

Research Article

Quantitative fiber analysis of leaves and stems of three local Algerian plant species

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Abstract

The escalating need for environmentally sustainable materials has catalyzed extensive research into natural fibers as viable substitutes for synthetic counterparts across various industrial sectors. This investigation focuses on the biometric evaluation of stem and leaf fibers from three native Algerian plant species: *Eucalyptus globulus*, *Argania spinosa* L., and *Ricinus communis* L., with the aim of assessing their structural properties and potential for sustainable exploitation in eco-friendly applications. The fiber extraction was conducted using an equal-volume mixture of acetic acid and hydrogen peroxide at 60°C for a duration of 72 hours. Fiber lengths from both stem and leaf samples of all species were measured precisely using a micrometer, with values ranging from 0.21 to 2 mm. To assess the morphological differences between species and tissue types, Student's t-test was employed to compare the mean fiber lengths. The results indicated that the calculated t-values exceeded the critical t-value, demonstrating statistically significant differences in fiber length between tissues within each species. Stem-derived fibers from *A. spinosa* and *E. globulus* were identified as long fibers, with lengths ranging from 0.79 to 2.00 mm. In contrast, leaf fibers from *E. globulus* and *R. communis* were categorized as medium-length fibers, measuring between 0.65 and 1.83 mm. Conversely, the stem fibers of *R. communis* and the leaf fibers of *A. spinosa* were classified as short fibers, with a length range of 0.21 to 0.87 mm. This suggests that stem and leaf fibers possess distinct morphological characteristics (tapered, bifurcated, rounded, and flattened forms), which may influence their mechanical properties and suitability for specific industrial applications. Two-way ANOVA revealed highly significant effects of species and organ on fiber length ($F = 17.315$; $F = 27.730$ respectively), with a dominant species \times organ interaction ($F = 148.587$). This interaction, accounting for the largest explained variance, underscores organ-specific genetic regulation of fiber elongation and cell wall deposition, precluding generalized species-level fiber length characterization. Understanding this variation is essential for optimizing the selection and processing of fibers for papermaking, composites and textile.

Keywords: *Argania spinosa* L., *Eucalyptus globulus*, Morphology, Natural fibers, *Ricinus communis* L.

INTRODUCTION

In response to evolving environmental regulations, sustainability imperatives, and the escalating demand on fossil resources driven by global population growth, optimizing the efficient use of natural resources has become increasingly critical (Mulenga *et al.*, 2025; Khanpit *et al.*, 2025). Cellulosic biomass, predominantly sourced from woody plants, has emerged as a vital renewable resource for bioenergy production that does not compete with food crops (Capron *et al.*, 2013). Natural fibers derived from such biomass are extensively utilized across diverse industrial sectors and serve as valuable raw materials for manufacturing eco-friendly and sustainable “green” products (Kicińska-Jakubowska *et al.*, 2012).

Historical evidence demonstrates that ancient civilizations utilized natural fibers effectively; for instance, the Egyptians incorporated straw to reinforce clay bricks, enhancing their mechanical stability (Marvila *et al.*, 2021). From the point of view of sustainable development, natural fibers, unlike synthetic polymers and plastics, are widely utilized due to their unique properties, including availability, low density, cost-effectiveness, moderate strength, biodegradability, and low processing requirements (Vinod *et al.*, 2021; Plakantonaki *et al.*, 2023; Ez-Zahraoui *et al.*, 2023). Their applications extend beyond textiles to pulp and paper production, cosmetics, composites, food products, insulation materials, and renewable energy sectors (Kicińska-Jakubowska *et al.*, 2012; Mohankumar *et al.*, 2021; Biskri *et al.*, 2025), with some fibers also exhibiting antibacterial activity attributed to bioactive compounds such as phenolics, flavonoids, tannins, and lignin (Zamora-Mendoza *et al.*, 2022; Raja *et al.*, 2025).

The Institute of Natural Fibers and Medicinal Plants (INF&MP), based in Poland, oversees global banks dedicated to the collection, testing, and characterization of various natural fibers, including bast, leaf, seed, fruit, plant, and animal fibers, with the aim of creating a comprehensive worldwide fiber repository (Spychalski *et al.*, 2015; Kozłowski *et al.*, 2020).

The objective of this study is to characterize the biometric properties of fibers isolated from the stems and leaves of three Algerian plant species: *Eucalyptus globulus*, *Argania spinosa* L., and *Ricinus communis* L. As not all plant kingdom residues are suitable as feedstock materials in bioenergy or biorefinery fields (Tsalagkas *et al.*, 2021), this work aimed to identify viable candidates based on their fiber characteristics. This study will serve as a foundation for further research aimed at exploring their potential applications in various industrial fields. Future studies will build upon these findings to evaluate the mechanical, chemical, and functional properties of these fibers, thereby advancing

their utilization in sustainable materials and bio-based product development.

MATERIALS AND METHODS

Study area and methodology

In the present study, leaf and stem samples from three species: *E. globulus*, *A. spinosa*, and *R. communis*, were collected in May 2025 from the University of Science and Technology of Oran (USTO) campus (35°44' N; 0°33'O).

Fragments of 1 cm from the branches and leaves of each species were immersed in tubes containing an equal-volume mixture of acetic acid and hydrogen peroxide. The samples were incubated at 60°C for 72 hours. The acetic acid serves to dissolve the pectic substances present in the middle lamella. Subsequently, a cell suspension was obtained using a Pasteur pipette, deposited between a slide and coverslip, and examined under a light microscope. Thirty (30) fibers from each organ (stem and leaf) of multiple individual plants per species (*E. globulus*, *A. spinosa*, and *R. communis*) were measured using an ocular micrometer for statistical analysis (Kaid-Harche and Djabeur, 2020).

Statistical analyses

Statistical analyses were performed using SPSS software version 27 (IBM Corp., Armonk, NY, USA). This study compares the average fiber lengths between stem and leaf tissues within each species (*E. globulus*, *A. spinosa*, and *R. communis*) using a t-test to assess intra-species variability, and whether fiber length varies significantly according to plant species and plant tissues using a two-way analysis of variance (ANOVA). Both tests were conducted at a 95% confidence level ($p \leq 0.05$) and data normality and homogeneity of variances were verified. These statistical analyses provide a robust framework to determine significant morphological differences both within and between species and tissue types.

Morphological study

For microscopic observation, the fibers were first stained with safranin, a histological dye that selectively binds to lignified tissues, imparting a distinct red coloration to these cell wall components. This staining enhances the contrast and allows for clearer differentiation of fiber structural features. Morphological analyses were performed using an Optika M 261 light microscope (Ponteranica BG, Italy) equipped with an Everfocus EQ350 digital camera. Images were captured at various magnifications to examine fiber surface characteristics, cell wall thickness, and overall fiber morphology.

RESULTS AND DISCUSSION

Fiber extraction methods and environmental influences

The extraction technique (chemical, mechanical, or biological) significantly affects the quality and performance of the resulting fibers. The method employed in this study effectively targets non-cellulosic components such as lignin, pectin, and waxes, which constitute the primary matrix surrounding cellulose and hemicelluloses in natural fibers. This mild chemical approach aligns with established protocols for fibers such as Alfa, flax, hemp, jute, and kenaf, preserving fiber integrity and morphology while minimizing shortening compared to harsher alkali treatments. In contrast, mechanical decortication suits bast fibers but may retain matrix residues that affect measured lengths, whereas biological enzymatic treatments provide eco-friendly alternatives for fibers (Sisal, Banana) despite variable yields (Belouadah *et al.*, 2015).

While Algeria encompasses diverse agroecological zones from Mediterranean coastal areas and semi-arid High Plateaus, to hyper-arid Saharan regions, this

study provides baseline morphological characterization from a controlled campus location in northwestern Algeria, which features a Mediterranean climate with mild, wet winters and hot, dry summers. Plant fiber characteristics are significantly influenced by environmental factors including soil composition, climate, irrigation, fertilization, and cultivation practices, as demonstrated by Hsieh *et al.* (2000) and Hussain *et al.* (2022) who found that cotton fiber quality varies substantially between genotypes and regions.

Data analysis

The average fiber lengths (mm) determined from stem and leaf samples of the investigated species: *E. globulus*, *A. spinosa*, and *R. communis* are tabulated in Table 1.

The biometric analysis of fiber lengths in stems and leaves of the three studied species (*E. globulus*, *A. spinosa*, and *R. communis*) revealed significant differences between tissues within each species. As shown in Table 2, the mean fiber length in *E. globulus* stems ($1.21 \text{ mm} \pm 0.23$) was significantly greater than in leaves ($0.96 \text{ mm} \pm 0.17$) ($t = 4.96$, $df = 29$, $p < 0.001$).

Table 1. Length (mm) of the 30 fibers of each species.

Fibre No	<i>Eucalyptus globulus</i> stem	<i>Eucalyptus globulus</i> leaf	<i>Argania spinosa</i> stem	<i>Argania spinosa</i> leaf	<i>Ricinus communis</i> stem	<i>Ricinus communis</i> leaf
1	1.45	0.95	1.3	0.51	0.52	0.8
2	1.1	1.2	1.7	0.48	0.48	0.82
3	1.35	0.84	0.98	0.3	0.68	0.95
4	1.05	0.95	1.45	0.45	0.515	0.67
5	0.95	0.75	1.56	0.47	0.7	0.78
6	1.03	0.7	1.2	0.76	0.61	1.07
7	1.03	1.28	1.25	0.52	0.53	0.98
8	1.3	1.05	1.65	0.3	0.56	1.4
9	1.1	0.73	1.1	0.38	0.58	1.05
10	0.96	1.25	0.95	0.52	0.56	1.24
11	1.5	1.3	0.89	0.41	0.45	1.65
12	1.25	0.95	1.35	0.65	0.51	1.5
13	1.45	0.98	0.9	0.43	0.71	1.72
14	1.25	1	1.5	0.32	0.68	1.05
15	1.1	1.1	1.01	0.31	0.87	1.08
16	1.2	0.65	1.37	0.45	0.5	0.86
17	1.85	0.93	1.84	0.22	0.59	0.87
18	1.15	0.89	1.75	0.46	0.56	0.91
19	1.8	1.15	1.25	0.34	0.43	1.04
20	0.95	1.05	2	0.23	0.53	1.645
21	1.2	0.97	1.36	0.65	0.53	1.74
22	1.3	1.04	1.42	0.56	0.51	0.83
23	1.12	0.99	1.37	0.41	0.555	1.83
24	1.01	1.02	0.97	0.26	0.56	1.35
25	1.02	0.87	1.58	0.36	0.76	0.98
26	1.4	0.78	1.03	0.28	0.565	1.02
27	1	1.05	1.24	0.21	0.49	1.57
28	1.1	0.9	1.11	0.42	0.54	0.93
29	1.17	0.65	0.79	0.39	0.65	1.93
30	1.21	0.94	1.49	0.29	0.6	0.75

Table 2. Results of the means, standard deviation of the fibers of species studied, variances and the t-values calculated for each pair

	Plant species	M	SD	V	T	DF	P
Pair 1	<i>Eucalyptus globulus</i> stem	1.2117	0.228	0.0416	4.963	29	0.000**
	<i>Eucalyptus globulus</i> leaf	0.9637	0.174	0.0317			
Pair 2	<i>Argania spinosa</i> stem	1.312	0.306	0.0558	14.29	29	0.000**
	<i>Argania spinosa</i> leaf	0.4113	0.134	0.0245			
Pair 3	<i>Ricinus communis</i> stem	0.5775	0.096	0.0175	8.4	29	0.000**
	<i>Ricinus communis</i> leaf	1.1672	0.368	0.0672			

** = Highly significant, where M = Means, SD = Standard deviation, V = Variance, T = t-value, DF = Degree of freedom, P = p-value

Similarly, *A. spinosa* stems exhibited longer fibers (1.31 mm \pm 0.31) compared to leaves (0.41 mm \pm 0.13), with a highly significant difference (t = 14.29, df = 29, p < 0.001). Conversely, in *R. communis*, leaf fibers (1.17 mm \pm 0.37) were significantly longer than stem fibers (0.58 mm \pm 0.10) (t = 8.40, df = 29, p < 0.001).

Fiber dimensions are key factors in assessing the quality and potential applications of plant fibers in pulping and other industries (Han *et al.*, 1999). The fiber length of *R. communis* stems ranged from 0.43 to 0.87 mm, while that of *A. spinosa* leaves varied between 0.21 and 0.76 mm. These measurements are consistent with lengths reported for agricultural residues such as rice straw (*Oryza sativa* L.) and *Brassica napus* L., which typically exceed 0.54 mm (Tsalagkas *et al.*, 2021), and are comparable to acacia pulps averaging 0.78 mm in length (de Assis *et al.*, 2019). Based on the classification by Marín *et al.* (2009), fibers measuring between 0.2 and 1.2 mm fall into the category of short fibers, indicating that the fibers from *R. communis* stems and *A. spinosa* leaves should be considered as short fibers. Literature reports indicate an average fiber length of 0.38 mm for *Stipa tenacissima* (Alfa), classifying these as short fibers utilized in paper manufacturing, orthopedic prosthesis production, and recent textile applications (Dellal, 2012). Additionally, these fibers serve as reinforcement elements in polymer matrix biocomposites (Sood and Dwivedi, 2018).

Additionally, the length of leaf fibers from *E. globulus* ranged from 0.65 to 1.3 mm, and those from *R. communis* leaves varied between 0.67 and 1.83 mm, placing them within the medium fiber category (Bokhari

et al., 2022), comparable to the fibers of *Helianthus annuus* L. (1.27 mm) and maize stalks (1.32 mm) (Tsalagkas *et al.*, 2021).

Lawsonia inermis (henna) fibers, classified as medium-length fibers, serve as suitable reinforcement materials for environmentally responsible composite manufacturing, with applications in biodegradable packaging, automotive interiors, building materials, and medical uses (Raja *et al.*, 2025).

Furthermore, stem fibers of *A. spinosa* and *E. globulus* were classified as long fibers, with lengths ranging from 0.79 to 2.0 mm and 0.95 to 1.85 mm, respectively (Marín *et al.*, 2009). These values are similar to those reported for *Oxytenanthera abyssinica* (2.1 mm) and *Phyllostachys edulis* (2.0 mm) (Yu *et al.*, 2023; Zha *et al.*, 2023), though shorter than kenaf (*Hibiscus cannabinus* L.) fibers, which measure approximately 3 mm in length (Han *et al.*, 1999). *Gossypium hirsutum* L. (cotton) and *Retama monosperma*, all classified as long fibers, are widely utilized across multiple industries: textiles for their spinnability and strength, medical products such as bandages and surgical meshes due to their biocompatibility, and biocomposites as sustainable reinforcements in automotive panels, construction materials, and packaging (Aizi *et al.*, 2015; Hussain *et al.*, 2022).

Smole *et al.* (2013) report that the geometrical dimensions of fibers, particularly fiber length, depend primarily on their location within the plant. Fibers derived from fruits and seeds typically measure only a few centimeters, whereas those obtained from stems and leaves can extend to lengths exceeding one meter.

Table 3. ANOVA table for fiber length (mm).

Source	DF	SS	MS	F	P
Species	2.000	1.951	0.976	17.315	0.000**
Organ	1.000	1.562	1.562	27.730	0.000**
S \times O	2.000	16.744	8.372	148.587	0.000**
Error	174.000	9.804	0.056		
Total	180.000	189.297			

** = Highly significant, where Species: *Eucalyptus globulus*, *Argania spinosa*, and *Ricinus communis*, Organ: stem and leaf, DF = Degree of freedom, SS = Some of square, MS = Mean square, F = F-statistic, P = p-value

Different types of dietary fiber possess unique functional and physical characteristics, such as particle size, hydrated volume expansion, water-holding capacity, and sensitivity to temperature, that influence their physiological effects (Parrott and Thrall, 1978). Compared to fibers from other plant species commonly used in industry, these species show a unique combination of structural features that could enhance their suitability for applications in composite materials, textiles, or bio-based products. Further analysis of their chemical composition and microfibril angle would provide insights into their behavior under mechanical stress and their potential for sustainable material development (Li *et al.*, 2014).

Fiber length is undoubtedly a key parameter for composite performance, but practical suitability also depends critically on other properties such as structural strength, stiffness, chemical composition (polysaccharides and lignin content), thermal stability, and moisture absorption behavior (Bourmaud *et al.*, 2013; Gao Xun *et al.*, 2014; Wang *et al.*, 2018). This study provides preliminary morphological evidence of their potential as sustainable materials from North African arid regions; how-

ever, comprehensive evaluation of these additional physicochemical properties through targeted mechanical testing and chemical analyses remains necessary for confirming industrial viability, as Kaid-Harche and Djabeur (2020) noted that architectural diversity is likely a key quality factor for *Stipa tenacissima* paper fibers.

The two-way analysis of variance (ANOVA) was conducted to examine the effects of species (*E. globulus*, *A. spinosa*, and *R. communis*) and organ (stem and leaf), as well as their interaction (species \times organ) on fiber length. Results are summarized in Table 3.

The table presents the sum of squares, degrees of freedom (DF), mean squares, F-values, and significance levels (p -values). Data normality was verified using the Shapiro-Wilk test and homogeneity of variances was confirmed with Levene's test.

The analysis of the two-way ANOVA table shows that the observed F-values for the main effects of species ($F = 17.315$, $p < 0.001$) and organ ($F = 27.730$, $p < 0.001$) significantly exceed the critical F-value (approximately 4.75), confirming that both factors independently contribute to significant variation in fiber morphology. This finding aligns with established literature

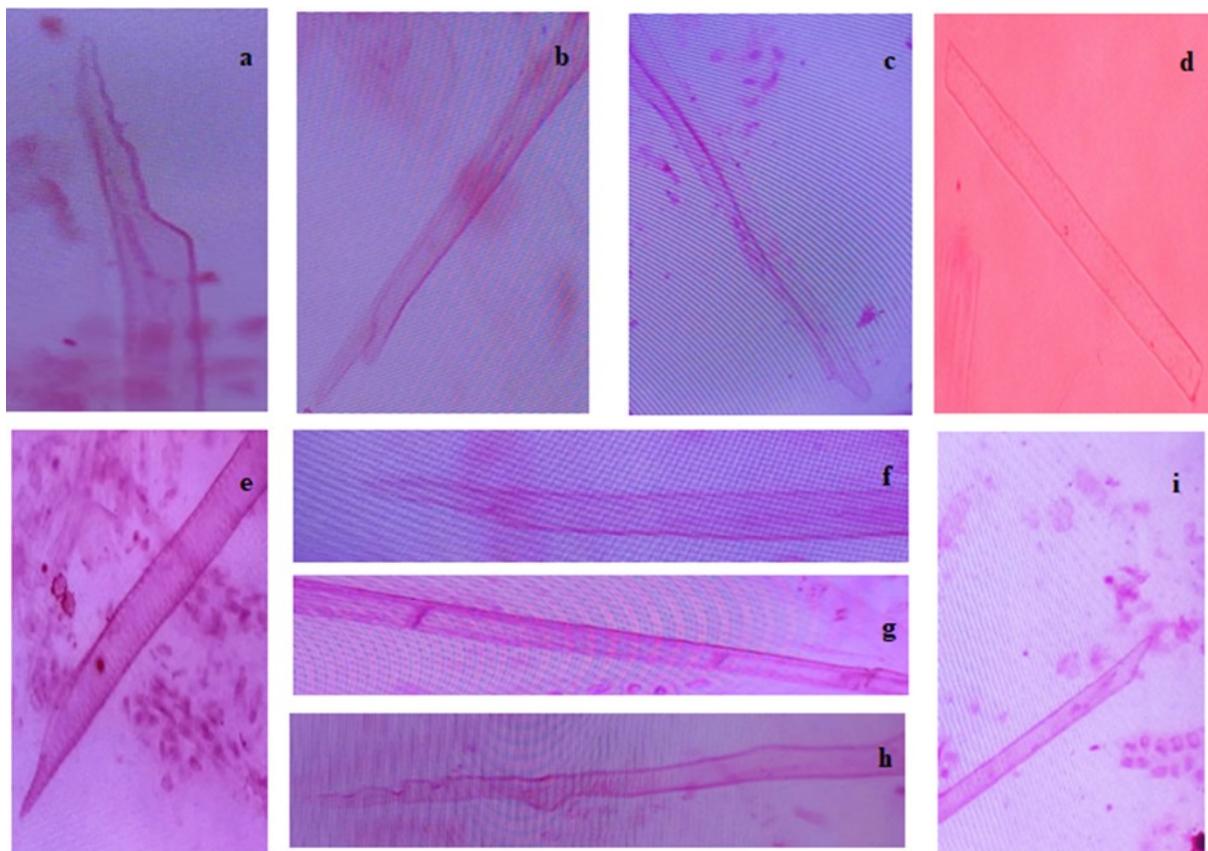


Fig. 1. Photomicrographs of stained fibers showing: (a) fiber with slightly festooned wall at the tip from *Eucalyptus globulus* leaf; (b) fiber portion with bifurcated end from *Eucalyptus globulus* leaf; (c) two fibers with tapered ends from *Eucalyptus globulus* stem; (d) flattened tip fiber from *Argania spinosa* leaf; (e) fiber portion with tapered end from *Argania spinosa* stem (note septa inside the fiber); (f) tapered tip fiber from *Argania spinosa* stem; (g) fiber with slightly rounded end from *R. communis* stem (note septa); (h) festooned fiber from *Ricinus communis* leaf; (i) fibers with slightly tapered ends from *Ricinus communis* leaf (X 2100, Bar on micrographs represents 5µm).

where interspecific genetic divergence is a primary driver of fiber trait diversity (Zobel and Van Buijtenen, 2012), and where fundamental anatomical differences between organs necessitate distinct cellular dimensions to fulfill specialized mechanical and hydraulic functions (Alves and Angyalossy-Alfonso, 2000).

However, the most critical finding is the exceptionally significant species \times organ interaction ($F = 148.587$, $p < 0.001$). The magnitude of this interaction, evidenced by its large sum of squares ($SS = 16.744$) which dominates the model's explained variance, indicates that the effect of species on fiber length is fundamentally dependent on the organ being considered, and vice-versa. This strong genotype-by-tissue interaction suggests that the genetic programs regulating cell elongation and secondary cell wall deposition are differentially expressed or have divergent outcomes in different plant organs. Such complex phenotypic plasticity is a recognized phenomenon in xylogenesis, where trait heritability and expression can vary dramatically between different wood tissues and cell types, leading to significant genotype \times tissue interactions for fiber properties (González-Martínez *et al.*, 2007).

The practical implication is that a species cannot be characterized by a single generalized fiber length. For instance, one species may develop very long fibers in stems but short fibers in leaves, while another may show the opposite pattern or minimal divergence. This has direct consequences for the assessment of plant material for biomaterial or pulp applications, as the optimal source (species) is intrinsically linked to the target organ, a consideration underscored in reviews of wood quality and utilization (Walker, 2006). The low mean square error ($MS\ Error = 0.056$) attests to the precision of the measurements within treatment groups, reinforcing the reliability of the detected interaction effect.

Morphological study

The fibers of the studied species: *E. globulus*, *A. spinosa*, and *R. communis*, exhibited considerable morphological diversity.

They present various shapes, including tapered (Fig. 1: c, e, f, i), bifurcated (Fig. 1b), rounded (Fig. 1g), and flattened forms (Fig. 1d). The fiber cell walls are generally thick and often display scalloped margins (Fig. 1: a, h), accompanied by numerous pit fields (Fig. 1e). Moreover, internal septation within the fibers was observed, indicating a level of structural complexity (Fig. 1g).

The diversity of shapes and forms observed in natural fibers is largely attributable to their adaptation to varying climatic zones, providing valuable inspiration for researchers seeking novel applications across diverse economic sectors (Kicińska-Jakubowska *et al.*, 2012). Sanjay *et al.* (2018) highlight that the mechanical strength of these fibers depends primarily on their

chemical composition and matrix bonding, as well as the environmental and geological conditions of the growth site.

Conclusion

The biometrics analysis of the stem and leaf fibers of three local Algerian plant species: *E. globulus*, *A. spinosa*, and *R. communis*, has been studied. The results demonstrated significant variations in fiber dimensions both between species and between tissue types, highlighting notable morphological diversity. Specifically, fibers from *R. communis* stems and *A. spinosa* leaves were classified as short fibers (0.21 to 0.87 mm), whereas leaf fibers of *E. globulus* and *R. communis* fell into the medium fiber category (0.65 to 1.83 mm). Stem fibers of *A. spinosa* and *E. globulus* were identified as long fibers (0.79 to 2 mm), comparable to those of other well-known species used in industrial applications. These findings demonstrate the immense potential of these Algerian plant fibers as valuable raw materials for various biocomposite and sustainable material applications. These preliminary findings warrant further investigation into their mechanical, chemical, and performance properties to confirm industrial viability. Further research should investigate the mechanical, chemical, thermal, and morphological properties of fibers from *E. globulus*, *A. spinosa*, and *R. communis* using different analytical approaches. Scanning electron microscopy (SEM) evaluates surface morphology and fiber-matrix interfacial interactions for composite reinforcement potential. Fourier transform infrared (FTIR) spectroscopy provides insights into chemical composition and functional groups, while X-ray diffraction (XRD) reveals crystallinity and amorphous content in natural fibers to predict mechanical behavior and matrix compatibility.

Data availability statement: The original contributions presented in this study are included in the article. Further inquiries can be directed to the corresponding author.

Conflict of interest

The authors declare that they have no conflict of interest.

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