# DETERMINATION OF MOISTURE DEPENDENT PHYSICO-MECHANICAL PROPERTIES OF DETARIUM SENEGALENSE

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**Abstract:** The study investigated the moisture dependent physico-mechanical properties of tallow (Detarium senegalense) seeds. A randomized complete block design comprising of eight treatments with three replications were used. The initial moisture contents of the tallow seeds were determined before and after oven drying. Moisture conditioning were done in four moisture levels (19.65, 20.72, 21.90 and 22.81% d.b). The findings showed that the length, width and thickness of the seeds ranged between 3.1 to 4.6, 2.7 to 4.2 and 1.2 to 2.3 mm, respectively, while the mean of geometric diameter and equivalent surface area ranged between 2.92 to 6.6 mm and 26.79 to 119.36 $cm^2$, respectively. The mechanical properties investigated were force, stress, strain, energy, deformation and Young's modulus and were found to be in the range of 99.000 – 1152.500 N, 1.641 – 12.832 $N/mm^2$, 3.980 – 13.369 mm/mm, 0.680 – 3.083 Nm and 1.393 – 4.734 mm $N/mm^2$ in the major orientation and 19.655.670 – 2465.300 N, 1.876 – 14.853 $N/mm^2$, 8.808 – 28.556 mm/mm, 0.176 – 10.20.721.90 Nm and 1.515 – 5.786 mm. 0.22.818 – 0.794 $N/mm^2$ in the minor orientation respectively. The coefficient of friction was also affected by moisture content. It increased on galvanized steel (1.28 – 1.42) and plywood (1.90 – 2.40) but decreased on plastic (1.57 – 1.00) as moisture increase. The effect of moisture content on both the physical and mechanical properties was found to be significant ($p \leq 0.05$) at (19.65, 20.72, 21.90 and 22.81% d.b) moisture contents except for stress at yield, strain at break, energy at break and yield, deformation at peak and Young modulus. The results obtained in this study will provide useful information for mechanization of various unit operations involved in post-harvest processing and also in the development and evaluation of optimization parameters for efficient and effective processing equipment. Further studies on other engineering properties of tallow seed (thermal and aerodynamics) are needed to have comprehensive data in the study area.

**Keywords:** Moisture, Dependent, Physico, Mechanical, pod

## Introduction

Tallow commonly known as *Detarium senegalense* or Sweet detar is a species of plant in the Fabaceae family and a genus that is represented by eight species (Adenkunle*et al.,*2011). However, only three species are found in West African forests: Detarium macrocarpum Harms, Detarium microcarpum Guillemin and Perrottet and *Detarium senegalense*. These three species are very similar morphologically but appear to differ in ecological distribution (Elkamali, 2011). It grows naturally in the drier regions of West and Central Africa, (Germplasm Resources Information Network [GRIN], 2009). It mostly grows in dry forests (Kouyate, and Van-Damme, 2006). In Asia it grows in Indonesia and Singapore and in the Caribbean in Trinidad and Tobago (Elkamali, 2011). *Detarium senegalense* is a medium sized to fairly large tree up to 35–40 m tall (Adenkunle *et al.,*2011), bole is branchless up to 12–15 m, straight or irregular, cylindrical, up to 60–100 cm in diameter, without buttresses but sometimes swollen at base bark, surface finely fissured, becoming scaly, grayish to blackish, with large, round lenticels, inner bark thickness, fibrous, red brown, with some sticky gum, crown large, dark green, with spreading branches. Savannah type leaves glaucous beneath, flowers are creamy white in dense inflorescences (Elkamali, 2011). The tree has very large leafy crown and are bright green with common stalk 5-13 cm long (Keay *et al.,* 1989). Different parts of the plant have been reported to possess medicinal value (Kouyate, 2005). It is known by various tribal names as 'Ofo' (Igbo), 'Taura' (Hausa) and 'Ogbogbo' (Yoruba) (Olapade, and Peters, 2018). Among the Ibo tribe of southeastern Nigeria, the plant is believed symbolizing truth and honestly (Akah *et al.,*2012) and used the seed flour mainly as a soup thickener. A detarium meal were observed to elicit significant reduction in the plasma glucose levels of the human subjects investigated (Onyechi *et al.,* 1998). The gum from the plant is reported to have shown promising antidiabetic effect in experimental rats (Sowemimo *et al.,* 2011). The greenish and sweet acidulous fruit pulp is edible and can be eaten raw or cooked. It is also used to prepare sweetmeat or as an ingredient of ice cream. However, it may also be toxic, and caution is needed. The seed is oily and edible, and pounded seed is used as cattle feed. In Nigeria the seed flour is used traditionally as a emulsifying, flavouring and thickening agent in foods (Burkill, 1995) often used as a soup thickener (Adenkunle *et al.,*2011). The bark is added to palm wine to accelerate fermentation and to make it bitterer. Seeds have been effective in controlling blood glucose levels in diabetic individuals (Cisse *et al.,*2010) also are taken as antidote against arrow poison and snake bites (Akah *et al.,*2012), also as emetic, insecticide, arachnicide and the smoke of burnt seeds as mosquito repellent. In spite of the economic importance of the African seed, there exists a dart of information about its physical and mechanical properties that could be used to design machines required for processing the seed. Therefore, the aim of this study is to determine the moisture dependent physico-mechanical properties of Tallow seed pod.

## Materials and Methods

The seeds of detarium senegalense were cleaned manually to remove all foreign materials such as stones, immature and broken seeds. The sample were then be poured into a polyethylene bag and the bag was tightly sealed. Hundred seeds were selected at random from the lot and their physical and mechanical properties include size, shape, static coefficient of friction, angle of repose, axial dimensions, surface area, sphericity, porosity, moisture content; density (bulk and true), strength, hardness, shear and compressive stress was conducted on each sample. The physical properties of tallow seeds were determined.

***Determination of Size and Shape of Tallow Seed***

This involves measuring the axial dimensions and calculation of mean diameters, sphericity and aspect ratio of tallow seed. The major (length), intermediate (width), and minor (thickness) dimensions of tallow seed was measured using a digital Vanier calliper of resolution 0.01mm. At each moisture content level, 100 tallow seeds were used; i.e. twenty-five seeds measured and replicated four times. The means of the major, minor and the intermediate dimensions were calculated for further calculation of other engineering properties of tallow seed.

***Moisture Content***

Distilled water was added to the sample and sealed in separate polythene bags which was kept in a refrigerator $4^0C$(Abba *et al.*,2018) for even distribution of water to the seeds, The initial moisture content (dry basis) of the seeds were determined by oven drying the samples until a relatively constant weight is achieved/reached (Kawuyo *et al.*,2011)and (Adedeji *et al.*,2015).

$$Q = \frac{W_i(M_f - M_i)}{(100 - M_f)} \quad (1)$$

Where; Q = the mass of water added (kg), $W_i$ = the mass of sample (kg),$M_i$ = the initial moisture content of sample (%)$M_f$= the final moisture content of sample (%)

**Arithmetic Mean Diameter**: The arithmetic mean diameter of the tallow seeds were determined using the procedures reported by (Anya, 2013)

$$D_a = \frac{a + b + c}{3} \quad (2)$$

Where; a = major diameter (mm),b= minor diameter (mm),c = intermediate diameter (mm) of the seed pod

**Geometric Mean Diameter:** The geometric mean diameter ware determined from the physical dimensions (major diameter (a), minor diameter (b) and the intermediate diameter(c)) of the seeds. It was obtained from the relationship reported by (Bup *et al.*,2013) and (Orhevba *et al.*,2013)

$$D_g = (abc)^{1/3} \quad (3)$$

Where; a=Major diameter, b=Minor diameter,c = Intermediate diameter of the seed pod

**Determination of True Density:** The true density was determined using the toluene displacement method. About 10 seeds of known mass were lowered into a measuring cylinder containing toluene. The true density of a seed is defined as the ratio of the mass of a sample of a seed to the solid volume occupied by the sample. The seeds volume and their true densities were determined using the liquid displacement method. Toluene ($C_7H_8$) (Bup *et al.*,2013;

$$(\rho_t) = \frac{M}{V_t} \quad (4)$$

Where; M= Mass of the tallow seed pod (g), $V_t$ = Volume of toluene displaced ($cm^3$).

***Determination of Angle of Repose***

The angle of repose is the angle with the horizontal at which the material will stand when piled. This was determined by using a cylindrical container open at both ends. The cylinder was placed on a wooden table, filled with the seeds and raised slowly until it formed a cone of seeds. (Idowu *et al*, 2012)

$$\phi = \tan^{-1}\left(\frac{2h}{d}\right) \quad (5)$$

Where; $\emptyset$= Angle of repose ($^0$), h= Height of the cone formed by the seeds (cm), d= Diameter of the base of the cone formed by the seed pod (cm)

***Determination of Static Coefficient of Friction***

The static coefficient of friction $\mu$was determined for three structural materials (plywood, plastic and galvanised sheet). For this measurement, one end of the friction surface will be attached to an endless screw. The seed was placed on the surface and gradually raised by the screw (Sunmonu, 2015)

$$\mu = \tan\theta \quad (6)$$

Where; $\mu$ = coefficient of static friction, $\theta$ = the angle from the horizontal plane

**Hardness of the Materials:** Hardness, often defined as a measure of material's resistance to penetration. Nevertheless its meaning differed between professions; hardness was used to refer to resistance to permanent deformation (Wiemann and Green, 2007). Hardness value gives an indication of the amount of energy per unit area needed to crush a given agricultural material, this is very necessary for the development of machines that can grind or crush agricultural materials, (Alonge, 2003). Plate 1 show tallow pod universal testing machine at major axis. It is equally important in the evaluation of seed's resistance to cracking under harvesting and handling conditions, (Olaoye, 2000).

$$H_M = \frac{4F}{\pi d^2} \quad (7)$$

Where; $H_M$ =Meyer's hardness (N/mm2),F= the applied load (N),d = diameter of indentation, (mm)

Plate 1: Universal Testing Machine at Major Axis

**Results and Discussion:**
The results in Table 1 shows the averages of length, width and thickness were found to be 3.6, 3.3 and 1.5 mm respectively. The findings showed that the length, width and thickness of the seeds ranged between 3.1 to 4.6, 2.7 to 4.2 and 1.2 to 2.3 mm, respectively, while the mean of geometric diameter and equivalent surface area ranged between 2.92 to 6.6 mm and 26.79 to 119.36 $cm^2$respectively. Values are presented in Table 1. These values may be used to determine the size of aperture as well as the size of the machine components. The mean value of the sphericity was 0.85 and 0.75. Figure 1 show the compressive results of tallow Seeds obtained from the axial orientation at 19.65% (d.b). Suggesting that the least force to break the seed can only be obtained the at least moisture content.

Table 1: Physical properties of the Tallow seed

| Properties | Min value |
|---|---|
| Length (mm) | 3.1 |
| Volume ($cm^3$) | 7.56 |
| Width (mm) | 2.7 |
| Thickness (mm) | 1.2 |
| Sphericity (%) | 1.02 |
| Geometry Mean Diameter (mm) | 2.92 |
| Surface Area ($cm^2$) | 26.79 |
| Arithmetic Mean | 2.27 |

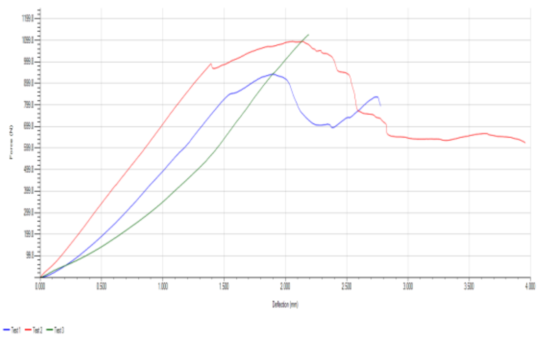

Figure 1: Compressive Results of tallow Seeds obtained from the UTM in the axial orientation at 19.65% (d.b).

***Effect of Moisture Content on Bulk Density***
The bulk density of tallow seed significantly varied in a linear fashion from 353 to 365 $kg/m^3$ with the increase of moisture content from 19.65 to 22.81% db Figure 2. This is as a result of pore spaces within the fibre of the seed. This indicated that there was increase in mass with negligible effect on volume as the seed gained moisture. (2009) observed the same trend for hazel nut. However, other researchers showed negative linear relationship between bulk density on other hosts and moisture content (Singh *et al.*, 2010, Balasubramanian, 2001, Aydin, 2007 and Dursun *et al.*,2007). The model equation and coefficient of determination $R^2$ are expressed as;
Y = 5.4781MC + 247.98 , $R^2$ = 0.88(25)

***Effect of Moisture Content on Angle of Repose***

Figure 1 showed the variation of the static angle of repose with seed moisture content increase from 19.65 to 22.81`%. The values were found to increase from 31.6 to 37.8° with an increase with moisture content from 19.65 to 22.81%. The increasing trend of angle of repose with moisture content occurs because the surface layer of moisture surrounding the particle holds the aggregate of seed together by the surface tension (Pradhan *et al.*, 2008). The values of the angle of repose (θ) and coefficient of determination for tallow seeds bear the following relationship with its moisture content(Mc):

$$Y = 6.3381MC - 93.711 \quad R^2 = 0.94 \qquad (9)$$

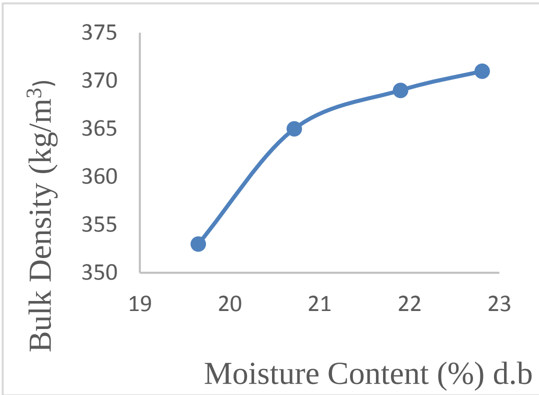


Figure 2: Relationship between Moisture Content (%) and Bulk Density ($kg/m^3$)

***Effect of Moisture Content on Coefficient of Friction***
The static coefficient of friction of tallow seeds obtained experimentally on three structural surfaces in moisture range of 19.65 to 22.81% (db). Figure 3: shows that the static coefficient of friction increases as moisture increase on galvanised steel and plywood and decreases on plastic. The highest value was observed on plywood and the lowest on galvanised steel. The increase might be due to the increase in adhensive force which made it difficult to move on the surfaces and the decrease due to increase in cohesive force owing to the smothness and more polished surface of plastic which made it easy to move on it. This result is in agreement with Abba *et al.* (2018) Fadavi (2013) for wild pistacho nuts, Idowu *et al* (2012) for sandbox seed and Hasbavi (2013) for Iranian okra seeds. The model equation and coefficient of determination $R^2$ are expressed as;

$$CFgs = 0.0438MC + 0.4107 \quad R^2 = 0.97 \qquad (10)$$

$$CFpw = 0.1446MC - 1.0108 \quad R^2 = 0.72 \qquad (11)$$

$$CFpl = -0.1738MC + 4.9769 \quad R^2 = 0.99 \qquad (12)$$

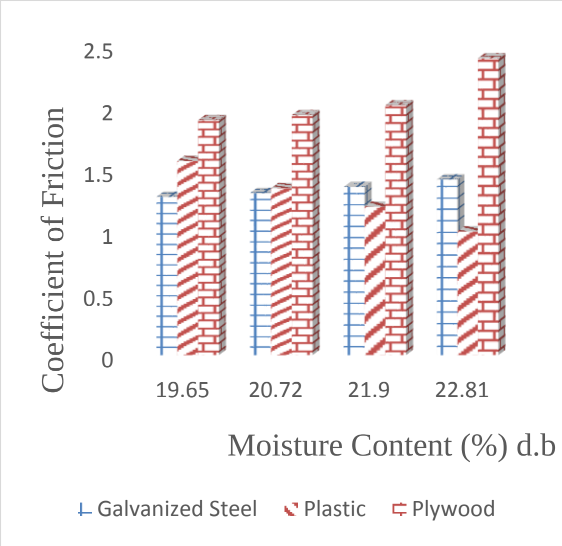


Figure 3: Relationship between Moisture Content (%) and Coefficient of Friction

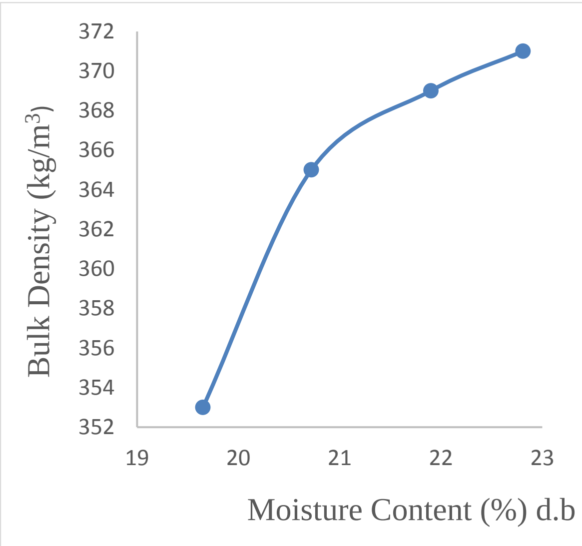


Figure 4: Relationship between Moisture Content (%) and Bulk Density (kg/$m^3$)

**Effect of Moisture Content on Force at Peak:** The force at peak decreased (1054.6 – 875.5 N) as moisture content increased from 19.65 to 20.72 % and with further increased in moisture to 21.90 % in the major axis the force at peak decreased to 857.5 N Figure 3 Similarly, there was an increased in force at peak (1819.8 – 2968.7 N) as moisture content increased from 19.65 to 20.72 % in the minor axis and later decreased to 1529.7 N as moisture content reached 22.81 %. This might be due to more moisture in seed, the softer the seed and requires less force. Similar trends were observed by Abba *et al.*, (2018) for neem seed, Hojat (2009) for fennel seed, Gana *et. al.* (2014) for soya beans, Bamgboye and Adebayo (2012) for Jatropha curcas, Fabunmi *et. al.* (2013) for desma seeds and contrary to Hazbavi (2013) for Iranian okra. The effect of moisture content was significant at ($p \leq 0.05$) Table 1 The model equation and coefficient of determination $R^2$is expressed as;

$F_{peak}$ Major Axis: $Y=4.6614x^2 – 296.84 + 3875.9$ $R^2 = 0.58$ (13)

Minor Axis: $Y = 319.65.7x^2 + 13403x – 137555$ $R^2 = 0.75$ (14)

**Effect of Moisture Content on Force at Break:** The force at break decreased (848.30 – 519.56 N) as moisture content increased from 19.65 to 20.72 % and with increased in moisture to 21.90 %, it decreased to 918.9 N Figure 3 then finally decreased to 787.7 N in the major axis. Similarly, there was an increased in force at break (3698.327 – 3718.400 N) as moisture content increased from 19.65 to 20.72 % in the minor axis and later decreased to 1573.903 N as moisture content reached 22.81 %. This might be due to more moisture in seed, the softer the seed and requires less force to break the seed. Similar trends were obtained by Fabunmi (2017) for Raphia seeds, Abba *et al*, 2018), Fadeyibi and Osunde (2012) for Rubber seed. Table 2 shows that the effect of moisture content was significant at ($p \leq 0.05$) on tallow seed. The model equation and coefficient of determination $R^2$is expressed as;

$F_{break}$Major Axis:$Y= 54.429x^2 - 21.9087.3x + 24718$ $R^2 = 0.58$ (15)

Minor Axis:$Y = -69.262x^2 + 20.722.814.1x – 11345$ $R^2 = 0.75$ (16)

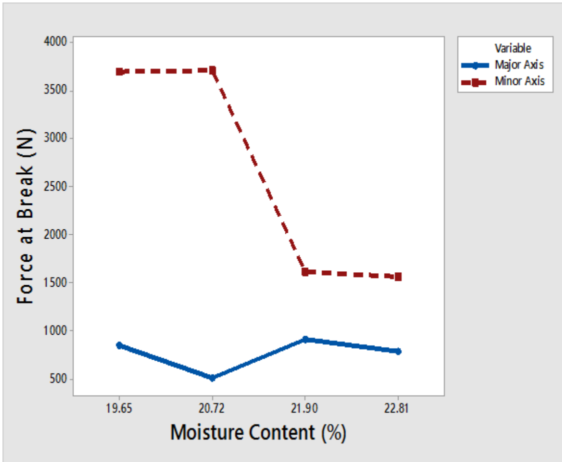


Figure 5: Relationship between Moisture Content (%) and Force at Break (N)

Table: 2 Analysis of Variance (Mean Square) for Force of Tallow Seeds at Peak, Break and Yield (N)

| Sources of Variation | df | Peak | Break | Yield |
|---|---|---|---|---|
| Replication | 2 | 622.810702.9* | 1487430.881* | 537141.714*ns* |
| Treatment | 7 | 635617.96*ns* | 6955730.22.816* | 344018.438*ns* |
| Orientation | 1 | 1980419.658.28* | 42942957.62* | 11146692.81* |
| Moisture Content | 3 | 1407796.594* | 16019.65909.71* | 962510.014* |
| M.C*Orientation | 3 | 3710497.603* | 46565266.13* | 1950344.566* |
| Error | 14 | 254995.5 | 363320.72.2 | 258361.9 |

Table:3 Force at Peak for varying treatments (N)

| Deformation at Break for varying treatments (mm)<br>Treatment Treatment Treatment | | | | | |
|---|---|---|---|---|---|
| Combination | I | II | III | Total | Mean |
| M1MX | 2.775 | 3.957 | 2.190 | 8.922 | 2.974 |
| M2MX | 3.677 | 3.522 | 2.797 | 9.996 | 3.332 |
| M3MX | 2.896 | 2.804 | 4.387 | 10.049 | 3.349 |
| M4MX | 4.734 | 2.530 | 3.495 | 10.759 | 3.586 |
| M1MX | 1.515 | 4.559 | 3.445 | 9.519 | 3.173 |
| M2MX | 4.282 | 3.565 | 2.432 | 10.279 | 3.426 |
| M3MX | 4.648 | 3.444 | 2.557 | 10.649 | 3.549 |
| M4MX | 4.353 | 3.656 | 4.664 | 12.673 | 4.224 |
| Replic. Total | 28.88 | 28.037 | 25.967 | 78.049 | 27.613 |
| Mean | 3.61 | 3.505 | 3.246 | | 3.452 |

M1, M2, M3 and M4 are moisture contents of 19.65, 20.72, 21.90 and 22.81% d.b respectively;
MX and MNX are the major axis and minor axis of tallow seed respectively.

Table: 4 Force at Break for varying treatments (N)

| Deformation at Break for varying treatments (mm)<br>Treatment Treatment Treatment | | | | | |
|---|---|---|---|---|---|
| Combination | I | II | III | Total | Mean |
| M1MX | 795.300 | 622.81.700 | 1125.900 | 2544.900 | 848.300 |
| M2MX | 732.19.650 | 342.390 | 484.090 | 1558.680 | 519.560 |
| M3MX | 786.000 | 1060.100 | 910.600 | 2756.700 | 918.900 |
| M4MX | 1063.000 | 790.300 | 509.800 | 228163.100 | 787.700 |
| M1MX | 302.780 | 4951.100 | 5841.101 | 11094.981 | 3698.327 |
| M2MX | 3111.000 | 2193.400 | 4112.00 | 11155.201 | 3718.400 |
| M3MX | 1633.400 | 1508.500 | 1723.200 | 4856.1 | 1621.700 |
| M4MX | 1491.310 | 1707.100 | 1522.81 | 720.72.71 | 1621.700 |
| Replic. Total | 9914.591 | 3176.59 | 1621.909 | 9913.90 | 3686.857 |
| Mean | 1239.323 | 1647.07 | 9913.90 | 16528.748 | 1710.857 |

M1, M2, M3 and M4 are moisture contents of 19.65, 20.72, 21.90 and 22.81% d.b respectively;
MX and MNX are the major axis and minor axis of tallow seed respectively.
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Table:5 Young's Modulus for varying treatments (N/mm$^2$)

| Deformation at Break for varying treatments (mm)<br>Treatment Treatment Treatment | | | | | |
|---|---|---|---|---|---|
| Combination | I | II | III | Total | Mean |
| M1MX | 121.562 | 113.939 | 86.893 | 321.90 | 107.464 |
| M2MX | 43.900 | 72.692 | 209.648 | 326.24 | 108.746 |
| M3MX | 96.898 | 99.939 | 42.845 | 239.68 | 279.894 |
| M4MX | 52.128 | 54.191 | 30.525 | 136.844 | 45.614 |
| M1MX | 16.205 | 44.972 | 52.332 | 113.509 | 37.836 |
| M2MX | 40.294 | 51.775 | 62.100 | 154.169 | 51.389 |
| M3MX | 11.630 | 26.611 | 38.300 | 76.541 | 25.513 |
| M4MX | 12.243 | 24.623 | 31.100 | 67.966 | 22.655 |
| Replic. Total | 396.923 | 488.742 | 553.743 | 1424.345 | 479.111 |
| Mean | 49.615 | 661.093 | 69.218 | | 59.889 |

M1, M2, M3 and M4 are moisture contents of 19.65, 20.72, 21.90 and 22.81% d.b respectively;
MX and MNX are the major axis and minor axis of tallow seed respectively.

**Conclusion:** It can be concluded that the energy required to rupture the seed at any axis would not exceed 99.00-1152.500 and the hardest seed has a hardness of 1.641-12.832N/mm$^2$. Cracking the seed should be done at the least moisture content for storage, this is necessary because addition of moisture reinforces the strength of the seed.

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