

Agave americana fibre— A sustainable reinforcement for hybrid biocomposites

Ashish Hulle^a, U J Patil & R K Purohit

Department of Textiles, DK TE Society's Textile and Engineering Institute, Ichalkaranji 416 115, India

Agave Americana fibre has emerged as a promising sustainable reinforcement in the realm of hybrid biocomposites. This review synthesizes the current research, encompassing the mechanical, thermal and environmental aspects of *Agave Americana* fibre-based composites. The integration of Agave fibres into hybrid biocomposites presents exciting opportunities for enhancing material properties, while concurrently reducing the ecological footprint associated with traditional reinforcement materials. The review critically evaluates the methodologies employed in the fabrication of *Agave Americana* fibre-reinforced hybrid biocomposites. Moreover, the examination extends to the multifaceted sustainability considerations, encompassing its biodegradability, renewability and cultivation practices. A comprehensive analysis of the life cycle assessment underscores the environmental benefits of this fibre as a sustainable reinforcement, offering valuable insights into its potential as a green alternative in the textile industry. The review highlights the pivotal influence of *Agave americana* fibre on the development of lightweight, high-performance materials with reduced environmental impact. The integration of this fibre into hybrid biocomposites not only augments material performance but also aligns with the imperative shift towards sustainable practices in the textile and materials science domains.

Keywords: *Agave americana* fibre, Biodegradability, Hybrid biocomposites, Life cycle assessment, Renewability, Sustainable textile technology

1 Introduction

Agave americana, commonly known as a century plant, belongs to the Agavaceae family and is native to America¹. The plant is renowned for its robust and resilient fibres extracted from the leaves, specifically the Agave leaves². Indigenous communities have traditionally used these fibres for various purposes, including rope-making and textile production³.

Agave americana leaf fibre (AALF) exhibits unique characteristics that make it suitable for applications in composite materials. The fibres have inherent strength and stiffness, attributed to their composition being rich in cellulose, hemicellulose and lignin⁴. Studies have reported tensile strengths comparable to those of other natural fibres, such as sisal and jute, positioning AALF as a potential reinforcement material in composites⁵. Figure 1 shows the *Agave Americana* plant, extracted fibres and their microscopic appearance.

The increasing global concern for environmental sustainability has propelled the exploration of eco-friendly alternatives in various industries, including materials science⁷. In biocomposites, the choice of reinforcement materials plays a crucial role in

determining the environmental impact of the final product⁸. Sustainable reinforcements offer a practical solution for mitigating the ecological footprint associated with conventional materials.

Agave fibre is a natural and renewable resource that fits the rising need for eco-friendly, sustainable material production⁹. Unlike synthetic fibres, which are derived from non-renewable resources and contribute to environmental degradation, AALF offers a greener alternative. The cultivation of Agave plants requires minimal water and agrochemical inputs, further enhancing their eco-friendly profile¹⁰.

The primary aim of this review is to consolidate the current research on *Agave Americana* fibre in hybrid biocomposites (HBC) and provide a comprehensive understanding of the mechanical, thermal and environmental aspects associated with their incorporation into composite materials. It will encompass studies evaluating the strength and stiffness of *Agave americana* fibre-based composites and comparing them with traditional reinforcement materials¹¹. Additionally, it will delve into the thermal properties of Agave composites and explore their potential applications in diverse temperature-sensitive environments¹². Review highlights the environmental aspects of Agave fibre, including its eco-friendly features, biodegradability and renewability¹³.

^aCorresponding author.
E-mail: ashishhulle@gmail.com

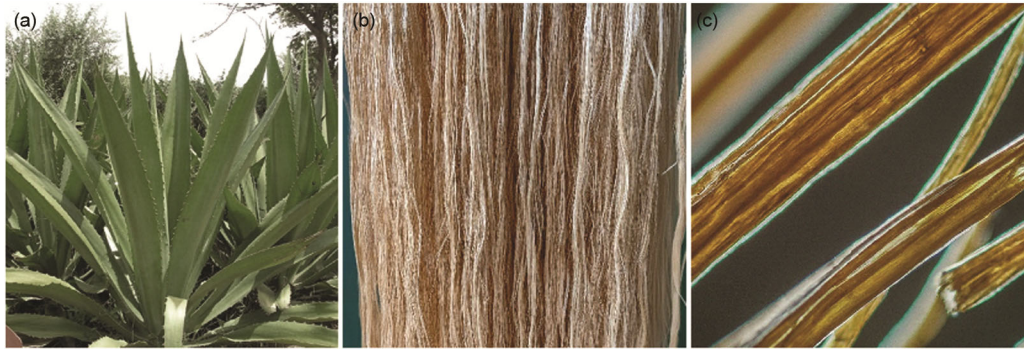


Fig.1 — (a) *Agave americana* plant, (b) extracted fibres and (c) microscopic appearance⁶

Table 1 — Mechanical properties of different reinforcement agents¹⁹

Reinforcement	Tensile strength, MPa	Modulus GPa	Elongation at break, %
<i>A. americana</i>	300-600	20-30	2-4
Jute	300-700	15-30	1.2-1.8
Flax	250-700	20-30	2.7-3.5
Hemp	550-900	40-60	1.5-2.5
Glass fibre	2000-4000	70-90	1.8
Aramid	3000-3150	63-67	2.4-3.6
Carbon fibre	1500-7000	230-700	< 1:0

2 Mechanical Properties

2.1 Strength and Stiffness

AALF exhibits notable strength and stiffness characteristics, rendering it a viable candidate for reinforcement in hybrid biocomposites¹⁴. The tensile strength of *Agave americana* fibres has been reported to be 300-600 MPa, highlighting its robust nature¹⁵. Additionally, the stiffness of the fibre, reflected in its Young's modulus, falls within the range of 20-30 GPa, emphasizing its capacity to contribute structural integrity to composite materials¹⁶.

These mechanical properties can be attributed to the fibrous composition rich in cellulose and hemicellulose, providing fibres with inherent strength. The unique microstructure of the fibre, characterized by longitudinally aligned cellulose fibrils, contributes to its impressive tensile strength¹⁷. The stiffness, on the other hand, arises from the interconnected network of cellulose and lignin, forming a rigid matrix within the fibre structure¹⁸. Comparative mechanical properties of various reinforcements are shown in Table 1.

2.2 Comparison with Traditional Reinforcements

In comparison to traditional reinforcement materials such as glass and synthetic fibres, *Agave americana* fibres demonstrate competitive mechanical properties. Studies have shown that its tensile strength is comparable to glass fibre, a widely

used reinforcement material²⁰. Moreover, the specific stiffness was found to be comparable to or even higher than some synthetic fibres, further highlighting its potential as a reinforcing element²¹. This comparison extends to factors beyond strength and stiffness. *Agave* fibres have the advantage of being lighter than glass fibres, contributing to the development of lightweight composites²². Additionally, its lower density can reduce the overall weight of composite materials, making it appealing for applications in which weight is a crucial consideration²³.

2.3 Implications for Material Performance in Hybrid Biocomposites

The strength and stiffness characteristics of *Agave americana* fibre have profound implications for the overall performance of hybrid biocomposites. When incorporated into composite matrices, the fibres contribute to enhanced mechanical properties, such as improved tensile strength, flexural strength and impact resistance²⁴. Combining this fibre with other natural or synthetic reinforcements in hybrid biocomposites offers a synergistic effect, optimizing the balance of mechanical attributes²⁵.

Furthermore, the inherent stiffness of the AALF contributes to the rigidity of the composite and influences its dimensional stability and load-bearing capacity²⁶. The controlled interplay between the fibre and matrix materials ensures that the resulting hybrid biocomposites exhibit tailored mechanical properties suitable for specific applications, ranging from automotive components to construction materials.

The mechanical properties of the fibre make it a promising reinforcement material for hybrid biocomposites. Its strength and stiffness characteristics, when compared with those of traditional materials, underscore its potential to improve material performance and sustainability in various industries.

Table 2 — Performance of hybrid biocomposites reinforced with AALF¹⁹

Material	Tensile strength MPa	Flexural strength MPa	Impact strength kJ/m ²	Thermal stability (Onset degradation), °C	Biodegradability
AALF/Kenaf	40-60	50-70	8-12	250-270	High
AALF/Flax	35-50	45-60	6-10	230-250	High
AALF/Jute	30-40	40-50	5-8	220-240	High
AALF/Sisal	35-45	45-55	6-9	210-230	High
AALF/Glass fibre	60-80	70-90	12-15	>300	Low
AALF/Carbon fibre	80-100	100-120	15-20	>400	Low
Polypropylene (PP)	20-30	30-40	2-4	130-150	Low
High-density polyethylene (HDPE)	25-35	35-45	3-5	140-160	Low
Cellulose nanofibres(CNF)	50-70	60-80	8-12	>300	High

3 Thermal Properties of *Agave americana* Fibre

3.1 Based Composites

Thermal Conductivity and Stability

Agave americana fibre-based composites exhibit noteworthy thermal properties, with a focus on thermal conductivity and stability. The thermal conductivity of these composites is influenced by the inherent characteristics of the Agave fibre, which is composed of cellulose, hemicellulose and lignin. The thermal conductivity is typically lower than that of synthetic fibres, making this fibre an insulating material²⁴. The ability of the fibres to resist heat flow is beneficial for applications where thermal insulation is essential, such as in construction materials.

Furthermore, the fibre exhibits good thermal stability, maintaining its structural integrity at elevated temperatures. Studies have reported that the decomposition temperature of this fibre is 220–300°C²⁷. This high thermal stability ensures that the fibres do not undergo significant degradation under normal operating conditions, contributing to the durability of the composites.

3.2 Impact on Overall Thermal Behaviour of Hybrid Biocomposites

AALF affects the thermal behaviour of hybrid biocomposites, complementing other materials for improved thermal characteristics. The fibres function as insulators, reducing heat transfer within the composite. Incorporating *Agave americana* fibres enhances the material's resistance to temperature changes. Combining with other reinforcing elements helps counter thermal expansion and contraction, promoting overall dimensional stability²⁸. This is especially beneficial in applications sensitive to temperature fluctuations, like automotive components or electronic devices. Table 2 compares the mechanical, thermal and environmental performance of hybrid biocomposites reinforced with *Agave americana* leaf fibres to those

reinforced with other common natural and synthetic fibres.

3.3 Potential Applications in Temperature-sensitive Environments

The thermal properties of *Agave americana* fibre-based composites make them well-suited for applications in temperature-sensitive environments. The excellent thermal insulation properties of these composites open possibilities in the construction industry for developing energy-efficient building materials. Such composites can be integrated into walls, roofs and insulation panels to enhance thermal resistance and reduce energy consumption²⁹.

Moreover, in automotive applications where temperature variations are common, these composites can be employed in interior components, such as door panels and dashboard elements, to provide structural support and thermal insulation³⁰. Using these composites in electronic devices and casings is also promising because they can improve heat dissipation and thermal management.

4 Environmental Considerations

4.1 Eco-friendly Attributes of Fibre

Agave Americana fibre stands out for its notable eco-friendly attributes, making it a sustainable choice for various applications. The cultivation of Agave plants requires minimal water compared to the traditional crops used for fibre production³¹. Water efficiency is crucial in regions facing water scarcity, as it contributes to sustainable agricultural practices.

Furthermore, *Agave americana* plants thrive in arid and semi-arid regions, with a minimal need for agrochemical inputs³². This characteristic reduces the environmental impacts associated with the excessive use of fertilizers and pesticides in conventional agriculture. The cultivation of Agave plants aligns with sustainable agriculture principles by promoting resource efficiency and minimizing the negative effects on the surrounding ecosystems.

Fibre extraction involves a straightforward process requiring minimal energy compared to the production of synthetic fibres. The energy-efficient nature of Agave fibre extraction contributes to lower greenhouse gas emissions, emphasizing its environmentally friendly profile³³.

4.2 Biodegradability and Renewability

Agave americana fibre stands out for its eco-friendly features, particularly its biodegradability. The natural composition, mainly cellulose and hemicellulose, aids microbial soil decomposition³⁴, unlike non-biodegradable synthetics causing lasting pollution. Derived from Agave plant leaves, this fibre continually renews. The plant's ability to regenerate ensures a sustainable resource³⁵, aligning with circular economy principles and reducing reliance on finite resources. *Agave americana* fibre's biodegradability and renewability play a role in minimizing environmental impact across its lifecycle. Unlike persistent synthetic fibres, Agave fibre products can return to the ecosystem as organic matter in a sustainable loop²⁷. These eco-friendly attributes, including water efficiency and minimal agrochemical inputs, position AALF as a conscious choice. Its biodegradability and renewability further reduce the ecological footprint linked with traditional fibres.

4.3 Sustainable Cultivation Practices and Environmental Impact

Sustainable practices are crucial in shaping *Agave americana* fibre production, preventing soil degradation and ecological issues linked to traditional methods. Practices like rain-fed agriculture and agro forestry reduce reliance on irrigation, cutting water usage and minimizing the environmental footprint³⁶. Additionally, intercropping with other complementary crops promotes biodiversity and enhances soil health through natural interactions³².

To further reduce the environmental impact, sustainable cultivation practices advocate organic farming methods that avoid using synthetic pesticides and fertilizers. Instead, natural pest control measures and organic fertilizers are employed to reserve soil fertility and minimize chemical runoff, which otherwise can pollute nearby water sources²⁷. Studies indicate that sustainable cultivation practices contribute to a lower carbon footprint and reduced energy requirements compared to conventional methods³⁷.

5 Methodologies in Fabrication

5.1 Review and Critique of Fabrication Techniques

Developing *Agave americana* fibre-reinforced biocomposites involves crucial fabrication techniques that impact the overall material performance. This section reviews various methods, discussing their strengths, limitations and effects on mechanical, thermal and environmental aspects.

One standard method is hand lay-up, where fibres are manually placed on a mould and infused with a matrix material. This cost-effective approach allows design flexibility and suits small-scale production²⁴. However, it may lead to uneven fibre distribution, potentially causing variations in the composite's mechanical properties²⁵. Compression moulding, another prevalent technique, applies heat and pressure to shape fibres and the matrix within a mould. This ensures better fibre distribution and improves overall mechanical properties³⁸. Yet, the energy-intensive nature raises environmental concerns, requiring a careful balance between performance and sustainability. Filament winding involves winding fibres onto a rotating mandrel and infusing them with a matrix suitable for complex geometries. This method provides excellent strength due to continuous and oriented fibres³⁵. However, it can be time-consuming and may need specialized equipment, impacting its feasibility for large-scale production. Injection moulding has gained attention for efficiently producing complex shapes with high reproducibility. Fibres and matrix material are injected into a mould under high pressure and temperature, resulting in well-formed components³⁹. While offering speed and precision, challenges may arise in achieving optimal fibre alignment, affecting the final mechanical properties.

Choosing a fabrication technique depends on the intended application and desired properties of *Agave americana* fibre-reinforced biocomposites. A critical assessment of the advantages and limitations associated with each method is essential for decision-making in material development.

5.2 Key Methodologies Employed in Hybrid Biocomposite Production

The production of hybrid biocomposites involves several methodologies to achieve optimal material properties and performance. This section critically examines the key methodologies employed in the fabrication of *Agave americana* fibre-reinforced hybrid

biocomposites, encompassing aspects such as pre-treatment of fibres, matrix choice and integration of additional reinforcing agents.

5.2.1 Pre-treatment of Fibres

Pre-treatment of *Agave americana* fibres is a crucial step to enhance their compatibility with the matrix material and improve adhesion. Alkaline treatment, a commonly employed method, involves immersing the fibres in alkaline solutions such as sodium hydroxide (NaOH) for the removal of impurities, increasing the surface roughness and introducing hydroxyl groups, promoting better interaction with the matrix²⁷.

5.2.2 Matrix Selection

The choice of matrix material significantly influences the overall performance of hybrid biocomposites. Polymeric matrices such as polypropylene, epoxy and polyester are commonly used in manufacturing AALF-reinforced hybrid biocomposites. The selection depends on the desired application and the specific mechanical and thermal requirements of the composite²⁴. For instance, polypropylene matrices contribute to lightweight and cost-effective composites, whereas epoxy matrices enhance the mechanical strength and resistance to environmental factors.

5.2.3 Integration of Additional Reinforcing Agents

To further enhance the mechanical properties of *Agave Americana* fibre-reinforced biocomposites, the integration of secondary reinforcing agents is often explored. Nanomaterials, such as nanocellulose and nanoclays, are incorporated to improve the strength and stiffness of composites at the nanoscale²⁵. The synergistic effect between the fibres and nano materials contributes to the overall enhancement of the mechanical properties.

5.2.4 Hybridization with Synthetic Fibres

Hybridization combines fibres with synthetic fibres, such as glass or carbon to create hybrid biocomposites. This approach leverages the strengths of both natural and synthetic fibres to achieve a balance between cost, performance and sustainability³⁸. The hybridization strategy enhances mechanical properties such as tensile strength and modulus, offering a broader range of applications for the resulting biocomposite.

5.2.5 Layering and Orientation of Fibres

The arrangement and orientation of the fibres within the composite structure play a crucial role in determining the mechanical properties. Studies have

explored the impact of fibre orientation on the tensile, flexural and impact properties. Proper alignment and layering of fibres enhance load-bearing capabilities and overall mechanical performance⁴⁰. The optimization of fibre orientation is essential for tailoring hybrid biocomposites to specific application requirements.

5.2.6 Processing Techniques

Various processing techniques, including injection moulding, compression moulding and extrusion, have been employed in the fabrication of *Agave americana* fibre-reinforced HBCs. The choice of processing method depends on factors such as the desired shape, complexity and cost-effectiveness of production³⁵. For instance, injection moulding is suitable for intricate geometries, whereas compression moulding is effective for larger components.

5.3 Challenges and Opportunities in Manufacturing Process

Manufacturing hybrid biocomposites incorporating *Agave Americana* fibre presents both challenges and promising opportunities, shaping the trajectory of sustainable material development.

Challenges

(i) *Fibre Heterogeneity*– The inherent variability in fibre properties, stemming from factors like plant age and growth conditions, poses a challenge to achieve consistent material performance²⁴. Variations in fibre diameter and length can affect the mechanical properties of the resulting biocomposite.

(ii) *Interfacial Adhesion*– Reaching strong interfacial adhesion between fibres and matrix material is still challenging. Despite surface treatments, achieving an optimal bond at the fibre-matrix interface is complex, influencing the overall mechanical integrity of the biocomposite²⁵.

(iii) *Scalability and Cost-Efficiency*– Transitioning from lab-scale to industrial-scale production poses challenges related to scalability and cost-efficiency. Maintaining the desired material properties while scaling up production demands innovative solutions to optimize processing parameters and reduce overall production costs³⁷.

Opportunities

(i) *Advanced Surface Modification Technique*– Exploring advanced surface modification techniques, such as plasma treatment or nanomaterial incorporation, presents opportunities to enhance interfacial adhesion. These techniques can improve the compatibility between fibres and the matrix material, addressing challenges related to adhesion⁴¹.

(ii) *Hybridization with Advanced Materials*– Hybridizing *Agave Americana* fibres with advanced materials, such as graphene or carbon nanotubes, offers opportunities to synergize the unique properties of different materials. This approach can enhance mechanical and thermal performance, expanding the application range of biocomposites⁴².

(iii) *Precision Manufacturing Technologies*– Leveraging precision manufacturing technologies, such as 3D printing or automated fabrication processes, provides opportunities to address challenges related to fibre alignment and distribution within the matrix. These technologies can contribute to achieving uniformity in material properties, enhancing overall performance³⁰.

(iv) *Waste Utilization*– Opportunities exist in using *Agave americana* waste generated during fibre extraction. Developing processes to repurpose waste material into secondary products or incorporating it into other composite materials contributes to sustainability and reduces environmental impact⁴³.

6 Life Cycle Assessment

A detailed Life Cycle Assessment (LCA) is crucial for understanding the environmental impact of *Agave americana* fibre-based biocomposites. LCAs examine every stage of a product's life, from raw material extraction to disposal. Studies on *Agave americana* fibre focus on water and energy use, greenhouse gas emissions and land use. LCAs show that cultivating *Agave americana* has a lower environmental impact than some traditional fibres, thanks to the plant's hardiness, reducing the need for extensive agricultural inputs³⁷. Sustainable fibre production, as assessed through LCA, reveals a positive environmental profile, considering factors like energy consumption, greenhouse gas emissions and land use.

Comparing AALF with conventional materials like glass or carbon fibres indicates promising environmental sustainability. Studies show lower energy consumption and carbon emissions in fibre cultivation and processing compared to glass and carbon fibres. Additionally, its biodegradability contributes to its favourable environmental profile³⁰. This not only underscores the eco-friendly aspects of this fibre but also highlights its role in reducing the ecological footprint of traditional materials.

The renewable nature of the fibre, along with its lower environmental impact in cultivation and processing, positions it as a green alternative. Its biodegradability aligns with the growing emphasis on

sustainable practices across industries. LCAs also consider factors like carbon sequestration in *Agave americana* plants, positively impacting the overall carbon balance⁴³. These sustainability benefits make fibre a compelling choice for developing environmentally responsible materials. Table 3 exhibits the life cycle stages of AALF-reinforced biocomposites with potential environmental impacts and considerations for sustainability.

7 Applications in Sustainable Textile Technology

7.1 Development of High-Performance Materials

Agave americana fibre emerges as a significant contributor to the development of high-performance materials in sustainable textile technology. Fibre's inherent strength and stiffness make it an excellent reinforcement choice for biocomposites. Studies reveal that *Agave americana* fibre-reinforced composites exhibit favourable mechanical properties, including tensile strength and modulus, making them suitable for applications in textiles requiring durability and robustness²⁴. The integration of AALF enhances the overall performance of textile materials, paving the way for the creation of sustainable alternatives with comparable or superior mechanical characteristics to traditional counterparts.

7.2 Reduction of Ecological Footprint

One of the key environmental advantages of *Agave americana* fibre in sustainable textile technology lies in its potential to significantly reduce the ecological footprint of the textile industry. The cultivation of *Agave americana* requires fewer resources than traditional textile crops, such as cotton. With its ability to thrive in arid conditions and limited need for pesticides or fertilizers, *Agave americana* contributes to water and resource conservation³⁷. Additionally, AALF biodegradability addresses concerns related to textile waste, offering an eco-friendly end-of-life disposal option. Adopting this fibre in textile production aligns with the textile industry's increasing emphasis on sustainable practices, addressing both environmental and resource sustainability challenges.

7.3 Alignment with Global Sustainable Practices and Trends

The integration of *Agave americana* fibre into sustainable textile technology aligns seamlessly with global sustainable practices and trends. The textile industry, recognizing the environmental impact of traditional materials and processes, is actively seeking alternatives that prioritize sustainability. This fibre fulfils

Table 3 — Life cycle stages of AALF reinforced biocomposites¹⁹

Life cycle stage	Potential environmental impacts	Considerations for sustainability
Raw material acquisition	<ul style="list-style-type: none"> • Land-use cultivation • Water usage for irrigation • Potential for soil erosion 	<ul style="list-style-type: none"> • Sustainable farming practices to minimize land-use impact and water footprint • Less water needed • Inherent soil erosion protection
Fibre processing	<ul style="list-style-type: none"> • Energy consumption during fibre extraction and purification • Potential use of chemicals in the processing steps • Wastewater generation from processing activities 	<ul style="list-style-type: none"> • Natural fibre retting does not consume energy • Bio-based retting does not need harsh chemicals • Wastewater acts as manure
Composite production	<ul style="list-style-type: none"> • Energy consumption composite manufacturing • Potential air emissions • Waste generation 	<ul style="list-style-type: none"> • Using renewable energy sources for composite production • Choosing low-emission matrix materials and processing methods • Minimizing waste through efficient production and scrap recycling options
Use phase	<ul style="list-style-type: none"> • Biocomposite textile product durability and lifespan • Maintenance needs and environmental impact of cleaning or treatments 	<ul style="list-style-type: none"> • Designing durable biocomposite textiles to prolong their lifespan • Developing eco-friendly cleaning methods or treatments with minimal environmental impact
End-of-life	<ul style="list-style-type: none"> • <i>Agave americana</i> fibre and matrix material biodegradability • Biocomposite material recycling or composting potential • Landfill disposal, with methane emission consideration 	<ul style="list-style-type: none"> • Prioritize biodegradable matrices for end-of-life biodegradation • Design biocomposites for recyclability • Explore industrial composting options for end-of-life biocomposite textiles

this need by offering a renewable and environmentally friendly material option. Its cultivation and processing require less energy and water, contributing to the industry's efforts to minimize resource consumption and promote responsible production methods⁴³. As global awareness of climate change and environmental issues grows, the adoption of AALF represents a proactive step toward aligning with evolving sustainability trends.

8 Conclusion

Agave americana fibre is a promising sustainable reinforcement for hybrid biocomposites, highlighting impressive mechanical properties and eco-friendly attributes. The integration of this fibre sets a precedent for the future of sustainable textile technology. Its success highlights the potential to create high-performance materials with reduced environmental impact, paving the way for a more eco-conscious textile industry. Embracing this sustainable alternative can catalyze transformative shifts toward environmentally responsible practices in textile technology.

References

- 1 Gentry HS, *Agaves of Continental North America*, 1stedn (University of Arizona Press), 1982.
- 2 Kishore K & Patil PG, *J Appl Polym Sci*, 115 (2) (2010) 2225.
- 3 Hodgson WC, *Food Plants of the World: Identification, Culinary Uses, and Nutritional Value*, 1stedn (CRC Press), 2001.
- 4 Mandal A & Chakrabarty D, *Carbohydr Polym*, 86 (3) (2011) 1291.
- 5 El-Sabbagh A & El-Sabbagh NM, *Mater Des*, 35 (2012) 296.
- 6 Kadole PV & Hulle AA, *Agave americana* Fibres: *Extraction, Characterization and Applications*, 1stedn (Lambert Academic Publishing, Germany), 2014.
- 7 Azapagic A J, *Clean Prod*, 12 (9) (2004) 639.
- 8 Müssig J, *Industrial Applications of Natural Fibres: Structure, Properties, and Technical Applications*, 1st edn (John Wiley & Sons) 2009.
- 9 Cherian BM & Leao AL, *Compos Part B-Eng*, 122 (5) (2017) 114.
- 10 Dey P & Singha K, *Bio Resources*, 5 (3) (2010) 928.
- 11 Pickering KL & Efendy MG, *Compos Part [A] Appl Sci*, 37 (6) (2006) 855.
- 12 Fiore V & Scalici T, *Compos Part B-Eng*, 74 (8) (2015) 74.
- 13 Faruk O, Bledzki AK & Fink HP, *Compos Sci Technol*, 74 (1) (2014) 41.
- 14 Cherian BM & Leao AL, *Compos Part B-Eng*, 122 (5) (2017) 114.
- 15 El-Sabbagh NM, El-Midany MSI & El-Sabbagh AA, *Polym Compos*, 33 (7) (2012) 1104.
- 16 George RHS & Muthukumarappan S, *J Nat Fibres*, 9 (2) (2012) 93.
- 17 Subyakto & Syafri A, *IOP Conf Ser -Mater Sci*, 345 (1) (2018) 12031.
- 18 Boufi J, Lopez A, Vilaseca M & Cañigueral JL, *Compos Sci Technol*, 6 (12) (2008) 1601.

- 19 Kadole PV, Hulle AA & Katkar PM, *Agave Americana Fibre Reinforced Composites: Manufacturing and Characterization*, 1stedn (Scholar's Press, Germany), 2015.
- 20 Fiore V, Scalici M, Sarasini S, Tirillò S & Valenza F, *Compos Part B-Eng*, 74 (8)(2015) 74.
- 21 Rozman HD, Misri MS, Ishak ZAM, Sapuan SM & Zainudin ES, *Resour Conserv Recy*, 85 (2014) 121.
- 22 Sanjay MR, Prasad KP & Umanath LC, *Mater Today-Proceed*, 5 (10) (2018) 16358.
- 23 Wang R, Li Y, Hui D & Fu C, *Compos Part B-Eng*, 45 (5) (2013) 1427.
- 24 Sanjay MR, Arpitha Y, Naik MD, Madhu S & Senthamarakannan P, *Compos Part B-Eng*, 147 (1) (2018) 80.
- 25 Ramesh PS, Rajadurai S, Malhotra SK & Choudhary BP, *Mater Res Express*, 6 (3)(2018) 35318.
- 26 Lee LJ, Hong NT, Ismail MUS & Choong TY, *Mater Today-Proceed*, 5 (10) (2018)19289.
- 27 Sapuan SM, Rozman HD, Ishak ZAM, Hassan MRH & Zainudin ES, *J Therm Anal Calorim*, 97 (1) (2009) 243.
- 28 Boufi J, López A, Vilaseca M & Cañigueral JL, *Compos Sci Technol*, 68 (2008) 3045.
- 29 Gunasena FH, Sampath W & Ismail N, *Polymers*, 13 (11) (2021) 2118.
- 30 Abdullah MZ, Sulong AB, Khan ZA, Sultan MTH & Lee KK, *S Mater Des*, 32 (7)(2011) 4306.
- 31 Hulle A A, Kadole PV & Katkar PM, *Fibres*, 3 (1) (2015) 64.
- 32 Gentry HS, *Agaves of Continental North America*, 2ndedn (University of Arizona Press),2004.
- 33 Sulong B, Yusoff HM, Khan ZA & Sultan MTH, *Compos Part B-Eng*, 54 (2) (2013)90.
- 34 Prabakaran SRS, Ghazali MYA, Sultan MTH & Asyraf MRM, *Compos Part B-Eng*, 45 (1) (2013) 620.
- 35 Prasad RVS, *R Mater Des*, 28 (10) (2007) 1878.
- 36 Pimienta-Barrios G, *Agroforest Syst*, 39 (3) (1998) 257.
- 37 Ornelas-Paz A, *J Clean Prod*, 167 (1) (2017) 702.
- 38 Boufi J, López A, Vilaseca M & Cañigueral JL, *Compos Sci Technol*, 68 (12) (2008)1601.
- 39 Long AC, Yang Y & James LW, *J Mater Res Technol*, 9 (4) (2020) 4438.
- 40 Subhedar K M, Chauhan G S, Singh B P & Dhakate R, *Ind J Engg Mat Sci*, 27 (6) (2020) 1100.
- 41 Rongzhi Li, Lin Ye & Yiu-Wing Mai, *Comp A: Appl Sci Manuf*, 28 (1) (1997) 73.
- 42 Sanjay M R & Yogesha B, *Materials Today: Proc*, 4 (2) (2017) 2739.
- 43 De Vries J & van der Meer L P, *Int J Life Cycle Assess*, 12 (7) (2007) 422.