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# Orientation-Engineered Sansevieria Fibers for Sustainable Prosthetic Reinforcement

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Research Article

**Abstract:**
The development of sustainable materials for prosthetic applications has become increasingly important due to concerns related to environmental impact, cost, and accessibility. Natural-fiber-reinforced composites (NFRCs) offer promising alternatives to synthetic composites due to their low density, renewability, and environmentally friendly characteristics. This study investigated the potential of *Sansevieria trifasciata* fibers as reinforcement in vinyl ester composites for prosthetic socket applications. The fibers were mechanically extracted and treated with 5% sodium hydroxide (NaOH) to improve fiber–matrix adhesion. Composites with a fiber volume fraction of 30% were fabricated using two fiber architectures: unidirectional alignment and woven configurations with weave distances of 0, 2.5, 5.0, and 7.5 mm. The mechanical performance was evaluated using tensile testing (ASTM D3039) and Charpy impact testing (ASTM E23). The unidirectional composite exhibited the highest tensile strength (60.27 MPa) and Young's modulus (78.71 GPa), indicating efficient load transfer along the fiber direction. Meanwhile, the woven composites with 2.5 mm spacing (W-2.5) showed the highest impact strength (0.093 J/mm²) due to improved energy absorption mechanisms such as crack deflection and fiber pull-out. These results demonstrate that fiber orientation significantly influences the mechanical performance of Sansevieria fiber composites, highlighting their potential as sustainable and cost-effective reinforcement materials for prosthetic socket structures.

**Keywords:** Biocomposite; Reinforced composites; *Sansevieria trifasciata*; Vinyl ester; Prosthesis materials

## 1. INTRODUCTION

The continuous development of materials science has significantly influenced the advancement of composite materials for structural, industrial, and biomedical applications. In recent years, increasing attention has been directed toward natural-fiber-reinforced composites (NFRCs) as sustainable alternatives to conventional synthetic fiber composites. Natural fibers offer several advantages, including low density, renewability, biodegradability, corrosion resistance, and relatively competitive specific mechanical properties compared with synthetic reinforcements (1-3). These characteristics have encouraged the use of NFRCs in various sectors such as automotive engineering, aerospace structures, and biomedical devices (4, 5).

In prosthetic engineering, material selection plays a critical role in ensuring mechanical reliability, user comfort, and long-term durability of prosthetic components. Prosthetic sockets, which serve as the interface between the amputee limb and the prosthetic device, must possess sufficient strength, stiffness, and impact resistance to withstand repetitive loading during daily activities. Conventional materials used in prosthetic sockets—such as carbon fiber composites, fiberglass laminates, and thermoplastic polymers—provide excellent mechanical performance but are often costly and environmentally unfriendly (6-8). In many developing countries, the high cost and limited accessibility of these materials remain significant barriers to the widespread availability of prosthetic devices, thereby restricting access to rehabilitation technologies for many amputees (9, 10).

Natural fibers have therefore emerged as promising candidates for developing cost-effective and environmentally sustainable prosthetic materials. Among these fibers, *Sansevieria trifasciata* (commonly known as snake plant or "lidah mertua") has attracted increasing interest due to its availability, renewability, and favorable mechanical characteristics. Previous studies have reported that Sansevieria fiber reinforced polymer composites exhibit promising tensile and flexural


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properties, indicating their potential for structural applications (11-13). In addition, vinyl ester resins have been widely used as composite matrices due to their excellent chemical resistance, mechanical reliability, and superior performance compared with conventional polyester resins (14).

Despite these promising developments, limited research has investigated the influence of fiber orientation and woven architecture on the mechanical performance of Sansevieria fiber composites, particularly in the context of biomedical and prosthetic applications. Fiber orientation is known to significantly affect load transfer efficiency, stiffness, fracture behavior, and energy absorption in composite materials. Understanding how different fiber orientations influence mechanical performance is therefore essential for optimizing composite structures intended for prosthetic socket reinforcement.

The novelty of this study lies in the orientation engineering of Sansevieria fibers within a vinyl ester matrix to tailor the mechanical properties of sustainable prosthetic composites. Specifically, this work evaluates the effect of unidirectional fiber alignment and woven configurations with varying weave distances (0–7.5 mm) on tensile and impact properties. Mechanical characterization was conducted through tensile and Charpy impact testing to assess the influence of fiber architecture on composite performance. By comparing the obtained mechanical properties with those of existing prosthetic materials, this research aims to demonstrate the feasibility of Sansevieria fiber composites as sustainable, cost-effective reinforcements for prosthetic socket applications.

## 2. MATERIALS AND METHODS

### 2.1 Materials

The primary reinforcement material was *Sansevieria trifasciata* fibers, sourced from locally grown plants older than one year. Fibers were mechanically extracted, followed by alkalization using 5% NaOH solution for 60 minutes to improve fiber–matrix adhesion (15). The matrix employed was vinyl ester resin (FORTCHEM 411 VE), purchased from Bratachem, with baseline mechanical properties summarized in Table 1.

Table 1. Properties of vinyl ester resin (FORTCHEM 411 VE).

| Property | Value | Standard |
|---|---|---|
| Density (g/cm3) | 1.002 | |
| Tensile strength (MPa) | 80 ~ 90 | ASTM D-638 |
| Tensile elongation (%) | 5 ~ 6 | ASTM D-638 |
| Flexural strength (MPa) | 125 ~ 152 | ASTM D-256 |

### 2.2 Fiber Preparation

Fiber extraction followed the method of Sanjay *et al.* (16), involving mechanical decortication to remove non-fibrous material, followed by natural drying. The appearance of the fibers from the *Sansevieria trifasciata* leaves is shown in Figure 1. Alkali treatment was applied to enhance interfacial bonding between fibers and matrix by increasing surface roughness and reducing hemicellulose content (15, 17).

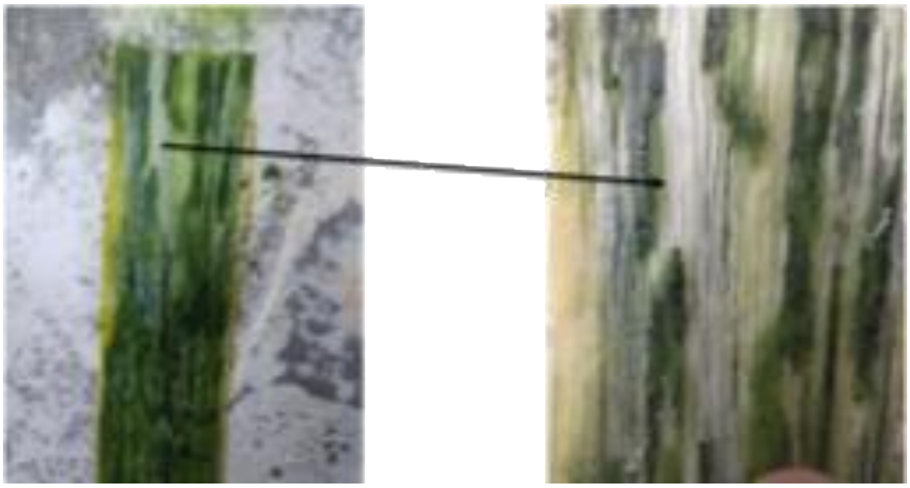

Figure 1. Appearance of fibers on *Sansevieria trifasciata* leaves.

### 2.3 Composite Fabrication

Composites were fabricated with a fiber volume fraction of 30% and matrix content of 70%. Two fiber orientations were designed: (i) unidirectional alignment, and (ii) woven orientations with varying weave distances (0, 2.5, 5.0, and 7.5 mm). Samples were coded according to fiber orientation (Table 2). Furthermore, the weave orientation is varied with no distance (0 mm), giving a distance between the weaves of 2.5 mm, 5.0 mm, and 7.5 mm, as shown in Figure 2.

Table 2. Composite configurations.

| Sample Code | Fiber Orientation | Weave Distance |
|---|---|---|
| U | Unidirectional | - |
| W-0 | Woven | 0 mm |
| W-2.5 | Woven | 2.5 mm |
| W-5.0 | Woven | 5.0 mm |
| W-7.5 | Woven | 7.5 mm |

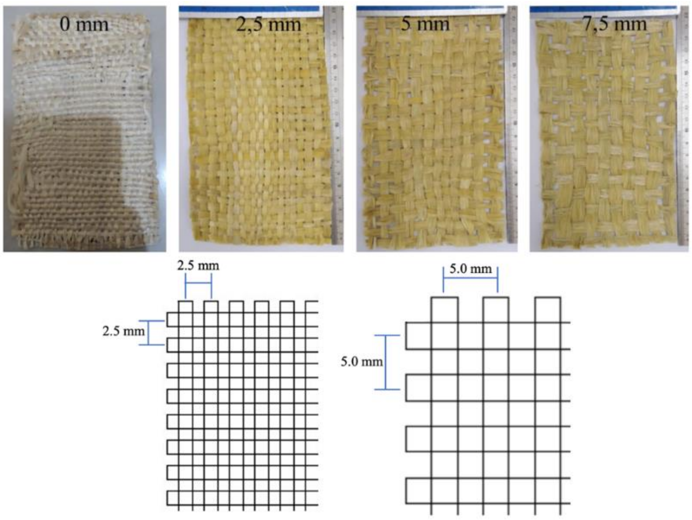


Figure 2. Distance between woven fibers.

## 2.4 Mechanical Testing

Tensile properties were measured in accordance with ASTM D3039 (18). Rectangular specimens with dimensions of 200 × 20 × 3 mm were prepared and tested using a universal testing machine (Gotech GT-7001-LC30, Taiwan) at room temperature. For each specimen type, five replicates were tested to ensure data reliability, and the average values were reported. Impact resistance was evaluated using the Charpy impact method following ASTM E23 (19). The test specimens had dimensions of 55 × 10 × 10 mm and were prepared with a 45° V-notch. Impact testing was performed using a Charpy Impact Testing Machine (JB 300B, Taiwan). The absorbed impact energy per unit area was calculated to determine the impact strength of the composites. The dimensions and visual appearance of the tensile and impact test specimens are presented in Figure 3.

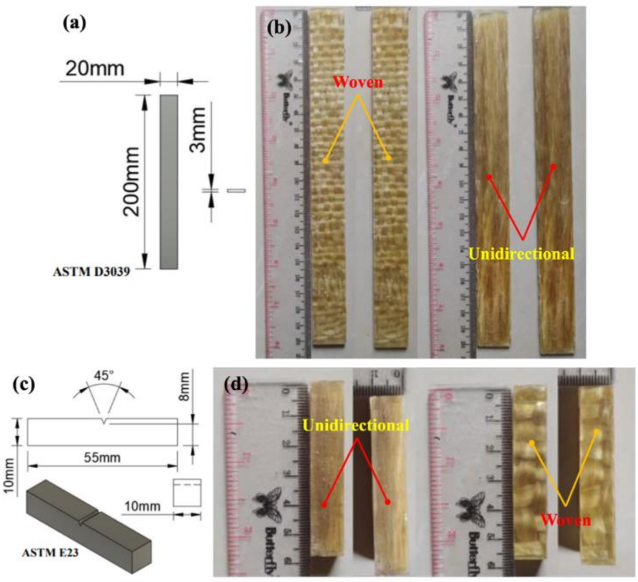


Figure 3. Dimensions of the tensile and impact test specimens used.



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### 2.5 Fractography

Post-failure analysis of fractured specimens was conducted visually and compared against failure mode classifications described in ASTM D3039 and related literature (18). Emphasis was placed on identifying fiber pull-out, cohesive failure, and matrix cracking.

## 3. RESULTS AND DISCUSSION

### 3.1 Tensile Properties

Figure 4 illustrates the tensile strength. Unidirectional orientation exhibited the highest tensile strength (60.27 MPa) and stiffness (78.71 GPa). In contrast, woven orientations displayed significantly lower tensile performance, with maximum tensile strength recorded at 23.04 MPa for W-2.5 specimens. The decline in performance with increasing weave distance suggests weaker load transfer efficiency due to reduced fiber alignment. The superiority of unidirectional composites aligns with the principle that fiber alignment parallel to load direction maximizes stress transfer (20). Comparisons with rami (80 MPa) and kenaf composites (76.56 MPa) (21, 22) indicate that Sansevieria fibers achieve moderately high tensile performance but excel in stiffness. Tensile strength reflects the maximum stress that the composite can sustain before fracture, which is strongly influenced by fiber–matrix interfacial bonding and failure mechanisms such as fiber breakage, pull-out, and matrix cracking.

The Young's modulus results of the composites with different fiber orientations are presented in Figure 5. The unidirectional Sansevieria fiber composite exhibited the highest stiffness with a Young's modulus of 78.71 GPa, which is significantly higher than those of the woven fiber configurations. In contrast, the woven specimens showed a substantial reduction in stiffness, with modulus values decreasing progressively from 19.05 GPa (W-0) to 9.76 GPa (W-7.5).

The superior stiffness observed in the unidirectional composite can be attributed to the parallel alignment of fibers with the loading direction, which enables efficient load transfer between the matrix and reinforcing fibers. When fibers are aligned along the tensile axis, the applied stress is directly carried by the fibers, resulting in higher resistance to elastic deformation. Conversely, in woven configurations, the presence of fiber undulation and transverse fiber segments reduces the efficiency of load transfer, thereby lowering the overall stiffness of the composite.

Furthermore, the decrease in Young's modulus with increasing weaving distance indicates that fiber misalignment and reduced packing density play an important role in governing the stiffness of the composite. Larger weaving distances introduce greater fiber waviness and increase the proportion of matrix-dominated regions. As a result, the composite exhibits reduced resistance to elastic deformation.

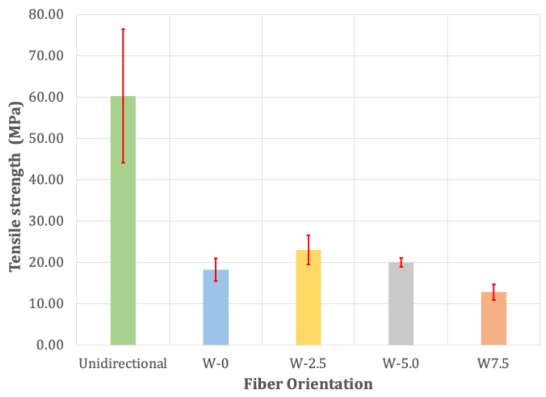


Figure 4. Tensile strength of composites with different fiber orientations.

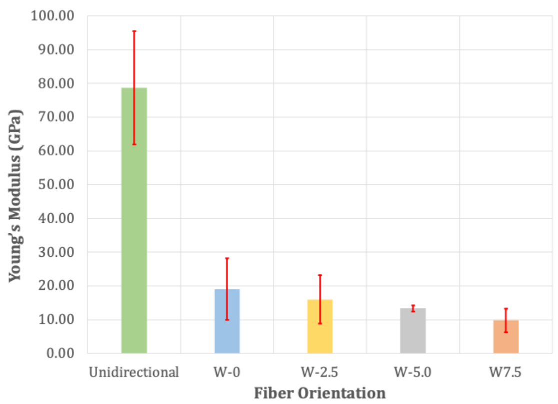


Figure 5. Young's Modulus of composites with different fiber orientations.

### 3.2 Impact Properties

The impact properties of the composites with different fiber orientations were evaluated using the Charpy impact test, and the results are presented in Figure 6. The composite with woven fiber orientation and 2.5 mm spacing (W-2.5) exhibited the highest impact strength of 0.093 J/mm², indicating superior resistance to sudden loading compared with the other configurations. In contrast, the W-0 specimen showed the lowest impact strength (0.062 J/mm²), suggesting limited energy absorption capability in tightly woven structures.

The improved impact performance observed in the W-2.5 configuration can be attributed to the more favorable fiber architecture that promotes effective energy dissipation during fracture. Moderate weave spacing allows greater interaction between fibers and matrix, enabling mechanisms such as crack deflection, fiber bridging, and fiber pull-out, which contribute to increased impact toughness. These mechanisms delay crack propagation and enhance the ability of the composite to absorb impact energy before failure. Such behavior parallels observations in other NFRCs where hybrid orientations improve impact resistance (23).

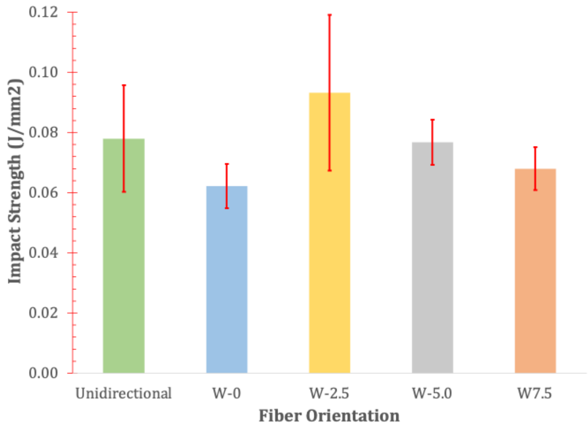


Figure 6. Impact strength of composites with different fiber orientations.

### 3.3 Failure Modes

The fracture characteristics of the composite specimens subjected to tensile and impact loading are presented in Figure 7 and Figure 8, respectively. The observed failure modes were analyzed with reference to the classification described in ASTM D3039, which is commonly used to identify fracture patterns in fiber-reinforced polymer composites.

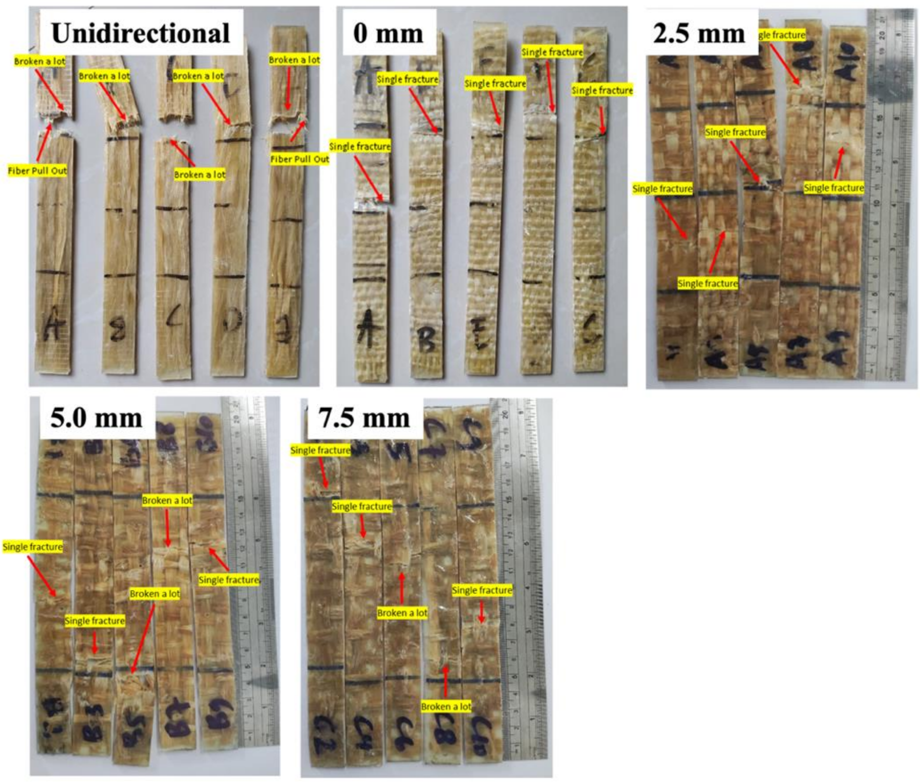


Figure 7. Fracture mode resulting from tensile test.

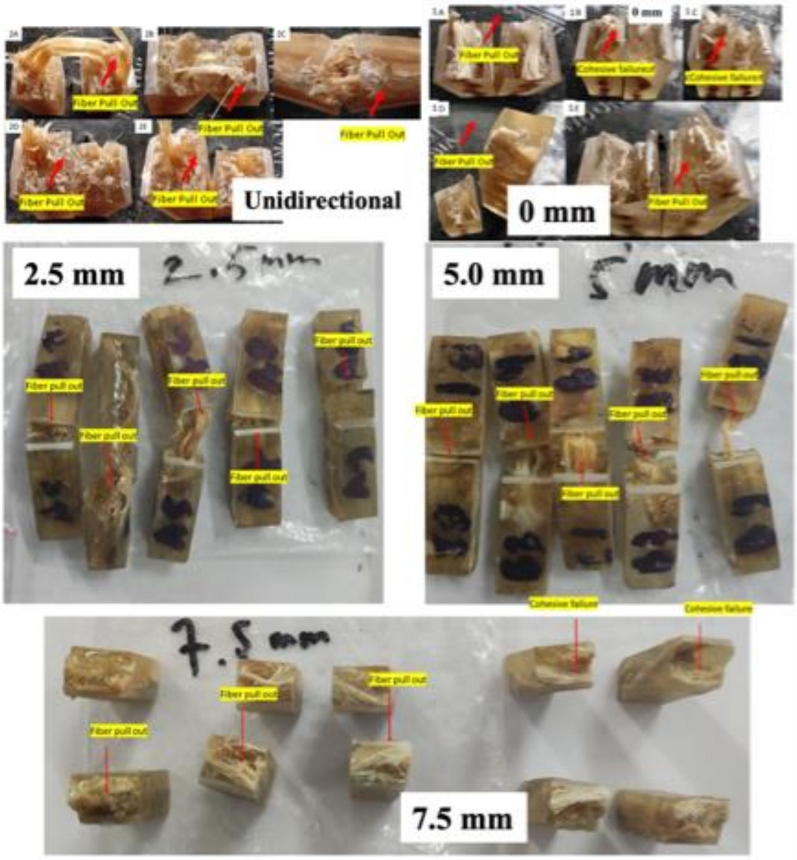


Figure 8. Fracture mode resulting from impact test.

Under tensile loading, the fracture surfaces indicate several typical failure mechanisms of natural fiber reinforced composites. The dominant failure modes include fiber breakage, fiber pull-out, and matrix cracking, which reflect the interaction between the reinforcing fibers and the polymer matrix during load transfer. In specimens with unidirectional fiber orientation, failure tends to occur along the fiber direction, characterized by relatively straight fracture paths and localized fiber breakage. This behavior suggests that the applied tensile load was effectively transferred along the aligned fibers, resulting in higher tensile strength and stiffness.

In contrast, the woven fiber composites exhibit more complex fracture patterns due to the presence of fiber interlacing and waviness. The woven architecture introduces local stress concentrations and promotes crack deflection during loading. As a result, the fracture surfaces show a combination of fiber pull-out, matrix debonding, and delamination between fiber bundles. These mechanisms indicate that the load transfer between fibers and matrix is influenced by the geometric arrangement of the woven structure.

For the impact-tested specimens, fracture morphology demonstrates a more irregular and rougher surface compared to the tensile fracture surfaces. Impact loading typically produces rapid crack propagation, accompanied by energy-dissipation mechanisms such as fiber pull-out, bundle separation, and matrix fracture. The presence of extensive fiber pull-out observed in several specimens indicates that significant energy was required to overcome the interfacial bonding between the fibers and the matrix. This phenomenon contributes to the improved impact toughness observed in the woven configurations, particularly for the W-2.5 specimen.

Overall, the fracture analysis suggests that the fiber orientation and architectural configuration significantly influence the failure behavior of the composites. Unidirectional fibers primarily enhance load-bearing capacity under tensile loading, whereas woven structures promote multiple energy-absorbing mechanisms during dynamic loading conditions. These findings confirm that optimizing fiber arrangement is essential for tailoring both the strength and toughness of Sansevieria fiber reinforced polymer composites.

### 3.4 Comparison with Prosthetic Socket Materials

A comparison with other natural fiber composites listed in Table 3 further highlights the stiffness advantage of Sansevieria-reinforced composites with synthetic prosthetic socket materials such as PLA reinforced with carbon fiber, Kevlar, and fiberglass (24). The Young's modulus obtained for the unidirectional Sansevieria composite (78.71 GPa) is substantially higher than those reported for several natural fiber composites, such as rami fiber composites (3.00 GPa), kenaf fiber composites (3.17 GPa), ijuk/palm fiber composites (6.60 GPa), and rattan skin fiber composites (13.80 GPa) reported in previous studies. This indicates that Sansevieria fibers possess excellent stiffness characteristics and can effectively enhance the elastic rigidity of polymer composites.

The relatively high stiffness of Sansevieria fiber composites suggests their potential for structural applications requiring high rigidity, particularly in prosthetic socket structures where dimensional stability and load-bearing capability are essential. The results demonstrate that optimizing fiber orientation, especially through unidirectional alignment, plays a critical role in maximizing the stiffness performance of natural fiber reinforced polymer composites. This positions Sansevieria composites as viable substitutes for synthetic reinforcements in prosthetic devices, particularly in resource-limited settings.

Table 3. Comparison of mechanical properties of polymer composites with *Sansevieria trifasciata* fiber compared to references.

| Fiber/Orientation | Tensile Strength (MPa) | Young's Modulus (GPa) | Absorbed Energy (Joules) | Impact Strength ($J/mm^2$) | Reference |
|---|---|---|---|---|---|
| *Sansevieria trifasciata*/ Unidirectional | 60.27 | 78.71 | 6.24 | 0.078 | |
| *Sansevieria trifasciata*/ W-0 | 18.24 | 19.05 | 4.97 | 0.062 | |
| *Sansevieria trifasciata*/ W-2.5 | 23.04 | 15.97 | 7.46 | 0.093 | |
| *Sansevieria trifasciata*/ W-5.0 | 20.01 | 13.31 | 6.16 | 0.077 | |
| *Sansevieria trifasciata*/ W-7.5 | 12.85 | 9.76 | 5.46 | 0.068 | |
| Coconut Fiber | 58.00 | | | | (24) |
| Mendong Fiber | 26.60 | | | | (25) |
| Pineapple leaf fiber | 33.57 | | | | (26) |
| Rami fiber | 80.00 | 3.00 | | | (27) |
| Ijuk/Aren (Palm Fiber) | 36.37 | 6.60 | | | (28) |
| Rattan skin fiber | 21.65 | 13.80 | | | (29) |
| Kenaf Fiber | 76.56 | 3.17 | | | (30) |
| Sugarcane Fiber | 32.19 | 0.36 | | | (31) |
| Eight perlon layers | 40.20 | 1.06 | | | (32) |
| Orthocryl lamination 80:20 + hardener | 54.00 | 2.50 | | | (33) |

## 4. CONCLUSION

This study evaluated the mechanical performance of *Sansevieria trifasciata* fiber reinforced vinyl ester composites with different fiber orientation configurations for potential use in prosthetic socket applications. The results demonstrate that fiber architecture significantly influences the mechanical behavior of the composites.

The unidirectional fiber configuration exhibited the highest tensile performance, achieving a tensile strength of 60.27 MPa and a Young's modulus of 78.71 GPa, indicating efficient load transfer along the fiber direction and improved stiffness for load-bearing applications. In contrast, woven fiber configurations exhibited enhanced impact resistance, with the W-2.5 configuration providing the highest impact strength of 0.093 $J/mm^2$, which is associated with improved energy dissipation mechanisms such as crack deflection, fiber bridging, and fiber pull-out.

Comparative evaluation with other natural fiber composites and commonly used prosthetic materials indicates that Sansevieria fiber composites provide competitive mechanical properties while offering advantages in terms of sustainability, availability, and cost-effectiveness. These findings suggest that Sansevieria fibers can serve as promising renewable reinforcements for environmentally friendly prosthetic components.

Overall, the results highlight that fiber orientation engineering is an effective approach for tailoring the strength, stiffness, and impact resistance of natural fiber composites for biomedical applications. Future research should focus on optimizing fiber–matrix interfacial bonding, investigating long-term mechanical performance such as fatigue and creep behavior, and validating the material through prototype prosthetic socket fabrication and biomechanical testing to further advance sustainable prosthetic technologies.

## AUTHORSHIP CONTRIBUTION STATEMENT

Deru Assadullah Hanif: conceptualization, data analysis and interpretation, writing – original draft; Assadul Muhammad: conceptualization, data analysis and interpretation, writing – review & editing; Abrar Ridwan: data collection, writing – review & editing; Novia Gesrian Tuti: data collection, writing – review & editing; Muhammad Hanif Ramlee: data analysis and interpretation, writing – review & editing; Ahmad Kafrawi Nasution: conceptualization, data collection, data analysis and interpretation, writing – review & editing.

## DATA AVAILABILITY

Data are available within the article or its supplementary materials.

## DECLARATION OF COMPETING INTEREST

Authors declare that there is no conflict of interest regarding the publication of the paper.

## DECLARATION OF GENERATIVE AI

The authors declare that they have not used any type of generative AI for the writing of this manuscript, nor for the creation of images, graphics, tables, or their corresponding captions.

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