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Effect of Moisture Content, Seed Varieties and Seed Orientation on the Mechanical Properties of African Oak (*Afzelia africana*) Seeds

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ABSTRACT: The effect of moisture content on the mechanical properties of agricultural material is essential during design and adjustment of machines used during harvest, cleaning, separation, handling and storage. This study determined some mechanical properties of two varieties of African Oak seeds in Nigeria under different moisture contents range of 8 to 17 % (w.b) and three different seed orientation. The mechanical analysis of the samples tested showed that seed orientations, variety and moisture content had a significant effect on the mechanical properties. The correlation that existed between moisture content and the force-deformation properties was statistically significant at (P≤0.05) level. It is economical to crack the small and large samples at the major axis and at 11.0% moisture content in order to reduce energy and strength demand when necessary to crack and compress the samples properly. This research has generated data that are efficiently enough to design and fabricate processing and storage structures for small variety and large variety of African Oak seeds.
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KEYWORDS: Seed Orientation, Compressive force, Seeds Varieties, Moisture Content

1. INTRODUCTION

Afzelia africana is a leguminous tree plant that belong to the family of fabaccae. Afzelia africana, popularly called African oak or African mahogany (English), with trade names Apa (Yoruba), Akpalata (Ibo), Kawo (Hausa) and Gayoki (Fulani) is one of the most widely distributed species in Africa (Egwujeh *et al*., 2016). It is a large tree with very beautiful coloured seeds having two colours, black and yellow/orange at the bottom, which looks like a cap with extractable oil. Egwuje and Yusufu (2015) had reported that the cap-like structure which is always throne away during processing is a rich source of minerals, fat and vitamins. The seeds are edible and have high medicinal values. Legumes can be consumed as a whole seed or as flour after dehulling to remove the black, dried seed coat which might be bitter and or indigestible (Egwujeh and Ariahu, 2014). All parts of the plant are of immense traditional importance, its wood is used for carpentry, the saw dust for making and designing art work, its foliage for making soap, while the leaves are used to enrich soil because of their rich nitrogen content. The seed is a good source of nutrition to both human and animals, containing about 27.04% crud proteins, 31.71% crude fat, 3.27% ash, 33.09% total carbohydrates and 5.28% moisture. It contains 18-37% of oil. The oil has long shelf-life, contains valuable PUFA (polyunsaturated fatty acids) and can be used for cooking. The oil of *Afzelia africana* is semi-drying, needs little purification and can have several industrial applications. It is suitable for the formulation of alkyd resin and shoe polish. Linoleic acid is the predominant fatty acid. The co-product of oil extraction is a seed cake that can be fed to livestock (Ejikeme *et al*., 2010). The physicochemical and fuel properties of the *Afzelia africana* methyl esters shows its potentials in biodiesel production. The oil can release high amount of heat on combustion and can ignite easily in a combustion engine. The iodine and peroxide values shows increased stability of the oil during storage and transportation (Igwenyi *et al*., 2011).

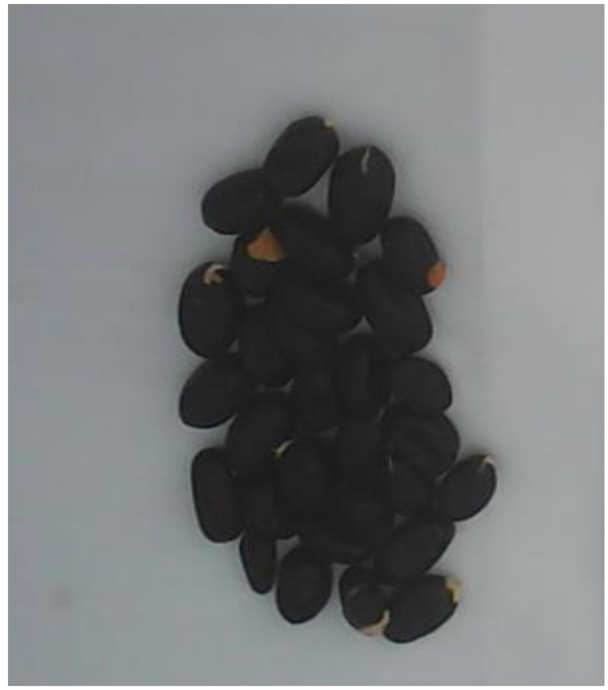
The mechanical properties of seeds are underestimated and still little known about them. Knowledge of the mechanical properties of seeds has a particular importance for the optimization technologies of harvest, handling, storage and processing of agricultural products, which relates to minimization of quantitative losses and mechanical damage caused among others decrease of seeds germination ability (Seifi and Alimardani, 2010). Knowledge of apparent elastic properties such as Poisson's ratio and elastic modulus of agricultural seeds is important for the prediction of their load-deformation behaviour and design of their processing machines (Eze and Eze, 2017). The risk of damaging and cracking the seeds during harvesting, conveying and processing is high. The shear stress and impact stress helps to determine the amount of pressure the seed plate should apply on the seed. These properties help in specifying the design considerations of planting equipment because it will be a waste of time, resources, effort and money if after fabricating, and the machine fails to deliver up to expectation (Zhu *et al*., 2023). Variability of mechanical properties of seeds depends on vast range of external factors, as well as on species-cultivar-relates traits (Zareiforoush *et al*., 2012). To develop a reliable machinery type, design, and manufacturing model package, the moisture content of *Afzelia africana* seeds as a critical aspect must be considered for effective and efficient processing.

Afzelia africana seeds have a wide range of applications and have great potential. There is little information on the basic mechanical properties of the seeds, which is an identified problem in the development of a new method of handling and processing the seeds. There is no equipment specifically designed and used in handling and processing *Afzelia africana* seeds. This is probably due to the lack of relevant data and information on the mechanical properties of the seeds with different moisture contents. Therefore, this study aims to determine the effect of moisture content, variety and seed orientation on some mechanical properties of *Afzelia africana* seeds in Nigeria. The present study is an attempt to optimize the moisture content of *Afzelia africana* seed based on the mechanical properties under laboratory condition. The levels of moisture content were selected based on the handling and processing operations. The findings of this study could be used for developing engineering models to optimize the processing output and serve as a database to be used in the design and development of machines used in postharvest processes such as dehulling, grinding and extraction machines for *Afzelia africana* seeds.

2. MATERIALS AND METHODS

2.1 Sample Preparation

This study was conducted on two varieties of African Oak seeds (small and large) accessions obtained from Guma Local Government, Benue State, Nigeria. The seeds were collected from the trees as they dropped without the influence of any human activity. The seeds were cleaned, screened and the intact ones were selected. The caps were manually detached using hands. Hundreds of seeds were randomly selected for various experiments and conditioned to different moisture contents and their mechanical properties were determined.



(a) Small Variety
(b) Large Variety
Plate 3: African Oak (*Afzelia africana*) seeds

2.2 Moisture Content Conditioning

African Oak seeds were conditioned by using an absolute thermo gravimetric method with a 60g infrared moisture analyzer (LSC - 50) with a readability of 0.1mg. African Oak seeds were selected at random from each variety and quickly kept to the sample pan. The maximum temperature of the analyzer was preset at

50°C and the analysis programmed to end automatically as soon as a constant residual weight of the sample was reached. The moisture content on display at this point was taken as the moisture content of the sample. The moisture content of the sample were preset at four different levels of 8%, 11%, 14% and 17%. These moisture levels were chosen since all the processing operations and storage of the seeds are performed in this range.

2.3 Determination of Mechanical Properties

The mechanical properties which include; rupture point, bio-yield point, modulus of elasticity and compressive strength be determined. Compression tests were performed on the two samples of African Oak seeds at different moisture content levels using the Universal Testing Machine at the National Centre for Agricultural Mechanization (NCAM) Ilorin, Kwara State. Testing conditions for the Machine were loading range: 0 - 500N; chart speed – 50rpm/mm and crosshead speed – 1.5mm/min. Each seed was placed between the compression plates of the ten sonometer. The seed was compressed at a constant deformation rate of 1.25mm/min. The applied forces at bio-yield and oil points and their corresponding deformations for each seed sample were read directly from the force-deformation curve. The mechanical behavior of seed was expressed in terms of force required for maximum strength of the seed, energy required to deform the seed to initial rupture and seed specific deformation. The rupture force was determined as the force on the digital display when the seed under compression makes a clicking sound. Each process was completed whenever the break point of the positioned seed was reached.

2.4 Experimental Design and Statistical Analysis

The experimental design for the statistical analysis follows a three-treatment effect (moisture content, variety and seed orientation) in a Completely Randomized Design (CRD) with five observations (replications) per experimental unit. All data collected were compared using three-way analysis of variance (ANOVA) at $P \leq 0.05$. All the data were analyzed using the SPSS statistical software.

3. RESULTS AND DISCUSSIONS

3.1 Effects of Moisture Content, Variety and Seed Orientation on Mechanical Properties

3.1.1 Effects of moisture content, variety and seed orientation on the compressive force

Analysis of Variance (ANOVA) at $P \leq 0.05$ of the effects of moisture content, variety and seed orientation on the compressive force (N) shows that the moisture content, variety, seed orientation and their interactions have significant effects on the compressive force (force at peak, force at yield and force at break), except for the interaction between variety and seed orientation which indicates no significant effect on the compressive force. This is in line with the work of Eze *et al*. (2021) who studied the effect of moisture content on the mechanical properties of watermelon seed varieties and observed that, as the moisture content of both samples varied, the maximum force required to crack the sample at both horizontal and vertical loading position.

The results of the effects of moisture content, variety and seed orientation on the compressive force are shown in Table 1. It was observed that, as the moisture content of both samples varied, the maximum force required to crack the sample at all the major, intermediate and minor axes varied. The trend of the variation in moisture content and cracking force of the sample were found to be parabolic. Eze *et al*. (2021) also reported a parabolic trend in moisture content variation with the maximum force required to crack the sample at both horizontal and vertical loading position. In terms of varietal effects, it was observed that the small variety required higher breaking force than the large variety. It was also observed that the samples required higher force at the minor axis than the major and intermediate axes and this could be attributed to structural lining of the sample was at minor axis. This findings gave an insight the maximum load required to crack both samples varies. Therefore it would be implored during the design and fabrication of processing machine for both samples.

Table 1: Mean Values of the Effects of Moisture Content, Variety and Seed Orientation on the Compressive Force (N)

Variety	Seed Orientation	Moisture Content (% w.b)			
		8	11	14	17
Force @ Peak (N)					
	Major Axis	1115.16±179.165	386.312±198.259	732.860±74.318	624.872±319.315
Small	Intermediate Axis	1266.087±225.409	1283.040±271.696	991.100±180.728	836.366±257.259
	Minor Axis	1416.960±542.522	1166.760±350.059	1027.100±314.903	1258.280±165.793
	Major Axis	816.180±95.536	258.314±111.472	644.186±189.572	245.704±147.243
Large	Intermediate Axis	1198.020±111.135	843.940±295.525	616.016±187.152	691.054±375.484
	Minor Axis	1558.560±497.662	295.870±80.724	672.686±207.754	638.992±474.382
Force @ Yield (N)					
	Major Axis	1115.160±179.165	375.952±181.711	710.140±53.514	620.292±317.058
Small	Intermediate Axis	1266.068±225.428	1283.040±271.696	939.880±237.235	836.366±257.259
	Minor Axis	1416.960±542.522	1166.760±350.059	1013.760±321.893	1144.420±364.116
	Major Axis	816.180±95.536	255.418±108.288	575.546±144.390	245.704±147.243
Large	Intermediate Axis	1198.020±111.135	843.940±295.525	598.776±214.049	691.054±375.484
	Minor Axis	1408.800±665.255	295.870±80.724	648.166±209.125	638.992±474.382
Force @ Break (N)					
	Major Axis	1094.840±170.302	383.126±193.551	725.340±81.068	624.872±319.315
Small	Intermediate Axis	1255.918±240.828	1281.420±271.374	985.840±170.354	836.366±257.259
	Minor Axis	1416.960±542.522	1164.700±352.608	1025.020±317.800	1258.280±165.793
	Major Axis	807.460±102.075	258.314±111.472	639.166±190.757	245.048±147.951
Large	Intermediate Axis	1198.020±111.135	843.940±295.525	616.016±187.152	684.174±377.859
	Minor Axis	1558.560±497.662	295.744±80.948	670.946±206.386	637.412±474.112

3.1.2 Effects of moisture content, variety and seed orientation on the deformation (mm)

Analysis of Variance (ANOVA) at P ≤ 0.05 of the effects of moisture content, variety and seed orientation on the compressive deformation (mm) shows that the moisture content, seed orientation and their interaction have significant effects on the compressive deformation (deformation at peak, deformation at yield and deformation at break) while seed variety indicates no significant effect on the compressive deformation. This agrees with Eze *et al*. (2021) who investigated the effect of moisture content on the mechanical properties of watermelon seed varieties and observed that the moisture content varied the compressive extension at both horizontal and vertical loading position.

The results of the effects of moisture content, variety and seed orientation on the compressive deformation are shown in Table 2. It was observed that, as the moisture content of both samples varied, the compressive deformation of the samples at all the major, intermediate and minor axes varied. The moisture content variation displays parabolic trends for both samples. Eze *et al*. (2021) also indicated that the moisture content variation displays parabolic trends for both the two varieties at both horizontal and vertical loading position. The compressive deformation of a biomaterial under compressive test tells the extent a particular load/force causes deformation at different applied load. This research therefore, reveals that, the major axis deforms faster, followed by the intermediate axis and lastly the minor axis, which could be attributed to structural lining of the sample was at minor axis. Considering the effects of variety, the small variety of African Oak seed deforms faster than large variety of African Oak seed and this should be considered during the design and fabrication of handling and processing machines.

Table 2: Mean Values of the Effects of Moisture Content, Variety and Seed Orientation on the Deformation (mm)

Variety	Seed Orientation	Moisture Content (% w.b)			
		8	11	14	17
Deformation @ Peak (mm)					
	Major Axis	2.133±0.251	0.568±0.274	1.871±0.423	0.885±0.327
Small	Intermediate Axis	1.589±0.164	1.037±0.182	1.466±0.321	0.853±0.159
	Minor Axis	1.044±0.365	0.709±0.149	0.775±0.110	0.980±0.225
	Major Axis	1.377±0.240	0.530±0.250	1.649±1.126	0.748±0.358
Large	Intermediate Axis	1.026±0.134	0.602±0.082	0.978±0.227	0.631±0.193
	Minor Axis	0.942±0.258	0.350±0.044	0.791±0.253	0.485±0.209
Deformation @ Yield (mm)					
	Major Axis	2.133±0.251	0.527±0.209	1.739±0.244	0.863±0.313
Small	Intermediate Axis	1.589±0.164	1.037±0.182	1.311±0.350	0.853±0.159
	Minor Axis	1.044±0.365	0.709±0.149	0.751±0.114	0.824±0.180
	Major Axis	1.377±0.240	0.515±0.223	1.308±0.670	0.748±0.358
Large	Intermediate Axis	1.026±0.134	0.602±0.082	0.910±0.296	0.631±0.193
	Minor Axis	0.819±0.316	0.350±0.044	0.756±0.290	0.485±0.209
Deformation @ Break (mm)					
	Major Axis	2.202±0.330	0.572±0.279	1.879±0.416	0.885±0.327
Small	Intermediate Axis	1.623±0.177	1.038±0.182	1.486±0.352	0.853±0.159
	Minor Axis	1.044±0.365	0.714±0.146	0.790±0.090	0.980±0.225
	Major Axis	1.378±0.240	0.530±0.250	1.814±1.362	0.749±0.358
Large	Intermediate Axis	1.026±0.134	0.602±0.082	0.978±0.227	0.638±0.203
	Minor Axis	0.942±0.258	0.351±0.041	0.793±0.257	0.496±0.230

3.1.3 Effects of moisture content, variety and seed orientation on the strain (%)

Analysis of Variance (ANOVA) of the effects of moisture content, variety and seed orientation on the compressive strain (%) shows that the moisture content, variety and seed orientation have significant effects on the compressive strain at peak and compressive strain at break while only moisture content and seed orientation shows significant effects on the compressive strain at yield but variety shows no significant effects on the compressive strain at yield.

The results of the effects of moisture content, variety and seed orientation on the compressive strain are shown in Table 3. It was observed that as the moisture content varied the compressive strain. At different moisture content level the compressive strain on the samples varies. The trend of the variation in moisture content and compressive strain of the sample were found to be parabolic. It was noticed that the compressive strain of the small variety samples on all the loading positions was higher than the compressive strain of the large variety samples. It implies that, the small variety sample is stronger at each of the loading positions. It was also noticed that the compressive strain of the small variety sample on all loading positions was higher than the large variety sample. It implies that, small variety sample is stronger at each of the loading positions. But for both samples, compressive strain was found to be higher at every minor axis, followed by intermediate axis and lastly major axis.

Table 3: Mean Values of the Effects of Moisture Content, Variety and Seed Orientation on the Strain (%)

Variety	Seed Orientation	Moisture Content (% w.b)			
		8	11	14	17
Strain @ Peak (%)					
	Major Axis	8.708±1.027	2.839±1.372	9.354±2.115	4.915±1.815
Small	Intermediate Axis	9.098±1.480	7.406±1.300	12.218±2.672	6.558±1.227
	Minor Axis	9.489±3.322	8.868±1.859	7.754±1.096	9.804±2.249
	Major Axis	5.295±0.922	2.121±0.999	7.852±5.361	5.754±2.754
Large	Intermediate Axis	8.553±1.116	4.628±0.634	8.895±2.062	4.855±1.487
	Minor Axis	9.416±2.581	3.502±0.435	7.906±2.527	5.389±2.317
Strain @ Yield (%)					
	Major Axis	8.708±1.027	2.637±1.045	8.694±1.218	4.792±1.737
Small	Intermediate Axis	9.098±1.480	7.406±1.300	10.925±2.916	6.558±1.227
	Minor Axis	9.489±3.322	8.868±1.859	7.506±1.135	8.240±1.797
	Major Axis	5.295±0.922	2.059±0.893	6.227±3.190	5.754±2.754
Large	Intermediate Axis	8.553±1.116	4.628±0.634	8.276±2.693	4.855±1.487
	Minor Axis	8.190±3.157	3.502±0.435	7.562±2.899	5.389±2.317
Strain @ Break (%)					
	Major Axis	6.989±3.622	2.862±1.395	9.393±2.079	4.915±1.815
Small	Intermediate Axis	8.238±2.601	7.413±1.297	12.386±2.930	6.558±1.227
	Minor Axis	9.489±3.322	8.923±1.831	7.898±0.905	9.804±2.249
	Major Axis	5.301±0.922	2.121±0.999	8.637±6.483	5.760±2.754
Large	Intermediate Axis	8.553±1.116	4.628±0.634	8.895±2.062	4.905±1.565
	Minor Axis	9.416±2.581	3.512±0.415	7.926±2.568	5.507±2.550

4. CONCLUSIONS

The results of the effect of seed orientation, variety and moisture content on the force deformation characteristics showed that they exhibited varying relationships with moisture content, variety and seed orientations. It can be inferred therefore that the force deformation characteristics of the samples tested showed that seed orientations, variety and moisture content had a significant effect on the mechanical properties. It was concluded that the data generated from mechanical properties of the small variety of African Oak seeds cannot be used in designing of food processing, handling and storage systems for the large variety of African Oak seeds as mechanical properties of both species tested varied with moisture content. This research work have solved a big problem as it revealed the variations existed between small and large African Oak seeds. It also generated data which aids the design and fabrication of handling equipment. The results of the force-performance properties of the African Oak seeds were observed to be moisture content dependent (8.0-17.0% wb). The correlation that existed between moisture content and the force-deformation properties was statistically significant at ($P \leq 0.05$) level. It is economical to crack the small and large samples at the major axis and at 11.0% moisture content in order to reduce energy and strength demand when necessary to crack and compress the samples properly.

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