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Comparative Analysis of Short and Semi-Long Date Palm Fiber Lengths on the Physical, Mechanical, and Morphological Characterization of Epoxy Bio-Composites

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ABSTRACT

This study seeks to investigate the influence of Date Palm Fibers (DPFs) length on the physical, mechanical, and morphological properties of epoxy bio-composite materials. Two types of fibers were employed to enhance the bio-composites. The initial category comprised Short Date Palm Fibers (SDPF), whereas the subsequent category encompassed Semi Long Date Palm Fibers (LDPF). Apparent density and tensile tests were performed to evaluate the impact of these fibers on the epoxy matrix. LDPF markedly improved the apparent density, modulus of elasticity, and maximum stress of the bio-composite materials, resulting in enhancements of 42.08%, 65.17%, and 74.20%, respectively, relative to SDPF bio-composites. Further validation of these findings was achieved via Scanning Electron Microscopy (SEM), which demonstrated improved fiber-matrix adhesion and increased homogeneity in the LDPF bio-composite materials. Furthermore, no cavities were detected on the fracture surface. The results demonstrate that Semi Long Date Palm Fibers (LDPF) are superior to Short Date Palm Fibers (SDPF) in enhancing epoxy matrices. This results in improved physical and mechanical characterization in applications employing bio-composite materials.

KEYWORDS

Date Palm Fibers
Epoxy Matrix
Physical Characterization
Mechanical Characterization
Short Date Palm Fibers
Semi Long Date Palm Fibers
Bio-based Materials

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1 Introduction

In recent years, the field of bio-composite materials has seen growing interest in using Date Palm Waste (DPW) as a natural reinforcement, due to its distinctive physical and mechanical characterizations, sustainability, and abundant availability in date-producing regions [1-3]. Date Palm Fibers (DPFs), rich in cellulose, hemicellulose, and lignin, are considered ideal materials for enhancing the mechanical characterizations of various bio-composite materials [2, 4]. Numerous studies have demonstrated that fibers extracted from date palm can improve the physical and mechanical characterizations of bio-composites when used as reinforcements in various polymer matrices, such as epoxy and polyester [2, 5-7].

Despite these advantages, the results of these studies have shown considerable variation, reflecting the significant influence of factors such as fiber length, fiber content, and the matrix type [2, 5, 7]. For instance, a study [8], revealed that Short Date Palm Fibers (SDPF) enhanced the tensile characterizations of an epoxy matrix, with the improvement proportional to the fiber content. Conversely, another study [9], indicated that longer fibers increase the modulus of elasticity of epoxy bio-composites, with better performance observed as fiber length increased. Additionally, the apparent density of the bio-composites decreased with the incorporation of DPF, in direct proportion to the fiber content or length [1, 10]. However, a notable scientific gap exists in understanding how to effectively compare these results due to variations in fiber sources and matrix types, highlighting the need for a more in-depth investigation into the effects of fiber length and matrix type on bio-composite characterizations.

While some studies have addressed the use of varying fiber lengths, the specific role of fiber length remains insufficiently understood. Fiber length is a critical factor influencing fiber dispersion, interfacial bonding, and stress-transfer efficiency, thereby affecting the physical and mechanical properties of biocomposite. Nevertheless, previous studies have generally been limited to examining single fiber lengths or broad, inconsistent length ranges, without establishing a clear classification of fiber lengths or conducting systematic comparisons between specific length categories [11-13]. This limitation reveals a significant scientific gap in the existing literature. Despite growing interest in valorizing date palm waste to develop sustainable materials, there remains a lack of clear understanding regarding how fiber length influences the performance of date palm fiber-reinforced biocomposite; furthermore, a critical fiber length beyond which significant improvements in composite properties are achieved has not yet been established. Consequently, several fundamental questions remain unanswered: How does fiber length affect the physical and mechanical properties of biocomposite reinforced with date palm waste fibers? Is there a critical fiber length that maximizes reinforcement efficiency? And

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to what extent can the systematic classification of fiber lengths contribute to optimizing the design and performance of these sustainable composites?

Based on this research gap, the present study aims to address this issue by selecting two categories of fibers with different lengths from the same source and using the same matrix. The first category includes Short Date Palm Fibers (SDPF) not exceeding 1 mm, while the second category consists of Semi Long Date Palm Fibers (LDPF) exceeding 1 mm. This classification enables precise comparison of the physical, mechanical, and morphological characterization of the bio-composite materials, helping identify the impact of fiber length on these properties and determine the threshold fiber length that improves or modifies them for industrial applications.

To achieve this, a set of samples was prepared using an epoxy matrix and Date Palm Fibers (DPFs) of varying lengths, maintaining the same fiber mass ratio. The samples underwent apparent density and tensile testing tests. Furthermore, to understand the behavior of the bio-composite material, Scanning Electron Microscopy (SEM) was conducted on the first- and second-category samples to evaluate fiber-matrix bonding. The obtained results provide a deeper insight into the impact of Date Palm Fibers (DPFs) length on the mechanical characterization of the bio-composite materials, offering valuable information for future applications and enriching the field of research in bio-composite materials.

2 Method and Methodology

The materials and methodology section emphasizes the techniques used to extract fibers and details the matrix used and its key characteristics. The Bio-based materials will be emphasized, along with their manufacturing process. This was accomplished as follows:

2.1 Fiber

The fibers utilized in this study were derived from the fronds of the "Deglet Noor" Date Palm Fiber (DPF), approximately 16 years old, sourced from the Biskra region, specifically the Tolga area in the Algerian Sahara. Annually, the desiccated palm leaves are gathered following the standard upkeep of the palm trees in the groves. Upon the palm leaves used from the Date Palm Waste (DPW), the petiole and the leaflets are removed, but the Rachis stalks are used and cut into lengths of 30-40 cm. Various procedures are used to obtain both short and semi-long fibers from Rachis stalks. The stalks extracted from the Rachis are soaking in distilled water for 5 to 10 days. Subsequently, the Rachis stalks are stored in black plastic bags for 30 to 45 days to facilitate the proliferation of fungus and bacteria during the fermentation process [14]. This biological method enhances

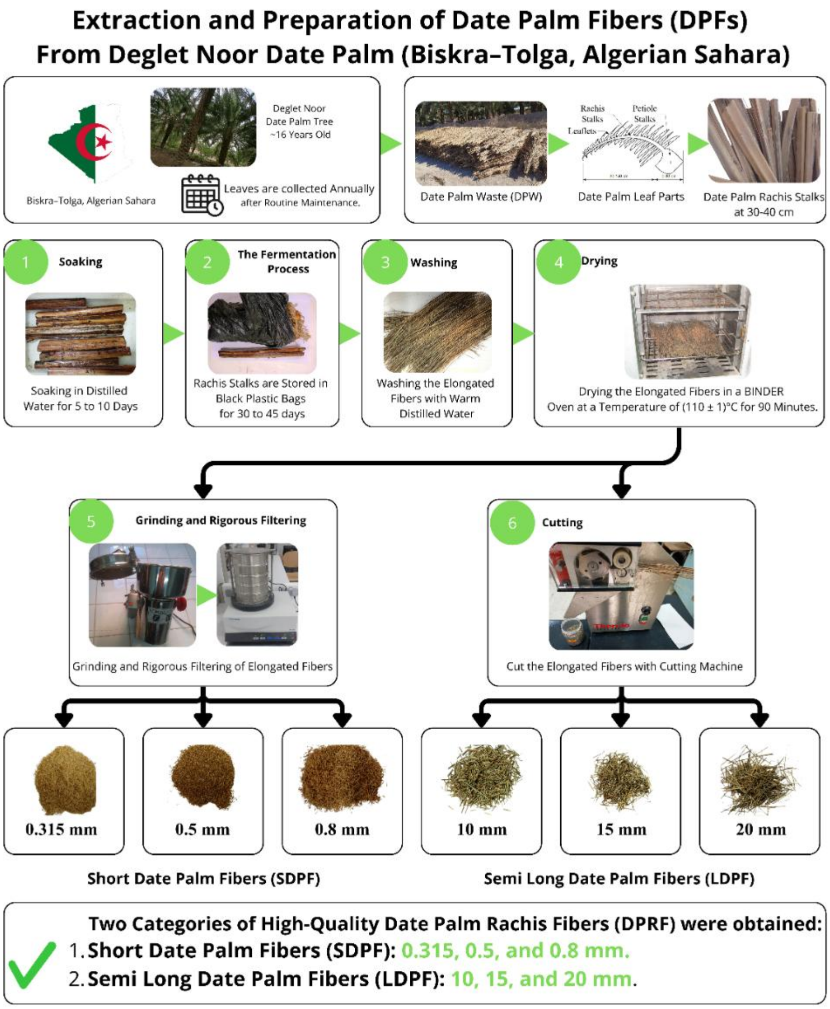

Fig. 1. Steps For Preparing Short Date Palm Fibers (SDPF) and Semi Long Date Palm Fibers (LDPF).

the mechanical extraction process by using a roller press [15]. The resultant elongated fibers, with diameters between 0.2 and 0.8 mm, are subjected to multiple washes with warm distilled water and subsequently dried in a BINDER oven at a temperature of (110 ± 1)°C for 90 minutes. After drying and multiple wash cycles, a portion of the fibers is grinded in an electric mill at 300 rpm for 60 seconds. The resultant short fibers undergo a rigorous filtering procedure utilizing a succession of vibrating metal sieves, according to AFNOR D258, D259, D260, D261, D262, D263, and D264 for 15 minutes to get fibers with sizes of 0.315, 0.5, and 0.8 mm, and it is named Short Date Palm Fibers (SDPF) [16]. In addition, another long fiber is severed with a specialized cutting machine into varying lengths of 10, 15, and 20 mm, and it is named Semi Long Date Palm Fibers (LDPF). All of these steps are shown in Figure 1.

2.2 Matrix (Epoxy Resin)

In this study, epoxy resin was used as the matrix material, supplied by Granitex Algérie Construction. Its viscosity in the liquid state is 11,000 MPa·s (110 Poise) at 25 °C, indicating a relatively high resistance to flow. After mixing the resin with the hardener at a 3:1 ratio, the liquid resin forms a solid in 15 to 45 minutes.

2.3 Bio-Composite Material Preparation

The bio-composite Date Palm Fiber/Virgin Epoxy samples were fabricated using a hand-lay-up molding technique. Removable plastic molds in plate configurations with a

Fig. 2. Key Steps in Preparing Bio-Composite Samples.

cubic shape and a muduim thickness were utilized to manufacture samples for physical characterization, whilst dumbbell shape (type I) molds were employed for samples intended for mechanical characterization. After the molding procedure, the samples were subjected to mechanical pressure by being clamped between two plates for 72 hours, as shown in Figure 2.

The bio-composite material samples were manufactured with a 15% mass ratio and categorized into two categories (E.SDPF.X and E.LDPF.Y), using Equation (1):

$$\textit{Bio-Composite Material} = 85\%\ \textit{Virgin Epoxy} + 15\%\ \textit{Date Palm Fiber (DPF)} \tag{1}$$

The bio-composite materials (E.SDPF.X) were reinforced with Short Date Palm Fibers (SDPF) at lengths of 0.315, 0.5, and 0.8 mm, classified as X: 1, 2, and 3, for each length and denoted as E.SDPF.1, E.SDPF.2, and E.SDPF.3, respectively. In addition, the bio-composite materials (E.LDPF.Y) were reinforced with Semi Long Date Palm Fibers (LDPF) at lengths of 10, 15, and 20 mm, classified as Y: 1, 2, and 3, for each length and denoted as E.LDPF.1, E.LDPF.2, and E.LDPF.3, respectively.

3 Characterization Methods

Three distinct methodologies were employed to characterize virgin epoxy and the bio-composite materials (E.SDPF.X and E.LDPF.Y) samples reinforced with two different categories of Date Palm Fibers (DPFs), namely Short Date Palm Fibers (SDPF) and Semi Long Date Palm Fibers (LDPF), respectively, regarding their physical, mechanical, and morphological characterizations, as outlined below:

3.1 Physical Tests (Apparent Density Test)

The apparent density of virgin epoxy and the bio-composite materials (E.SDPF.X and E.LDPF.Y) samples reinforced with two different categories of Date Palm Fibers (DPFs), namely Short Date Palm Fibers (SDPF) and Semi Long Date Palm Fibers (LDPF), respectively, was determined using the immersion method for non-cellular plastics, in accordance with ISO 1183-1:2025 and ASTM D792-20 standards [17, 18].

Five samples were extracted from the previously prepared plates of virgin epoxy and bio-composite materials (E.SDPF.X and E.LDPF.Y), which were formed into a muduim thickness, cubic shapes, as shown in Figure 3.

Each sample was initially weighed in dry air utilizing a high-precision analytical balance with an accuracy of 0.0001 g. Each sample was thereafter submerged in distilled water in a 0.1 mL graduated cylinder to determine its volume by liquid displacement. The apparent density of each sample was determined using Equation (2), and the results were averaged and presented with standard deviation for every five samples of each virgin epoxy and bio-composite material (E.SDPF.X and E.LDPF.Y).

$$P = m/V \tag{2}$$

where: ρ: The Sample Apparent Density (Kg/m^3), m: The Sample Mass (Kg), and V: The Volume after Sample Immersion, Subtracted by the Volume Prior to Immersion (m^3).

3.2 Mechanical Tests (Tensile Test)

The tensile mechanical characterizations were assessed by comparing the first category (E.SDPF.1, E.SDPF.2, and E.SDPF.3) and the second category (E.LDPF.1, E.LDPF.2, and E.LDPF.3) of bio-composite materials with virgin epoxy. Samples of bio-composite materials (E.SDPF.X and E.LDPF.Y) were reinforced with Short Date Palm Fibers (SDPF) and Semi Long Date Palm Fibers (LDPF), respectively. The samples formed a dumbbell shape (type I), as shown in Figure 4.

The tensile test for the samples was conducted in accordance with ASTM D638-14 standard [19]. The experiments were conducted utilizing an Instron 5969 apparatus, a computer-controlled device integrated with Bluehill3 software [20]. The cells had a maximum force capacity of 5 kN, and the test strain was set to 2 mm/min. The results were averaged and reported with standard deviation for every five samples of each virgin epoxy and bio-composite material (E.SDPF.X and E.LDPF.Y) for each tensile mechanical property. The tensile mechanical characterizations, including modulus of elasticity, deformation, and maximum stress for each sample, were calculated using Equations (3, 4, and 5), respectively.

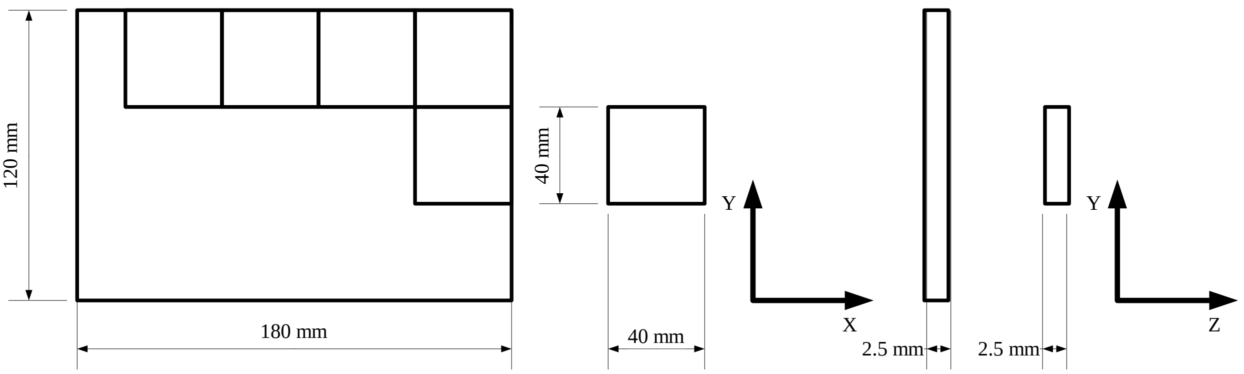

Fig. 3. Sample Dimensions for Apparent Density.

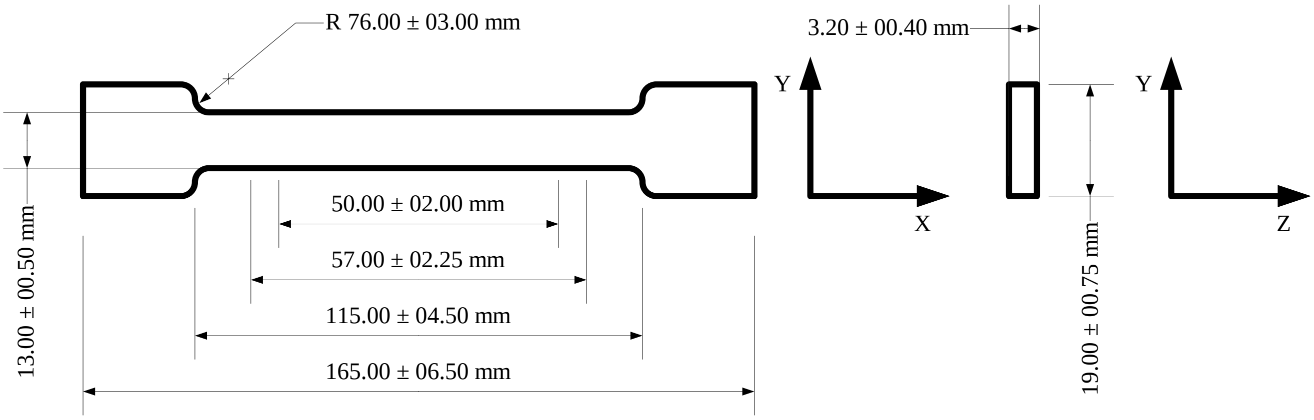

Fig. 4. Sample Dimensions for Tensile Characterizations.

Table 1. Apparent Density Measurement Results for Bio-Composite Materials Reinforced with Short Date Palm Fibers (SDPF) and Semi Long Date Palm Fibers (LDPF).

Symbol				**Apparent Density** ρ
Unit				**(Kg/m3)**
	Virgin Epoxy			1035.773 ± 21.151
Short Date Palm Fibers (SDPF)	**Bio-Composite Materials**	**E.SDPF.X**	**E.SDPF.1**	866.372 ± 22.712
			E.SDPF.2	845.840 ± 18.121
			E.SDPF.3	800.544 ± 20.245
Semi Long Date Palm Fibers (LDPF)		**E.LDPF.Y**	**E.LDPF.1**	740.213 ± 23.241
			E.LDPF.2	700.245 ± 31.321
			E.LDPF.3	620.819 ± 42.081

$$E = \frac{\Delta\sigma}{\Delta\varepsilon} \quad (3)$$

$$\varepsilon = \delta / L \quad (4)$$

$$\sigma_{max} = \frac{P}{A} \quad (5)$$

where, E: The Modulus of Elasticity of the Sample (MPa), $\Delta\sigma$: The Disparity in Applied Stress between the Two Deformation Points of the Sample (GPa), $\Delta\varepsilon$: The Difference between the Two Deformation Points of the Sample (mm/mm), ε: The Deformation of the Sample (mm/mm), δ: The Maximum Extensometer Displacement of the Sample (mm), L: The Extensometer Gauge Length of the Sample (mm), σ_{max}: The Maximum Stress of the Sample (MPa), P: The Maximum Load Applied to the Sample (N), and A: The Average Cross-Sectional Area of the Sample (mm^2).

3.3 Morphological Tests (Scanning Electron Microscopy (SEM))

The morphology of bio-composites (E.SDPF.X and E.LDPF.Y) reinforced with Short Date Palm Fibers and Semi Long Date Palm Fibers-at a constant fiber mass ratio of 15% by mass was examined post-tensile testing using a TESCAN VEGA3 Scanning Electron Microscope (SEM) [21]. Observations were performed on fracture surfaces to assess fiber-matrix interfacial adhesion and the quality of contact between the reinforcing fibers and the virgin epoxy matrix.

Before the SEM investigation, the sample surfaces were stabilized and silver-coated to improve electrical conductivity. The analyses were conducted at an accelerating voltage of 10 kV. The fracture surfaces of the bio-composite materials were analyzed at magnifications ranging from 200× to 498×.

4 Results and Discussion

The findings from the physical, mechanical, and morphological tests of the bio-composite materials (E.SDPF.X and E.LDPF.Y) reinforced with (SDPF) and (LDPF), respectively, were analyzed in relation to virgin epoxy as follows:

4.1 Physical Characterization

Table 1 shows the results of the apparent density measurements for bio-composite materials (E.SDPF.X and E.LDPF.Y) reinforced with (SDPF) and (LDPF) respectively, at a fixed mass ratios 15%.

Table 1 shows that the apparent density values of the bio-composite materials (E.SDPF.X and E.LDPF.Y) generally diminish with the incorporation of (DPFs) into the epoxy matrix. The reduction becomes more evident as the fiber length grows, although the consistent mass ratio of the fibers in all created bio-composite materials (E.SDPF.X and E.LDPF.Y). This suggests that fiber length affects both the internal distribution within the matrix and, perhaps, the bio-composite's microstructure. Moreover, the findings indicate that the standard deviations for bio-composite materials (E.SDPF.X) reinforced with (SDPF) are comparatively small compared to those reinforced with (LDPF). This is due to the morphological characterizations of (DPFs), which have an uneven structure and may contain internal or interstitial cavities. As the fiber length increases, the ratio of voids also escalates, challenging the uniform dispersion of fibers within the matrix. This consequently results in a decrease in apparent density and a decrease in the variability of the observed values.

Ultimately, it can be inferred that fiber length significantly influences the apparent density of bio-composite materials, even at a constant fiber mass ratio.

Figure 5 shows the apparent density results for bio-composites reinforced with both (SDPF) and (LDPF), compared with virgin epoxy. The results are displayed as a vertical bar, with labels indicating the percentage increase or decrease in the bio-composite materials' values relative to virgin epoxy.

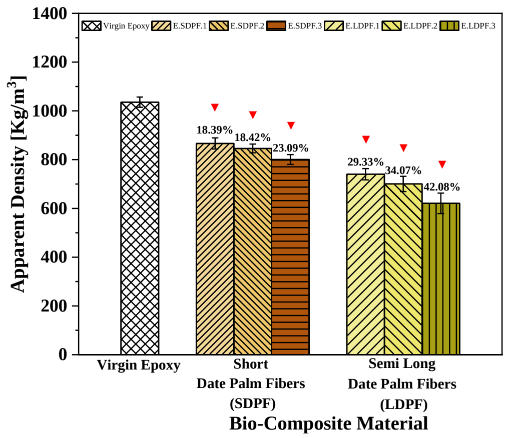

Fig. 5. Impact of Date Palm Fiber Length on the Apparent Density Characteristics of Epoxy Matrix-Based Bio-Composite Materials.

Figure 5 shows a clear and substantial reduction in the apparent density of the bio-composites (E.SDPF.X and E.LDPF.Y) upon the incorporation of (DPFs) as compared to virgin epoxy. The drop in apparent density showed significant variability, with the overall decrease ranging from 29.33% to 42.08% for samples containing (LDPF) with lengths of 10-20 mm in the bio-composite materials E.LDPF.1, E.LDPF.2, and E.LDPF.3. The bio-composite materials E.SDPF.1, E.SDPF.2, and E.SDPF.3 reinforced with (SDPF) demonstrated a significantly apparent density drop, not surpassing 23.09%, and it was in bio-composite material E.SDPF.3. As the fiber length increases, the apparent density decreases, but the apparent density of bio-composite materials (E.SDPF.X and E.LDPF.Y) is much lower in Semi Long Date Palm Fibers than Short Date Palm Fibers. This significant disparity clearly underscores the critical role of fiber length in determining the bio-composite material's overall weight. It specifically shows that using longer Date Palm Fibers results in a greater decrease in the bio-composite's perceived apparent density. The data further support the notion that fiber length is a crucial determinant of lightweight bio-composite materials, with longer fibers being especially beneficial for improving these advantageous characteristics.

Ultimately, it can be inferred that integrating Semi Long Date Palm Fibers into bio-composite materials is essential for reducing the material's weight, thereby validating the significant influence of fiber length on the bio-composite's overall physical characterizations.

4.2 Mechanical Characterization

Table 2 shows the results of the tensile measurements for bio-composite materials (E.SDPF.X and E.LDPF.Y) reinforced with Short Date Palm Fibers and Semi Long Date Palm Fibers, respectively, at a fixed mass ratio of 15%.

Table 2 shows the findings from the tensile tests on the manufactured bio-composite materials (E.SDPF.X and E.LDPF.Y), clearly indicating that their tensile mechanical characteristics increase gradually with increasing fiber length. The modulus of elasticity and maximum stress showed significant concurrent increases with increasing fiber length, underscoring the critical role of fiber length in the material's mechanical characterizations.

Table 2. Tensile Measurement Results for Bio-Composite Materials Reinforced with Short Date Palm Fibers (SDPF) and Semi Long Date Palm Fibers (LDPF).

Symbol				Modulus of Elasticity E	Deformation ε	Maximum Stress σ_{max}
Unit				**(MPa)**	**(mm/mm)**	**(MPa)**
	Virgin Epoxy			970.917 ± 11.846	0.136 ± 0.008	19.669 ± 0.443
Short Date Palm Fibers (SDPF)	**Bio-Composite Materials**	**E.SDPF.X**	**E.SDPF.1**	982.355 ± 16.401	0.046 ± 0.013	19.671 ± 0.446
			E.SDPF.2	1054.533 ± 22.720	0.034 ± 0.001	20.853 ± 1.497
			E.SDPF.3	1130.363 ± 35.992	0.014 ± 0.002	28.361 ± 2.241
Semi Long Date Palm Fibers (LDPF)		**E.LDPF.Y**	**E.LDPF.1**	1410.353 ± 75.513	0.017 ± 0.001	29.421 ± 1.556
			E.LDPF.2	1463.411 ± 99.522	0.015 ± 0.004	33.227 ± 1.804
			E.LDPF.3	1547.708 ± 75.302	0.022 ± 0.002	32.389 ± 1.937

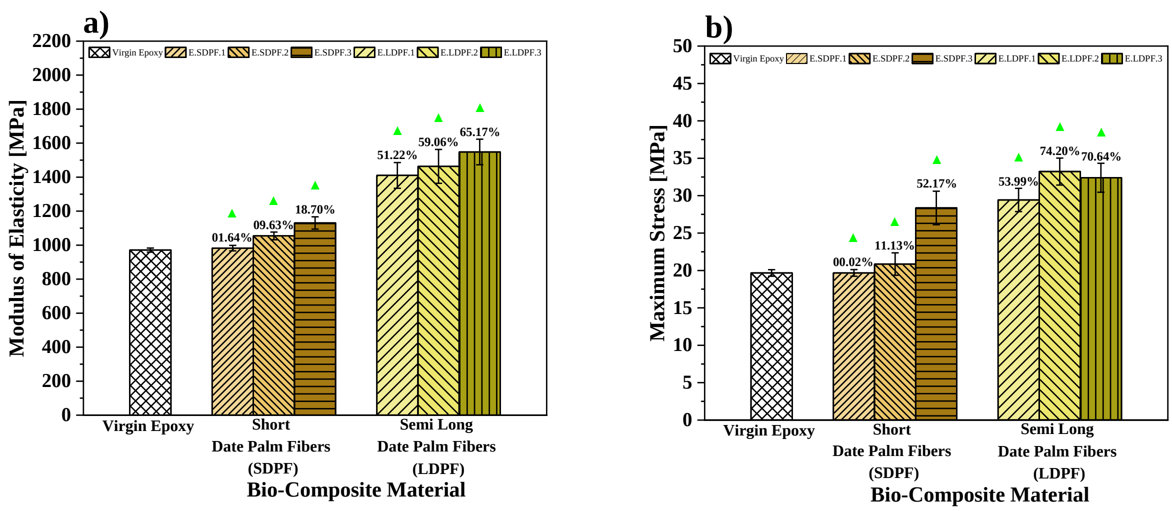

Fig. 6. Impact of Date Palm Fiber Length on the Tensile Mechanical Characterization of Epoxy Matrix-Based Bio-Composite Materials: a) Modulus of Elasticity, and b) Maximum Stress.

Furthermore, it was noted that the standard deviations in the second category (Bio-Composite Materials (E.LDPF.Y)) samples, which were augmented with Semi Long Date Palm Fibers, were greater than those of the first category (Bio-Composite Materials (E.SDPF.X)) samples utilizing Short Date Palm Fibers. This results from the more regular dispersion of short fibers inside the epoxy matrix, leading to a more consistent bio-composite structure. The use of semi-long fibers may have led to greater challenges in achieving uniform distribution, thereby explaining the increased variability in the experimental values.

Ultimately, despite this difference, the progressive increase in both the modulus of elasticity and the maximum stress with increasing fiber length indicates effective interfacial bonding between the epoxy matrix and the palm fibers. This bonding enables effective stress transfer and distribution throughout the bio-composite structure, hence improving the overall mechanical performance of the developed bio-composites.

Figures 6(a) and (b) shows the tensile results, including modulus of elasticity and maximum stress, for bio-composites reinforced with both Short Date Palm Fibers and Semi Long Date Palm Fibers, compared with virgin epoxy. The results are displayed as a vertical bar, with labels indicating the percentage increase or decrease in the bio-composite materials' values relative to virgin epoxy.

Figures 6(a) and (b) shows the findings indicate that the modulus of elasticity and maximum stress of bio-composite materials (E.SDPF.X and E.LDPF.Y) are markedly improved with the incorporation of Date Palm Fibers, with enhancements becoming more significant as fiber length increases. Bio-composite materials (E.SDPF.X) reinforced with Short Date Palm Fibers exhibit relatively modest enhancements, with a 18.70% rise in modulus of elasticity and a 52.17% increase in maximum stress in bio-composite material (E.SDPF.3). The slight enhancement observed with Short Date Palm Fibers is due to their reduced length, which creates weak areas in the bio-composite, thereby diminishing its tensile-stress capacity. The shorter fibers may result in a less uniform distribution inside the matrix, thereby undermining the material's mechanical stress.

Conversely, bio-composite materials (E.LDPF.Y) reinforced with Semi Long Date Palm Fibers exhibit significant improvements, achieving a 65.17% increase in modulus of elasticity and a 74.20% increase in maximum stress in bio-composite material (E.LDPF.3) and (E.LDPF.2), respectively. This significant improvement is due to the robust interfacial bonding between the epoxy matrix and the elongated fibers, which enables effective load transmission and distribution, thereby enhancing the material's mechanical characterizations. The notable enhancement in Semi Long Date Palm Fibers bio-composite materials (E.SDPF.Y) can be ascribed to the superior cohesion between the fibers and the matrix, particularly due to the infiltration of the epoxy resin into the fibers' hollow structure. This leads to a more consistent and resilient fiber-matrix interaction, augmenting the bio-composite material's capacity to withstand stress and strengthening its overall structural integrity.

Ultimately, the findings underscore the essential roles of fiber length and fiber-matrix bonding quality in enhancing the mechanical characterizations of bio-composite materials.

4.3 Morphological Characterization

Figures 7(a-d) shows the outcomes of a Scanning Electron Microscopy (SEM) study of the fracture surfaces of the bio-composite materials (E.SDPF.X and E.LDPF.Y), subsequent to tensile testing.

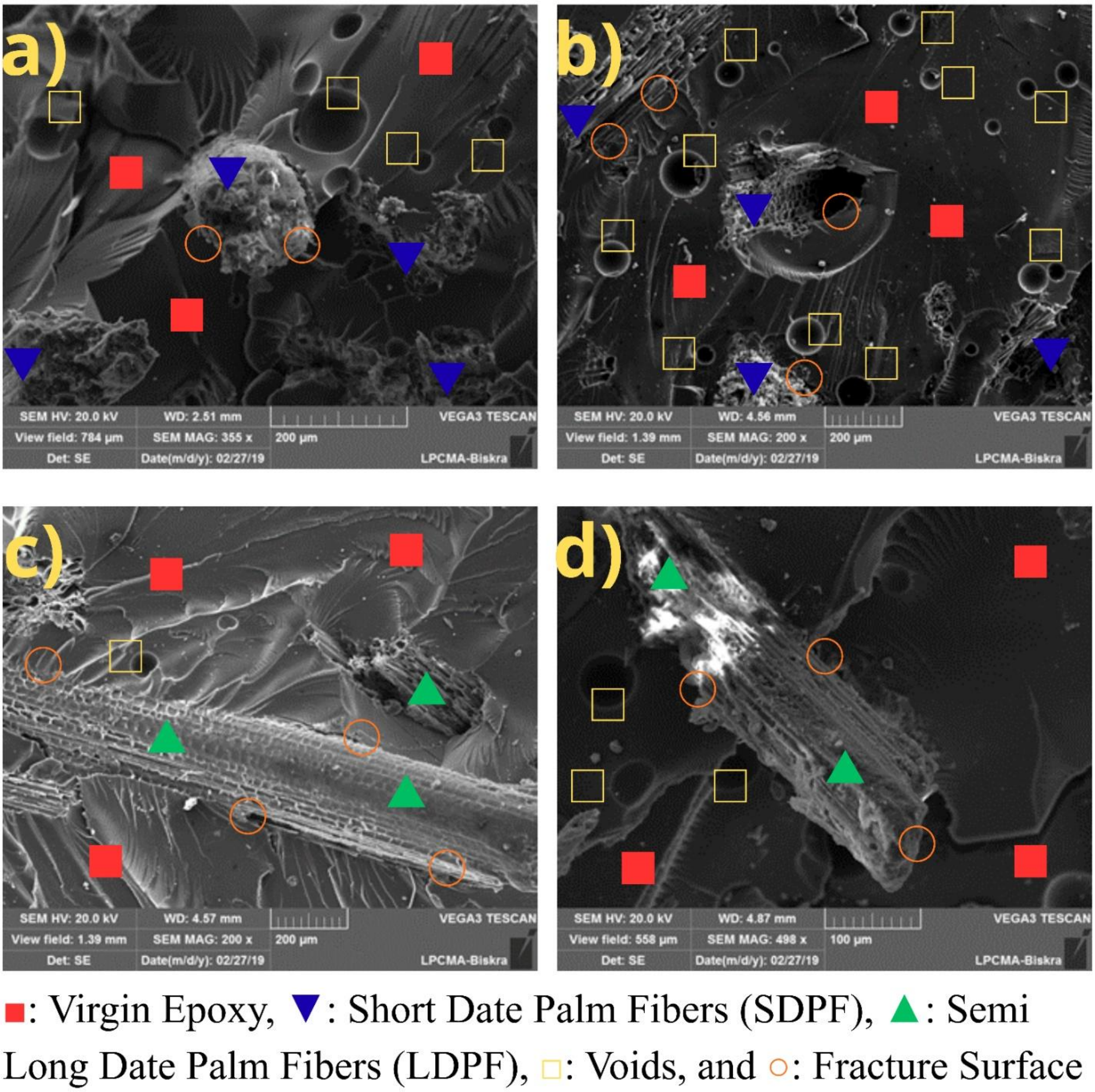

Fig. 7. Scanning Electron Microscopy (SEM) Morphology of the Fracture Surface of the Bio-Composite Materials (E.SDPF.X and E.LDPF.Y) after Tensile Loading: a, and b) Short Date Palm Fibers (SDPF), and c, and d) Semi Long Date Palm Fibers (LDPF).

Figures 7(a-d) show the first category, augmented with Short Date Palm Fibers and the second category, enhanced with Semi Long Date Palm Fibers, demonstrating notable disparities. Significantly, the absence of voids surrounding the fibers on the fracture surface suggests that the fibers remain anchored within the (LDPF) bio-composite materials, which can endure the applied pressures owing to the synergistic influence of various forces (Normal and Shear). This phenomenon is ascribed to the polar characteristics of the epoxy resin, which enhance its uptake by the cellulose-lignin fibers, thereby fostering physical and/or chemical interactions at the interface between the fibers and the matrix, as shown in Figure 7a. Conversely, the (SDPF) demonstrate considerable slippage, and numerous voids persist on the bio-composite surface post-fracture, as shown in Figure 7(a) and (b). The quantity of voids in the Short Date Palm Fibers bio-composite (First Category) is significantly greater than in the Semi Long Date Palm Fibers bio-composite (Second Category), where voids are nearly absent.

Ultimately, this suggests a more uniform and cohesive connection between the Semi Long Date Palm Fibers and the epoxy matrix, in contrast to the Short Date Palm Fibers, which accounts for the enhanced mechanical capabilities previously noted.

The comparison of the current findings with previously published studies on (DPF)-reinforced epoxy bio-composite materials, specifically those with a fiber mass ratio of 15%, suggests that the results obtained in this study align with the values reported in the literature. This agreement enhances the credibility of the experimental findings and substantiates the legitimacy of the chosen scientific framework. A study reported elastic modulus values of 1.205-1.216 GPa for bio-composite materials reinforced with fibers measuring 0.315 and 0.8 mm in length, respectively [22]. Likewise, a study reported an elastic modulus of 1.894 GPa for bio-composite materials with fiber lengths of 0.315 mm [23]. Conversely, a study reported elastic modulus values of 1.18 GPa for long fibers and 2.24 GPa for short fibers, which deviates from the pattern identified in the current study [24]. The minor disparities may be attributed to variations in fiber parameters, such as type, length, and content, as well as differences in composite construction methods and mechanical testing conditions.

Ultimately, the current study provides an extensive experimental dataset, facilitating a more thorough understanding of the mechanical characterization of (DPF)-reinforced bio-composite materials in relation to fiber length and aiding in the identification of prospective future applications for these materials.

5 Conclusion

This study examined the influence of fiber length on the physical, mechanical, and morphological characteristics of palm fiber-reinforced epoxy bio-composite materials. The study assessed the influence of Short Date Palm Fibers (SDPF) (First Category) and Semi Long Date Palm Fibers (LDPF) (Second Category) on apparent density, modulus of elasticity, maximum stress, and Scanning Electron Microscopy (SEM) by physical, mechanical, and morphological tests, respectively.

The results indicated a distinct and progressive improvement in both physical and mechanical qualities with increasing fiber length. Bio-composite materials reinforced with Semi Long Date Palm Fibers (LDPF) exhibited considerable enhancements in apparent density, modulus of elasticity, and maximum stress relative to those reinforced with Short Date Palm Fibers (SDPF). The exceptional performance of Semi Long Date Palm Fibers (LDPF) underscores their ability to enhance the cohesion and uniformity of the epoxy matrix, thereby strengthening the bio-composite's overall integrity. The investigation by scanning electron microscopy (SEM) corroborated these findings, demonstrating enhanced fiber-matrix adhesion and structural consistency.

This study's results validate the efficacy of Semi Long Date Palm Fibers (LDPF) in improving the physical and mechanical characterization of epoxy matrices, rendering them a significant choice for bio-composite applications. These fibers exhibited enhanced performance compared to Short Date Palm Fibers (SDPF), thereby augmenting the matrix's cohesion and uniformity. Moreover, subsequent research could explore the impact of integrating Short Date Palm Fibers (SDPF) and Semi Long Date Palm Fibers (LDPF) in hybrid bio-composite materials, potentially providing an optimal approach to enhance both physical and mechanical characterization, hence ensuring improved performance and consistency. Moreover, investigating the effects of fiber surface treatments and matrix modifications may further improve the efficacy and expand the applications of Date Palm Fiber (DPF)-reinforced bio-composite materials across diverse industrial sectors.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

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Abbreviations

DPF	Date Palm Fiber
DPFs	Date Palm Fibers
DPW	Date Palm Waste
E.LDPF.1	Bio-Composite Material Utilizing an Epoxy Matrix Reinforced with Long Date Palm Fibers Measuring 10 mm in Length.
E.LDPF.2	Bio-Composite Material Utilizing an Epoxy Matrix Reinforced with Long Date Palm Fibers Measuring 15 mm in Length.
E.LDPF.3	Bio-Composite Material Utilizing an Epoxy Matrix Reinforced with Long Date Palm Fibers Measuring 20 mm in Length.
E.LDPF.Y	Bio-composite Materials Reinforced with Long Date Palm Fibers
E.SDPF.1	Bio-Composite Material Utilizing an Epoxy Matrix Reinforced with Short Date Palm Fibers Measuring 0.315 mm in Length.
E.SDPF.2	Bio-Composite Material Utilizing an Epoxy Matrix Reinforced with Short Date Palm Fibers Measuring 0.500 mm in Length.
E.SDPF.3	Bio-Composite Material Utilizing an Epoxy Matrix Reinforced with Short Date Palm Fibers Measuring 0.800 mm in Length.
E.SDPF.X	Bio-composite Materials Reinforced with Short Date Palm Fibers
LDPF	Long Date Palm Fibers
SDPF	Short Date Palm Fibers
SEM	Scanning Electron Microscopy