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THE EFFECT OF MOISTURE CONTENTS ON THE PHYSICAL PROPERTIES OF BOTH BAMBARA GROUNDNUT SEEDS AND PODS IN SOUTH AFRICA

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ABSTRACT

Bambara groundnut (*Vigna subterranean (L) Verdc*) is an indigenous African crop. In South Africa, the crop is grown by rural subsistence farmers. This crop is classified as a drought-tolerant crop and it can produce good yields in poor soil conditions. However, statistics show that Bambara groundnut production is currently neglected by industries due to the lack of research on the crop focused on postharvest technologies, and agro-processing. Current research on the crop is mostly focused on agronomic and growing characteristics. Data on the physical properties and processing equipment for the Bambara groundnuts are limited. The objectives of this study were to investigate the effect of moisture contents on both Bambara groundnut seeds (shelled) and pods (unshelled). The physical properties of the pods and seeds were measured at three moisture content levels. The finding showed that axial dimensions, geometric mean diameter, sphericity, volume, and weight increase as moisture content increases. The static coefficient of friction of seeds and pods increased from 0.15 to 0.19 and 0.29 to 0.31, respectively. Simirlarly, the bulk density of shelled and unshelled groundnuts increased from 500 to 955, and 355 to 422 kg.m^{-3}, respectively. The results also showed that the true density of seeds rose from 994 to 1832 kg.m^{-3} and for the unshelled groundnuts it increased linearly from 532 to 655 kg.m^{-3}. The required forces for cracking both bambara groundnut seeds and kernels showed a declining trend as moisture increased from 6 to 20%. The cracking forces required for Bambara groundnuts kernels at 6, 15, and 20 % are 32.5 ±12 N, 29.9 ±15.3 N, and 28.9 ±9 N, respectively. As the moisture increased, the data deviation from the mean decreased from 16.30 to 10.1 N. In terms of designing agro processing eqiupment or machinary such as a shelling machine, the physical properties from the lower moisture content are recommended.

Key words: cracking force, physical properties, moisture content, Bambara groundnuts

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INTRODUCTION

Bambara groundnut (*Vigna subterranean (L) Verdc*) is an African legume crop that is currently neglected by commercial farms [1, 2]. This crop serves as a cheap and high-quality protein source in Africa [2]. These groundnuts are consumed mostly by humans and local animals [3, 4]. The Bambara groundnut crop is also known to produce reasonable yields in low productive soils [5]. In South Africa, Bambara groundnuts are produced by subsistence farmers mainly for household consumption and for sale to the local market [3, 6]. In recent years, available literature mostly has focused on the agronomic aspects of Bambara groundnuts than physical properties of the shelled nuts [3, 7, 8]. Consequently, the production of this type of crop loses value from potential investors during industrialisation. The lack of knowledge about the physical properties of crops such as Bambara groundnuts has resulted in a lack of processing, harvesting, handling, and storage equipment [9, 10]. In South Africa, the production of Bambara groundnuts is labour intensive as it is done manually by local people [3].

Mpotokwane *et al.* [8] determined the physical properties of Bambara groundnut seeds at a moisture content of 7.17 to 8.99 %. A study by Baryeh [11] further investigated the physical properties of Bambara groundnut seeds at different moisture contents. However, during the design of processing, harvesting, shelling, and storage equipment, the properties of the whole groundnuts (seeds and pods) are required. This limitation can be addressed by determining the physical properties of both the Bambara groundnut seeds and pods at different moisture content levels. The objective of this study was to investigate the effect of moisture contents on the physical properties of both Bambara groundnut seeds (shelled) and pods (unshelled). The properties include dimensions, weight, sphericity, and surface area, coefficient of static friction, porosity, and cracking force. The findings from this study could potentially assist in the design, and manufacture of equipment to process Bambara groundnuts in South Africa.

MATERIALS AND METHODS

Sample preparation

A sample of Bambara groundnuts were bought from a local market in Malelane, South Africa. The groundnuts were sun-dried for one week and stored at room temperature (23 ◦C). The samples were cleaned from all foreign materials and soil particles before storage. The initial moisture content of the samples was determined using the standard oven dry method [12, 13, 14]. The samples were

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oven-dried for 24 hours, and Equation 1 was used to calculate the initial moisture content (wet basis).

$$MC_{wd}=\frac{W_i-W_d}{W_i}\times 100 \quad \text{.........(1)}$$

Where MC_{wd} = moisture content (%w.b),
W_i = initial mass (kg), and
W_d = mass of the groundnuts after drying (kg).

The initial moisture content of samples was calculated to be 6.0 %. The samples were then separated into three groups of 100 groundnuts per group. The samples were set at three different moisture content levels of 6, (initial moisture content), 15, and 20 %. To achieve the higher moisture contents, the samples were prepared by adding a calculated amount of distilled water (Q), which was determined by using Equation 2 [15]. The samples were kept in the freezer at 4 ± 1 ^{0}C for one week for a uniform distribution of the moisture content within groundnuts [16, 17].

$$Q=\frac{W_i(M_f-M_i)}{100-M_f} \quad \text{.........(2)}$$

Where W_i = initial mass (Kg),
M_i = initial moisture (%), and
M_f = required moisture (%).

Data collection

The experiments were divided into two parts. In the first part, the physical properties of Bambara groundnut pods were determined at three different moisture contents of 6, 15, and 20 %. In the second part, groundnuts were manually shelled, and the physical properties of the nuts were measured. The physical properties that were measured include dimensions, sphericity, surface area, weight, volume, static coefficient of friction, porosity, and cracking force. These moisture content levels were selected because most South African local farmers process dried Bambara groundnuts [3]. During harvesting, local farmers pull off the plants from the soil and leave the groundnuts pods for a day or two to sun-dry [3].

Dimension, geometric mean diameter, sphericity, volume, and surface area

Throughout the experiments, samples were taken out from the refrigerator and allowed to warm up for a period of one hour [11]. The dimensions were measured in three different axis (x, y, and z) which are the length (L), width (W), and thickness (T) using a Vernier caliper. The geometric mean diameter (D_g), which is

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a function of average dimensions of length, width, and thickness was calculated from Equation 3 [6, 8].

$$D_g = (LWT)^{\frac{1}{3}} \quad \text{...(3)}$$

Where D_g = Geometric mean diameter (mm),
L = length (mm),
W = width (mm), and
T = thickness (mm).

Sphericity (Ø), which is a parameter that describes how close the groundnuts are to a perfect sphere. Equation 4 was used to calculate the sphericity of the groundnuts [8].

$$\emptyset = \frac{(LWT)^{\frac{1}{3}}}{L} \quad \text{...(4)}$$

The volume (V) and surface area (S) of pods and nuts were calculated using Equation 5 and 6, respectively [6,18].

$$V = \frac{\pi B^2 L^2}{2(2L-B)} \quad \text{...(5)}$$

$$S = \frac{\pi B^2 L^2}{2L-B} \quad \text{...(6)}$$

where $B = (WT)^{0.5}$

Weight

The weight of each groundnut was measured using a digital weighing balance calibrated to a 0.001 accuracy [8, 11]. The weight of each seed and pod was measured in grams.

Coefficient of static friction

The static coefficient of friction was measured at three different moisture contents (6, 15, and 20%). A galvanised steel sheet was used to measure this parameter. This type of steel was used because it is commonly used in small scale agricultural machines and storage facilities. The seeds and pods were placed on an adjustable tilting surface and the height at which nuts begin to move was recorded. Equation 7 was used to calculate the coefficient of static friction [6]. The experimental procedure for measuring the coefficient of static friction is demonstrated below (Figure 1).

$$\propto = \tan^{-1}\left(\frac{h}{l}\right) \text{ ....(7)}$$

where $\propto = \text{the angle of repose (mm)}$
$h = \text{a hight at which the pods or nuts starts to slide (mm), and}$
$l = \text{lenght of the plates (300mm)}$

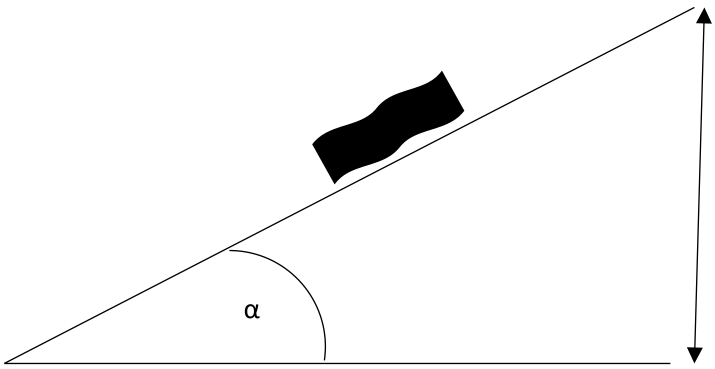

Figure 1: Experimental set up of coefficient of static of friction

Porosity

Bulk density is the ratio of mass to volume [8]. This parameter was determined by filling a 500 ml beaker with groundnuts and the weight of the samples were measured [6, 18, 19]. The bulk density was calculated as the ratio of the weight to volume of the beaker. True density was determined using the toluene displacement method, where a 500 ml beaker was filled with groundnuts and toluene chemical. The toluene was used because it has a lower surface tension and specific mass compared to water [19]. As a result, the groundnuts in the solution would not absorb this chemical. The mass of the toluene present in the container was used to calculate the true density [6, 18, 19]. Porosity was calculated by using Equation 8 [8].

$$P = \left(1 - \frac{\rho_b}{\rho_t}\right) \times 100 \text{ ....(8)}$$

Where ρ_b=bulky density $\left(kg.m^{-3}\right)$, and
ρ_t=true density $\left(kg.m^{-3}\right)$

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Cracking force

The cracking force required to crack the Bambara groundnut seeds and kernels were measured using a Universal Texture Analyser INSTRON 3340 equipment, which compresses the kernels and nuts until they start cracking [6]. The samples were placed on fixed plate during the experiments (figure 2). The results were recorded in the form of line graphs and tables. Figure 2 demonstrates how the equipment works.

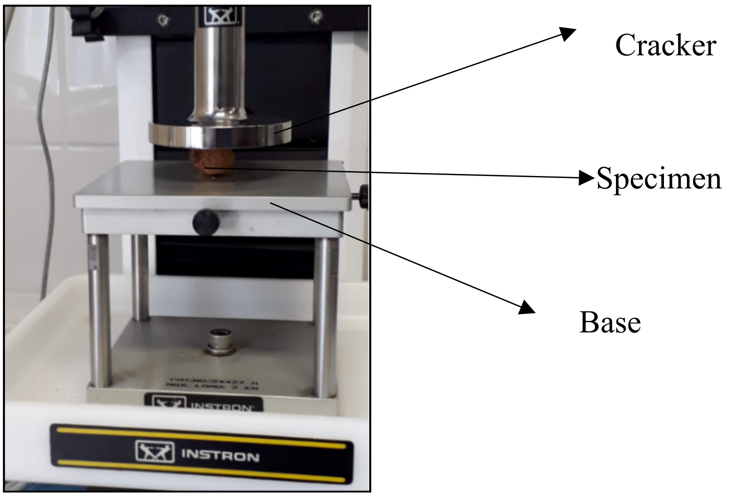

Figure 2: Texture analyser equipment which demonstrates how the cracking force was measured experimentally

Statistical Analysis

The data was analysed using 2016 Microsoft Excel, where descriptive statics were determined from summary of the data analysis option. The statistics were analysed at a 95% confidence level from the mean. Graphs and Tables were used to present the findings of the study. The regression statistical analysis method was used to determine the strength between the physical properties of Bambara groundnuts and moisture content.

RESULTS AND DISCUSSION

Dimensions, geometric mean diameter, sphericity, volume and surface area

The length of the pod ranged from 19.7 to 21.1 mm as moisture content rose from 6 to 20% (Table 1). The width and thickness ranged from 14.9 to 15.6 mm, and 13.5 to 13.7 mm, respectively (Table 1). The results show that there is a positive linear relationship between the moisture content and dimensions. During the measurement of axial dimensions, it was identified that some of the pods had double seeds, which only affected the length (L) of the groundnut. Therefore, the standard error on the length was found to be higher than that of the width (W), and

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thickness (T) of the pods. The presence of double seeds in the pods caused challenges during the design of the shelling machine. The relationship between axial dimensions (L, W, and T) and moisture contents (M_C) are represented by linear regression Equation 9 to 11. The dimensions of Bambara groundnuts are small compared to filbert nuts. The length, width, and thickness of filbert nuts ranges from 25 – 27 mm, 19- 21 mm, and 17 – 21 mm, respectively [6].

$$L = 0.099M_C + 19.27 \quad (R^2 = 0.92) \quad \text{......(9)}$$

$$W = 0.05M_C + 14.70 \quad (R^2 = 0.89) \quad \text{......(10)}$$

$$T = 0.013M_C + 13.40 \quad (R^2 = 0.96) \quad \text{......(11)}$$

The geometric mean diameter also increased as the moisture content increased as presented in Table 1. As moisture content increased, the groundnuts expanded. This expansion affected the length of the groundnuts. A similar trend was also reported in a study where the relationship between moisture contents and coriander seeds were investigated [18].

The average length of the Bambara groundnut seeds increased from 11.3 to 11.8 mm (4.2 % increase), the width increased from 9.3 to 9.7 mm (3.7 %) while, the thickness increased from 8.6 to 8.9 mm (3.4 %). A similar trend was reported by Baryeh [11] where the physical properties of Bambara groundnut seeds were determined at different moisture content levels (5 to 35 %). Baryeh [11] also stated that as moisture content increases, the seeds slightly expand in different directions. These findings were also established in this study. As a result, the geometric mean diameter slightly increased from 9.66 to 10.4 mm (Table 2).

The linear regression equations describe the relationship between axial dimensions and moisture content (Equation 12 to 14). The regression (R^2) showed a stronger relation between axial dimensions and moisture content.

$$L = 0.0354M_C + 11.2 \quad (R^2 = 0.99) \quad \text{......(12)}$$

$$W = 0.0261M_C + 9.34 \quad (R^2 = 0.099) \quad \text{......(13)}$$

$$T = 0.0215M_C + 13.4 \quad (R^2 = 0.99) \quad \text{......(14)}$$

The sphericity of Bambara groundnut pods decreased from 80.3 to 78.3%, and seed sphericity declined from 86.1 to 85.7% (figure 3). The results show that seeds

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are more spherical than pods. Baryeh [11] and Mpotokwane *et al.* [8] reported that the sphericity of shelled nuts increased with moisture content, which follows a similar trend with the findings obtained from the experiments conducted in this study. In this study, the sphericity of unshelled groundnuts showed a declining trend as the moisture increased. The sphericity declined because, as moisture content rose, the kernels did not expand equally in all directions. Therefore, the shape of the groundnuts became less round. Similar results were reported in a study where the relationship between moisture content and the sphericity of soya beans were investigated [20]. In terms of design considerations, at lower moisture content the groundnut pods tend to roll faster.

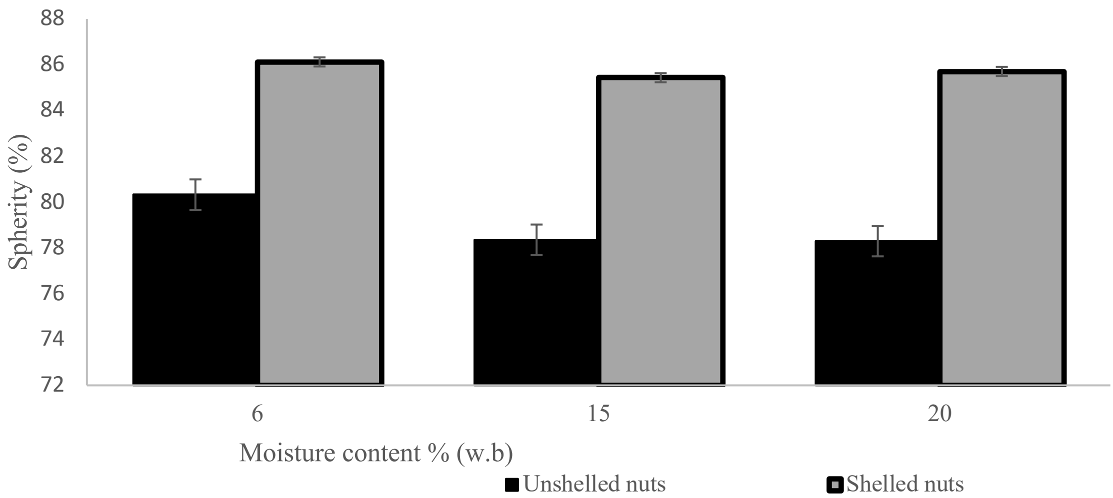

Figure 3: The sphericity of both Bambara groundnut pods and seed at different moisture contents

In this experiment, the volume of unshelled Bambara groundnuts increased from 1 615 to 1 806 mm^3. The volume of the shelled groundnuts also increased from 392 to 510 mm^3. The projected area of the Bambara groundnut pods rose from 9 691 to 10 835 mm^2. A similar trend was observed in other nuts as reported by Pliestic *et al.* [6] and Mpotokwane *et al.* [8]. As the size of Bambara groundnuts increase, the volume and surface area also increase linearly. Such a trend relating to the surface area was also reported by Pliestic *et al.* [6] and Yalcin and Ersan [18]. Therefore, the Bambara groundnuts will need a smaller hopper or storage facilities at lower moisture contents.

Weight

The findings show that as moisture content increased from 6 to 20 %, the average weight of each shelled and unshelled groundnut also increased linearly from 0.540

to 0.673 g, and 0.810 to 0.960 g, respectively. As the moisture content increased, the standard deviation of unshelled groundnuts also increased. This shows that the kernels had a higher water holding capacity. Consequently, the weight of unshelled nuts increased significantly with moisture content [20]. Similar findings were reported by Baryeh [11] where physical properties of Bambara groundnuts were determined. In this study, it was found that the deviation from mean was smaller in lower moisture content (Table 3). In terms of the design of a shelling or crushing machine, at lower moisture content, the machine will have a low capacity because the groundnuts have a lower weight at lower moisture content.

Static coefficient of friction

During the experiments, it was observed that as moisture content increased in both Bambara groundnut seeds and pods, the static coefficient of friction also increased. The shelled Bambara groundnuts static coefficient of friction increased from 0.290 to 0.310, while the pod's static coefficient of friction increased from 0.150 to 0.190 in galvanised steel sheeting. A similar trend was observed by Pliestic *et al.* [6], where the physical properties of filbert nuts and kernels were determined at different moisture contents. Baryeh [11], reported that the static coefficient of friction of shelled Bambara groundnuts (seed) increased from 0.290 to 0.580 at moisture content ranges from 5 to 35% (w.b) on a galvanised iron sheeting. The results were higher compared with results obtained in this study. This is because Baryeh [11] conducted the friction experiment on iron sheeting while in this study, a galvanised sheet was used during experiments.

The increase in the static coefficient of friction in both shelled and unshelled nuts is caused by the moisture present, which offers the cohesive force on the contact surface [6]. As a result, the groundnuts experience more friction at higher moisture content. The regression analysis (R^2) for both shelled and unshelled nuts are close to 1 (figure 4). This shows that there was strong relation between the moisture content and the static coefficient of friction.

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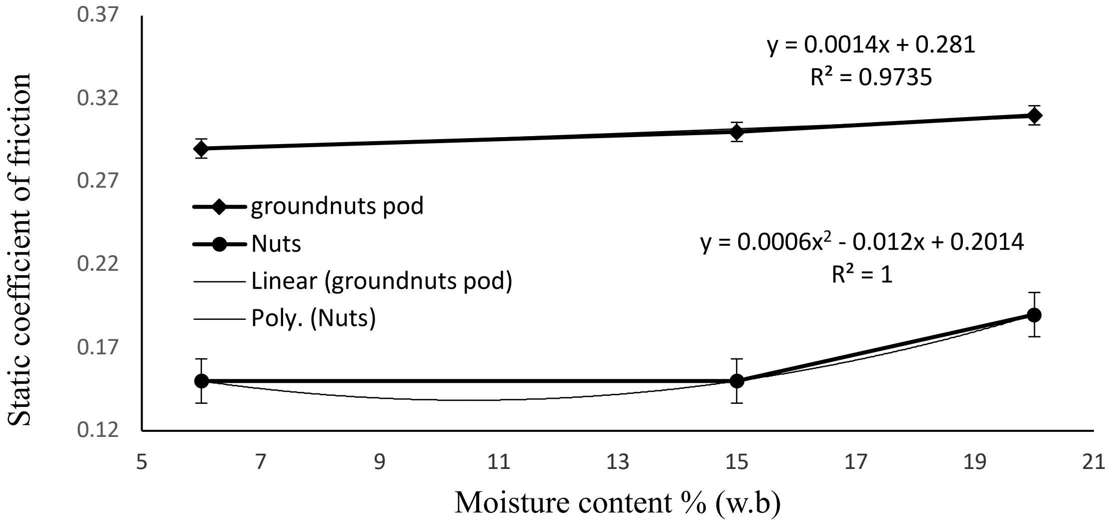

Figure 4: The static coefficient of friction at different moisture content levels

Porosity

The porosity of both seeds and pods ranged from 49 to 47%, and 35 to 32 %, respectively. It was found that the porosity of groundnuts decreased linearly as moisture content increased from 6 to 20 % (figure 5). Baryeh, [11], reported that the porosity of Bambara groundnuts seeds decreased non-linearly as moisture content increased. However, Pliestic *et al.* [6] reported that the porosity of Filbert nuts increased as moisture content increased. Therefore, based on the outcomes of this study, it was observed that the groundnuts expanded as moisture content increased. Consequently, the space between the groundnuts was reduced. A similar trend was reported by Kibar and Oz Turk [20], where physical and mechanical properties of soya beans were determined. Kibar and Oz Turk [20] reported that the porosity of soya beans decreased from 22.58 to 20.61 % at moisture content ranging from 8 to 16 %. The porosity of the beans is lower compared to Bambara groundnuts and filbert nuts [6, 11]. Therefore, at lower moisture contents, the Bambara groundnuts require a smaller storage space.

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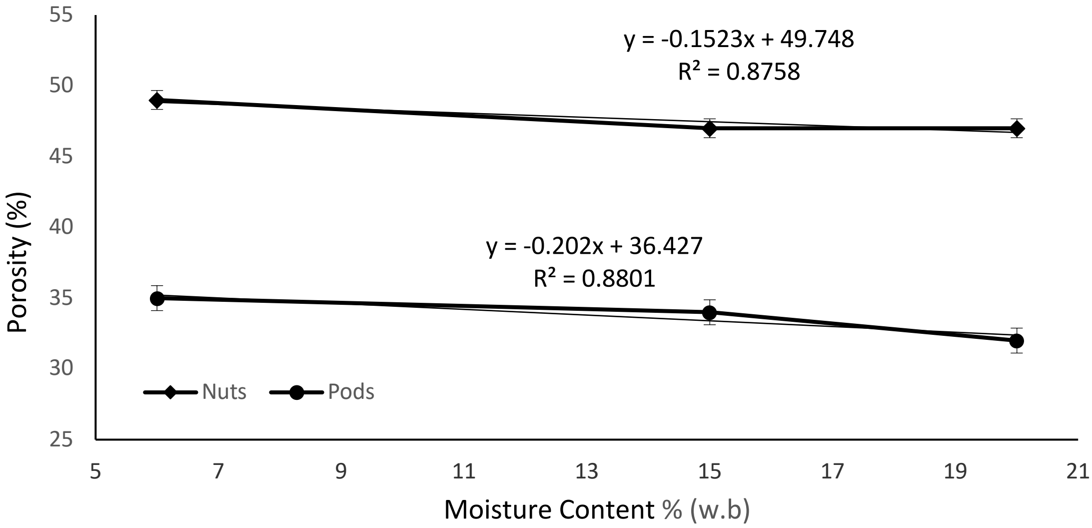

Figure 5: Porosity of Bambara groundnuts at different levels of moisture contents

Bulky density

The bulk density of shelled Bambara groundnut seeds increased exponentially while the bulk density of pods increased linearly as moisture content increased from 6 to 20%. The bulk density for Bambara groundnut seeds and pods increased from 500 to 955 kg.m^{-3}, and 355 to 422 kg.m^{-3}, respectively. However, Baryeh [5] reported that the bulk density of Bambara groundnut seeds declined from 795 kg.m^{-3} to 696 kg.m^{-3} as moisture content increased from 5 to 35% (w.b). Baryeh [11] used a pycnometer to measure the bulky density, and in this research, a beaker was used to measure the bulky density of seeds. The mass of the groundnuts samples were measured using a beaker filled with groundnuts [6, 8]. The bulk density of groundnuts was calculated as ratio of the mass of groundnuts to the volume of the beaker [6, 8]. Therefore, in this experiment it was found that as the moisture content increased, the weight of the groundnuts increased linearly. The bulk denisty increased in both shelled and unshelled groundnuts (figure 6). It was also reported that moisture content increased the mass of individual groundnuts. Therefore, the bulk desinty was expected to increase with moisture content.

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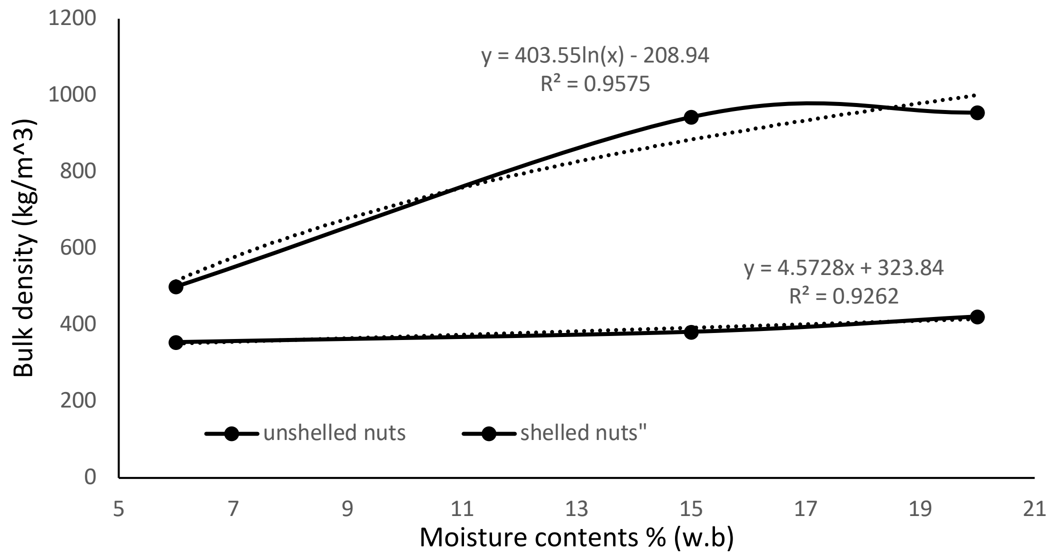

Figure 6: The bulk density of Bambara groundnuts at different moisture content

True density

The true density of both shelled and unshelled nuts increased from 994 to 1 832 kg.m^{-3}, and 994 to 1 832 kg.m^{-3}, respectively. The true density of shelled nuts increased non-linearly while the true density for unshelled nuts increased linearly. A similar trend was observed by Muhammad *et al.* [19] during the determination of physical properties of groundnuts. The findings in this study show that there is strong correlation between moisture contents and true density (figure 7). However, the findings of true density of Bambara groundnuts seed reported by Baryeh [11] showed a declining trend.

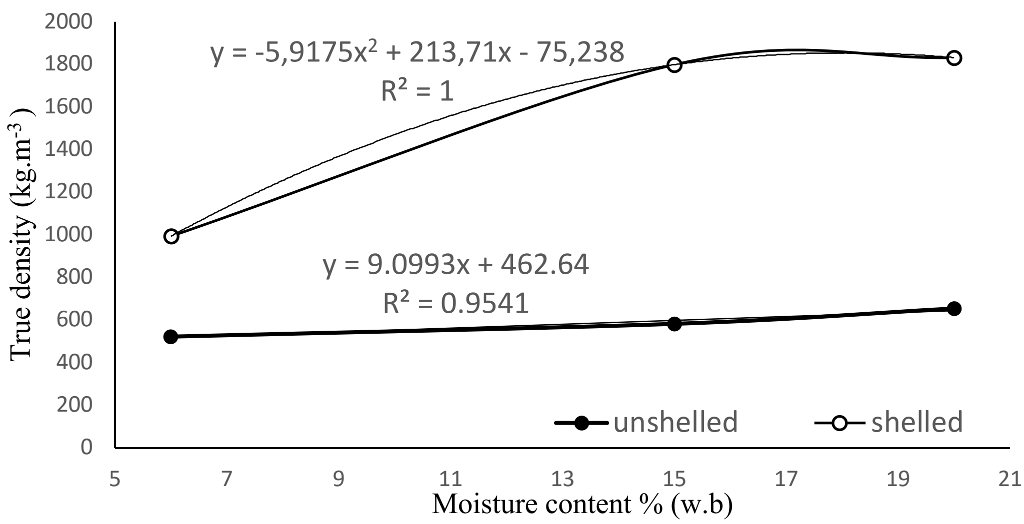

Figure 7: True density of Bambara groundnuts at moisture content ranges from 6 to 20 %

Cracking force

The cracking forces required for Bambara groundnuts kernels at 6, 15, and 20 % are 32.5 ±12, 29.9 ±15.3, and 28.9 ±9 N, respectively. It was observed that as moisture content increased, the kernels became softer (figure 8). Pliestic *et al.* [6] observed a similar trend where the cracking force for filbert nuts declined as the moisture content increased. In this instance the required force for cracking filbert nuts declined from 690 to 580 N as moisture increased from 6.19 to 28.71 %.

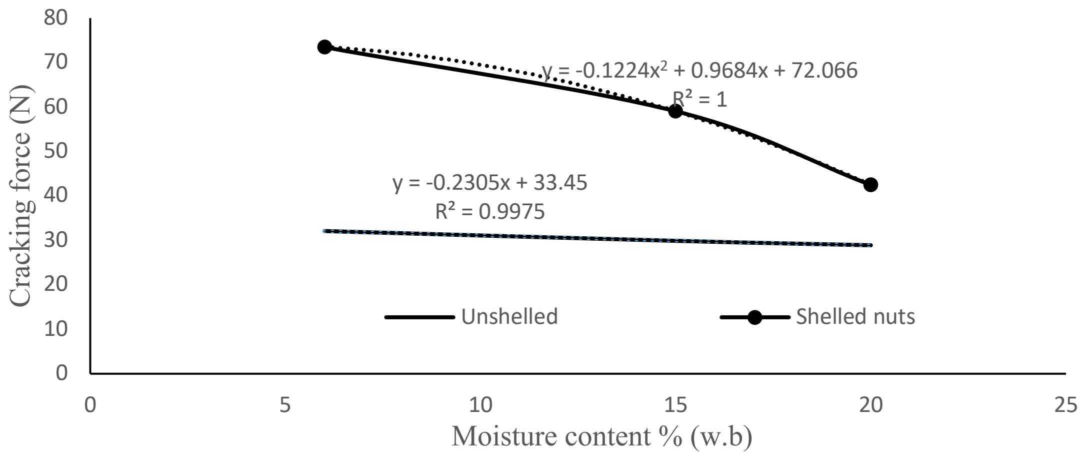

Figure 8: The required cracking force at different moisture content

The average force for cracking Bambara seed nuts at 6, 15, and 20 % moisture content was 73.5 ± 16.3, 59 ±15.6, and 42 ± 10.1 N, respectively. As the moisture increased, the data deviation from the mean decreased from 16.30 to 10.1 N. Figure 8 showed the relationship between moisture content and cracking force. The linear regression analysis (R^2) of both shelled, and unshelled nuts are closed to 1. This indicates that there was a close relationship between moisture content and cracking force.

CONCLUSION, AND RECOMMENDATIONS FOR DEVELOPMENT

In this study, the effect of the moisture content on the physical properties of Bambara groundnuts were investigated. The findings show that the axial dimensions, geometric diameter, and volume for both Bambara groundnut seeds and pods increased as moisture content levels increased. The sphericity of the groundnuts was found to decline as moisture content increased. It was observed that as the moisture content increased, the nuts did not expand equally in all directions. Therefore, the nuts became less round as the moisture content increased. The static coefficient of friction was found to be higher for unshelled groundnuts because as moisture increased, the kernel gained more water and increased contact time on the galvanised steel. The required cracking force for both kernels and seeds declined as moisture content rose. During the investigation it was further observed that as the moisture content increased, the skin of both seed and kernel nuts became weaker. As a result, the required cracking force declined. The findings of this study can be used to design post-harvesting processing equipment including shelling and grinding machines for Bambara groundnuts. It is recommended from the results of this study that further research be done to determine the physical and chemical properties of Bambara groundnuts in a wide range of moisture content levels to accommodate other food processing such as canning.

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Table 1: Axial dimensions and standard error for the Bambara groundnut pods (standard error)

Moisture content (%)	Dimensions of shelled groundnuts (mm)			Geometric mean diameter (mm)
	length	width	thickness	
6	19.7(±0.47)	14.9(±0.38)	13.5(±0.30)	15.8
15	21.0(±0.38)	15.6(±0.31)	13.6(±0.28)	16.4
20	21.1(±0.49)	15.6(±0.34)	13.7(±0.27)	16.5

Table 2: Axial dimensions and the standard deviation for Bambara groundnuts seeds

Moisture content (%)	Dimensions of shelled groundnuts (mm)			Geometric mean diameter (mm)
	length	width	thickness	
6	11,2(±1.56)	9,34(±0.87)	8,58(±0.81)	9,66
15	11,6(±1.40)	9,58(±0.93)	8,76(±0.83)	9,91
20	11,8(±1.50)	9,72(±1.20)	9,02(±0.74)	10,4

Table 3: The weight of both shelled and unshelled groundnuts at different moisture contents

Moisture content (% w.b) ± SD	Unshelled nuts (g) ± SD	Shelled nuts (g) ± SD
6	0.81(±0.28)	0.54(±0.17)
15	0.85 (±0.26)	0.58 (±0.19)
20	0.96 (±0.38)	0.67 (±0.17)

REFERENCES

1. **FAO**. Food and Agriculture Organisation of the United Nations. The State of Food Security in the World. FAO, Rome, 2010.

2. **Oyeyinka AT, Pillay K, Tesfay S and M Siwela** Physical, Nutritional and Antioxidant Properties of Zimbabwean Bambara Groundnut and Effects of Processing Methods on their Chemical Properties. *International Journal of Food Science & Technology*. 2017; **52(10):** 2238-2247.

3. **DAFF**. Department of Agriculture and Fisheries (DAFF). Production Guideline for Bambara Groundnuts. Pretoria, South Africa, 2011.

4. **Ugwuoke IC, Okegbile OJ and IB Ikechukwu** Design and Fabrication of Groundnut Shelling and Separating Machine. *International Journal of Engineering Science Invention.* 2014; **3(4):** 60-66.

5. **Unigwe AE, Gerrano AS, Adebola P and M Pillay** Morphological Variation in Selected Accessions of Bambara Groundnut *(Vigna Subterranea L. Verdc)* in South Africa. *Journal of Agricultural Science*. 2016; **8(11):** 69-99.

6. **Pliestic S, Dobricevic N, Filipovic D and Z Gospodaric** Physical Properties of Filbert Nut and Kernel. *Biosystems Engineering.* 2006; **93(2):** 173-178.

7. **Mkandawire C** Review of Bambara Groundnut (Vigna Subterranea (L.) Verdc.) Production in Sub-Sahara Africa. *Agricultural Journal*. 2007; **2(4):** 464-470.

8. **Mpotokwane S, Gaditlhatlhelwe E, Sebaka A and V Jideani** Physical Properties of Bambara Groundnuts from Botswana. *Journal of Food Engineering.* 2008; **89(1):** 93-98.

9. **Atiku A, Aviara N and M Haque** Performance Evaluation of a Bambara Groundnut Sheller. Agricultural Engineering International: *CIGR Journal.* 2004; **5(1):** 60-66.

10. **Oluwole F, Abdulrahim A and M Oumarou** Development and Performance Evaluation of Impact Bambara Groundnut Sheller. International Agrophysics. 2007; **21(3):** 269-274.

11. **Baryeh EA** Physical Properties of Bambara Groundnuts. Journal of Food Engineering, 2001; **47(1):** 321-326.

12. **AOAC**. Official Methods of Analysis Association of Official Analytic Chemists, (18thEd). Washington, D.C., United State of America. 2005.

13. **Asoegwu S, Ohanyere S, Kanu O and C Iwueke** Physical Properties of African Oil Bean Seed (Pentaclethra macrophylla). Agricultural Engineering International: *CIGR Journal*. 2006; **5(1):** 142-148.

14. **Raghtate A and C Handa** Design Consideration of Groundnut Sheller Machine. *International Journal of Innovative Research in Science*

15. **Koocheki A, Razavi S, Milani E, Moghadam T, Abedini M, Alamatiyan S and S Izadkhah** Physical Properties of Watermelon Seed as a Function of Moisture Content and Variety. *International Agrophysics.* 2007; **21(4):** 349-359.

16. **Adejumo O, Alfa A and A Mohammed** Physical Properties of Kano White Variety of Bambara Groundnut. *Proceedings of the Nigerian Institute of Agricultural Engineers.* 2005; **27(1):** 203-210.

17. **Prosper EO and H Uguru** Moisture Dependent Physical Properties of Gmelina Fruits and Nuts. *International Journal of Scientific Research in Science, Engineering and Technology*. 2018; **4(4):** 2395-4099.

18. **Yalcin C and K Ersan** Physical Properties of Coriander Seeds. *Journal of Food Engineering*. 2007; **80(2):** 408-416.

19. **Muhammad AI, Ahmad RK and I Lawan** Effect of Moisture Content on some Engineering Properties of Groundnut Pods and Kernels. Agricultural Engineering International. *CIGR Journal*. 2018; **19(4):** 200-208.

20. **Kibar H and T Ozturk** Physical and Mechanical Properties of Soybean. *International Agrophysics*. 2008; **22(3):** 239-244.