Research Article
doi:10.25081/jpc.2021.v49.i3.7454
Journal of Plantation Crops, 2021, 49(3): 200-213

Selected engineering properties of palmyrah (*Borassus flabellifer*) leaf base

S. Santhosh Kumar, I.P. Sudagar*, P. Rajkumar, Ravindra Naik[1] and R. Kavitha

Tamil Nadu Agricultural University, Coimbatore- 641 003, Tamil Nadu, India
[1]ICAR- Central Institute of Agricultural Engineering Regional Centre, Coimbatore- 641 007, Tamil Nadu, India

(Manuscript Received: 29-08-2021, Revised: 16-10-2021, Accepted: 21-10-2021)

Abstract

Natural fibres are attracting a lot of attention these days, from industrial applications and basic research, to producing eco-friendly goods. The engineering characteristics of the palmyrah leaf base (*Borassus flabellifer*) were assessed in this study. The test specimen's were prepared as per the ASTM standards. The average length of the palmyrah leaf base was around 532±1.96 mm, and 22.74±0.23 mm thickness, 472.6±3.23 g density and volume of 0.893±0.027 g cm^3 and 173.14±5.393 cm^3 were recorded. The mechanical properties were obtained by tensile test, impact test, flexural test, and shore-D hardness test. Tensile strength was observed to be 8.77±0.2 MPa, percentage of elongation was 40 per cent and the flexural strength 147±2.44 MPa. Significant hardness and lower impact strength confirms the viscoelastic nature of the palmyrah leaf base. The data obtained was analysed statistically using Weibull analysis. The palmyrah leaf base properties obtained will be useful for palm related researchers and industrialists to calculate design consideration for fibre extraction machines and developing fibre related products.

Keywords: Engineering properties, flexural test, leaf base, natural fibre, palmyrah

Introduction

Borassus flabellifer is commonly called palmyrah palm, a species that originated from the Indian sub-continent and South-East Asia, which can adapt and grow well both in arid and semi-arid conditions. The other names of palmyrah palm are *Tal* (Hindi), *Talgachh*/*Takajhar* (Bengali), fan palm, brab tree, toddy palm *etc.,* (Krishnaveni *et al*., 2020).

The distribution of this palm is from South East Asia to Guinea, India, Myanmar and Cambodia. India ranks first in palmyrah palm tree population with 85.9 million trees, out of which 51 million are in the state of Tamil Nadu (Krishnaveni *et al*., 2020; Rao *et al*., 2021). The palmyrah palm tree starts yielding from 25th year in arid regions and from 12 to 20th year in semi-arid regions. The tree grows up to a height of 15 to 18 m, and the diameter of the trunk is about 0.6 m. The young trees are covered with more dry leaves, and as it grows, they have only narrow petiole leaves; the trunk resembles that of coconut trees but is much darker (Burkill, 1966; Davis and Johnson, 1987). The apical bud of the trunk is sweet with plenty of nutrients. The crown of the tree contains 30 to 40 palmate leaves, in duplicate and strongly costapalmate with 1-1.5 m diameter. The tree gives out one palmate leaf every month. Both male and female palmyrah can be utilised to obtain inflorescence sap (*neera*). *Neera* is tapped in Tamil Nadu between February and July. A single palmyrah tree can yield 150 litres of *neera* and 24 kg jaggery (*gur*) every year (Krishnaveni *et al*., 2020).

The various parts of the palmyrah tree, *viz*., seed, seed coat, male inflorescence, leaves, and fruits are known for their significant biological and pharmacological functions like antimicrobial activity, anti-inflammatory, anthelmintic, sedative, anti-arthritic, cytotoxic, anti-bacterial, hypoglycemic, antipyretic, *etc.* (Jerry, 2018; Gummadi *et al*., 2016). The economics of a single palmyrah tree is

**Corresponding Author: ips7@tnau.ac.in*

₹ 4240 year-1; the products obtained from palmyrah palm include *neera*, *gur*, palm candy, coir, fibre, firewood *etc.,* (Krishnaveni *et al*., 2020).

High strength palmyrah and sisal fibres have been hybridised with coir-reinforced epoxy composites made in compression moulds to increase their mechanical properties (Nagarjun *et al*., 2020). The palmyrah fibre (treated and untreated) reinforced epoxy composite, added with tamarind seed powder acts as a particulate composite. The mechanical properties of untreated to treated fibre composites increased from 33 to 67 per cent due to good adhesion between fibre, tamarind seed powder, and matrix material (Srinivasan *et al*., 2020).

A single palm produces five different fibre types: loosened fibre from the leaf stalk's base, lengthy fibre from the leaf stalk, fibre from the stem of the stem, fibre produced from the pericarp and the fibrous substance of the leaves (Burkill, 1966). Baskets, rope, brushes, matting *etc.,* are among the indigenous applications of fibres. With increasing length, tensile strength and elongation decrease, whereas the initial modulus increases. On increasing fibre diameter, overall mechanical strength increases (Mukherjee and Satyanarayana, 1986). A traditional process like retting involves anaerobic and biological organisms as a medium to decompose lignin, pectin and other substances, which takes about 2-6 weeks. Another fibre extraction methods involve harvesting the leaf base and soaking in water for 8 to 12 hours, followed by shade drying to remove the excess water and scrubbing the non-fibrous layer with the help of sickle, metallic comb-like materials *etc*. Degumming is a process in which polyphenols and other micronutrients are precipitated by hot alkali solutions followed by bleaching (Amanuel, 2020). Degumming is time-consuming with high production costs. Hence there is a need to develop palmyrah fibre extraction equipment, which farmers and entrepreneurs could adopt. The physical properties such as length, breadth, thickness and weight of the leaf base will be useful for designing machine parts, and the mechanical properties such as tensile strength, flexural strength, impact strength, stress relaxation behaviour and hardness can be used for determining the force and power required for the defibering process of leaf base. The engineering properties of palmyrah leaf base stalk is essentially required for designing of fibre extraction machine. Because of the above, the engineering properties of the palmyrah leaf base was recorded in this study.

Materials and methods

Collection of leaf bases

The palmyrah fruits mature during August, and ripened fruits fall during September and October. The crown of the tree contains 30 to 40 palmate leaves, and the leaf base can be harvested from October (Krishnaveni *et al*., 2020). The palmyrah leaf base sample was collected from palms maintained at the Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu, India. The palmyrah leaf base was collected for analysis from 10 palmyrah trees (around 20 years old) by the conventional method using a sickle, and average results were recorded.

Physical properties

The length, weight and thickness of the Indian palmyrah palm leaf base were determined. In size,

Fig. 1. Palmyrah leaf base

150 mm digital calliper (1139-150) was used to measure the thickness of the palmyrah leaf base, and rule tape was used for measuring the length and height.

Moisture content determination

The moisture content was estimated using the oven-dry method at 104°C for 24 hours (Henderson and Perry, 1997; Dauda *et al.*, 2014; 2015). The whole palmyrah leaf base is depicted in Figure 1. The palmyrah leaf base was divided into three parts *viz.,* upper, middle and lower (Fig. 2) since it has a varying diameter (Ghahraei *et al.*, 2011; Galedar *et al.*, 2008; Hoque, 2019). All measurements were determined in the laboratory at a temperature and relative humidity of 28 - 30°C and 72 to 74 per cent, respectively. The moisture content was calculated using equation (1),

$$M.C.\ (wb) = \frac{M.C_i - M.C_i}{M.C_i} \quad (1)$$

Where,

M.C. (wb) = Moisture content in wet basis (%),

$M.C_i$ = Initial moisture content (%),

$M.C_f$ = Final moisture content (%).

Measurement of volume and density

The water displacement method was used to evaluate the volume of each specimen. The palmyra leaf base was tied in a string and lowered down into a container or measuring cylinder filled with water. The amount of water displaced is measured as the volume (V_s) of palmyrah leaf base from equation (2).

$$Vs = \frac{\text{Weight of the liquid displaced by solid}}{\text{Density of liquid}} \quad (2)$$

The palmyrah leaf base consists of two identical segments, and they are of irregular shape. The volume and bulk density was calculated using the water displacement method. The bulk density of the palmyrah leaf base can be calculated from equation (3)

$$\rho = \frac{M}{V} \quad (3)$$

where,

ρ = bulk density of palmyrah leaf base (g cm^3),

m = the mass of the leaf base sample (g),

v = the volume of displaced water (cm^3).

Tensile strength

Natural fibre reinforced composites show higher mechanical properties than synthetic fibre (Sanjay *et al.*, 2018). The tensile strength of the palmyra palm leaf base was analysed as per ASTM standard. The dimension of the sample taken for the test was 3.0×12.7×64 mm. The tensile strength test was carried out on a universal testing machine (Model: Instron model 1011; Make: M/s Instron Corp., Canton, MA, USA) with a crosshead speed of 2 milliseconds and a 0-40 mm gripper flat surface

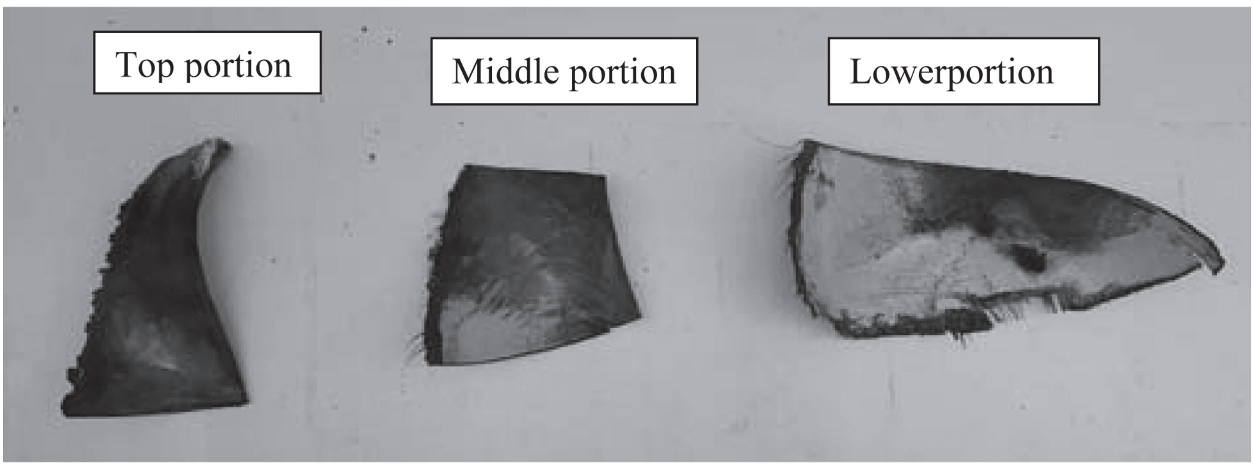

Fig. 2. Three parts of palmyrah leaf base

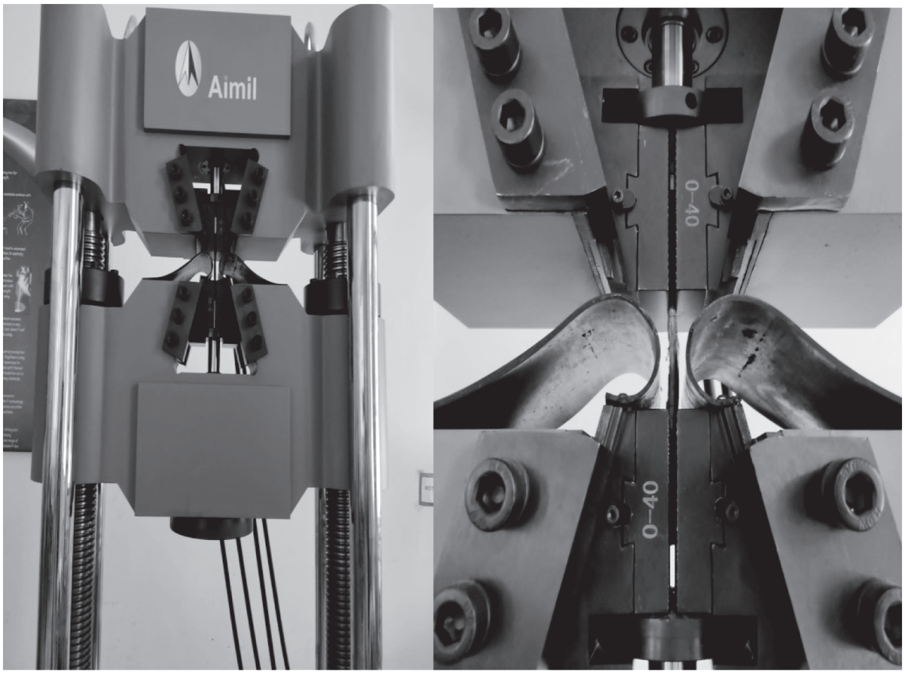

Fig. 3. UTM machine loaded with sample for tensile test

tensile probe was used (Shinoj *et al*., 2010; Bhoopathi *et al*., 2017). Lower crosshead speed helps to provide precise measurements. The test was carried out on five specimens, and the average value was calculated from it. A view of tensile strength samples and probe attachment for sample mounting is shown in Figure 3. The tensile strength was derived from the equation (4) (Shinoj *et al*., 2010),

$$\sigma_t = \frac{Fmax}{A} \qquad (4)$$

Where,

F_{max} = maximum load N

A = cross-sectional area m^2

The percentage elongation (E) of the sample is the percentage of increase in the length of the sample at its breaking point and is calculated from the equation (5),

$$E = \frac{(L-Lo)}{Lo} \text{ x100} \qquad (5)$$

Where,

E = Percentage of elongation

L_O = actual length of the sample (m)

L = length of sample at breaking point (m)

Tensile stress (MPa), tensile modulus (MPa), and elongation at break (mm) were measured by the data acquisition system from the Universal Testing Machine (Model: Instron model 1011; Make: M/s Instron Corp., Canton, MA, USA). The values was obtained in graphical representation, and mean values are calculated.

Flexural properties

Flexural strength and flexural modulus were calculated using 3 point bending test (ASTM D790: (ASTM, 2007). The UTM machine is fitted with the probe and other necessary attachments for 3 point bending test (Bhoopathi *et al*., 2017). The dimension of the sample taken for the test was 3.0 mm x 12.7 mm x 64mm. A universal testing machine (DRTX- 30KN model, force range: 0-30 KN, max head travels: 600 mm) was used for the experiment. The UTM machine, with 3 point bending test attachment loaded with the sample for measuring flexural properties, is shown in Figure 4. The test was repeated five times and the average value was calculated from the UTM software. The flexural strength (S) was calculated from the equation (6) (Shinoj *et al*., 2010),

$$S = \frac{3P'L}{2bd^2} \quad (6)$$

Where,

S = flexural strength (Pa),

P = load (N),

L = span length (m),

b = sample width (m),

d = sample thickness (m)

Flexural modulus/ modulus of elasticity of bending test is the ratio of stress to corresponding strain within elastic limit. Flexural modulus is calculated by equation (7),

$$E_H = \frac{L'S}{4bd^3} \quad (7)$$

Where,

E_H = modulus of elasticity in bending (Pa),

S = slope of the tangent to the initial straight-line portion of the load-deflection curve (N/m).

Impact strength

The amount of energy required to break the specimen using the impact force is impact strength. An izod-charpy impact testing machine (MODEL: D256, Range of measurement: 0-25 J) was used to determine impact strength. When the testing machine's pendulum is released and swings downward, the hammer, fixed to the end of the pendulum, hits with sudden impact and breaks the sample held in between the pair of jaws at equilibrium (Turaka *et al*., 2021). After some energy has been expended in shattering the specimen, the hammer continues to travel upward with the remaining energy. A scale reads the remaining energy in the pendulum after shattering the specimen. The energy used is the difference between the initial energy stored in the pendulum and the remaining energy in the pendulum after the breakage of the sample (Shinoj *et al*., 2010; Bhoopathi *et al*., 2017; Costa *et al*., 2020).

In conformance with ASTM D 256-06 (ASTM, 2006), an Izod-charpy digital impact machine (MODEL: D256, Range of measurement: 0-25J)

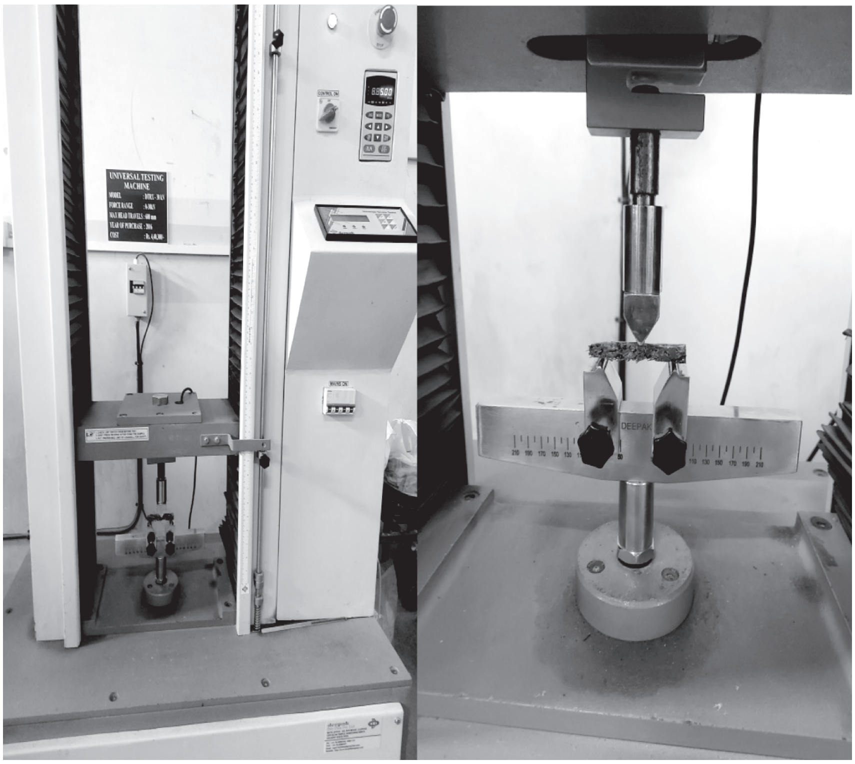

Fig. 4. UTM machine loaded with sample for flexural properties

was used to perform an Izod impact test. The sample dimensions were 63 mm x 12.7 mm x 3 mm. izod-charpy impact tester is shown in Figure 5.

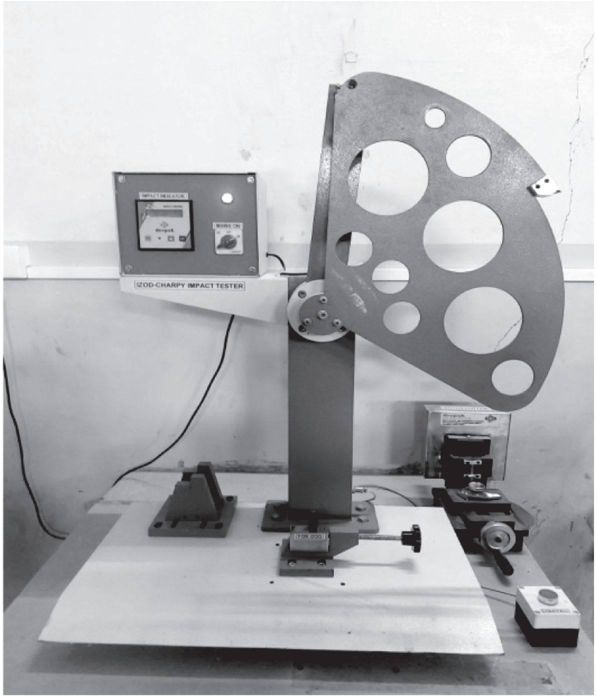

Fig. 5. Izod- charpy impact testing machine loaded with sample

The impact strength can be calculated by equation (8) (Shinoj *et al*., 2010),

$$\text{Fracture Energy} = mg(h_o - h_f) \quad (8)$$

Where,

m = mass of pendulum hammer (g),

g = acceleration due to gravity (9.81 m s^{-2})

h_o = the initial height of pendulum hammer (m),

h_f = the height of the pendulum hammer after fracture (m).

Hardness

Hardness is defined as the resistance of a material to permanent indentation (Shinoj *et al*., 2010) and is measured using a durometer. Pressing the needle inside the sample with a given force and time and measuring the indentation depth is the working principle of the durometer (Ando *et al*., 2009). ASTM D2240 type A and type B are the most common scales where type A is for softer materials like plastic, rubber *etc.,* and type D is for harder samples like composites. Durometer measures the depth of indentation in the sample by a given force. The depth of indentation is dependent on the hardness of the sample, shape of the pushing needle and duration of the test (Shinoj *et al*., 2010).

The dimensions of the samples taken for the analysis was 63mm x 12.7 mm x 3mm, and the samples were conditioned at 23±2°C and 50±5°C relative humidity for more than 40 hours. The impact test was carried in an analogue type shore D hardness tester (Model: DRHTD; Make: Yuzuki DRHTO 0-100 HD) (Fig. 6).

Fig. 6. Shore D Durometer for measurement of hardness

Stress relaxation behaviour

The specimen was suddenly brought to a certain deformation in a stress relaxation experiment. The stress needed to keep the deformation constant calculated as a function of time (Mohsenin, 1980). The stress relaxation test was carried out on an Instron model 1011 Universal testing machine (M/s Instron Corp., Canton, MA, USA) with a crosshead speed of 5 mm min^{-1}. The sample dimensions taken were 3 mm x 10 mm x 75 mm. The sample was mounted on the tensile test probe, and the load and corresponding deformation readings were recorded in triplicate. A graph was plotted with stress on the y-axis and time on the x-axis. Stress was calculated from equation (9),

$$\text{Stress} = \text{load (N)} / \text{area (mm)} \quad (9)$$

Statistical analysis

At a 5 per cent confidence level, the mean, standard deviation and coefficient of variation for physical and mechanical characteristics were obtained. The experimental data were analysed for significance using Weibull distribution analysis, a continuous probability distribution named after Swedish mathematician Waloddi Weibull who described it in 1951. The statistical analysis was undertaken by Minitab 19 statistical software (Maache *et al*., 2020; Khan *et al*., 2020).

Results and discussion

Physical properties

The mean with the standard deviation of the physical properties of the palmyrah leaf base was measured. The results are presented in Table 1.

Table 1. Physical properties of palmyrah leaf base

Portion	Length (mm)	Weight (g)	Thickness (mm)
Upper	240.0±2.93	185.8±1.26	11.4±0.27
Middle	155.0±0.84	130.4±3.10	6.2±0.31
Lower	137.5±2.15	156.5±1.81	5.1±0.09
Total	532.0±1.96	472.6±3.21	22.7±0.23

Moisture content

The moisture content (wet and dry basis) of the palmyrah leaf base sample at its three portions (top, middle and bottom portions) were taken in triplicate, and average values were taken.

The measurement of the moisture content of the leaf base at three sections was intended to measure the condition of the leaf base. The moisture content in the middle portion (39 % w.b) is more when compared with the moisture content in the lower portion (36.5 % w.b). The middle portion of the palmyrah leaf base is attached to the bark of the palmyrah tree and covered with other leaf bases, and it is least exposed to the environment. Hence, the moisture content is higher compared with the upper and lower portions. The upper portion of the palmyrah leaf base contains a very less moisture content (21.3% w.b) when compared with the middle and lower portion. The average moisture

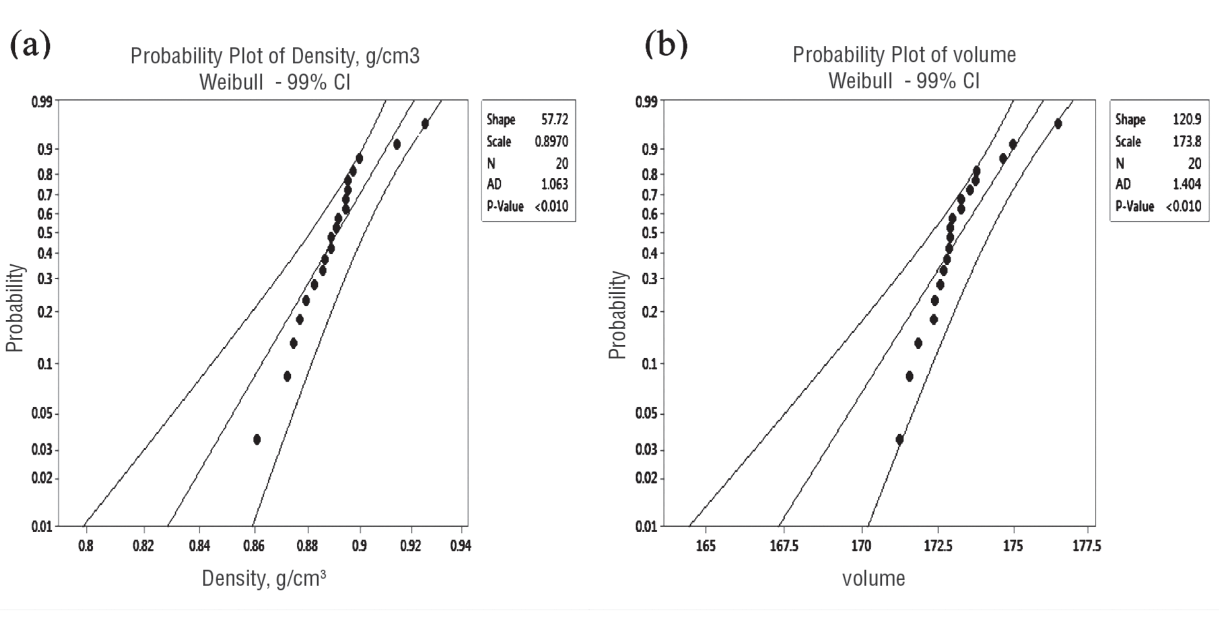

Fig. 1 (a). Weibull distribution of Desnsity for palmyrah leaf base. (b). Weibull distribution (cm^3) of volume for palmyrah leaf base

content of the palmyrah leaf base is 32.2 per cent (w.b).

Volume and density

The total volume of the palmyrah leaf base ranged from 171.2 cm^3 to 176.5 cm^3. The average volume of the palmyrah leaf base was found to be 173.2±5.4 cm^3. The probability plot for volume is shown in Figure 1a. The volume values of palmyrah leaf base samples are uniformly distributed. Thus, the data is near the reliability plot value ($P<0.05$) of 173.8 mm.

Correspondingly, the highest and smallest bulk density values were obtained to be 0.861 g cm^{-3} and 0.925 g cm^{-3}. The bulk density of the palmyrah leaf base was 0.893±0.0279 g cm^{-3} on average. The bulk density value will be useful in designing the feed hopper for the fibre extraction machine. The probability plot for density values are shown in Figure 1b; bulk density values of palmyrah leaf base samples are uniformly distributed. Thus results are near the reliability plot value ($P<0.05$) of 0.89 g cm^{-3}.

Tensile strength

The tensile properties of the palmyrah leaf base are shown in Table 2. The tensile strength of the PLBS was 8.77±0.2 MPa. The palmyrah fibre obtained from the leaf stem of the palmyrah tree had a tensile strength of approximately 280 MPa (Manikandan *et al*., 2004; Shinoj *et al*., 2010). Tensile strength of oil palm fibre-LLDPE composite was less than 17.7 MPa for zero per cent fibre content and 9.41 MPa for 50 per cent fibre concentration which is similar to that of PLBS. The composite made from both NaOH- treated and untreated palmyrah fibre, the tensile strength of the treated composite (67.23 N mm^{-2}) was higher in comparison to untreated composites (51.53 N/mm^2), which is 6 to 7 times greater than the raw leaf base (Mahesh *et al*., 2013) whereas tensile strength of treated palmyrah petiole fibre was 56.56 MPa (Srinivasababu *et al*., 2014). Scewbean mesquite (*P. pubescens*) had a tensile strength of 5.909 MPa, similar to the result obtained from the palmyrah leaf base (Wang *et al*., 2010). The tensile modulus of the palmyrah leaf base sample was 34.98 MPa which is very low compared to the oil palm-LLDPE

Table 2. Tensile properties of palmyrah leaf base

Sl. No	Properties	Values
1.	Tensile strength, MPa	8.77±0.2
2.	Yield stress, MPa	6.6±0.1
3.	Percentage elongation, %	40.0±0.9
4.	Elongation at break, mm	20.0±0.2
5.	Peak load, KN	1.0±0.0

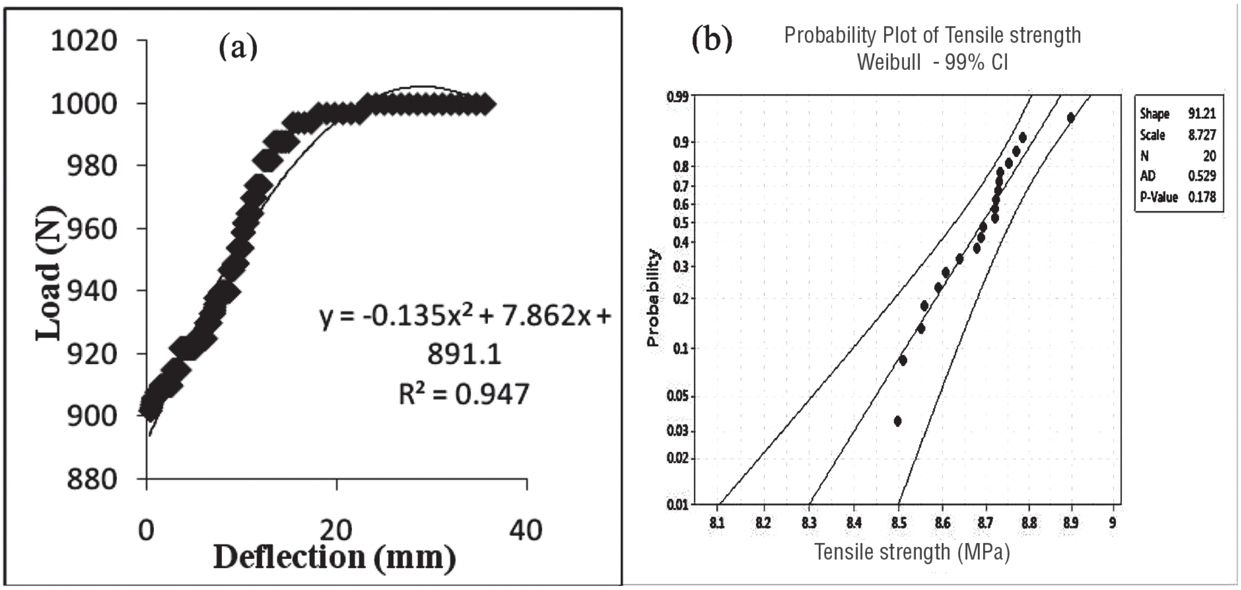

Fig. 2. (a). Tensile property of palmyrah leaf base (b). Weibull distribution for tensile strength of palmyrah leaf base

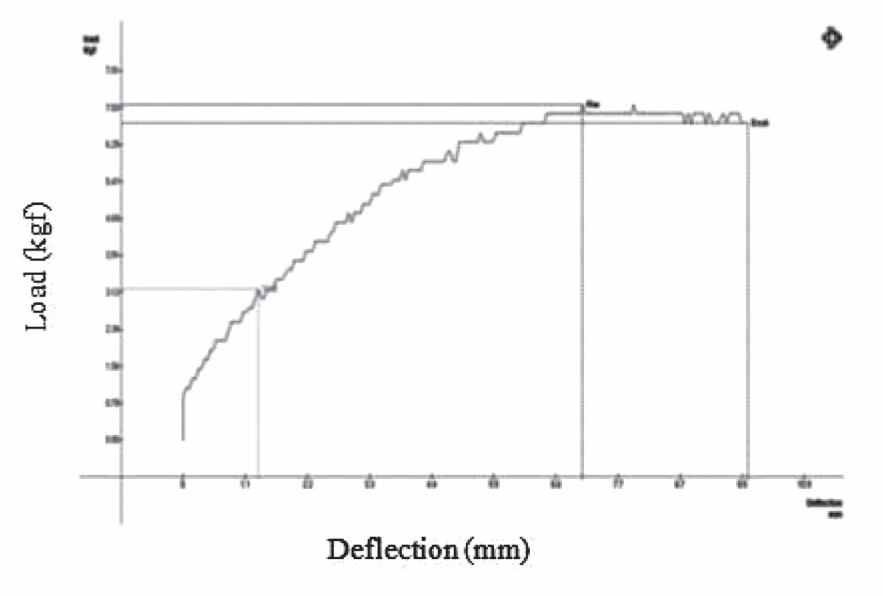

Fig. 3. Flexural properties of palmyrah leaf base sample (Load vs Deflection)

composites (Shinoj *et al*., 2010). Petiole fibres of *Phoenix* sp., treated with acrylic acid, had the highest tensile modulus of 9.26 GPa (Rajeshkumar, 2020). Hence, the stiffness of the PLBS is low and low load is low sufficient for deformation. The load required by the machine for disintegrating the fibres from the leaf base can be calculated using the tensile strength of the palmyrah leaf base.

The yield stress was achieved at 6.58 MPa, with elongation percentage of palmyrah leaf base was 40 per cent and elongation at break 20 mm; these parameters confirm good deformability and the

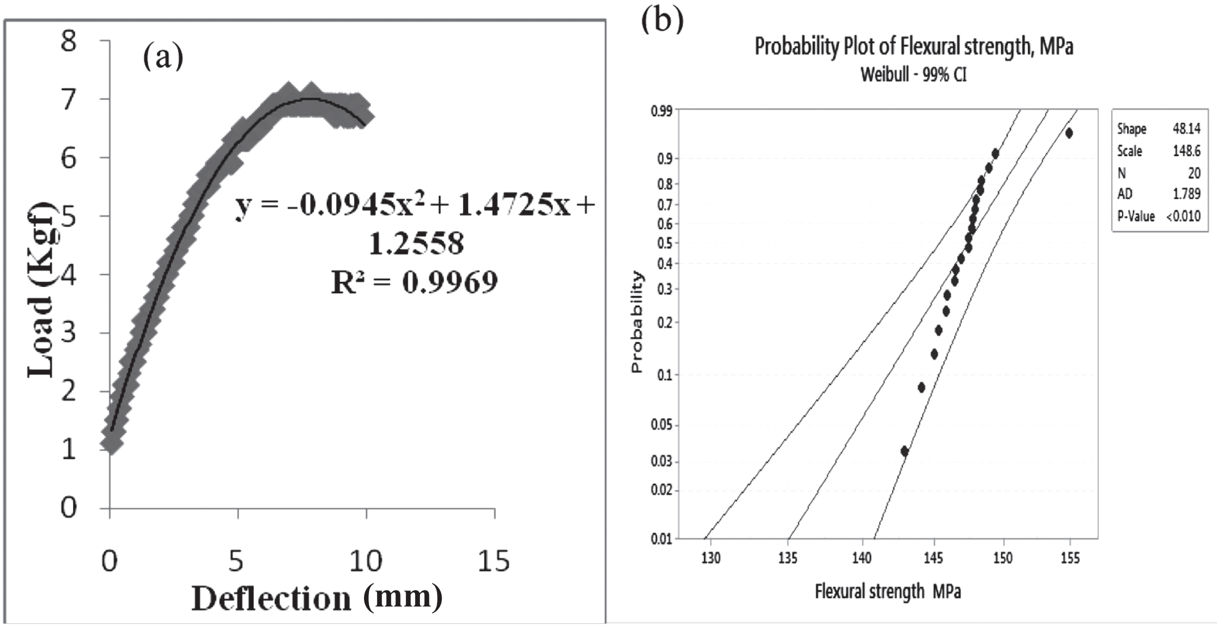

Fig. 4. (a) Excel graph for flexural properties of palmyrah leaf base sample. (b) Weibull distribution for flexural strength of palmyrah leaf base

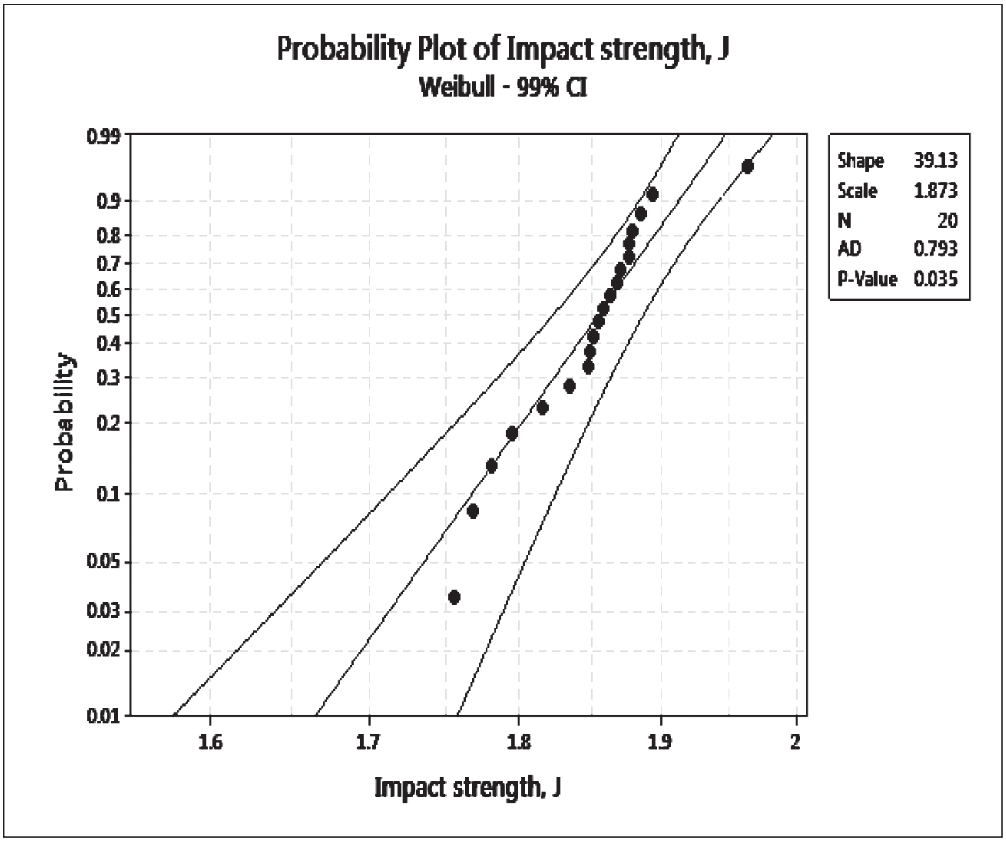

Fig. 5. Weibull distribution for impact strength of palmyrah leaf base

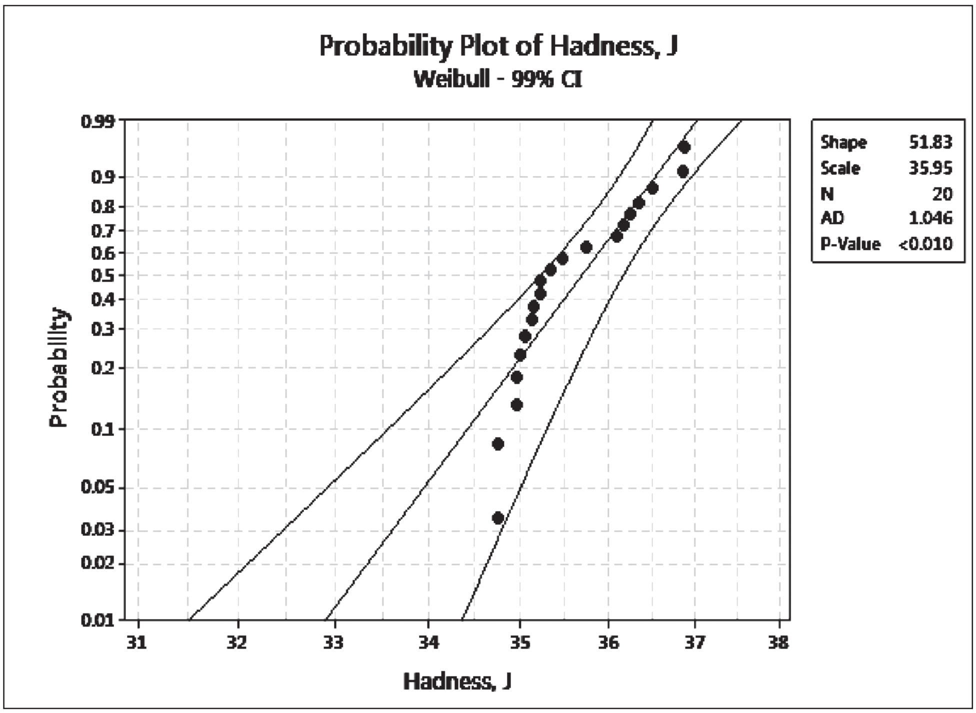

Fig. 6. Weibull distribution for hardness value of palmyrah leaf base

elastic nature of the leaf base. In an earlier study, elongation at break of oil palm fibre-LLDPE composite at zero per cent fibre content showed a similar value (18.72 mm) (Shinoj *et al*., 2010). Figure 2a shows that the tensile properties of the palmyrah leaf base follow second-order polynomial distribution (R^2=0.9476). From Figure 2b, the scale factor value of tensile strength for palmyrah leaf base is 8.72 MPa which is found to be nearer to the experimental results.

Flexural properties

The experiments were conducted in triplicate, and the average values were noted. The flexural strength (S) of the palmyrah leaf base sample was calculated to be 147.28±2.44 MPa, and the flexural modulus of the palmyrah leaf base was calculated as 31.7±0.49 GPa. The flexural strength of Scots pine wood (*Pinus sylvestris* L.) was 72.8 MPa (Buyuksar *et al*., 2016). An artificial board was made from banana stems, and the flexural strength was found to be 3.14 MPa which was very less when compared with commercial wood strength of 87.21 MPa (Zulfikar, 2020). Hence this confirms that the flexural properties of the leaf base are considerably high.

Table 3. Flexural properties of palmyrah leaf base samples

S. No.	Properties	Load (kg f)	Load (N)	Deflection (mm)
1.	Yield stress	3.2±0.07	31.4±0.28	1.32±0.02
2.	Maximum load (f_{max})	7.1±0.06	69.6±2.34	7.03±0.09
3.	Failure	6.7±0.24	65.7±1.07	9.84±0.09

From Figure 4, it is observed that as the applied load increases, deflection increases to a peak load of 7.1 kg f (69.6 N) and attains deflection of 7.03 mm before failure. The yield stress is obtained at 31.4 N load (3.2 kg f) and 1.32 mm deflection. The failure of the specimen was observed at 65.7 N load (6.7 kg f) and 9.84 mm deflection. From Figure 4a, it is revealed that the flexural properties of the palmyrah leaf base follow second-order polynomial distribution (R^2=0.9969). From Figure 4b, the scale factor value of flexural strength for palmyrah leaf base is 147.28 MPa which is found to be nearer to the experimental results. This confirms that the data are statistically significant.

Impact strength

The impact strength of the palmyrah leaf base sample was evaluated using the Izod-Charpy impact tester. The palmyrah leaf base was subjected to an impact force of 1.85±0.05 J which is very low compared to other fibre composite materials. The impact strength of palmyrah petiole fibre reinforced composite increased by 97.07 per cent compared with raw one (Srinivasababu *et al*., 2014). The impact strength of *Mangifera indica* leaf stalk reinforced polyester Composites was measured as 7.5 J (Heckadka *et al*., 2018). The impact strength is very low since the total moisture content of the leaf base is 32.2 per cent w.b and the flexural properties of the base were high. The impact strength of the palmyrah leaf base sample will be useful in deciding the impact force to be applied during disintegration. The applied impact force must be lower than that of recorded impact strength to avoid breakage of fibres. From the reliability plot (Fig. 5), the scale factor value of impact strength for palmyrah leaf base is 1.85 J, which is found to be nearer to the experimental results.

Hardness

The hardness value of the palmyrah leaf base obtained from the Shore D hardness durometer was 35.6±1.04 kg cm^{-2}, hardness value of Ayous (*Triplochiton scleroxylon* K. Schum.) was found to be 37.65 kg cm^{-2} which is very similar to palmyrah leaf base (Ayata, 2020). Similarly, the hardness value of peach wood (*Prunus persica* L. Batsch.) and birch (*Betula pendula* L.) wood was estimated to be 54.8 and 52.6 kg cm^{-2} (Okan and Ayata, 2007). The hardness values can decide the load required to loosen the fibrous and non-fibrous layers in the leaf base. From the reliability plot (Fig. 6), the scale factor value of hardness value for palmyrah leaf base is 35.95 kg cm^{-2} which is found to be nearer to the experimental results.

Stress relaxation behaviour

The normalised stress relaxation curves (stress *vs* time) of the palmyrah leaf base is shown in Figure 7. The stress values were calculated from the data obtained using the UTM machine, and a graph was plotted for stress *vs* time. The relaxation increases with the increase in time and reaches constant at 32.18 N mm^{-2}. The stress relaxation properties of

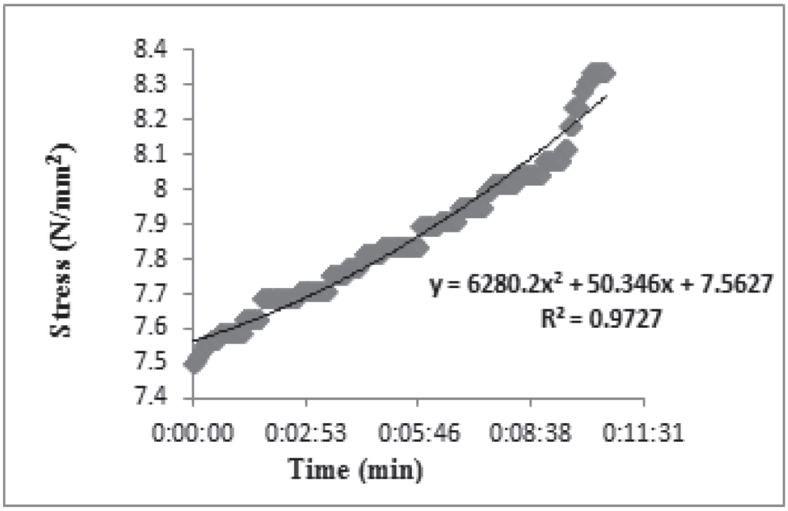

Fig. 7. Stress relaxation behavior of palmyrah leaf base sample

the palmyrah leaf base follow second-order polynomial distribution (R^2=0.9727).

Conclusion

The engineering properties of the palmyrah leaf base samples were excellent, with a flexural strength of the sample 147.28 MPa, hardness of 35.6 kg cm^{-2} and percentage elongation of 40 per cent, which is high when compared with the other wood pieces. This indicates the elastic and flexible nature of the leaf base sample. The impact strength (1.85 J) and tensile strength (8.77 MPa) of the palmyrah leaf base is low since there is less stiffness, high moisture content and confirms its viscoelastic behaviour with a high percentage of elongation (40%). The data obtained will be useful for the machine designers to incorporate in the design consideration of various palmyrah fibre extraction machine components. The developed equipment will be useful for palmyrah farmers and entrepreneurs. This will be useful for palm and other natural fibre researchers and in the domain of automobiles, false ceilings, car fibres, and composites to promote afforestation.

Acknowledgement

The authors thank Kongu Engineering College, KPR Institute of Engineering and Technology, and Scientific and Industrial Testing and Research Centre, Tamil Nadu, India, for providing facilities for undertaking the work.

Reference

Amanuel, L. 2020. Palm leaf sheath fiber extraction and surface modification. *Journal of Engineered Fibers and Fabrics* **15**:1558925020950724.

Ando, M., Kalacska, G. and Czigany, T. 2009. Shore D hardness of cast PA6 based composites. *Scientific Bulletin Series C: Fascicle Mechanics, Tribology, Machine Manufacturing Technology* **23**:15.

ASTM, D. 2006. Standard test method for determining the izod pendulum impact resistance of plastics. *West Conshohocken (PA): ASTM International*.

ASTM, I. 2007. Standard test methods for flexural properties of unreinforced and reinforced plastics and electrical insulating materials. *ASTM D790-07*.

Ayata, U. 2020. Ayous odununun bazý teknolojik ozelliklerinin belirlenmesi ve ýsýl islemden sonra renk ve parlaklýk ozellikleri. *Mobilya ve Ahsap Malzeme Araþtýrmalarý Dergisi* **3**(1): 22-33.

Bhoopathi, R., Ramesh, M., Rajaprasanna, R., Sasikala, G. and Deepa, C. 2017. Physical properties of glass-hemp-banana hybrid fiber reinforced polymer composites. *Indian Journal of Science and Technology* **10**(7): 1-7.

Burkill, I.H. 1966. *A Dictionary of the Economic Products of the Malay Peninsula.* Ministry of Agriculture and co-operatives, Kuala Lumpur, Malaysia. **2**(2):2444.

Buyuksar, U., As, N., Dundar, T. and Sayan, E. 2016. Comparison of micro-and standard-size specimens in evaluating the flexural properties of scots pine wood. *BioResources* **11**(4): 10540-10548.

Costa, U.O., Nascimento, L.F.C., Garcia, J.M., Bezerra, W.B.A. and Monteiro, S.N. 2020. Evaluation of Izod impact and bend properties of epoxy composites reinforced with mallow fibers. *Journal of Materials Research and Technology* **9**(1): 373-382.

Dauda, S.M., Ahmad, D., Khalina, A. and Jamarei, O. 2014. Physical and mechanical properties of kenaf stems at varying moisture contents. *Agriculture and Agricultural Science Procedia* **2**: 370-374.

Dauda, S.M., Ahmad, D., Khalina, A. and Jamarei, O. 2015. Effect of cutting speed on cutting torque and cutting power of varying kenaf-stem diameters at different moisture contents. *Pertanika Journal of Tropical Agricultural Science* **38**(4):549-561.

Davis, T.A. and Johnson, D.V. 1987. Current utilisation and further development of the palmyra palm (*Borassus flabellifer* L., Arecaceae) in Tamil Nadu State, India. *Economic Botany* **41**(2): 247-266.

Galedar, M.N., Jafari, A., Mohtasebi, S.S., Tabatabaeefar, A., Sharifi, A., O'Dogherty, M.J., Rafiee, S. and Richard, G. 2008. Effects of moisture content and level in the crop on the engineering properties of alfalfa stems. *Biosystems engineering* **101**(2): 199-208.

Ghahraei, O., Ahmad, D., Khalina, A., Suryanto, H. and Othman, J. 2011. Cutting tests of kenaf stems. *Transactions of the ASABE* **54**(1): 51-56.

Gummadi, V.P., Battu, G.R., Keerthana Diyya, M.S. and Manda, K. 2016. A review on palmyra palm (*Borassus flabellifer*). *International Journal of Current Pharmaceutical Research* **8**(2): 17-20.

Heckadka, S.S., Nayak, S.Y., Gouthaman, P.V., Talwar, A., Ravishankar, V.A., Thomas, L.G. and Mathur, A. 2018. Influence of sawdust bio-filler on the tensile, flexural, and impact properties of *Mangifera indica* leaf stalk fibre reinforced polyester composites. In *MATEC Web of Conferences* **144**: 02024.

Henderson, S.M. and Perry, R.L. 1997. *Principles of Process Engineering,* American Society of Agricultural Engineers, **4**: pp. 353.

Hoque, M.A. 2019. Physical and engineering properties of BARI released three groundnut varieties. *Bangladesh Journal of Agricultural Research* **44**(4): 609-620.

Jerry, A. 2018. A comprehensive review on the medicinal properties of *Borassus flabellifer*. *Journal of Academia and Industrial Research* **7**(7): 93-97.

Khan, A., Vijay, R., Singaravelu, D.L., Arpitha, G.R., Sanjay, M.R., Siengchin, S., Jawaid, M., Alamry, K. and Asiri, A.M. 2020. Extraction and characterisation of vetiver grass (*Chrysopogon zizanioides*) and kenaf fiber (*Hibiscus cannabinus*) as reinforcement materials for epoxy based composite structures. *Journal of Materials Research and Technology* **9**(1): 773-778.

Krishnaveni, T.S., Arunachalam, R., Chandrakumar, M., Parthasarathi, G. and Nisha, R. 2020. Potential review on palmyra (*Borassus Flabellifer L.)*. *Advances in Research* **21**(9): 29-40.

Maache, M., Chala, A. and Devers, T. 2020. Characterisation of spin coated tin oxide thin films for optoelectronic applications. *Journal of Nano and Electronic Physics* **12**(3): 030101-030105.

Mahesh, C., Kondapanaidu, B., Govindarajulu, K. and Murthy, V.B. 2013. Experimental investigation of thermal and mechanical properties of palmyra fiber reinforced polyster composites with and without chemical treatment and also addition of chalk powder. *International Journal of Engineering Trends and Technology (IJETT)* **5**: 259-271.

Manikandan, V., Ponnambalam, S.G. and Sabu Thomas, V.R. 2004. Mechanical properties of short and uni-directional palmyra fiber reinforced composite. *International Plastics Technology* **8**: 205-216.

Mohsenin, N.N. 1980. *Thermal Properties of Foods and Agricultural Materials*. Gordon and Breach, Science Publishers. New York. USA.

Mohsenin, N.N. 2020. *Physical Properties of Plant and Animal Materials: v. 1: Physical Characteristics and Mechanical Properties,* Routledge, Pennsylvania pp.729.

Mukherjee, P.S. and Satyanarayana, K.G. 1986. Structure and properties of some vegetable fibres. *Journal of Materials Science* **21**(1): 51-56.

Nagarjun, J., Kanchana, J. and Rajesh Kumar, G. 2020. Improvement of mechanical properties of coir/epoxy composites through hybridisation with sisal and palmyra palm fibers. *Journal of Natural Fibers*: 1-10. https://doi.org/10.1080/15440478.2020.1745126.

Okan, O. T. and Ayata, Ü. 2007. Determination of the hardness and the parameters of the surface roughness in peach wood. *Journal of Apitherapy and Nature* **3**(2): 75-86.

RajeshKumar, G. 2020. Characterisation of surface modified *Phoenix* sp. fibers for composite reinforcement. *Journal of Natural Fibers* **18**(12):2033-2044.

Rao, M.C.S., Swami, D.V., Ashok, P., Nanda, S.P. and Rao, B.B. 2021. Scope, nutritional importance and value addition in palmyrah (*Borassus flabellifer L.*): An under exploited crop. *Bioactive Compounds-Biosynthesis, Characterisation and Applications,* Intech Open pp. 1-16.

Sanjay, M.R., Madhu, P., Jawaid, M., Senthamaraikannan, P., Senthil, S. and Pradeep, S. 2018. Characterisation and properties of natural fiber polymer composites: A comprehensive review. *Journal of Cleaner Production* **172**: 566-581.

Shinoj, S., Visvanathan, R. and Panigrahi, S. 2010. Towards industrial utilisation of oil palm fibre: Physical and dielectric characterisation of linear low density polyethylene composites and comparison with other fibre sources. *Biosystems Engineering* **106**(4): 378-388.

Srinivasababu, N., Kumar, J.S. and Reddy, K.V.K. 2014. Manufacturing and characterisation of long palmyra palm/*Borassus flabellifer* petiole fibre reinforced polyester composites. *Procedia Technology* **14**:252-259.

Srinivasan, T., Kumar, S.B., Suresh, G., Ravi, R., Srinath, S.L., Paul, A.I. and Vishweshwaran, M. 2020. December. Experimental investigation and fabrication of palmyra palm natural fiber with tamarind seed powder reinforced composite. In *IOP Conference Series: Materials Science and Engineering* **988**(1): 012-022.

Turaka, S., Reddy, K.V.K., Sahu, R. and Katiyar, J.K. 2021. Mechanical properties of MWCNTs and graphene nanoparticles modified glass fibre-reinforced polymer nanocomposite. *Bulletin of Materials Science* **44**(3): 1-14.

Wang, S., Ren, L., Liu, Y., Han, Z. and Yang, Y. 2010. Mechanical characteristics of typical plant leaves. *Journal of Bionic Engineering* **7**(3): 294-300.

Zulfikar, A.J. 2020. The flexural strength of artificial laminate composite boards made from banana stems. *Budapest International Research in Exact Sciences (BirEx) Journal* **2**(3): 334-340.