}}\right] \quad (1)$$

$$\sigma_f = 0.98\left[\frac{FE^2{}_y}{d^2(1-\mu^2)^2}\right]^{1/3} \quad (2)$$

$$Ey = \sigma_f / \varepsilon \quad (3)$$

$$\varepsilon = \sigma_f / Ey \quad (4)$$

$$K = \frac{F}{D} \quad (5)$$

Where:
F=Compressive force (Average Load Failure) (N)
μ =Poisson ration=0.4
D=Deformation (mm)
d=Diameter of seeds (mm)
ε =Compression Strain (N/mm^2)
K=Stiffness (N/mm)

All experiments and analysis were carried out in triplicate. Data were subjected to one way analysis of variance (ANOVA) by using the Minitab 16, 2010 computer software. Observed Mean values were compared for significant difference ($p<0.05$) using Tukey's multiple comparison test.

3. Results and Discussions

Table 1 presents the relevant information deduced from the computer print-out of the Instron testing machine showing the effect of parboiling temperature and time on compressive force, deformation and seed diameter of African bread fruit. Table 2 presents the computation of the mechanical properties using the Force – Deformation results obtained from the Instron testing machine to validate equations 1 to 5.

Table 1. *Influence of Parboiling Temperature and Time on Force, Deformation and Seed Diameter of ABF Deduced from the Instron Testing Machine.*

Temperature (ϴ°C)	Retention Time (min.)	Force (N)	Deformation (mm)	Seed Diameter (mm)
28 (Raw)	0	135.366^{a}±0.000	9.007^{a}±0.113	16.227^{gh}±0.455
60	10	54.244^{b}±0.059	9.167^{a}±0.005	16.356^{gh}±0.422
	20	44.474^{c}±0.786	5.942^{abc}±0.061	15.904^{h}±1.051
	30	37.941^{d}±0.708	3.937^{bc}±0.059	17.712^{cdefg}±0.070
	40	32.147^{e}±0.069	3.457^{bc}±0.048	17.542^{defg}±0.072
80	10	18.932^{gh}±0;078	3.402^{abc}±0.573	17.90^{bcdef}±0.284
	20	12.173^{j}±0.336	2.871^{bc}±0.077	18.186^{bcdef}±0.266
	30	10.425^{kl}±0.008	2.419^{bc}±0.113	17.158^{efg}±0.048
	40	10.283^{kl}±0.058	2.385^{ab}±3.189	18.423^{abcd}±0.055
100	10	9.416l^{m}±0.946	2.232^{bc}±0.218	18.828^{abc}±0.115
	20	8.996^{mn}±0.120	2.573^{bc}±0.003	19.314^{ab}±0.514
	30	5.794^{o}±0.099	1.697^{c}±0.021	18.782^{abc}±0.582
	40	4.476^{o}±0.354	1.507^{bc}±0.049	19.673^{a}±0,065

* Values are mean of 3 replications ± Standard Deviation. Means that do not share a letter are significantly different.

Table 2. *Influence of Parboiling Temperature and Time on Mechanical Properties of ABF Computed.*

Temperature (°C)	Time (min.)	Stiffness (N/mm)	Compressive Stress (N/mm^2)	Compressive Strain (mm/mm)	Elastic Modulus (N/mm^2)
28 (Raw)	0	14.723^{a}±0.055	1.310^{bc}±0.044	1.096^{h}±0.044	1.188^{a}±0.015
60	10	5.905^{c}±0.013	0.531^{bc}±0.051	1.305^{g}±0.005	0.382^{j}±0.006
	20	7.536^{b}±0.005	0.834^{bc}±0.039	1.383^{efg}±0.007	0.634^{d}±0.052
	30	8.508^{b}±1.382	1.432^{bc}±0.027	1.527^{def}±0.010	0.916^{c}±0.032
	40	6.063^{c}±0.003	1.440^{bc}±0.029	1.553^{cde}±0.001	0.974^{b}±0.016
80	10	4.672^{cde}±0.008	0.705^{bc}±0.084	1.528^{cdef}±0.058	0.437^{hij}±0.008
	20	3.6404^{de}±0.023	0.630^{bc}±0.026	1.668^{abcd}±0.094	0.389^{j}±0.011
	30	4.359^{de}±0.007	0.881^{bc}±0.005	1.660^{bc}±0.012	0.537^{ef}±0.008
	40	3.628^{de}±0.023	0.616^{a}±0.016	1.662^{bcd}±0.038	0.^{396j}±0.006
100	10	4.550^{de}±0.015	0.945+±0.006	0.664^{j}±0.009	0.582e±0.10
	20	3.693^{de}±0.004	0.696^{bc}±0.003	1.623^{bcd}±0.053	0.428^{hij}±0.009
	30	3.348^{e}±0.007	0.843^{bc}±0.002	1.735^{abc}±0.72	0.481^{gh}±0.006
	40	3.320^{ide}±0.008	0.908^{bc}±0.006	1.870^{ab}±0.162	0.487^{fgh}±0.001

* Values are mean of 3 replications ± Standard Deviation. Means that do not share a letter are significantly different.

3.1. Influence of Parboiling Temperature and Time on the Compressive Force of ABF

The influence of temperature and time on the compressive force of parboiled African Bread fruit is presented on Table 1. The compressive force required for the raw ABF at ambient condition was 135.366 N. At 60°C of heating temperature, the compressive force value reduced to 54.244 N, 44.474 N, 37.941 N and 32.147 N after 10 min. 20 min 30 min and 40 min of parboiling respectively. These values reduced as both temperature and retention time increased. At 100°C of parboiling, the required compressive force values were 9.416 N, 8.996 N, 5.794 N and 4.476 N after 10 min., 20 min., 30 min., and 40 min. respectively during parboiling. For all the temperature treatments, the compressive force reduced sharply within the first 10 min of Parboiling temperature and time generally affected the compressive force of ABF and the observed differences in the compressive force were significant ($p \leq 0.05$).

The compressive force of ABF parboiling reduces with increasing temperature. This may be due to the fact that molecules of agricultural seeds imbibe moisture with increasing parboiling temperature and time which swells the hulls, carbohydrate and protein contents thereby weakening their integrity (intercellular adhesion) as parboiling time and temperature increases [16]. This result also agrees with the report of Reeve [32] which states that the compressive strength of potato cells reduces during heating process and that cell of potatoes generally ruptures during heating process. Also reported was that the fracture force of superheated Cocoa seeds reduces with increasing roasting temperature and time [33]. Using the compression force as the texture parameter, it was discovered that the compression load of hazelnuts roasting decreased with increased roasting temperature and time [30]. In another report [34], the compressive force of both Adikpo and Lafia varieties of groundnut was found to decrease with increasing blenching temperature and time. The effect of temperature and storage time significantly influenced the mechanical properties and moisture content of the pistachio nut [28]. It was also reported that the compression force necessary to affect the desired seed coat rupture of African nutmeg decreased with increased moisture content [24].

3.2. Influence of Parboiling Temperature and Time on the Deformation of ABF

A perusal on Table 1 reveals that the deformation of African Breadfruit at ambient temperature (28°C) was 9.007 mm. After the heating of the ABF in hot water to 60°C, this value was observed to be 9.167 mm at 10min, 5.942 mm at 20 min, 3.942 mm at 30 min and 3.4457 mm at 40 min residence time. Deformation further reduced as temperature goes to 100°C. Hence at 100°C, 10 min of heating deformation value was observed to be 2.232 mm, at 20 min, the value was also observed to be 2.573 mm. at 30 min, the value is 1.697 mm and 40 min the value was 1.507 mm. The observed values showed significant negative relationship between deformation and Parboiling temperature and time.

The deformation showed the same trend with compressive force. This situation may be due to the fact that hot water treatment increased the moisture uptake of African bread fruit, thereby softening the cell structures and reducing the turgidity of the seeds as was the case in compressive force. This may also suggest that deformation has a direct related with compressive force of the ABF. This finding agrees with other reports in the literatures which stated a positive relationship between force and deformation of Rapeseeds and Sunflower seeds and groundnut respectively under compression loading [19; 34]. There is a positive relationship between deformation with parboiling temperature and time for groundnut and African nutmeg respectively [24]. The varied report on the deformation behavior of different agricultural seeds confirms that different agricultural seeds display varied force-deformation properties [29].

3.3. Influence of Parboiling Temperature and Time on the Seed Diameter of ABF

Observing Table 1 reveals that the seed diameter of the parboiled seeds increased significant from 16.227 mm to 16.352 mm, when parboiled from ambient condition to 60°C for 10 min. It also increased from 16.711 mm to 19.673 mm when parboiled from 60°C, 10 min to 100°C for 40 min. The observation suggests that both temperature and time have a significant incremental effect on the overall diameter of parboiled African bread fruit.

The positive increase in the diameter of the parboiled ABF with increasing temperature and time may be due to water imbibition which swells the carbohydrate and protein content resulting in the increase in size of the fruits. This observation is in line with the report that who reveals that soaking time enhances the bulk density of wheat kernel [35]. Seed bulk and true density are related to seed diameter in dimensional analysis [16]. The soaking temperature and time increased the water imbibition of parboiled fragrant rice. In a related report, the presoaking temperature resulted in imbibition of moisture by the brown rice resulting in the swell of rice seeds [36].

3.4. Influence of Parboiling Temperature and Time on Stiffness of ABF

The result of the influence of Parboiling temperature and time on stiffness of African Breadfruit seeds is presented on Table 2. The stiffness reduced from 14.723 N/mm at ambient condition to 5.905 N/mm at 60°C of 10 min. parboiling. It reduced from 5.905 N/mm to 3.628 after 40 min. of parboiling at 80°C, thereafter reduced to 3.321 N/mm after 40 min of parboiling at 100°C. Table 2 shows that the stiffness of ABF parboiling reduced sharply within 10 min, for all the temperature treatments.

This shows that the prediction of stiffness dependent on temperature and time can be obvious with increasing parboiling temperature and time, in this case, from 100°C and that stiffness generally showed a decline with parboiling temperature and time.

The reduction in stiffness was significant and is consistent with the reports of well-meaning scholars in this field. Similarly, there exist a reverse relationship between roasting temperature and hardness of Pistachio nuts [28]. Agricultural seed cells generally rupture during heating processing [29]. It therefore follows that parboiling temperature generally influences the stiffness of African breadfruit Seeds and that the effect has an inverse relationship. Other findings stated in the literature that agrees with these reports are [26, 31, 34, 28].

The perceived undulating response of stiffness to parboiling temperature and time as shown in Table 2 is hypothesize to be due to the formation of gels of protein and starch structures of the African Breadfruit seeds at prolonged parboiling time. Reporting [37], stated that the stiffness of the gels of soy protein increased with the proportion of denatured protein which also increased with prolonged heating time. The complex structure and shape of most food materials poses a problem in predicting accurately their visco-elactic behaviors [18].

3.5. Influence of Parboiling Temperature and Time on Compressive Stress of ABF

The influence of parboiling temperature and time on the compressive stress of ABF is presented on Table 2. The compressive stress of African Breadfruit parboiling at ambient condition was 1.310 N/mm^2. The compressive stress value at 60°C was 0.531 N/mm^2 after 10 min, the compressive stress then reduced as parboiling temperature and time increased. At 10 min and 40 min of parboiling at 100°C, the compressive stress was observed to be 0.843 N/mm^2 and 0.908 N/mm^2 respectively.

As reported for other mechanical properties, the compressive stress response to parboiling temperature and time was fast within 10 min. for all the temperatures. The compressive stress generally experienced a negative trend with increasing temperature and time.

This finding is significant and is consistent with the findings stating that the failure stress of African nutmeg reduced with increasing temperature and time of parboiling [26]. A conclusion was also made that the stress experienced by Pistachio nuts reduces with high temperature of roasting [28]. In another development the compressive stress of Hezial nuts reduces with roasting time and temperature [29]. Other works reviewed in the literature inconformity with this finding [21, 34]. However, the serration of fracture stress to parboiling temperature and time after 10 min of parboiling can be attributed to the complex structure of the starch and protein content of ABF which gels when exposed to prolonged heating time [37]. This finding validates the report which states that the complex structure and shape of most food materials poses a problem in predicting accurately their rheological behavior [18].

3.6. The Influence of Parboiling Temperature and Time on Compressive Strain of ABF

The effect of parboiling temperature and time on the compressive strain as indicated in Table 2 shows that the compressive strain at ambient temperature was 1.096 mm/mm. At 60°C of 10 minutes parboiling time, the value of the compressive strain increased to 1.305 mm/mm. The compressive strain generally increased progressively with temperature and time, such that after 40 min. of parboiling at 60°C, 80°C, and 100°C, the compressive strain was 1.553 mm/mm, 1.662 mm/mm and 1.870 mm/mm respectively. The positive trend observed in the compressive strain is significant ($p \leq 0.05$). This positive trend may be due to the fact that the compression strain increased the pressure on the hulls of the African breadfruit seeds which tries to maintain its original volume thereby increasing the strain energy experienced by the hulls or walls of the seed coat.

The increase in the strain energy of the parboiled ABF is an important characteristic which may account for the maintenance of the integrity of the cotyledon during compressive dehulling. This observation is in conformity with the stated report that heating time and temperatures increases the strain energy of sunflower seeds in a compression loading [21]. The compression of an agricultural seeds, assumed to maintain its volume, generates pressure on the hulls of the seed, thereby increasing the inner pressure leading to the seed coat tension which builds up till it ruptures resulting in the seed coat cracking [17]. This also agrees with the findings which states that strain energy of African nutmeg loaded both axially and laterally increased with increasing temperature and time [26].

3.7. Effect of Parboiling Temperature and Time on Elasticity Modulus of ABF

Table 2 reveals that the Elasticity modulus of African Breadfruit seeds before parboiling was 1.188 N/mm^2. After parboiling for 10 min. at 60°C, the Modulus of elasticity value reduces to 0.382 N/mm^2. This drop in Modulus of elasticity value in the first 10 min of Parboiling was the same for all temperatures (60°C, 80°C, and 100°C). At 40 min of 100°C parboiling time, the modulus of elasticity value reduces to 0.481 N/mm^2. The observed negative relationship of parboiling on the Modulus of Elasticity of African Breadfruit may be due to moisture uptake of the seeds with increasing parboiling temperature and time which may have brought about a gradual change in the integrity of the cellular matrix due to heating and moisture imbibitions. It was also observed that the modulus of elasticity of African Breadfruit seeds reduced sharply within 10 min and increased slightly within 20 min for all the temperatures as shown in Table 2. The serration of the elasticity modulus after 10 min is hypothesised to be as a result of the onset of gelation and extensive rearrangements in the network structure of the gelling protein and starch which takes place at prolonged heating time [37]. The result stated here agrees with the report of [33] which states that blanching temperature had a negative trend on the elastic modulus of groundnut during blanching. Young's modulus tends to decrease as the temperature of African Nutmeg pre-heating increases [26]. In another report, the elastic modulus of sunflower seed decreased as the moisture content increased for all the loading rates and varieties studied [38]. This negative trend of modulus of elasticity with parboiling temperature and time is also in conformity with the findings of [39] also supported by the report of [18].

4. Conclusion

The influence of parboiling temperature and time on the mechanical properties of African Breadfruit seeds was investigated. It was discovered that parboiling temperatures and time influences the mechanical properties of African Breadfruit. The influence of parboiling temperature and time on the mechanical properties of African Breadfruit can be divided into two parts; those mechanical properties that reduce with increasing parboiling temperature and time and those that increase with increasing parboiling temperature and time. The Mechanical properties such as compressive force, deformation, stiffness, compressive stress and the elasticity modulus reduced with increasing parboiling temperature and time. These therefore suggest that parboiling reduces the energy requirement for mechanical dehulling of ABF. The compressive strain and seed diameter increased with increasing parboiling temperature and time. The influence of parboiling on the mechanical properties of African Breadfruit seeds is progressively significant within 10 min of parboiling for all the temperature treatments. This suggests the best parboiling duration for compressive seed cracking for optimum dehulling. The information obtained in this work should be utilized to optimise the unit operations of parboiling and dehulling African Breadfruit seeds. It can now be used for the design of process lines and machines for parboiling and dehulling of African Breadfruit seeds to reduce the drudgery inherent in these unit operations.

Abbreviation

ABF means African Breadfruit Seeds.
Ambient condition=28°C

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