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Moisture-Dependent Mechanical Properties of Flame Tree (*Delonix Regia*) Seeds

John Ogidan[1], Waleola Akinfiresoye[1], Olapeju Adenekan[2]

[1]Department of Agricultural Technology, Federal Polytechnic Ile-Oluji, Nigeria.

[2]National Centre for Technology Management (NACETEM), Ile-Ife, Nigeria.

*Corresponding Author:

Email: johogidan@fedpolel.edu.gov.ng

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Abstract

The seeds of *Delonix regia* (Flame Tree), commonly known for their medicinal properties, have not been fully explored for their mechanical properties, thereby hindering their mechanization in production and handling processes. This study investigates some moisture-dependent mechanical properties of *Delonix regia* seeds, using standard ASABE (American Society of Agricultural and Biological Engineers) protocols. Seeds were subjected to different moisture content levels, and mechanical properties such as compressive strength, rupture force, and deformation were evaluated. The results show a decrease in compressive strength from 2.919 to 2.398 MPa as moisture content increased from 7.78% to 21.67%. Similar reductions were observed in rupture force and crushing energy from 56.972N – 35.756N and 41.2mJ – 29.011m respectively. These findings provide critical data for designing equipment for seed handling and processing these seeds. Further research is necessary to explore other technological applications of the seeds.

Keywords:
Moisture Content, Mechanical Properties, *Delonix regia* seed, Rupture Force, Compressive Strength

INTRODUCTION

Delonix regia, commonly known as the flame tree or royal poinciana, is a flowering plant belonging to the Fabaceae family and subfamily of Leguminosae. Its other common names include Panséké, flamboyant flame tree, gold mohur, flame tree, Julia tree, peacock flower, and flame of the forest. This plant was previously placed in the genus Poinciana, named after Phillippe de Longvilliers de Poincy (1583-1660), who is credited with introducing the plant to America (Abdullahi and Abdullahi, 2005). Native to Madagascar, this tree is renowned for its striking red and orange flowers, making it a popular ornamental plant in tropical and subtropical regions worldwide (Abdullahi & Abdullahi, 2005). The fruits (pods) are green and flaccid when young, turning to dark brown, hard woody pods, 30-50 cm long, 3.8 cm thick, 5-7.6 cm broad, ending in a short break when mature, with many horizontally partitioned seed chambers inside, indehiscent, finally splitting into two parts. The Seeds which are up to 30-45 are hard, grayish, glossy, 2 cm long, oblong, shaped very much like date seeds, and transversely mottled with a bony testa with each seed weighing around 0.4 gm. (Arora *et al*., 2010)

While the tree is widely appreciated for its aesthetic appeal, the seeds of *Delonix regia* have attracted attention for their potential medicinal and industrial uses similar to the seeds of date palm (*Phoenix* spp) (Adenekan *et al*., 2017). Pharmacological studies have identified the seeds as rich in flavonoids and fatty oils, giving them anti-inflammatory, antibacterial, and wound-healing properties (Lawal *et al*., 2010). The seeds yield 18 to 27.5 % fatty oil known as the "*pongam*" or "*karanga*" oil of commerce which is mainly used in the tanning industry. The oil and its "*karjan*" possess insecticidal and anti-bacterial properties. The oil also finds use in soap making, illuminating, and pharmaceutical preparations. The oil cake is a good fertilizer. The seed cake can also be used in poultry ration to substitute the black "*til*" component of ration. The seed is carminative (prevents formation of gas in the alimentary canal), purifies and enriches the blood, and is used in cases of inflammation, "ear ache" and chest complaint. Despite these benefits, there is limited information on the mechanical properties of *Delonix regia* seeds, which is essential for their industrial application. Seeds of *Delonix regia* contain flavonoids that are used as wound-healing agents in households (Lawal *et al.*, 2010)

In agricultural and industrial processing, understanding the mechanical properties of seeds is critical for designing and optimizing equipment for harvesting, processing, and storage. These mechanical properties, including compressive strength, rupture force, and energy absorption, vary significantly with moisture content. This is particularly important for seeds like *Delonix regia*, which have hard, woody shells. Changes in moisture levels can affect the seed's structural integrity, influencing the forces required for dehulling, milling, and other processing activities (Chukwu & Sunmonu, 2010).

Previous studies have explored the mechanical properties of various seeds, including African oil bean (Aremu *et al*., 2014), faba bean (Altuntas & Yildiz, 2005), and cumin (Saiedirad *et al*., 2008). These studies indicate that moisture content plays a significant role in determining the compressive strength, rupture force, and energy required to process seeds. However, comprehensive mechanical data specific to *Delonix regia* seeds are lacking, posing a challenge to the development of efficient mechanized processes for their handling and processing.

This study aims to fill this gap by investigating the moisture-dependent mechanical properties of *Delonix regia* seeds. By analyzing key parameters such as compressive strength, rupture force, and deformation at varying moisture content levels, this research provides valuable insights into the behavior of the seeds under mechanical stress. The findings will not only contribute to the scientific understanding of *Delonix regia* but also offer practical implications for the design of equipment used in the processing and handling of the seeds.

LITERATURE REVIEW

Mechanical properties

Mechanical properties are those which indicate the behavior of biomaterials under applied forces. Some of these properties as listed by Goyal *et al.*, (2007) include hardness, toughness, terminal velocity, impact strength, drag coefficient, compressive strength, and impact and heart resistance. Mechanical damage to seeds and grains which occur during harvesting, threshing and handling can seriously affect viability and germination power, growth vigor, insect fungi attach and quality of final product (Mohsenin, 1986). According to Chukwu and Sunmonu (2010), the evaluation of mechanical properties of agricultural produce during postharvest handling, processing, and storage aids the determination of design parameters for harvesting and postharvest systems. Mechanical properties such as compressive strength, impact and shear resistance are important and, in some cases, necessary engineering data in studying size reduction of cereal grains as well as seed resistance to cracking under harvesting and handling conditions (Mohsenin, 1986). Obi *et al.* (2014) reported that in the design of a dehulling machine, mechanical properties such as rupture force, hardness and energy used for rupturing fruits are useful information. Saiedirad *et al*. (2008) reported the effects of moisture content, seed size, loading rate and seed orientation on force and energy required for fracturing cumin seed (*Cuminumcyminum* Linn).

The rupture force indicates the minimum force required for shelling the nut and grinding the seed and fruit. The deformation at rupture point can be used for the determination of the gap size between the surfaces to compress the seed for shelling. Ahmadi *et al*. (2009) reported that rupture force on both fennel seed (*Foeniculum vulgare*) length and width sections decreased logarithmically with moisture content in the above moisture range. Tavakoli *et al.* (2009) also reported that the rupture force for Soybean grains decreased from 270.66 to 191.09 N, while the rupture energy increased from 318.34 to 376.68 mJ, as the moisture content increased from 6.92 to 21.19 % d.b.

Aremu *et al*. (2014) in a study of the mechanical properties of African oil bean seeds found that as the moisture content increased, the compressive strength and rupture force decreased significantly. Similar findings were reported by Altuntas & Yildiz (2005) for faba bean seeds and by Saiedirad *et al*. (2008) for cumin seeds. These studies suggest that seeds with lower moisture content require higher compressive forces to rupture, due to their increased hardness and brittleness. This pattern of decreasing mechanical strength with increasing moisture content has been attributed to the softening of seed tissues as they absorb moisture (Bart-Plange *et al*., 2012).

Ahmadi *et al*. (2009) examined fennel seeds and noted that as moisture content increased, both the rupture force and energy required for cracking the seeds decreased. These results are consistent with other studies, indicating that moisture content affects the internal structure of seeds, making them more susceptible to mechanical damage under lower forces. Similarly, Tavakoli *et al*. (2009) reported that soybean grains exhibited a decrease in rupture force and an increase in rupture energy as moisture content increased from 6.92% to 21.19%. Okey & Okey (2013) explored the prospects of using *Delonix regia* seed oil for biodiesel production and highlighted the importance of understanding the seed’s physical properties, such as density and viscosity, which affect oil extraction and processing. While their research provided valuable insights into the oil characteristics, it did not address the mechanical behavior of the seeds, leaving a gap in the literature regarding the seeds' processing characteristics in agricultural and industrial settings.

Recent studies on the mechanical properties of other seeds, such as pigeon pea (Oduma *et al*., 2013) and shea nut (Olaniyan & Oje, 2002), suggest that mechanical data such as rupture force, compressive strength, and energy absorption are essential for designing effective processing equipment. As *Delonix regia* seeds possess a hard, woody shell, understanding their mechanical properties is crucial for developing efficient technologies for dehulling, milling, and other processing tasks. Please provide a clear objective for the study.

MATERIALS AND METHODS:

Seeds of *Delonix regia* were collected from the flame tree at Faculty of Agriculture, University of Ibadan, and soaked at room temperature (28-32°C) for varying durations to achieve moisture contents ranging from 7.78% to 21.67% (wet basis). The seeds were cleaned to remove any adhering debris and foreign materials.

Mechanical tests were conducted following ASABE standard S 353.2: Moisture Measurement -Unground Grain and Seeds ASABE, 2017. The seeds were subjected to pressure loading along their longitudinal, transverse, and width axes. For the compression Test, a Universal Testing Machine (UTM) was used to perform the compression test.

The seeds were placed between two flat parallel plates, and a compressive load was applied along the seed's natural axis until failure occurred. Compressive strength, rupture force, and energy at break were recorded and analyzed. The graphical representation: of the relationships between moisture content and mechanical properties was presented using appropriate plots.

RESULTS AND DISCUSSION

Effect of Moisture Content on Compressive Strength of *Delonix regia* Seed

The results of the compressive strength of *Delonix regia* seeds as presented in Table 1 reveal that the maximum compressive strength decreased from (2.919±0.119)Mpa to (2.398±0.176)Mpa as the moisture content increased from 7.78% to 21.67%. The decrease in compressive stress with moisture content may be because, as the seeds absorb moisture, they become softer and the forces acting would be minimal leading to a reduction in stress (Bart-Plange *et al*., 2012). Similar trends were reported for African oil bean seed (Aremu *et al*., 2014), Figure 1 shows the graphical relationship between the compressive stress with moisture content.

Table 1: Compressive Strength and Rupture Force of *Delonix regia* seeds at five moisture contents

Moisture Content	Loading Position	Maximum Compressive Stress (MPa)	Compressive Stress at Break (MPa)	Compressive Stress at Yield (MPa)	Maximum Force (N)	Force at Break (N)
7.78% (wb)	L	2.919 (0.919)	0.167 (0.078)	1.495 (0.203)	56.972(1.253)	2.879 (1.347)
	W	0.882 (0.036)	0.051 (0.024)	0.452 (0.061)	17.223 (0.379)	0.870 (0.407)
	T	0.617 (0.025)	0.035 (0.016)	0.316 (0.043)	12.033 (0.265)	0.608 (0.285)
10.91% (wb)	L	2.822 (0.315)	0.156 (0.004)	1.411 (0.108)	51.078 (3.723)	2.630 (0.849)
	W	0.853 (0.095)	0.047 (0.001)	0.426 (0.033)	15.441 (1.125)	0.795 (0.257)
	T	0.596 (0.066)	0.033 (0.001)	0.298 (0.023)	10.788 (0.786)	0.556 (0.179)
14.83% (wb)	L	2.630 (0.849)	0.143 (0.007)	1.358 (0.020)	47.200 (0.816)	2.512 (0.787)
	W	0.795 (0.257)	0.043 (0.002)	0.410 (0.006)	14.268 (0.247)	0.759 (0.238)
	T	0.556 (0.179)	0.030 (0.001)	0.287 (0.004)	9.969 (0.172)	0.531 (0.166)
17.76% (wb)	L	2.558 (0.102)	0.129 (0.004)	1.099 (0.009)	38.411 (1.430)	2.254 (0.055)
	W	0.773 (0.031)	0.039 (0.001)	0.332 (0.003)	11.612 (0.432)	0.681 (0.017)
	T	0.540 (0.022)	0.027 (0.001)	0.232 (0.002)	8.112 (0.302)	0.476 (0.012)
21.67% (wb)	L	2.398 (0.176)	0.095 (0.006)	0.863 (0.046)	35.756 (1.759)	1.951 (0.453)
	W	0.725 (0.053)	0.029 (0.002)	0.261 (0.014)	10.809 (0.532)	0.590 (0.137)
	T	0.506 (0.037)	0.020 (0.001)	0.182 (0.010)	7.552 (0.372)	0.412 (0.096)

NOTE: Values in brackets are standard deviation.

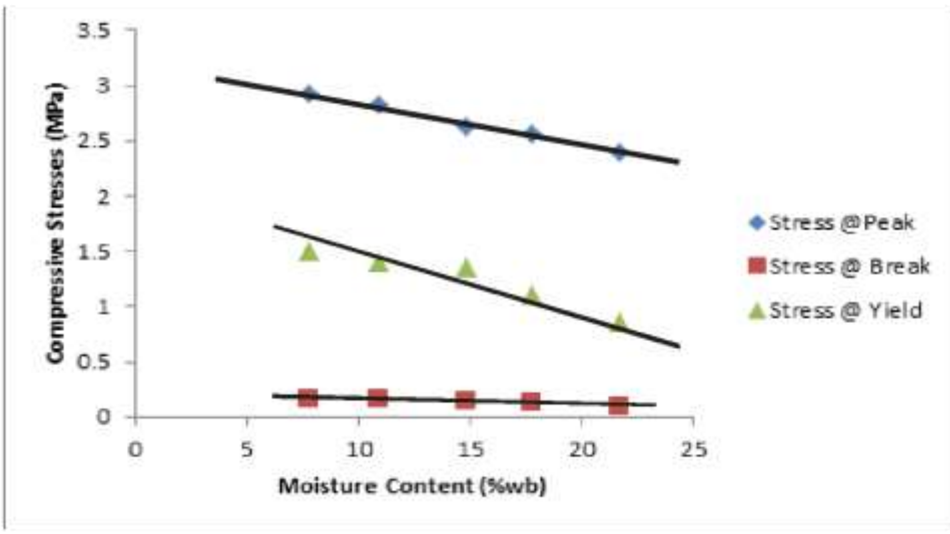

Figure 1: Compressive Stress of *Delonix regia* Seeds as a function of moisture content

The relationship between the moisture content (Mc) and Maximum Compressive Strength (Cs) of *Delonix regia* seed can be expressed mathematically using the equation below:

Cs = -0.038Mc + 3.217 (R^2 = 0.993)__________ **(1)**

Effect of Moisture Content on Rupture Force of *Delonix regia* Seed

The force required to initiate seed rupture for loading along the three loading axes at different moisture contents is presented in Table 1. It can be observed that the rupture force decreased as the moisture content increased from 7.78% to 21.67% w.b. The rupture force values ranged from 56.972N to 35.756N. This indicated that seeds with lower moisture content need a higher compression load for rupture. The decrease in rupture force with moisture content is because the seeds have a softer texture at higher moisture content. This is in line with a report by Obi *et al*. (2014) for Pigeon Pea Aremu *et al*. (2014) also reported that the average force required to initiate African oil bean seed rupture decreased from 276.64 to 195.26N in the longitudinal axis with an increase in moisture content from 15.76 to 34.43(%wb). Altuntas and Yıldız (2005), and Olaniyan and Oje (2002) reported similar results for apricot pit, faba been and shea nut, respectively.

The compression force for the *Delonix regia* seeds was always highest at the length followed by the width and least at the thickness positions as recorded for all the levels of moisture content. This is however in contrast with the findings of Oduma *et al. (*2013) for the compression force of Pigeon Pea.

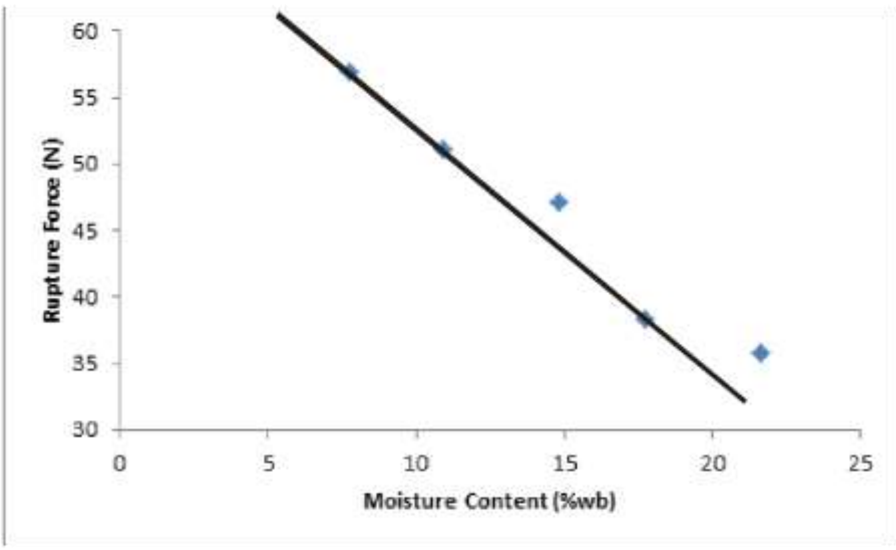

Figure 2: Rupture Force of *Delonix regia* Seeds as a function of moisture content

The relationship between the moisture content (Mc) and Rupture Force (R) of *Delonix regia* seed can be expressed mathematically using the equation below:

R = -1.579Mc + 68.919 (R^2 = 0.966)__________ **(2)**

Effect of Moisture Content on Energy at Break

As shown in Table .2, as the moisture content increases from 7.78% to 21.67%, the average energy at break also decreased from 41.2mJ to 29.011mJ. With increasing *Delonix regia* seed moisture content, less energy was required for the compression of the seed in a longitudinal compression direction. Bwade *et al*. (2013) reported the same trend for the Rupture energy of Pumpkin Seed. The energy requirement for crushing the *Delonix regia* seeds with the seed moisture content is displayed in Figure 3

The equation below reveals the relationship between the energy to break (E_b) *Delonix regia* seeds and the seeds' moisture content.

E_b = -0.873Mc + 48.117 (R^2 = 0.995) ________ **(3)**

Table 2: Summary of some mechanical properties of *Delonix regia* seeds at five moisture contents

Moisture Content	Loading Position	Force at Yield (N)	Maximum Compressive Strain	Compressive Strain at Break	Maximum Energy (J)	Energy at Break (J)
	L	26.508(2.839)	0.067 (0.010)	0.092 (0.005)	32.350(2.154)	41.200(2.482)
7.78% (wb)	W	8.013 (0.858)	0.020 (0.003)	0.028 (0.002)	9.749 (0.651)	12.455(0.750)
	T	5.599 (0.600)	0.014 (0.002)	0.020 (0.001)	6.832 (0.455)	8.701 (0.524)
	L	24.995 (1.279)	0.054 (0.012)	0.086 (0.004)	31.878(2.286)	38.411(1.430)
10.91% (wb)	W	7.556 (0.387)	0.016 (0.004)	0.026 (0.001)	9.637 (0.691)	11.612(0.432)
	T	5.279 (0.270)	0.011 (0.003)	0.018 (0.001)	6.733 (0.483)	8.112 (0.302)
	L	19.867 (0.011)	0.048 (0.005)	0.067 (0.010)	28.974(0.654)	35.756(1.759)
14.83% (wb)	W	6.006 (0.003)	0.015 (0.001)	0.020 (0.003)	8.759 (0.198)	10.809(0.532)
	T	4.196 (0.002)	0.010 (0.001)	0.014 (0.002)	6.119 (0.138)	7.552 (0.372)
	L	18.974 (0.654)	0.037 (0.004)	0.042 (0.014)	24.637(1.025)	32.496(0.441)
17.76% (wb)	W	5.736 (0.198)	0.011 (0.001)	0.013 (0.004)	7.448 (0.310)	9.824 (0.133)
	T	4.007 (0.138)	0.008 (0.001)	0.009 (0.003)	5.203 (0.216)	6.863 (0.093)
	L	18.791 (0.406)	0.017 (0.003)	0.024 (0.004)	19.151(0.378)	29.011(0.295)
21.67% (wb)	W	5.680 (0.123)	0.005 (0.001)	0.007 (0.001)	5.789 (0.114)	8.770 (0.089)
	T	3.969 (0.086)	0.004 (0.001)	0.005 (0.001)	4.045 (0.080)	6.127 (0.062)

NOTE: Values in brackets are the standard deviation.

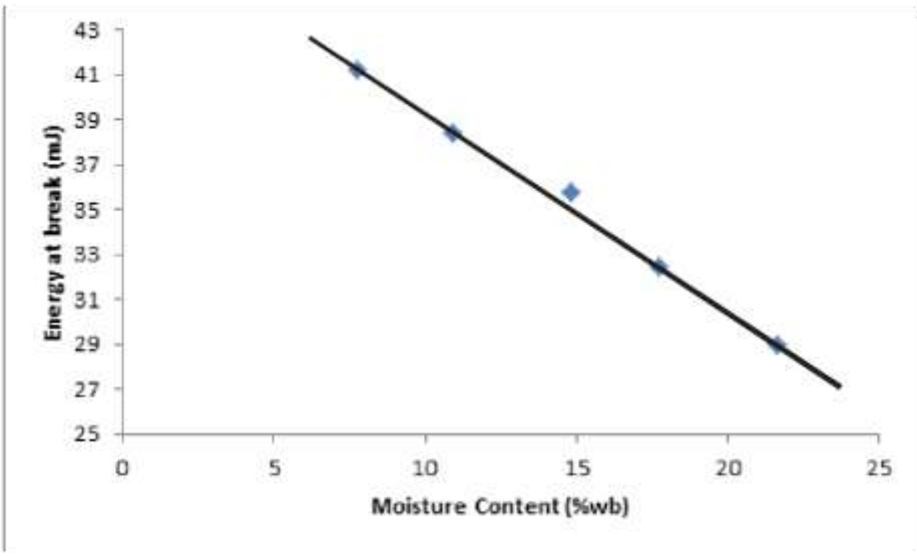

Figure 3: Energy to break *Delonix regia* Seeds as a function of moisture content

Effect of Moisture Content on Deformation

The variation of *Delonix regia* seeds' moisture content versus deformation at maximum compressive stress is shown in Figure 4 below. It can be seen that the average deformation at maximum compressive stress of *Delonix regia* seeds decreased with an increase in moisture content from 1.321mm to 0.882mm. The trend of variation illustrates that as moisture content increases, the maximum deformation of *Delonix regia* seeds decreased. This trend was also reported for Pigeon Pea grown in Nigeria by Obi *et al.*, (2014). This is however in contrast with the findings of Bamgboye and Adebayo (2012) for *Jatrophacurcas* seed.

The relationship between moisture content (Mc) and maximum deformation (D_m) can be expressed mathematically using the equation below.

$$D_m = -0.032Mc + 1.604 \quad (R^2 = 0.95) \qquad \textbf{(4)}$$

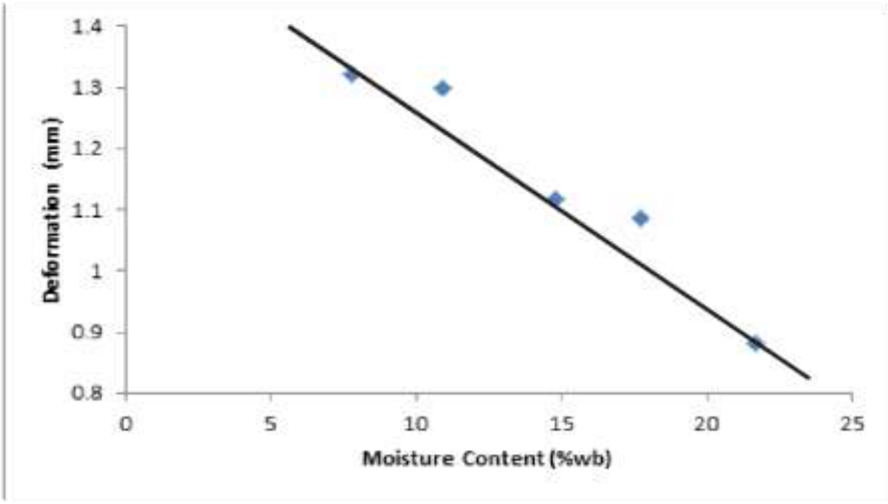

Figure 4: Deformation of *Delonix regia* Seeds as a function of moisture content

Compressive Strain

As shown in Table 2, as the moisture content increased from 7.78% to 21.67% (wb), the compressive strain at break decreased from 0.067mm/mm to 0.017mm/mm. A similar result was discussed for the compressive strain of Shea kernel by Bart-Plange *et al.* (2012). The relationship between moisture content (Mc) and compressive strain at break (S_b) of *Delonix regia* seeds can be expressed mathematically as follows.

$$S_b = -0.003Mc + 0.094 \quad (R^2 = 0.965) \qquad (5)$$

Figure 5 shows the graph of the measured values of compressive strain at break with moisture content.

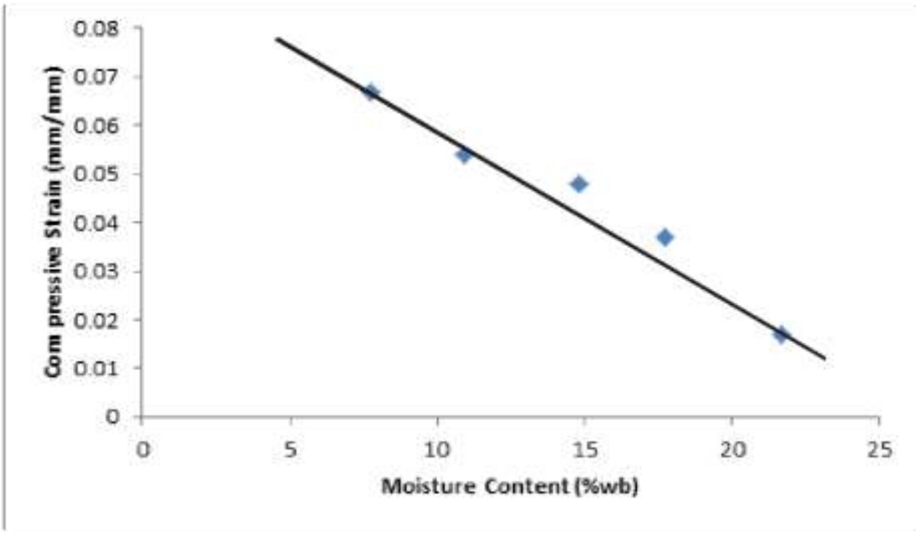

Figure 5: Compressive Strain of *Delonix regia* Seeds as a function of moisture content

CONCLUSION

This study investigated some moisture-dependent mechanical properties of *Delonix regia* seeds at 7.78, 10.91, 14.83, 17.76, and 21.67 wet basis moisture content. The results showed that with increase in moisture content from 7.78 – 21.67%wb, the maximum compressive strength decreased from (2.919±0.119)Mpa to (2.398±0.176)Mpa, the rupture force decreased from 56.972N to 35.756N, the average energy at break also decreased from 41.2mJ to 29.011mJ, the average deformation at maximum compressive stress of *Delonix regia* seeds decreased from 1.321mm to 0.882mm and the compressive strain at break decreased from 0.067mm/mm to 0.017mm/mm.

This suggests that seeds become softer and less resistant to mechanical stress as they absorb moisture. Seeds with lower moisture content exhibited higher rupture force, implying they are more resistant to breakage. The study demonstrated that moisture content has a significant impact on the mechanical behavior of flame tree seeds. Drier seeds are more mechanically robust and resistant to various forces, whereas seeds with higher moisture content are more prone to mechanical damage.
Based on the findings of this study; to minimize mechanical damage during handling, transportation, and processing, flame tree seeds should be kept at optimal moisture levels. Maintaining seeds at a lower moisture content (around X%) will reduce the likelihood of mechanical damage such as crushing or breakage. Also, it is recommended to store seeds at lower moisture content to preserve their mechanical strength and viability. This will help in maintaining seed integrity, especially for agricultural purposes where seed quality is crucial for successful germination and plant growth.

Future studies should investigate the technological application of different varieties of flame tree seeds or related species to provide a broader understanding of the moisture-dependent mechanical properties of leguminous tree seeds.

Data availability statement: The dataset generated and analyzed for this study are available upon request from the corresponding author.

Ethics statement: This study was conducted in accordance with ethical guidelines for scientific research. The flame tree seeds used were sourced responsibly ensuring that no harm is done to the natural habitat or ecosystem during collection. The data collected were handled with integrity and the findings of the study were accurately reported to support transparency and reproducibility.

Author contributions: John Ogidan, conceptualized and designed the methodology of the study and also led the writing of the original draft. Waleola Akinfiresoye supervised the data collection, sample preparation and conducted mechanical test, contributed to data analysis and interpretation. Assisted in editing and reviewing the manuscript. Olapeju Adenekan prepared the figures and graphical representation, and contributed to writing and revising the final manuscript

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Conflict of interest: The authors have no competing interests to declare.

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