Effect of Seed Size on The Mechanical Properties of *Gmelina* Seed

[1]Oderhowho Nyorere, [1]Hilary Uguru

Abstract:
The knowledge of mechanical properties of agricultural products under compressive loading is a vital factor in the design and development of their harvesting, handling and processing machines. In this research, the following mechanical parameters; bio-yield force, bio-yield energy, bio-yield strain, rupture force, rupture energy and maximum compressive force of the gmelina seed was determined under quasi compression loading in longitudinal position, in respect to two seed sizes (small and large). Results obtained show that gmelina seed size had significant effect on the mechanical parameters investigated. The average compressive force required to cause the seed rupture was significantly lower in the small size (475.8 N) than what is required to rupture the large seed (711.9 N). Also, the energy absorbed per unit volume at rupture increased with an increase in seed size, 0.266 Nm for the large seed and 0.168 Nm for the small seed. Minimum bio-yield energy observed was 0.104 Nm for small seed, while the large seed required 0.166 Nm to yield. Data gotten from this study will be very useful in the design of the gmelina seed handling and processing machines.

Keywords: *Mechanical properties, gmelina seed, seeds size, rupture point, bio-yield point.*

1.0 INTRODUCTION

Gmelina arborea Roxb. (Family Verbenaceae) is a fast-growing tree, which grows on different localities and prefers moist fertile valleys, they attain moderate to large height up to 40 m and 140 cm in diameter. It is commonly called *gmelina* and white beech (English), *melina* (Spanish), *gamar* in Bangladesh, *melina/gambar* in India, *gemelina* in Indonesia, *yemane* in Philippines and *soh* in Thailand, and it has many regional names [1]; [2]. It also occurs naturally in Myanmar, Thailand, Laos, Cambodia, Vietnam, and in southern provinces of China, and has been planted extensively in Sierra Leone, Nigeria and Malaysia [3]. *Gmelina* thrives best where the extremes of temperature range from 19^{0}C to 35^{0}C, where there is a distinct dry season, but where the relative humidity never drops below 40 per cent. Further, the optimum rainfall is from 1800 to 2300 mm per annum. Provenances at the extreme upper altitudinal limit of its range have some tolerance to frost. Gmelina growth best on deep, loamy, calcareous, and moist soils, and will check or fail on poorer soils [4].

The *gmelina arborea* kernels are not consumed by human beings, but contains a high-quality biodiesel. *Gmelina* seeds contains very little kernel but the kernel is quite rich in oil (53 wt.%) [5]. Fatty acid profile of biodiesel from *Gmelina arborea* seed oil was determined [5] and the discovered that the biodiesel consists of 15.09 wt.% of methyl palmitate (C16:0), 44.88 wt.% of methyl oleate (C18:1), 11.16 wt.% of methyl stearate (18:0), 15.95 wt.% of methyl gondoate (C20:1), 4.21 wt.% of methyl arachidate (C20:0) and 8.67 wt.% of methyl behenate (C22:0). *Gmelina* seed oil have been found to be a sustainable material for biodiesel and alkyd resin synthesis in terms of its availability and renewability. *Gmelina* seed oil-based biodiesel have been produced keeping two criteria in mind; the biodiesel met all the technical and industrial standards of ASTM D6751 and EN 14214, and, met all the ecologically relevant standards [5]; [6].

[1] Agricultural and Bio-Environmental Engineering Department, School of Engineering, Delta State Polytechnic, Ozoro, Nigeria. Erobo2011@gmail.com

The optimal design and development of harvesting and processing equipment requires an understanding of the dynamic behaviour of biomaterial particulates. In agricultural and food processes involving particulates, interest is not only focused on the mechanical behaviour and flow of particles within the bulk system but also on the resulting deformation of the individual particles [7]. The surface of contact between seed and the compression plate changes during compression, making compression stress, the most popular and univocal physical parameter, difficult to use [8]. Seed hardness, which is affected by seed size and microstructure, is also an important factor that influences about milling energy and seed damage during storage. Hardness, defined as the force required to deform or to crush the seed, describes accurately only the mechanical resistance of seeds of the same size and shape. Generally, agricultural materials and food products deform in response to applied forces and the amount of force required to produce a given amount of deformation varies widely among different materials [9]. The dependence between compressive force and deformation of a given oil-bearing crop can also be used to estimate the energy which is characterized by the area under the force-deformation curve [10].

The physical and mechanical properties of *gmelina* timber and fruits [11]; [12]; [13]; [14], and some structural aspects of plant morphology [2]; [6]; [15] have been previously studied, yet the mechanical properties of the *gmelina* seeds with respect to size variation have not been detailed investigated. The present study deals with the determination of some mechanical properties of *gmelina* seeds, which will provide relevant data for the design and development of handling and processing systems.

2 MATERIALS AND METHODS

2.1. Samples collection

Gmelina fruits were collected locally from Delta State Polytechnic, Ozoro, Delta State, Nigeria. They were soaked in water for ten days, to facilitate the separation of the fruit pulp from the seed. The recovered seeds were air-dried under a shade for seven days, for them to attained uniform moisture content. Lastly, the seeds were inspected and foreign material, broken and immature seeds were removed.

2.2 *Gmelina* seed size determination

To determine the average size of the seed, the three linear dimensions of the seed, namely length (L), width (W), and thickness (T) were carefully measured using digital vernier caliper reading to 0.01 mm. Since the width and thickness of the *gmelina* seed exhibit very small differences, they were merged into a single parameter (diameter), thus, the gmelina seed was geometrically represented with length (L) and diameter (D) parameters.

Geometric mean diameter (D_g) and total surface area of the seed were computed using the following equations [16].

Geometric mean diameter

$$D_g = \sqrt[3]{L \times D}$$

Surface area

The surface area (S) of the seed was determined according to the following equation.

$$S = \pi D_g^2$$

2.3 Mechanical properties determination

The mechanical parameters test of the gmelina seed was performed using a Universal Testing Machine (Testometric model, series 500-532) equipped with a 50 N compression load cell and integrator, and measurement accuracy of 0.001 N, at the Material Testing Laboratory of the National Center for Agricultural Mechanization (NCAM), Ilorin, Kwara state, Nigeria. Each *gmelina* seed was compressed on the longitudinal direction between two parallel rigid plates (Figures 1), at the crosshead speed of 15 mm/min, until rupture point. As compression progresses, a load-deformation curve was plotted automatically in relation to the response of each seed to compression, and the mechanical parameters generated automatically by the machine. Each test was repeated 20 times and the average taken.

Due to the changing in the surface area contact between the seed and the compressive plate during compression, the comparable values of fracture (rupture) force or fracture stress are difficult to determine; therefore, fracture energy [9]; [17]; [18] seems to be a more robust parameter of seed hardness.

Figure 1: A gmelina seed undergoing compressive loading

Gmelina seeds like other biological materials has complex biomechanical systems of very complex behaviour and cannot be characterized by simple constants [16], it is therefore necessary to introduced some concepts such as bio-yield and rupture points. The bio-yield point indicates the initial cell rupture in the whole seed and is used as a criterion for maximum allowable load that the *gmelina* seed can sustains without showing any visible damage (micro failure point) [19]. The rupture point dictates failure over a significant volume of material causing fracture planes or cracks in the macrostructure of the *gmelina* seed. The rupture energy (Toughness) is the work required to initiate rupture of the *gmelina* seed, which is the area under the force-deformation curve up to the rupture point [16]. The deformation (strain) of the seed is the change in the original dimension of the seed during compression.

2.4 Statistical analysis

The experiments were conducted with twenty replications for each gmelina seed size. The analysis of variance (ANOVA) was carried out using SPSS 20.0 software. The F test was used to determine significant effects of each treatment, and Duncan's multiple ranges test was used to separate means at a 5% level of significance

3.0 RESULTS AND DISCUSSION

The seeds were categories into two size lots (small and large) as presented in Table 1. The analysis of variance (ANOVA) result indicates that seed size created a significant ($P \leq 0.05$) effect on all the six mechanical parameters investigated (Table 2), while the separated means of the mechanical parameters in respect to seed size are presented in Table 3.

Table 1: Gmelina seed categories

Seed size	L (mm)	D (mm)	D_g (mm)	S (mm^2)
Small	14.2	6.7	4.56	65.33
Large	17.6	11.8	5.92	110.12

Table 2: Analysis of variance (ANOVA) of seed size on the mechanical parameters of *gmelina* seed

Source of variation	**Parameter**	**df**	**F**	**Sig**
Size	Bio-yield force	1	29.60	0.000616*
	F_{max}	1	33.71	0.000402*
	Rupture force	1	29.58	0.000617*
	Bio-yield energy	1	13.16	0.006702*
	Rupture energy	1	17.46	0.003085*
	Bio-yield strain	1	46.32	0.000137*

* =Significant at (P<0.05), ns= non-significant, F_{max} = Maximum compressive force

Table 3: Mean comparison of the six mechanical parameters of gmelina seed in different seed size categories.

Parameter	**Seed size**	
	Large	**Small**
Bio-yield force (N)	$657.64^a±78.1$	$427.71^b±53.1$
F_{max} (N)	$724.81^a±78.4$	$483.33^b±49.9$
Rupture force (N)	$711.95^a±84.2$	$475.48^b±48.6$
Bio-yield energy (Nm)	$0.166^a±0.04$	$0.104^b±0.02$
Rupture energy (Nm)	$0.266^a±0.05$	$0.168^b±0.02$
Bio-yield strain (%)	$4.660^a±0.11$	$3.250^b±0.45$

±Standard deviation; The means with the same superscript in the same row are not significantly different (P ≤ 0.05) according to Duncan's multiple ranges test.

From the results presented in Table 3, the force required to initiate *gmelina* seed bio-yielding increased (about 35 %) as seed size increase from small to large seed. The maximum compressive force for the seeds ranged from 483.33 N for the small seed to 724.81 for the large seed. Owolarafe *et al.* [20] retorted average cracking force, and average pressure required for cracking of fresh palm fruit are 2301 N and 5.79 N mm^{-2}, respectively. The reason for the far greater maximum compressive of the palm fruit over gmelina seed, is because while palm fruit has a very thick shell, gmelina seed has thin shell. Therefore, greater force is needed to break the palm fruit nut when compared to the gmelina seed. Similar trend was reported for gmelina fruit were the compressive properties increased with resect to increase in seed size [14]. The results of the whole compression of intact *gmelina* seed the seed bio-yield occurs at 3.25 % deformation or force equivalent of 427.71 N for the small seeds; and 4.66 % or force equivalent of 657.64 N for the large seeds.

Energy absorbed at seed rupture also increased by about 37 % as the seed size from small to large size. This may be attributed to the fact that large seeds are capable of being more deformable under compressive loading and subsequently yielding an increase in rupture energy [21]. In reality, the internal tissues of the gmelina seed is gotten damaged before the cracking (rupture) of the seed. According to Sadowska et al. [8], despite variability of the size and the fracture force of seeds representing different accessions and varieties, there was a clear tendency towards an increase in fracture force along with an increase in seed size. This behavioral trend agrees with the theory of normal behavior of viscoelastic materials like processed apple. (Fletcher, 1971). Similar trend was reported [21] on cumin seed, where the force and energy required to initiate the fruit failure and rupture increased as fruit size increased from small (16.5mm to 35.2 mm). For plantain, all bio-yield and rupture parameters (strength, strain, and energy) increased with increased in loading cross-sectional area [22]. In addition, [23] investigated mechanical properties of Iranian sunflower seed under quasi static loading, and observed that absorbed energy and deformation at rupture increased for all sizes (small, medium and large) in both horizontal and vertical loading orientations.

The mechanical properties of agricultural material help in the proper design and development of harvesting, handling and processing machineries. Mechanical properties of agricultural seeds need an appropriate design of agrarian processing machines, but its specific application should be understood before determining them experimentally [16]. The mechanical properties of gmelina seed under compressive loading at different seed sizes are essential in the design of efficient cracking and other processing systems during gmelina oil expression.

4.0 CONCLUSIONS

This study reveals that there is a clear difference in the mechanical properties of gmelina seeds with respect to the seed sizes. All the mechanical properties investigated were significantly affected by the seed size, higher in the large seed than in the small gmelina seed. It can be concluded that the larger gmelina seed can withstand higher compressive force than the smaller seeds. The data obtained from this study will assist in the design and development of versatile machines to handle the processing of gmelina seeds.

REFERENCES

[1] Forestry/Fuelwood Research and Development Project (F/FRED). "Growing multipurpose trees on small farms, module 9: Species fact sheets (2nd ed.)." Bangkok, Thailand: Winrock International. Pp 127. 1994.

[2] D.N. Tewari. *A Monograph on Gamari (Gmelina arboreal Roxb)*. International Book Distributors. 1995

[3] J. Adegbehin, J. Abayomi, L. Nwaigbo. "Gmelina arboreal in Nigeria." *Commonwealth Forestry Review, 67(2):159–166.* 1998

[4] A.F.A. Lamb. *Gmelina arborea. Fast Growing Timber Trees of the Lowland Tropics* - no. 1. Commonwealth Forestry Institute, Oxford.1970.

[5] S. Basumatary, C. Dinesh, C. Dibakar. "Composition of biodiesel from *gmelina arborea* seed oil." *Adv. Appl. Sci. Res*. 3(5), 2745-2753. 2012.

[6] B. Sangay, B. Priyanka, O.D. Dibakar. "*Gmelina arborea* and Tarbernaemontana. divaricate seed oils as non-edible feedstock for biodiesel production." *J. Chem Tech Res.* 6 (2), 1440 - 1445. 2014.

[7] A.O. Raji, J.F. Favier, "Discrete element modelling of the impact parameters of a selected fruit: application." *Journal of Applied Science and Technology*, 21: 7–12. 2002.

[8] J. Sadowska, T. Jeliński, W. Błaszczak, S. Konopka, J. Fornal, W. Rybiński. "The effect of seed size and microstructure on their mechanical properties and frictional behavior." *International Journal of Food Properties*, 16:4, 814-825. 2013.

[9] H. Zareiforoush, M.H. Komarizadeh, M.R. Alizadeh. "Mechanical properties of paddy grains under quasi- -static compressive loading." *New York Science Journal*, 3: 40–46. 2010.

[10] G. Lysiak. "Fracture toughness of pea: Weibull Analysis." *Journal of Food Engineering*, 83: 436–443. 2007.

[11] USDA (United States Department of Agriculture). *Wood Handbook: Wood as an Engineering Material*. General Technical Report 113. Forest Products Laboratory, Wisconsin. 2003.

[12] J. Walker. *Primary Wood Processing: Principles and Practice*. Springer Verlag, New York. 2006.

[13] R. Moya, F. Muñoz. “Physical and mechanical properties of eight fast-growing plantation species in Costa Rica.” *Journal of Tropical Forest Science* 22(3): 317–328. 2010.

[14] P. Oghenerukevwe, H. Uguru. “Effect of fruit size and orientation on mechanical properties of *Gmelina* Fruit (*Gmelina arborea*) under quasi-static loading.” *International Journal of Engineering and Technical Research*. Volume-8, (4) pp 47 – 51. 2018.

[15] R. Moya, M. Tomazello. “Variation in the wood anatomical structure of *Gmelina arborea* trees at different ecological conditions in Costa Rica.” *Revista Biologia Tropical* 56: 689–704. 2008.

[16] N.N. Mohsenin. *Physical Properties of Plant and Animal Materials*. Gordon and Breach Science Publishers, New York pp 8-11, Books Ltd London 487 – 492. 1986.

[17] H. Köksel, D. Sivri, M.G. Scanlon, W. Bushuk. “Comparison of physical properties of raw and roasted chickpeas (l*eblebi*).” *Food Research International*, 31: 659–665. 1998.

[18] G. Łysiak. “Fracture toughness of pea: Weibull analysis.” *J. Food Eng.,* 83, 436-443. 2007.

[19] N.N. Mohsenin, C.T. Morrow. L.D. ‘The "Yield -Point" non-destructive technique for pending firmness of golden delicious apples.’ *Proc Am, Soc Hort. Sci*. 86(1) 70 – 80. 1965.

[20] O.K. Owolarafe, M.T. Olabige, M.O. Faborode. “Physical and mechanical properties of two varieties of fresh oil palm fruit.” *J. Food Eng.,* 78, 1228-1232. 2007.

[21] M.H. Saiedirad, A. Tabatabaeefar, A. Borghei, M. Mirsalehi, F. Badii, M. Ghasemi Varnamkhasti. “Effects of moisture content, seed size, loading rate and seed orientation on force and energy required for fracturing cumin seed (*Cuminum cyminum* Linn.) under quasi-static loading.” *Journal of Food Engineering*, 86: 565–572. 2008.

[22] S. Asoegwu, G.I. Nwandikom, and O.P. Nwammuo. “Some mechanical properties of plantain fruit.” *International Agrophysics*.12(2): 67 -77. 1998.

[23] R. Khodabakhshian, B. Emadi, M.H.A. Fard, M.H. Saiedirad. “Mechanical properties of sunflower seed and its kernel, *azargol* variety as a case study, under compressive loading.” *J. Agric. Sci. Technol*., 4 (2), 34-40. 2010.

Biography of Authors:

Eng. Oderhowho Nyorere, is a Senior lecturer in the department of Agricultural and Bio-Environmental Engineering, Delta State Polytechnic, Ozoro, Delta State, Nigeria. He holds B. Eng. in Agricultural Engineering; Masters in Agricultural and Bio-resources Engineering in Nigeria. His major research interest is in the area of thermal energy and storage of agricultural products in order to minimize agricultural waste in the food industry. He has authored many articles in reputed journals.

Hilary Uguru, is a lecturer in the department of Agricultural and Bio-Environmental Engineering, Delta State Polytechnic, Ozoro, Delta State, Nigeria. He holds B. Engr. in Agricultural and Bio-resources engineering, and currently undergoing his M. Engr programme at the Federal University of agriculture, Makurdi, Benue state, Nigeria. His major research interest is in the area of packaging and storage of agricultural products and special focus is on fruits, in order to minimize waste in the food industry. He has authored many articles in reputed journals