Recent Research Reviews Journal (ISSN: 2583-7079)
https://irojournals.com/rrrj

Characterizing Senna Alata Fiber and Echinochloa Frumentacea Leaf Fiber: A Novel Approach for Composite Applications

N. Shalom

Assistant professor, Noorul Islam Centre for Higher Education

E-mail: shalomnanthagopal@niuniv.com

Abstract

The characterization of natural fibres is used in the domain of materials science and engineering with the objective of generating new environmentally acceptable bio-composites. The purpose of this study is to create and characterize a bio-composite reinforced with Senna Alata fibre and Echinochloa frumentacea fiber. This study analyzes the mechanical, thermal, and morphological characteristics of the fibre. The physicochemical research indicated that the fibre has an excellent average density of 1270 kg/m3. In fact, Senna Alata Fiber (SAF) tensile strength ranges from 2300 to 5479 MPa and Echinochloa Frumentacea Leaf Fiber (EFLF) tensile strength ranges from 204.32 14.25 MPa. As a result, the current study suggests that SAF and EFLF can be used as reinforcing materials with maximum specific characteristics as well as minimal environmental impact in the manufacturing of bio- composite.

Keywords: Senna Alata Fiber (SAF), Echinochloa Frumentacea Leaf Fiber (EFLF), automotive, bio-composites, reinforcement, characterization.

1. Introduction

Nature is God's gift to man, which includes a multiple variety of plants and animals that are rich in potential resources. It is time to explore new eco-friendly materials to meet the challenges and requirements in the field of automotive and aerospace industries. This work is a comprehensive characterization of a new biofiber for potential reinforcement in polymer and textile applications. Engineers have more than 50,000 materials to develop products for a wide range of applications related to engineering and construction works. These materials span from centuries-old materials like copper, cast iron, and brass to more recently created sophisticated materials like composites, high-performance steels, functionally graded materials, and so on.

With such a diverse range of materials available, selecting the best material for the creation of a certain product is critical to achieving maximum efficiency.

Metal is commonly used in structural and engineering applications due to its incredible mechanical properties and versatility. Metals have multiple technical characteristics that make metal suitable for a variety of structural and engineering applications. These technical characteristics contribute to metals' suitability for structural and engineering applications by offering strength, durability, adaptability, and high working temperature which are essential for engineering applications. Materials are classified into four categories: (1) metals, (2) ceramics, (3) plastics, and (4) composites. Each category contains a large number of materials with a wide range of properties that overlap to the properties of other categories to some extent. One such category is composite, which incorporates the properties of two or more classes of materials that provide better properties than their constituents. A composite material is a mixture of two or more separate materials, each with its own set of properties that, when combined, provide a material with increased characteristics that outperform the individual components. In many applications, composite materials are used to overcome the technical limitations of conventional materials.

The advancements achieved during the 20th century are associated with the current development of composite materials. The fast expansion of the aviation and aerospace industries during and after World war II created a demand for lightweight and robust materials. Researchers and engineers began experimenting with synthetic fibres (such as fiberglass) and resins, which led to the creation of contemporary composite materials. Composite materials reached major attention and use in a variety of sectors in 1960s, including automotive components, aerospace parts, sporting goods, petroleum industries, consumer goods, and marine industries. Composite materials have long been a popular engineering material for a wide range of applications.

Polymer composites has enhanced competition in the worldwide lightweight components industry. The growing emphasis on energy efficiency, sustainability, and environmental concerns has increased demand for lightweight components across several industries. Automobile, aerospace, wind energy, and transportation industries are actively investigating ways to reduce weight and increase fuel economy, resulting in an increase in the use of polymer composites. These materials have the potential to replace many parts made of steel and aluminium with weight reductions of 60 to 80% and 20 to 50%, respectively.

A composite is a structural material made up of two or more combined components that are macroscopically mixed to generate a usable third material. The reinforcing phase is one ingredient, and the matrix is the one in which it is embedded. The reinforcing phase material might be fibres, particles, or flakes. In general, matrix phase materials are continuous. The matrix phase is generally continuous. The purpose of the matrix is to bond the stiffeners together due to its cohesive and adhesive properties. They transfer loads to and between the stiffeners and protect the stiffeners from the environment. The matrix also provides the composite with a solid form that is needed to produce the finished product. It is necessary for discontinuously reinforced composites because the reinforcements are too small. The matrix material is often chosen to be more ductile and less hard than the reinforcement, these characteristics are not universal and can vary depending on the specific application. The matrix material holds the reinforcement together and provides a continuous phase, while the reinforcement material enhances the mechanical properties of the composite.

In general, the properties of composites strongly depend on the properties of the materials they are composed of, their distribution, and the mutual interaction between them. In addition, the proportion of ingredients and the synergistic effect result in improved properties. In addition to the content, the geometry of the reinforcement (shape, size and size distribution) has a greater influence on the properties of the composite. The geometry of the reinforcement can be spherical, cylindrical or plate-like. The size and distribution of reinforcement determine the interface area and controls the texture of the material, which determines the strength of the composite. Reinforcement concentration, measured either as volume or mass fraction, is the most important parameter affecting the resulting composite properties (Abilash & Sivapragash 2013).

2. Related Study

Natural fibres are classified into three major classes based on their origin: lignocelluloses (plants), animals, and minerals(S. Gomez-Suarez et al.2022).Senna alata is a Leguminosae family medicinal herb. It is found in tropical and humid climates.The plant is widely distributed throughout Asia and Africa, where it is known by a variety of names(Oladeji OSetb et al.2020). Plant fibres with properties such as renewable, degradable, ecofriendly, and cost-effective nature, might make a viable rival to synthetic fibres in many ways(Rathinavelu et al., 2022). Senna alata leaves have a variety of biological functions due to their rhein and phenolic makeup.(Onyegeme-Okerentaet.al,2022) To assess the nutritional potentials and potential therapeutic qualities of Senna alata (L) Roxb leaf extract, proximate and phytochemical studies are performed(Onyegeme-Okerentaet.al,2017). The maximum concentration of phenolic components in the extracts was achieved using highly polar solvents; the methanolic extract demonstrated better extraction capacity for phenolic compounds from S. alata(Oladeji et al.,2016). Polymers mechanical properties are inadequate for various structural purposes. Mainly its strength and stiffness are low compared to metals and ceramics,this issue is overcome by reinforcing Natural treated fibers with polymers(Ablilash et al.,2013). The highly hydrophilic nature of these fibres, which is coupled with limited compatibility in the hydrophobic polymeric matrix, makes the fabrication of cellulose-based composite materials difficult (Abdelmouleh et al., 2004). Thermal analysis is an essential and effective approach for characterizing any material, such as a thermoplastic or thermosetting polymer matrix, as well as determining the impact of natural fibre addition into polymers(Agung et al.,2011). The pollution of petroleum products in the environment poses a significant threat to the environment. Kapok demonstrated long-term stability, with increased saturation duration and minimal bed height drop at higher packing density and oil viscosities. Malaysian kapok has showed substantial potential as a natural oil sorbent(Abdullah et al.,2010).

3. Materials and Methods

The below study explores the mechanical, thermal, and morphological properties of the fibre:Senna alata Fiber (Indran, S et al., 2015)and E. frumentacea plant Fiber (Rathinavelu et al.,2022) to investigate their efficiency as a composite reinforcement using a variety of characterization methods.

3.1 Plant Selection and Collection

(a) Senna Alata Fiber

Senna alata, often known as Cassia alata, is a common plant in the Leguminosae family. It is also called as craw-craw plant, candlebush, ringworm bush, acapulo or ringworm plant. The plant is widely distributed throughout Africa and Asia, where it is known by a variety of names. It contains a large number of bioactive chemical components. SAF (Senna Alata Fiber) was collected using a microbial degrading process from fields around Asarivilai in Kanyakumari district, Tamil Nadu, India (Saravanakumar et al 2013).

(b)ECHINOCHLOA FRUMENTACEA LEAF FIBER

E. frumentacea plant is utilized for fibre extraction in this investigation. This plant is also known as billion-dollar grass, Japanese millet, as well as Indian barnyard millet. E. frumentacea comes from Poaceae family,it is one of the grass variety of clade monocots.

3.2 Fibre Extraction

(a) Senna Alata Fiber: S.alata is submerged in water for a period of two weeks after being cleaned of dirt along with other foreign particles or impurities to facilitate microbial decomposition. It is cleaned in fresh water and dried for a week to eliminate excess moisture. The usual brushing method is used with a metal toothbrush to remove dirt in particles as well as in the outer layer. The retained inner layer consists of a bundle of fibres that have been separated for future usage. Figure 1 demonstrates the plant stokes and fibres extracted.

Figure 1. SAF Stem Fiber Extraction Process

(b) **Echinochloa Frumentacea Leaf Fiber**

In order to achieve microbial deterioration, the cleansed materials are submerged in a container of fresh water for more than one week. Following that, the stocks were manually combed to achieve homogenous fibres. The separated fibres are cleaned with water, which results in the removal of dust and impure particles. The separated fibre is sun-dried nearly for three days to remove any surplus moisture.

Figure 2. Extracted Fiber of ELFA[17]

3.3 Characterization

(a) SENNA ALATA FIBER: Microstructural analysis of SAF is performed using a microscope. The density, cross-sectional area and fineness of the fibre are determined by physical analysis. The chemical composition of SAF is determined by chemical analysis. A tensile test is also done on the vault to assess its mechanical properties.

(b)ECHINOCHLOA FRUMENTACEA LEAF FIBER: Echinochloa Frumentacea Leaf Fibres are often long and thin, having a cylindrical form. They are comprised of lignin, hemicellulose, and cellulose and have a generally smooth surface. Fibre maturity, methods of processing, and fibre treatment all influence tensile strength and itsdurability.

3.4 Microstructural Analysis

(a) SENNA ALATA FIBER

To study the internal structure of SAF, microstructural examination is done using SEM and polarised light microscopy. A polarised microscope is used to examine the microstructure of isolated healthy stems. To preserve the tissues, the stems are sliced into small pieces (10 x 10 mm) and soaked in FAA solution (5 ml of formaldehyde + 5 ml of acetic acid + 90 ml of 70% ethyl alcohol) for 24 hours. They are then dehydrated and embedded in paraffin using a graded succession of tertiary butyl alcohols (Sass, 1940). Microstructural samples are then produced by using a rotary microtome to cut them into 10-12 m thin slices. It is then placed on a glass slide and dyed with a toluidine blue solution combination to improve clarity (O'Brien et al 1964). For polarised light microscope histochemical studies, a Nikon polarised light microscope unit (Japan) is employed.

(b) ECHINOCHLOA FRUMENTACEA LEAF FIBER

The coarseness and pollutants present on the fiber surface were studied by utilizing a VEGA3-TESCAN SEM model from the Czech Republic. A thin coating of gold fixed sample was employed to avoid the accumulation of electric charges during the examination in order to get the absolute conductivity of materials. A Park XE-100 AFM was used to screen the topography on the EFLF surface quantitatively and qualitatively. This study was chosen to create high-resolution surface images(2D/3D) of EFLF in a non-contact way with nanoscale precision.

3.5 Physical Properties

(a) SENNA ALATA FIBER

The approach for measuring the fiber's cross-section and physical parameters (such as density and fineness) is explained in this section. The cross-sectional area of the fibre is required for estimating the fiber's tensile strength. Average fibre diameters that are obtained from 30 samples using Image-pro software and optical microscope images collected in the longitudinal direction. Image software is used to verify and confirm images captured in the transverse direction. Liquid immersion tests with toluene in a pycnometer are used to assess fibre density (Be'akou et al 2008). In a silica desiccator, the fibres are kept dry for further testing. Senna alata fibres are relatively tough and can survive normal wear and tear to some extent.

(b) ECHINOCHLOA FRUMENTACEA LEAF FIBER

Echinochloa frumentacea is a perennial herb that can grow to a height of 1 to 2 metres (3 to 6.5 feet) under ideal conditions. The plant's height, however, might fluctuate based on environmental circumstances. Density and diameter are the critical physical characteristics that dictate the tensile strength of the fibre and were discovered using suitable methodologies. Because plant fibres' diameters vary, optical microscopic pictures of 25 fibre samples taken in three separate locations were utilised to calculate diameter.

The SAF & EFLF density is determined using the following formula:

$$\rho_{SAF,EF} = \frac{m2-m1}{(m3-m1)-(m4-m2)}\rho t$$

In this equation,

m 1 (kg) – Empty pycnometer's weight

m 2 (kg)- weight representing pycnometer containing fibre weight

m3 (kg) - weight of a pycnometer containing toluene

m4 (kg) - weight of a pycnometer containing both fibre and toluene.

ρ_t represents the density of toluene, and $\rho_{SAF,EF}$ represents the density of SAF and EFLF in g/cm^3.

3.6 Chemical Analyses

a) Constitutes Analyses of SAF

The cellulose, lignin, hemicellulose, wax, and moisture content of SAF are determined by traditional chemical X-Ray Diffraction (XRD) and Fourier Transform Infrared (FT-IR) investigations. The SAF samples were crushed and extracted with ethanol using the soxhlet method for 6 hours. The resultant solution, which contains sugar, wax, and other alcohol-soluble compounds, is passed to a separatory funnel. To remove the wax from the alcohol solution, chloroform is added. Purified water is then added, resulting in the formation of distinct layers of chloroform and alcohol. After separation, the chloroform is evaporated from the solution, leaving a waxy residue.

(b) **Constitutes Analyses of EFLF**

To discover the chemical elements of the fibre, standard testing protocols were abandoned. The principal fibre component cellulose is quantified using Kushner-Hoffer technique, and the amount of hemicellulose was evaluated using the TAPPI (T 20305-74) method.

Equation (2) represents the expression used in the estimation of moisture proportion.

$$\text{Percentage of Moisture in SAF} = \frac{(W1-W2)}{W1} \times 100$$

In this equation, w1 represents the weight of undried fibre (moisture-containing fibre) and w2 represents the weight's of dehydrated fibre.

3.7 Thermal Characteristics

SENNA ALATA FIBER: The thermal stability of SAF is assessed by thermogravimetric analysis (TGA) on a Jupiter simultaneous thermal analyzer (Model STA 449 F3, NETZSCH, Germany). The TGA analysis is carried out in a nitrogen environment at a flow rate of 20 ml/min to prevent oxidative effects. To avoid temperature variations detected by the thermocouple, ten milligrams of SAF are crushed and maintained in an alumina crucible. The heating rate is kept constant at 10 °C/min, and the temperature ranges from 28 °C to 1000 °C.

ECHINOCHLOA FRUMENTACEA LEAF FIBER: Thermogravimetric analysis (TGA) was used to assess the thermal stability of the material by evaluating the mass decrease of EFLF when the temperature was increased. TGA can also authenticate the existence of diverse chemical ingredients through its step-by-step deterioration. The thermal behaviour was developed by gradually increasing the temperature 800℃ while maintaining a constant rate of 10℃/min.

4. Results and Discussion

Physical and Chemical Properties

The chemical components of plant fibre primarily influence its thermal, mechanical, crystalline properties and surface properties. The major structural component that makes up plant fibres is cellulose, and cellulose concentration is an essential factor. The existence of distinct EFLF components is confirmed using FT-IR and XRD in the following parts.

FOURIER TRANSFORM INFRARED Analysis of SENNA ALATA FIBER and ECHINOCHLOA FRUMENTACEA LEAF FIBER

(a) SENNA ALATA FIBER: SAF peaks are well-defined in FT-IR spectra at 3328, 2922, 2342, 1663, 1609, 1313, 1030, and 778 cm-1. The peak in 3328 cm-1 is due to carboxylic acid to O-H stretching caused by the existence of cellulose I (Jayaramudu et al 2010), while a minor peak at 2922 cm-1 is due to sp3 C-H stretching caused by cellulose vibrations (Kiruthika and Veluraja 2009). The existence of the C=C alkyne component is shown by the peak on 2342 cm-1 in SAF. The existence of the carboxyl carbonyl group on the C=O moiety, which shows a presence of hemicellulose, and is responsible for the small peak of 1663 cm-1. Smaller peak implies a lower proportion of hemicellulose, that's favorable because a larger amount will damage SAF's mechanical properties. The peak within the 1609 cm-1 band represents C=C aromatic stretching with an intense conjugated C-C bond and is attributable to the fiber's lignin concentration (Saravanakumar et al 2013). In a similar manner, the peak of 1313 cm-1 is due to significant acyl C-O stretching of phenols and esters with overlapping CH-H stretching. The band on 1030 cm-1 relates to the stretching vibration of the alkoxy C-O bond (Venkata Prasad et al 2010; Saravanakumar et al 2013), while a smaller peak at 778 cm-1 indicates the existence of salt solution concentration (Khan and Drzal 2004). Natural fibre bands differ by ±16 cm-1 depending on the study (Zhbankov et al 2002).

(b) ECHINOCHLOA FRUMENTACEA LEAF FIBER: FT-IR spectra contain important peaks indicating the presence of various functional groups in the sample, wherein each functional group indicates a distinct chemical component connected with it. The spectrum has eight distinct peaks. The presence of a peak at 3431 cm1 is a result of the O- H stretching in carboxylic acid residues of -cellulose in the fibre. Because of the C H range of CH and CH2 groups, the peaks seen at 2925 cm1 and 2842 cm1 suggest the presence of cellulose as well as hemicellulose fractions. The ensuing vibrational peaks at 1722 cm1 and 1648 cm1 are associated with a C O dispersion of hemicellulose carbonyl groups. The existence of lignin was confirmed by the C O spectrum of the acetyl group, as shown by a strong peak at 1281 cm1 followed by a peak at 1230 cm1. Similarly, a peak at 1160 cm1 proved the existence of fibre polysaccharides by suggesting C O C dispersion.

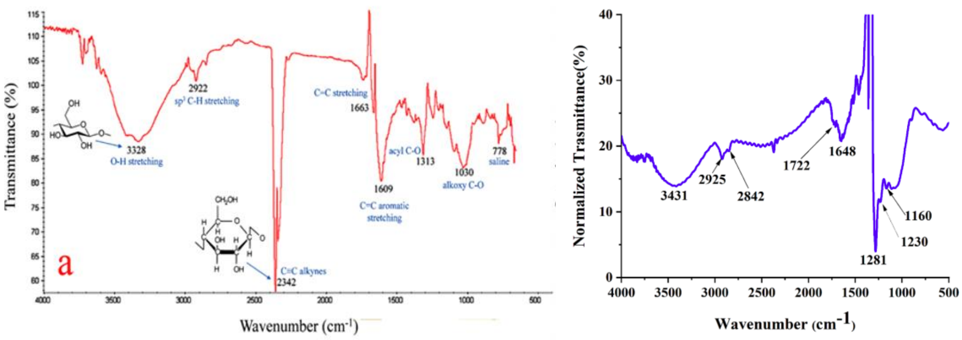

Figure 3. FT-IR Spectrum of the (a) SAF[19] (b) EFLF[18]

X-RAY DIFFRACTION analysis of SENNA ALATA FIBER & ECHINOCHLOA FRUMENTACEA LEAF FIBER

The analyzed SAF's XRD spectrum revealed two prominent peaks at 15.7o and 22.85o, which are attributable to the existence of type I cellulose with a monoclinic structure (Figure 5.a). Similarly, the XRD spectrum of EFLF has two prominent peaks at 17.3o and 24.8o.

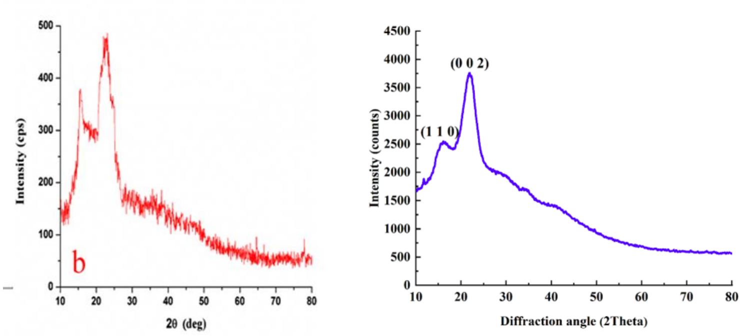

Figure 4. XRD Spectrum of the (a) SAF [19] (b) EFLF[18]

The chemical analysis demonstrated that the fibre had a satisfactory cellulose content. The average density of SAF is (1270 kg/m3) and EFLF is (896 ± 32.14 kg/m3)lower compared with synthetic fibres. Moreover, their mechanical property is comparable with synthetic fibres and provides higher specific strength and modulus, which suits them to be used in structural and textile industries. The thermal stability of reveals that the fibre is stable up to 485 °C for SAF and 330 °C for ELFA which is adequate to sustain the polymerization process temperature during the polymer composite production process. The analysis of single fibre tensile resulted in higher tensile strength 2300- 5479 MPa for SAF and 204.32 ±14.25 MPa for EFLF which is significantly higher than much natural fibre reported and is on par with synthetic fibres used extensively. The lower wax content with honeycomb surface morphology enhances the bonding properties during reinforcement. The thermal stability indicates that it can sustain polymerization temperatures. Thus, the findings of this characterization strongly support the use of SAF and EFLF in the production of sustainable fibre-reinforced polymer composites.

5. Conclusion

The current study examined the suitability of Senna alata and E. frumentacea as a composite reinforcement by analyzing its multiple special properties. Fibres from Senna alata and E. frumentacea were extracted and tested using standard protocols to determine their specific strength and potential for composite applications. A significant chemical composition is a high cellulose percentage with a lower wax content, which improves the mechanical strength and bonding qualities found in polymer composites. Because of its outstanding characteristics, the current study suggests that SAF and EFLF can be used for the fabrication in multiple bio-composite materials for Hi-tech applications in raw form or with composition.

References

[1] Abdelmouleh, M, Boufi, S, Belgacem, MN, Duarte, AP, Salah, AB & Gandini, A 2004, 'Modification of cellulose fibers with functionalized silanes: development of surface properties', International Journal of Adhesion and Adhesives, vol. . 24, No. 1, pp. 43-54.

[2] Abdullah, MA, Rahmah, AR & Man, Z 2010, 'Physico-chemical and sorption characteristics of Malaysian Ceiba pentandra (L.) Gaertn. as a natural oil sorbent", Journal of Hazardous Materials, vol. 177, No. 1-3, pp. 683-691.

[3] Ablilash, N & Sivapragash, M 2013, 'Tensile and compressive behavior of a modified sisal and jute fiber polypropylene composite', Journal of Polymer and Biopolymer Physics Chemistry, vol. 1, No. 1, pp. 1-8.

[4] Agung, EH, Sapun, SM, Hamdan, MM, Zaman, HMDK & Mustofa, U 2011, "Study of Abaca (Musa texillis Nee) Fiber Reinforced High Tensile Polystyrene (HIPS) Composites by Thermogravimetric Analysis (TGA)", International Journal of the Physical Sciences, Vol. 6, No. 8,

[5] pp. 2100-2106.

[6] Akil, HM, Cheng, LW, Mohd Ishak, ZA, Bakar, AA & Rahman MAA, 2009, "Water Absorption Study on Pultruded Jute Fiber Reinforced Unsaturated Polyester Composites", Composite Science and Technology, Vol. 69, pp. 1942-1948.

[7] Akil, HM, Omar, MF, Mazuki, AAM, Safiee, S, Ishak, ZAM & Abu Bakar, A 2011, 'Kenaf fiber reinforced composites: A review', Materials and Design, Vol. 32, No. 8-9, pp. 4107-4121.

[8] Alam, MS & Arifuzzaman Khan, GM 2007, "Chemical analysis of okra fiber (Abelmoschus esculentus) and its physicochemical properties", Journal of Textile and Apparel Technology and Management, Vol. 5, pp. 1-9.

[9] Alavudeen, A, Rajini, N, Karthikeyan, S, Thiruchitrambalam, M & Venkateshwaren N 2015, 'Mechanical properties of banana/kenaf fiber-reinforced hybrid polyester composites: effect of woven fabric and random orientation', Materials Design, vol. 66, pp. 246-257.

[10] AlMaadeed, MA, Kahraman, R, Khanam, PN & AlMaadeed, S 2013, 'Characterization of untreated and treated male and female data palm leaves', Materials and Design, vol. 43, pp. 526-531.

[11] Alsaeed T, Yousif B.F & Ku H 2013, 'Potential use of date palm fibers as reinforcement for polymer composites', Materials and Design, vol. 43, pp. 177-184.

[12] Amada, S & Untao, S 2001, 'Fracture properties of bamboo', Composites Part B, Vol. 32, No. 5, pp. 451-459.

[13] Amar, B, Salem, K, Hocine, D, Chadia, I & Juan, MJ 2011, 'Study and characterization of composite materials based on polypropylene load with olive husk flour', Journal of Applied Polymer Science, vol. 122, no. 2, pp. 1382-1394.

[14] S. Gomez-Suarez, E. Cordoba-Tuta, "Composite materials reinforced with fique fibers - a review," Rev. UISIng., vol. 21, no. 1, pp. 163-178, 2022, https://doi.org/10.18273/revuin.v21n1-2022013

[15] Oladeji OS, Adelowo FE, Oluyori AP, Bankole DT. Ethnobotanical Description and Biological Activities of *Senna alata*. Evid Based Complement Alternat Med. 2020 Feb 20;2020:2580259. doi: 10.1155/2020/2580259. PMID: 32148534; PMCID: PMC7054808.

[16] Rathinavelu, Ravichandaran & Sethupathi, P. Baskara. (2022). Comprehensive characterization of Echinochloa frumentacea leaf fiber as a novel reinforcement for composite applications. Polymer Composites. 43. 10.1002/pc.26775.

[17] Onyegeme-Okerenta, Blessing & Mo, Wegwu & T., Nwosu. (2017). Proximate and phytochemical composition of leaf extract of Senna alata (L) Roxb. Journal of Pharmacognosy and Phytochemistry. 6. 320-326.

[18] Oladeji, Oluwole & Adelowo, Funmilayo & Abraham, Odelade. (2016). Mass spectroscopic and phytochemical screening of phenolic compounds in the leaf extract

of Senna alata (L.) Roxb. (Fabales: Fabaceae). Brazilian Journal of Biological Sciences. 3. 209. 10.21472/bjbs.030519.

[19] Rathinavelu, Ravichandaran & Sethupathi, P. Baskara. (2022). Comprehensive characterization of Echinochloa frumentacea leaf fiber as a novel reinforcement for composite applications. Polymer Composites. 43. 10.1002/pc.26775.

[20] Indran, S., and R. Edwin Raj. "Characterization of new natural cellulosic fiber from Cissus quadrangularis stem." *Carbohydrate polymers* 117 (2015): 392-399.