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Comparative Study of Chemically Treated Agel Fiber-Reinforced Composites under Flexural Loading

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Abstract

Natural fiber composites are gaining attention as eco-friendly substitutes for synthetic fiber composites due to their renewability, reduced environmental footprint, and potential biodegradability. Nevertheless, the inherent hydrophilicity of natural fibers often leads to weak interfacial bonding with polymer matrices, which can compromise mechanical properties. This study examines the influence of NaOH and citric acid surface treatments on Agel fiber-reinforced composites produced via the hand layup technique, with flexural strength serving as the primary performance indicator. Three composite groups were prepared, untreated Agel fiber, NaOH-treated Agel fiber, and citric acid-treated Agel fiber. The specimens were cut and tested in bending, and the results were analyzed using normality testing, equal variance testing, one-way ANOVA, and Tukey pairwise comparison. The average flexural bending strengths of the untreated, citric acid-treated, and NaOH-treated composites were 36.922 MPa, 37.784 MPa, and 40.611 MPa, respectively. The statistical assumptions for parametric analysis were satisfied, with the data in each group showing normal distribution and equal variance confirmed. One-way ANOVA indicated a significant difference among the three groups ($F = 7.24$, $p = 0.005$). Tukey pairwise comparison showed that the NaOH-treated composite was significantly different from both the untreated composite ($p = 0.005$) and the citric acid-treated composite ($p = 0.031$), while the difference between untreated and citric acid-treated composites was not significant ($p = 0.678$). These results indicate that NaOH treatment is more effective than citric acid treatment in improving the flexural performance of Agel fiber composites under the conditions used in this study. The improvement is attributed to better fiber to matrix interfacial bonding caused by surface modification of the fiber. This study supports the potential of Agel fiber as a sustainable reinforcement material for composite applications.

Keywords: agel fiber, natural fiber composite, NaOH treatment, citric acid treatment, flexural strength

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1. Introduction

Natural fiber composites have attracted increasing interest as environmentally sustainable substitutes for synthetic fiber composites due to their renewability, biodegradability, and relatively low ecological impact. In comparison to glass and carbon fiber composites, they typically demand less energy during manufacturing, contribute to lower greenhouse gas emissions, and present more favorable options for disposal or recycling at the end of their lifecycle. As a result, their adoption is growing across sectors such as automotive, construction, aerospace, marine, and consumer goods, particularly in applications where both lightweight characteristics and environmental considerations are critical [1], [2], [3]. However, despite these advantages, natural fibers still face several limitations, including variability in properties, moisture sensitivity, and lower thermal stability [1], [4], [5]. Therefore, further research is essential to enhance the performance of natural fiber composites while preserving their environmental advantages.

A key challenge in natural fiber composites is the weak interfacial bonding between the fiber surface and the

polymer matrix. Natural fibers are inherently hydrophilic due to their cellulose-based composition, whereas most polymer matrices are hydrophobic. This incompatibility frequently results in poor adhesion, inefficient stress transfer, increased moisture absorption, and diminished mechanical properties. To address this problem, surface treatment techniques are commonly used to modify the fiber surface, remove impurities, increase roughness, and introduce functional groups that improve compatibility with the matrix. Among the most widely studied treatments are alkaline treatment using sodium hydroxide (NaOH) and chemical modification using citric acid (CA) [6], [7], [8], [9], [10].

Agel fiber, which is derived from the Agave plant, is one of the promising natural fibers for composite reinforcement. It has attracted interest because of its availability, low cost, and mechanical potential. Previous studies have shown that Agel fiber can be used in environmentally friendly composite products such as boat structures and hybrid composites. Its performance can be improved further through surface treatment and composite design.

Specifically, alkaline treatment using NaOH has been shown to eliminate surface impurities such as lignin, hemicellulose, and waxes, thereby enhancing surface roughness and promoting better fiber–matrix adhesion. Nevertheless, excessive NaOH concentration or treatment time may damage the fiber structure and reduce mechanical performance, so careful control of treatment conditions is important [11], [12], [13].

Citric acid treatment has gained attention as an eco-friendly and sustainable approach to enhancing the surface properties of lignocellulosic fibers. Through esterification, citric acid reacts with hydroxyl groups on the fiber surface, thereby decreasing hydrophilicity and improving interfacial adhesion with polymer matrices. This treatment may also improve moisture resistance, thermal stability, and load transfer within the composite. For agave-like fibers, citric acid has shown potential to clean the surface, alter chemical functionality, and support stronger bonding with polymer systems [8], [10]. Because of these benefits, citric acid offers an interesting comparison with traditional alkali treatment in the modification of Agel fiber.

In composite manufacturing, the hand layup method remains one of the most accessible and practical fabrication techniques, especially for experimental studies. It allows fibers to be arranged manually with the matrix material, making it suitable for investigating the influence of fiber treatment on composite behavior [14]. In this study, untreated Agel fiber, NaOH-treated Agel fiber, and citric acid-treated Agel fiber are used to fabricate composites through hand layup. The resulting composite specimens are then cut and subjected to bending tests to evaluate their flexural performance. Bending behavior is a critical indicator of composite quality because it reflects the ability of the material to resist deformation and carry loads under service conditions.

This research is important because it compares three fiber conditions within the same composite fabrication process, allowing the effect of surface treatment on flexural performance to be examined more clearly. By comparing untreated fiber with chemically treated fibers, the study can show how NaOH and citric acid influence interfacial bonding, stiffness, and overall bending strength. The results are expected to enhance understanding of how Agel fiber can be optimized for composite applications and to support the development of more sustainable materials for structural and semi-structural purposes.

The main objective of this study is to investigate the effect of NaOH and citric acid treatments on Agel fiber reinforced composites produced by hand layup, with particular focus on bending test performance. The study also aims to compare the mechanical behavior of untreated, NaOH-treated, and citric acid-treated fiber composites in order to determine which treatment provides the most effective improvement. Through this study, the research aims to advance the development of natural fiber composites that are both environmentally sustainable and mechanically reliable.

Overall, this study is positioned within the broader effort to replace conventional synthetic reinforcement with renewable fiber alternatives. By focusing on Agel fiber and comparing two different chemical treatments, the research contributes to the ongoing development of natural fiber composites with improved interfacial properties and better

mechanical performance. The results may serve as a reference for future studies on fiber treatment optimization, composite fabrication, and the use of Agel fiber in practical engineering applications.

2. Material and Method

The materials used in this study consisted of natural fiber reinforcement, chemical treatment agents, and a polymer matrix. Plain-weave agel fiber was used as the reinforcing material and was obtained from local store. The single fibers had a thickness of 0.5 mm and a width of 1.5 mm. Citric acid (CA) was used as an eco-friendly chemical treatment obtained from local chemical store, and applied at 5% weight in distilled water. Sodium hydroxide (NaOH) was used as the alkaline treatment agent, supplied by local chemical store, and used at the same molarity as the citric acid solution. The polymer matrix used in this study was commercially available clear epoxy resin, with a resin-to-hardener weight ratio of 2:1.

The woven agel fibers were cut into 170 mm × 17 mm and immersed in either NaOH or citric acid solution, stirred continuously using magnetic stirrer for 2 hours, then rinsed and oven-dried.

Dried woven agel fiber then placed into silicone mold. The epoxy resin and hardener mixture then added evenly in 8 plies of woven agel fiber to make the composite with 90% weight ratio of resin-hardener mixture. After curing, the composite plates were demolded and cut into 170 mm × 25 mm (length × width). Three-point bending test were conducted on an 80 mm support span in accordance with ASTM D790.

3. Result and Discussion

3.1. Result

The bending test was conducted to evaluate the flexural performance of Agel fiber-reinforced composites with three different conditions, untreated fiber, NaOH-treated fiber, and citric acid-treated fiber. The average flexural strength of the untreated composite was found to be 36.922 MPa, while the citric acid-treated composite showed 37.784 MPa, and the NaOH-treated composite exhibited a value of 40.611 MPa as shown in Figure 1.

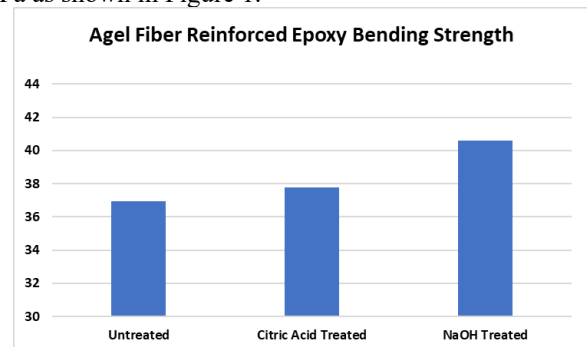


Figure 1. Agel fiber reinforced epoxy bending strength comparison from different treatment

Based on these results, the NaOH-treated composite showed the highest flexural bending strength, followed by the citric acid-treated composite, while the untreated composite exhibited the lowest value. This trend indicates that chemical treatment improved the bending performance of the Agel fiber composites, with NaOH treatment giving

the most pronounced increase under the conditions used in this study.

The improvement in flexural strength after chemical treatment may be explained by better fiber–matrix adhesion. In untreated fiber composites, the presence of surface impurities such as waxes, hemicellulose, and lignin can weaken interfacial bonding and reduce stress transfer during bending. After NaOH treatment, some of these non-cellulosic constituents are partially removed, resulting in a rougher fiber surface and better mechanical interlocking with the matrix [15], [16]. Citric acid treatment may also enhance adhesion through surface modification and possible esterification reactions, although the improvement in bending strength was smaller than that of NaOH-treated specimens in this study [10], [17], [18]. The difference among the three groups suggests that the type of chemical treatment has a measurable effect on the load-carrying capability of the composite during flexural loading.

A one-way analysis of variance (ANOVA) was conducted to assess whether the differences in mean flexural bending strength among the three composite groups were statistically significant. Prior to the ANOVA, the data were evaluated using normality and equal variance tests to confirm that the assumptions for parametric analysis were met.

The normality test showed that the data for each group were normally distributed, with p-values of 0.107, >0.150, and >0.150 for the untreated, citric acid-treated, and NaOH-treated composites, respectively as shown in Figure 2.

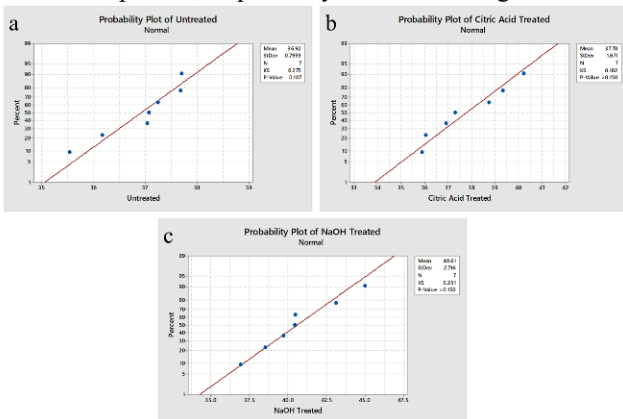


Figure 2. Normality test for a) untreated; b) citric acid treated; c) NaOH treated

Figure 3 showed the equal variance test also indicated that the assumption of homogeneity of variance was satisfied, with a test result of Multiple Comparisons and Lavene’s Test’s p-value of 0.076 and 0.132 respectively.

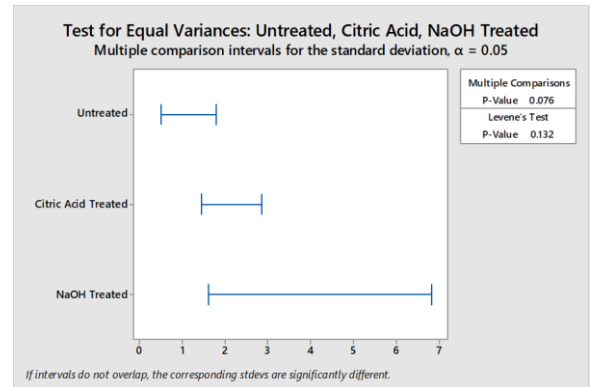


Figure 3. Test for equal variance of untreated, citric acid treated, and NaOH treated sample

Since the assumptions for parametric testing were satisfied, a one-way ANOVA was used to compare the mean flexural strengths of the three groups. The analysis yielded an F-value of 7.24 and a p-value of 0.005, indicating a statistically significant difference in flexural bending strength among the treatment groups as shown in Figure 4.

Analysis of Variance					
Source	DF	Adj SS	Adj MS	F-Value	P-Value
Factor	2	52.15	26.073	7.24	0.005
Error	18	64.81	3.601		
Total	20	116.96			

Figure 4. Analysis of variance result

This means that the chemical treatment condition had a statistically significant effect on the bending strength of the Agel fiber composites.

To identify which groups differed significantly from one another, Tukey pairwise comparison test was conducted after the ANOVA. The comparison between untreated and citric acid-treated composites produced a p-value of 0.678, indicating that the difference was not significant. The comparison between untreated and NaOH-treated composites produced a p-value of 0.005, showing that the difference was significant. The comparison between citric acid-treated and NaOH-treated composites produced a p-value of 0.031, which suggests that the difference was significant as shown in Figure 5.

Tukey Simultaneous Tests for Differences of Means					
Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
Citric Acid - Untreated	0.86	1.01	(-1.73, 3.45)	0.85	0.678
NaOH Treated - Untreated	3.69	1.01	(1.10, 6.28)	3.64	0.005
NaOH Treated - Citric Acid	2.83	1.01	(0.24, 5.42)	2.79	0.031

Individual confidence level = 98.00%

Figure 5. Tukey pairwise comparison test result

The Tukey test results indicate that the NaOH-treated composite is significantly different from the untreated and citric acid-treated composites, while no significant difference exists between untreated and citric acid-treated composites. In general, the NaOH-treated composite had the highest bending strength and showed the greatest improvement relative to the untreated composite as shown in Figure 6.

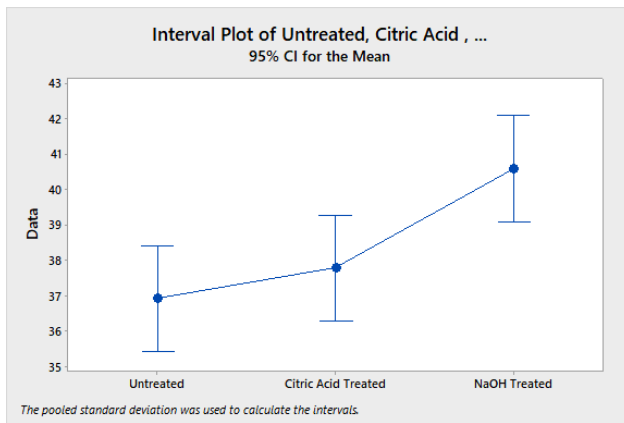


Figure 6. Interval plot of flexural bending test for each treatment

The citric acid-treated composite also showed a slight increase over the untreated specimen, but the improvement was smaller than that of NaOH treatment. This suggests that NaOH was more effective than citric acid in improving the interfacial bonding and load transfer capability of the Agel fiber composite under bending load.

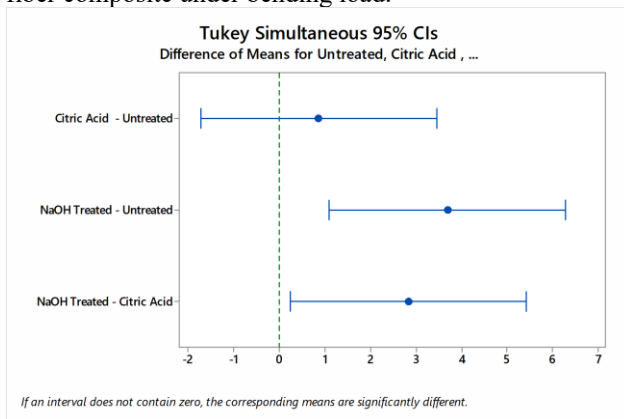


Figure 7. Tukey simultaneous 95% confidence interval

The Tukey simultaneous 95% confidence interval analysis was used to identify which pairwise differences in flexural bending strength were statistically meaningful after the one-way ANOVA. As shown in Figure 7, the comparison between the untreated composite and the citric acid-treated composite produced a confidence interval of -1.72678 to 3.45144, which included zero, indicating that the difference between these two groups was not statistically significant. In contrast, the comparison between the untreated composite and the NaOH-treated composite produced a confidence interval of 1.10032 to 6.27854, which did not include zero, showing a significant difference in bending strength. Similarly, the comparison between the citric acid-treated composite and the NaOH-treated composite produced a confidence interval of 0.237987 to 5.41621, which also excluded zero, confirming a significant difference between these two treatment groups.

These confidence interval results are consistent with the Tukey pairwise p-values and support the conclusion that NaOH treatment provides the greatest improvement in flexural bending strength. The interval for untreated versus citric acid-treated composites crossing zero indicates that citric acid treatment did not produce a strong enough improvement to be distinguished statistically from the untreated condition. On the other hand, the intervals for

comparisons involving NaOH treatment were entirely away from zero, which means that NaOH treatment significantly enhanced the composite's bending performance. This suggests that NaOH was more effective in improving fiber to matrix interfacial bonding, leading to better stress transfer under flexural loading, while citric acid treatment showed only a limited effect under the treatment conditions used in this study.

3.2. Discussion

The results of this study clearly demonstrate that chemical treatment has a measurable effect on the flexural bending strength of Agel fiber-reinforced composites. Based on the experimental data, the untreated composite exhibited a mean flexural strength of 36.922 MPa, the citric acid-treated composite showed a slight increase to 37.784 MPa, and the NaOH-treated composite achieved the highest value of 37.784 MPa. This trend indicates that surface modification improves the mechanical performance of the composite, although the degree of improvement depends on the type of treatment applied.

Prior to statistical analysis, the assumptions required for parametric testing were verified. The normality test confirmed that all datasets were normally distributed, with p-values of 0.107, >0.150, and >0.150 for untreated, citric acid-treated, and NaOH-treated composites, respectively. In addition, the homogeneity of variance assumption was satisfied, as indicated by the equal variance test results, where the Multiple Comparisons and Levene's test produced p-values of 0.076 and 0.132, respectively. Since both normality and homogeneity requirements were met, the use of one-way ANOVA was appropriate and statistically valid.

The ANOVA results showed an F-value of 7.24 with a p-value of 0.005, indicating that there is a statistically significant difference in flexural bending strength among the composite groups. This confirms that the type of chemical treatment applied to the Agel fiber significantly influences the mechanical performance of the resulting composite. However, ANOVA alone does not identify which specific groups differ, so further analysis using Tukey pairwise comparison was conducted.

The Tukey test results revealed that the difference between untreated and citric acid-treated composites was not statistically significant ($p = 0.678$), despite the slight increase in mean strength. This suggests that, under the treatment conditions used in this study, citric acid modification did not produce a sufficiently strong improvement in interfacial bonding to significantly enhance flexural performance. In contrast, the comparison between untreated and NaOH-treated composites showed a significant difference ($p = 0.005$), indicating that NaOH treatment effectively improves bending strength. Similarly, the comparison between citric acid-treated and NaOH-treated composites also showed a significant difference ($p = 0.031$), confirming the superior performance of NaOH treatment over citric acid treatment.

From a materials engineering perspective, the superior performance of NaOH-treated composites can be attributed to the alkali treatment mechanism. NaOH removes surface impurities such as lignin, hemicellulose, and waxes, resulting in increased surface roughness and improved mechanical interlocking between fiber and matrix. This

leads to more efficient stress transfer under bending loads and ultimately higher flexural strength. On the other hand, although citric acid treatment is known to promote esterification and reduce fiber hydrophilicity, the results suggest that the extent of chemical modification achieved in this study was not sufficient to significantly enhance load transfer compared to the untreated condition.

Overall, the statistical and mechanical results consistently show that NaOH treatment is the most effective method among those investigated for improving the flexural bending strength of Agel fiber composites. While citric acid treatment offers a more environmentally friendly alternative, its effectiveness may depend strongly on process parameters such as concentration, curing conditions, and the presence of catalysts. Therefore, further optimization of citric acid treatment is recommended to fully realize its potential as a sustainable surface modification technique.

4. Conclusion

The results of this study show that chemical treatment significantly affects the flexural bending strength of Agel fiber-reinforced composites. The untreated composite exhibited a strength of 36.922 MPa, the citric acid-treated composite slightly increased to 37.784 MPa, and the NaOH-treated composite achieved the highest value of 40.611 MPa. Statistical analysis confirmed that the data met parametric assumptions and that there was a significant difference among groups (ANOVA, $F = 7.24$, $p = 0.005$). Tukey testing further indicated that NaOH-treated composites were significantly stronger than both untreated and citric acid-treated composites, while no significant difference was found between untreated and citric acid-treated samples. These findings demonstrate that NaOH treatment is more effective in improving flexural performance due to better fiber–matrix bonding, whereas citric acid treatment showed limited improvement under the conditions used, suggesting that further optimization is required for it to be competitive.

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Reference

- [1] I. Elfaleh *et al.*, “A comprehensive review of natural fibers and their composites: An eco-friendly alternative to conventional materials,” *Results in Engineering*, Sep. 2023, doi: 10.1016/j.rineng.2023.101271.
- [2] B. Dev, A. Rahman, R. Alam, R. Repon, and Y. Nawab, “Mapping the progress in natural fiber reinforced composites: Preparation, mechanical properties, and applications,” *Polymer Composites*, May 2023, doi: 10.1002/pc.27376.
- [3] D. Thapliyal *et al.*, “Natural Fibers Composites: Origin, Importance, Consumption Pattern, and Challenges,” *Journal of Composites Science*, Dec. 2023, doi: 10.3390/jcs7120506.
- [4] A. Karimah *et al.*, “A review on natural fibers for development of eco-friendly bio-composite: characteristics, and utilizations,” *Journal of Materials Research and Technology*, Jul. 2021, doi: 10.1016/j.jmrt.2021.06.014.
- [5] T. Islam *et al.*, “Advancements and challenges in natural fiber-reinforced hybrid composites: A comprehensive review,” *SPE Polymers*, Jun. 2024, doi: 10.1002/pls2.10145.
- [6] P. Jagadeesh, M. Puttegowda, S. M. Rangappa, and S. Siengchin, “A review on extraction, chemical treatment, characterization of natural fibers and its composites for potential applications,” *Polymer Composites*, Sep. 2021, doi: 10.1002/pc.26312.
- [7] M. Aravindh *et al.*, “A Review on the Effect of Various Chemical Treatments on the Mechanical Properties of Renewable Fiber-Reinforced Composites,” *Advances in Materials Science and Engineering*, Jan. 2022, doi: 10.1155/2022/2009691.
- [8] J. De and R. Baxi, “Experimental Investigation and Analysis of Mercerized and Citric Acid Surface Treated Bamboo Fiber Reinforced Composite,” *IOP Conference Series: Materials Science and Engineering*, vol. 225, Aug. 2017, doi: 10.1088/1757-899x/225/1/012154.
- [9] M. Varma and S. Chandran, “Surface treatment of natural fibers for enhancing interfacial adhesion and mechanical properties in biocomposites - a comprehensive review,” *Composite Interfaces*, vol. 32, pp. 1729–1765, Apr. 2025, doi: 10.1080/09276440.2025.2498795.
- [10] I. W. P. Y. Asana, R. N. Baiti, and K. W. Widantha, “The Effect of Reinforcement Surface Treatment With Citric Acid on The Flexural and Hardness Properties of Epoxy/Wood Sawdust Composites,” *LOGIC*, vol. 25, no. 2, pp. 100–106, Jul. 2025, doi: 10.31940/logic.v25i2.100-106.
- [11] G. Ngurah, N. Santhiarsa, G. Bagus, W. Kusuma, I. Gede, and A. Negara, “Mechanical Characterization of NaOH-Treated Agel Fiber-Cotton Composites,” *Journal of Mechanical Engineering Science and Technology (JMEST)*, Nov. 2023, doi: 10.17977/um016v7i22023p214.
- [12] H. Hestiawan, Jamasri., and Kusmono, “A Preliminary Study: Influence of Alkali Treatment on Physical and Mechanical Properties of Agel Leaf Fiber (Corypha gebanga),” *Applied Mechanics and Materials*, vol. 842, pp. 61–66, Jun. 2016, doi: 10.4028/www.scientific.net/amm.842.61.
- [13] S. Majhi, S. Pradhan, V. Prakash, and S. Acharya, “Influence of alkali treatment on the interfacial shear strength of Agave lechuguilla fiber and its significance as a reinforcing material in polymer composites for mechanical applications,” *Polymer Composites*, Mar. 2023, doi: 10.1002/pc.27336.
- [14] M. Nuryanta *et al.*, “The effect of stacking sequence on the properties of hybrid agel/glass fiber reinforced polymer composite laminates,” presented at the IOP Conference Series: Earth and Environmental Science, Aug. 2024. doi: 10.1088/1755-1315/1381/1/012014.
- [15] A. M. Del Campo, J. Robledo-Ortiz, M. Arellano, M. Rabelero, and A. Pérez-Fonseca, “Accelerated Weathering of Polylactic Acid/Agave Fiber

- Biocomposites and the Effect of Fiber–Matrix Adhesion,” *Journal of Polymers and the Environment*, vol. 29, pp. 937–947, Oct. 2020, doi: 10.1007/s10924-020-01936-z.
- [16] S. Messaoui, K. E. Borchani, L. Ghali, N. Guermazi, N. Haddar, and S. Msahli, “Effect of a New Composition Ratio and of a New Chemical Treatment on Natural Alfa Fiber/polypropylene Composites Manufacturing and Their Mechanical Properties,” *Journal of Natural Fibers*, vol. 19, pp. 10126–10141, Oct. 2021, doi: 10.1080/15440478.2021.1993485.
- [17] M. M. Hassan, N. Tucker, and M. J. Le Guen, “Thermal, mechanical and viscoelastic properties of citric acid-crosslinked starch/cellulose composite foams,” *Carbohydrate Polymers*, vol. 230, p. 115675, Feb. 2020, doi: 10.1016/j.carbpol.2019.115675.
- [18] N. Kharchi *et al.*, “Citric acid treatment: A new approach to improving *Ampelodesma mauritanica* fibers-poly-lactic acid composites,” *Industrial Crops and Products*, Jan. 2025, doi: 10.1016/j.indcrop.2024.120143.