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RESEARCH ARTICLE

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Influence of dammar gum application on the mechanical properties of pineapple leaf fiber reinforced tapioca biopolymer composites

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Abstract

The objective of this work is to investigate the influence of the utilization of dammar gum (DG), which is a biodegradable and renewable binder, on the mechanical properties of short pineapple leaf fiber (PALF) reinforced tapioca biopolymer (TBP). Samples with variable DG concentrations (10%, 20%, 30%, and 40% by weight) and a constant 30% PALF composition were created with varying TBP percentages using an internal mixing process and compression molding. The results showed that PALF-TBP with 10% DG had the highest mechanical properties with tensile, flexural, and impact strength of 19.49 MPa, 18.53 MPa and 13.79 KJ/m^2, respectively. Scanning electron microscopy (SEM) images prove the enhanced mechanical characteristics. In addition, Fourier transform infrared spectroscopy (FTIR) analysis showed that the DG improves the matrix and PALF interface. The results show that the utilization of DG significantly enhanced the mechanical characteristics of composites. In addition, it is anticipated that it will be able to create PALF-TBP-DG composites as a potential alternative for conventional polymers in various applications, especially in engineering applications such as automotive and packaging industries. Therefore, it is expected to be capable of contributing to sustainable development goals (SDGs).

Highlights

- Recent studies show that damar gum (DG) has potential as a sustainable binder.
- Optimal composition is a critical factor in bio-composite manufacturing.
- The mechanical properties improved the most when 10 wt% of DG was applied.
- DG could serve as a viable substitute for petroleum-derived coupling agents.
- Bio-composites may serve as alternative polymers for forthcoming applications.

KEYWORDS

bio composites, dammar gum, natural fiber composites, pineapple leaf fiber, sustainable development goals (SDGs), tapioca biopolymer

1 | INTRODUCTION

Natural fiber composites are increasingly favored and sought after as a viable substitute for petroleum-based polymers.[1,2] The proliferation of non-biodegradable waste originating from petroleum-derived polymers has led to several detrimental ecological ramifications.[3–7] Most of the conventional polymers are not biodegradable. This phenomenon contributes to the pollution, climate change, and resource depletion. In addition, the utilization of non-biodegradable and non-renewable polymers always increase energy consumption and greenhouse gas emissions.[8–10] Hence, the potential resolution of the issue lies in the advancement of environmentally sustainable materials, exemplified as natural fiber composites. A significant improvement in the natural fiber composites domain pertains to applying biodegradable and renewable matrices, specifically biopolymers generated from starch, to produce a polymer with complete biodegradability. Tapioca biopolymer (TBP) is an alternative to petroleum-based matrices. TBP exhibits a reduced environmental footprint compared to matrices composed of traditional polymers due to its origin from renewable tapioca starch. Over time, it can naturally decompose, alleviating concerns about the buildup of plastic waste.[11,12] Environmentally conscious customers and enterprises will find products built using TBP matrices are more attractive where TBP could create more environmentally friendly composite materials, with proper waste management and disposal. This alternative will reduce dependence on finite fossil fuels and comply with environmental requirements.[13] As a polymer derived from starch, TBP is anticipated to be more compatible with natural fibers during composite fabrication. According to previous research, the optimal processing temperature for TBP is 165°C.[12] In contrast, most natural fibers degrade at temperatures of 200°C.[11,14–16] The compatible range of processing temperatures renders TBP a viable option for utilization with diverse categories of natural fibers, facilitating the natural fiber composites fabrication without fiber decomposition.

Combining natural fiber and TBP in biocomposite production seems to be a possible method for sustaining this biopolymer's biodegradability. Pineapple leaf fiber (PALF) exhibits promising potential compared to other natural fibers due to its widely available and created from pineapple plant leaves that regenerate after harvesting, it is both inexpensive and effective In addition, PALF's significant crystalline cellulose composition and relatively low hemicellulose and lignin constituents are another advantage. As a result, it exhibits outstanding mechanical properties compared to other natural fibers.[17–20]

On the other hand, less attention is paid to using pineapple leaves as a recycled material. Thailand, Philippines, Brazil, Costa Rica, Hawaii, Indonesia, and Malaysia are among the world's largest pineapple producers, with over 2.1 million acres under production. Approximately 20,000 to 25,000 tons of pineapple leaf detritus are generated per acre during harvesting, posing the most significant challenge for pineapple-producing nations.[4,21,22] Therefore, the utilization of PALF in composites can help pineapple-producing countries overcome their problems with leftover pineapple plant debris. By giving the abandoned plant components a use, PALF lessens waste issues and environmental harm. In addition, it boosts the value of pineapple farming, generates employment and diversify the economy. Consequently, it is expected that including pineapple leaf waste as a reinforcing component in natural fiber composites will present a feasible alternative and solution to the challenges of post-harvest residual pineapple leaves.

Nonetheless, a significant drawback of natural fiber composites is incompatibility issue between the natural fibers and the polymer matrix. This phenomenon has led to low interfacial adhesion between natural fibers and the polymer matrix, which has resulted less effectiveness of stress transfer from matrix to fiber.[23] As a result, this phenomenon produces composites with inadequate mechanical properties, which can limit its use primarily to engineering applications such as automotive, marine, or packaging industries.[24,25]

A prior investigation examined the employment of alkali treatment and coupling agents to enhance the interfacial adhesion and mechanical properties of composites made from PALF-TBP. Alkali treatment improves the cleanliness and alters the surface of the PALF, which enhance its ability to stick or adhere to the tapioca biopolymer (TBP).[26–28] However, applying 5% (w/v) alkali treatment with 1 h immersion duration does not significantly improve the tensile performance of 30% of PALF reinforced TBP composites, which can only enhance 2.8% the improvement of tensile properties.[29]

On the contrary, it has been demonstrated that incorporating a coupling agent can effectively augment the interfacial adhesion of the composite material. The coupling agents react with the fiber's surface, forming chemical interactions between the matrix and fiber. The chemical composition of coupling agent facilitated an interaction with the PALF surface, resulting in the formation of chemical bonds that acted as a bridge between the fiber and TBP matrix.[30,31] The dry blending technique has seen considerable use of maleic anhydride polypropylene (MAPP) and maleic anhydride polyethylene (MAPE) as the most employed coupling agents. Previous study indicate that the utilization of MAPP created a reaction with the fiber surface by forming a bridge of chemical bonds like PP chain which produces better

wetting between fiber and polypropylene (PP) matrix. Contrary, MAPP appeared to be less effective when the polyethylene (PE) matrix was used in the composites. Therefore, the selection of suitable coupling agent plays a significant role in enhance the interfacial adhesion between natural fiber and polymer matrix.

In addition, previous research indicates that using MAPE and MAPP can enhance the interfacial adhesion between PALF and TBP. In addition, 7% MAPP was chosen as the optimal combination for enhancing PALF-TBP tensile properties.[29] The utilization of 7% MAPP is able to increase 23.6% of PALF-TBP composites. Meanwhile, using 3% of MAPE is capable of enhancing 14.6% of tensile properties for 30% PALF reinforced TBP composites. However, both coupling agents are derived from petroleum and are not renewable resources.

Dammar gum (DG) was chosen as a renewable component for PALF-TBP composites in this study. DG is a renewable substance obtained from trees in India and East Asia belonging to the Dipterocarpaceae family. DG is a triterpenoid substance composed of numerous triterpenes and their oxidation products.[32–34] Most DG is produced by tapping trees, nevertheless, some are collected from the ground. The gum's hue ranges from clear to pale yellow, while the fossilized form is gray-brown. Dammar gum and its glass qualities provide adhesion, color retention, flexibility, and vapor resistance. Ancient Malay shipbuilders frequently used DG to seal traditional Malay wooden vessels.[35] It is commonly combined with natural fibers such as jute, and the combination and efficacy are excellent.[36] However, the introduction of modern ships rendered the combination of natural fiber and DG obsolete.

The incorporation of DG in PALF-TBP composites offers numerous notable benefits. DG is predicted to function as a bonding agent, enhancing the contact between the TBP matrix and the PALF. By efficiently distributing mechanical stress, this enhanced adhesion reduces the likelihood of the composite materials experiencing splitting at the fiber-matrix contact. Furthermore, DG assists in reducing the moisture absorption of the composites. It acts as a barrier, inhibiting the entry of excessive moisture into the fabric and so preventing swelling and degradation of the fibers. Consequently, PALF-TBP composites have enhanced resistance to moisture or humid conditions.

The recyclability of DG is a key element in its choice as a constituent in these composites. The resin produced by these trees has the ability to organically regenerate within a specific timeframe, making DG a sustainable and environmentally friendly material option.[33,37] Furthermore, DG possesses the property of biodegradability, implying that when the composite approaches the end of its useful lifespan, it can undergo natural decomposition without causing any harm to the environment.[38,39] This aligns with the primary goal of creating composite materials that possess durability and longevity, while still being easily disposable and environmentally sustainable.

Consequently, the primary objective of this study is to investigate the effect of DG incorporation on the mechanical properties of PALF-TBP composites. In addition, the study aimed to determine the optimal DG concentration for maximizing the mechanical properties of PALF-TBP-DG composites.

2 | MATERIALS AND METHODS

2.1 | Material

The TBP utilized in this investigation was produced by Indochine Bio Plastiques Sdn. Bhd. a company based in Johor Bahru City, Johore, Malaysia. The biopolymer in the study originated from *Manihot esculenta*, which is recognized as an industrial species. The harsh taste of these tapioca species renders them inappropriate for human consumption. Table 1 presents the attributes that were utilized.

The PALF bundles were purchased from Pemalang, Central Java, Indonesia. The fiber was derived by scraping pineapple leaves. The RL-L10 MPL crushing equipment was then utilized to shorten the length of the fiber. The subsequent phase is the sieving process using an automatic SS304 GMP sieving machine for fibers with a length of less than 2.00 mm. The DG utilized in this study was purchased from Kalimantan, Indonesia. DG has a melting point of 150°C and degrades at 200°C. Additionally, the density of DG varies between 1.04 and 1.12 g/cm^3. Figure 1 depicts the gray-brown physical condition of DG.

2.2 | Composites manufacturing

Short PALF, TBP, and DG were dried at 80°C by using vacuum oven for 24 h. Previous studies have determined

TABLE 1 The mechanical and thermal properties of TBP.

Properties	Value
Tensile strength	14 MPa
Maximum strain	37%
Density	1.1 g/cm^3
Melt flow index	36 g/10 min
Range of processing temperature	165–185°C

FIGURE 1 The physical condition of DG.

that the optimal fiber content is 30% by weight.[40,41] The subsequent process is the TBP and DG compound with a constant fiber percentage of 30% based on the following equation:

$$1 = v_f + v_m + v_{dg}$$

where v_f is the percentage of fiber, v_m is the TBP percentage, and v_{dg} is the weight percentage of DG. The specific compounding composition in sample fabrication is presented in Table 2.

In the compounding procedure, the Brabender Plastograph EC internal mixing apparatus was preheated to a temperature of 165°C and adjusted to a rotation speed of 40 revolutions per minute (rpm). Prior to the insertion of the fiber, a mixture comprising TBP and DG was heated at the specified temperature and allowed to reach a stable state. The composites were mixed for a total of 20 min. Then, the internal mixer's mixed compounds were cut into pallets.

The subsequent step was the fabrication of a composite plate through the use of compression molding, creating a 180 mm × 180 mm × 6 mm plate. The mold temperature was set to 165°C, and a 6.0 MPa of constant pressure was applied during a preheating phase lasting 5 min, followed by a subsequent press phase lasting 10 min. Following this, a cooling period of 10 min was seen under identical pressure conditions.[42] After that, the tensile, flexural, and impact samples were laser-cut using a Thye Hong laser cutting equipment in accordance with ASTM D638, ASTM D790, and ASTM D6110, respectively.[25,43–45] Figure 2 depicts the tensile test sample following laser cutting.

2.3 | Mechanical testing method

The 5 kN Shimadzu AGS-J universal testing machine was utilized in the tensile and flexural tests following ASTM D638 and ASTM D790, respectively.[43,44] A crosshead speed of 1 and 1.28 mm/min was set for flexural and tensile tests, respectively. Five samples of each sample type were tested for failure. In addition, the tensile and flexural modulus were determined using the Chord modulus, E, where the modulus value was computed between 0.1% and 0.5% strain value. The modulus calculation is as follows:

$$E = (\sigma_{0.5\%\varepsilon} - \sigma_{0.1\%\varepsilon})/(\varepsilon_{0.5\%} - \varepsilon_{0.1\%})$$

where σ is the value of stress, and ε is the strain value from the stress–strain curve. Meanwhile, the Wolpert impact tester was used for the Charpy impact test. The measurement was conducted in accordance with ASTM D6110 at 50 ± 5% of relative humidity and 23 ± 2°C of

TABLE 2 Detail compounding proportions in sample fabrication.

Sample	PALF (%)	TBP (%)	DG (%)
DG0	30	70	0
DG10	30	60	10
DG20	30	50	20
DG30	30	40	30
DG40	30	30	40

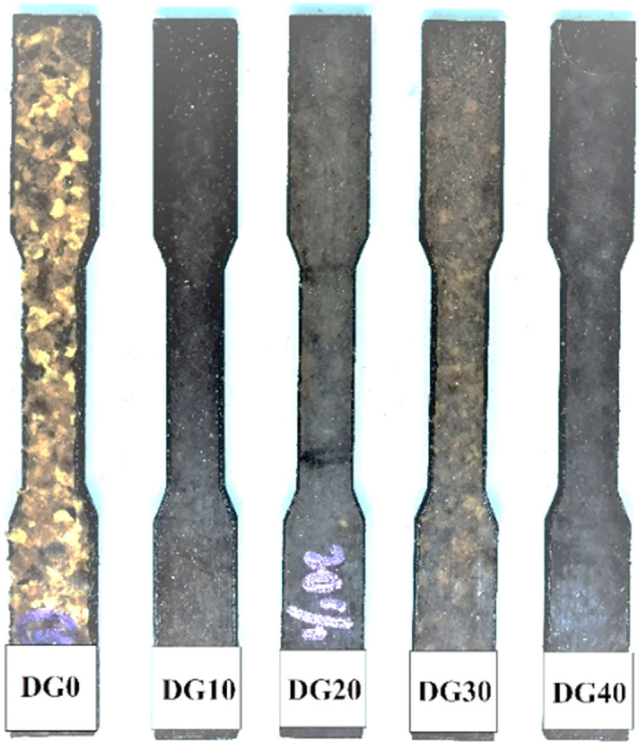

FIGURE 2 A tensile test sample of DG0, DG10, DG20, DG30, and DG40 after laser cutting.

room temperature.[45] The applied impact load was 4 J pendulum at a height of 160°.

2.4 | Fracture morphology

The surfaces of the tensile samples were visually inspected using a JEOL JSM-6380LA scanning electron microscope (SEM). The study aimed to evaluate the impact of DG inclusion on the bonding between the fiber-matrix interface by comparing and examining the surface morphology of composites with different percentages of DG.

2.5 | Fourier transform infrared spectroscopy (FTIR) analysis

The final testing in this study was FTIR. FTIR was performed in this study utilizing Perkin Elmer Spectrum 100 FTIR equipment. The range of 600 to 4000 cm^{-1} wave number was examined throughout the samples. The discoveries of FTIR analysis can be used to predict the presence of interactions in a composite sample. The interaction between the various elements in composite materials can be determined by recognizing the band position shifting of the spectra. Figure 3 depicts the comprehensive procedure carried out in the current study, commencing with material preparation, and concluding with FTIR analysis.

3 | RESULTS AND DISCUSSION

3.1 | Influence of dammar gum utilization on mechanical properties

Table 3 depicts the relationship between tensile properties and percentages of DG. Using DG with a concentration of 10% increases tensile strength and modulus by 24% and 50%, respectively. It is worth noting that the DG has adhesive properties, which are expected to be capable of improving fiber binding in PALF-TBP composites. In addition, DG also provides cohesion and enhances the strength of PALF-TBP composites. However, tensile strength was observed to decrease about 12% as the DG content increased from 10% to 20%. The tensile strength of materials containing 30% and 40% DG is 16.34 and 15.76 MPa, respectively.

Nonetheless, all the acquired results surpass the tensile strength of pure PALF-TBP, which is 15.71 MPa. Therefore, the findings show that 10% DG concentration is the optimal amount in the fabrication of PALF-TBP-DG composites. Moreover, the utilization of DG over the certain optimum concentration will decrease the tensile strength as seen when the DG concentrations increased from 10% to 20%. However, this optimum concentration can vary depending on the material, processing, and application. The decrease in tensile strength after 10% DG concentration was likely caused by the plasticizing effect, in which DG has a lower molecular weight than TBP. The plasticizing phenomenon gradually diminishes the rigidity of the composite material.[31,46–48] Consequently, reducing the tensile strength. This result is consistent with previous study on using MAPP and MAPE in PALF reinforced TBP composites, in which the tensile strength decreased after the optimal coupling agent concentration.

In a previous study, Gassan and Bledzki researched the impact of coupling agent concentration exceeding the optimal level on the tensile characteristics of polypropylene (PP) composites reinforced with flax and jute fibers. Their findings indicated a deterioration in these qualities when the concentration surpassed the optimal threshold.[49] The self-entanglement of fibers, as opposed to the movement of fibers within the polymer matrix, is attributed to the excess of coupling agents migration around the fibers. The findings of this study are consistent with those of the current investigation, wherein an overabundance of DG was found to be the underlying cause of the self-entanglement phenomenon.[29]

In relation to the elastic modulus, a significant observation was made concerning the tensile modulus, which displayed an increase upon the inclusion of DG. This increase reached a maximum enhancement of 40%. It is primarily because obstruction increases as DG composition

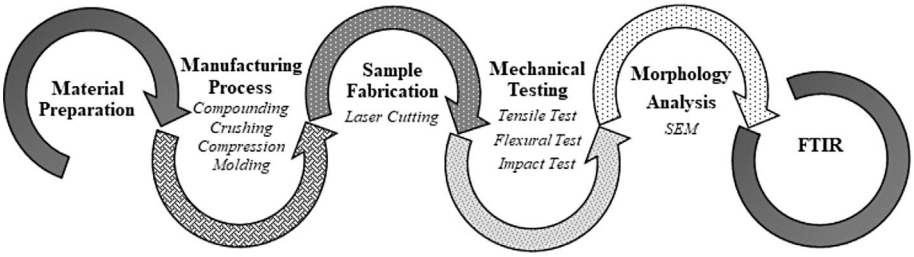

FIGURE 3 The process flow performed in the current study.

TABLE 3 Comparison of PALF-TBP-DG tensile properties with different DG percentages.

	Tensile strength (MPa)	Young's modulus (GPa)	Maximum strain (%)
Sample	**Mean ± SD**	**Mean ± SD**	**Mean ± SD**
DG0	15.71 ± 0.75	1.20 ± 0.04	6.59 ± 0.11
DG10	19.49 ± 1.32	1.80 ± 0.16	6.22 ± 0.01
DG20	17.09 ± 1.77	2.14 ± 0.19	5.96 ± 0.06
DG30	16.34 ± 0.25	2.56 ± 0.10	5.74 ± 0.03
DG40	15.76 ± 0.46	2.83 ± 0.50	5.62 ± 0.11

Abbreviation: SD, standard deviation.

increases, increasing stiffness. The present view is further strengthened by the finding of maximum tensile strain, as shown in Table 3, where an increase in DG content decreased the maximal strain value. The use of DG has consequently enhanced the brittleness and stiffness of the PALF reinforced TBP composite. The present finding is consistent with previous study that dammar gum can stiffen natural fibers like cotton, making natural fiber less flexible.[50]

Similar results were observed for flexural strength. Figure 4 depicts an increase of 16% in flexural with DG utilization up to 10% concentration. However, the flexural strength result has decreased as a consequence of the further increase in DG percentage. Once again, this can be attributed to the plasticizer effect, whereby an excessive amount of plasticizer can modify the structure of the TBP matrix and reduce its ability to support the PALF fibers mechanically. This rupture can lead to a weakening of the interfacial adhesion between the fibers and the matrix, causing a reduction in tensile strength.[25,51,52] In addition, Figure 3 demonstrates that impact strength follows a similar pattern to tensile and flexural properties. With DG utilization of 10%, a 2% increase was observed. Nonetheless, the use of DG by more than 10% decreased the impact strength of PALF reinforced TBP composites. Again, the results demonstrate that the optimal concentration of DG in PALF-TBP composites can enhance the fiber-matrix interface adhesion.[53] Thus, it is capable of increasing the value of the mechanical properties.

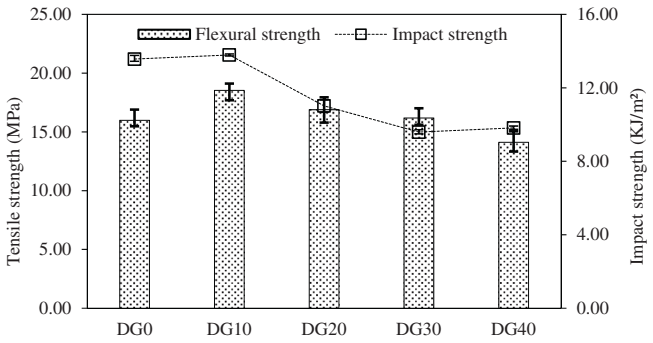

FIGURE 4 Different DG percentages influence the flexural and impact strength values for PALF-TBP-DG composites.

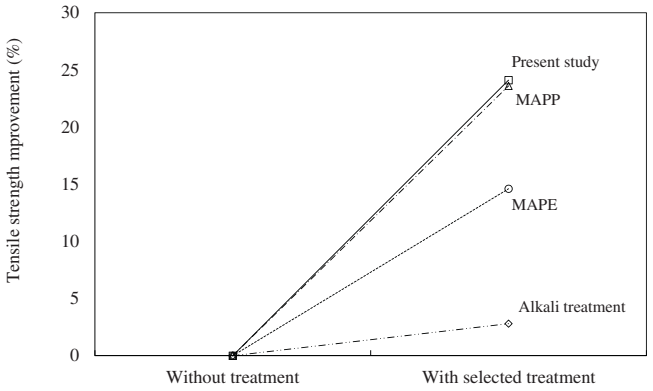

FIGURE 5 Enhancement of tensile strength between current findings and previous research.[29]

Figure 5 compares the tensile strength results of the present study with those of previous research. Moreover, a competitive increase in the tensile strength of PALF-TBP composites is indicated by the current study's DG10 result. Using 10% DG in PALF-TBP composites can increase tensile strength by 24.1%. This discovery is superior to MAPP and MAPE utilization, which could only increase tensile strength by 23.6% and 14.6% respectively.[29] The utilization of DG to PALF-TBP composites suspected that DG was act as a bonding agent to improve the PALF's and TBP matrix's contact. This improved adhesion lessens the possibility of the composite materials splitting at the fiber-matrix contact by effectively dispersing mechanical stress. Thus, increase the mechanical properties of the composites. Current results indicate that the combination of PALF-TBP and DG has enormous potential for the future development of renewable and eco-friendly polymers.

Therefore, the present study summarized that 10% DG is preferable for improving the tensile properties of

PALF reinforced TBP composites. However, neither 30% nor 40% DG utilization significantly enhances the mechanical properties of PALF reinforced TBP composites. Consequently, the most exciting finding of the present study is the crucial function that optimal DG percentage plays in achieving maximum mechanical properties.

3.2 | Fracture morphology on failure samples

Scanning electron microscopy (SEM) offers a highly effective approach to assess the surface morphology and fracture locations inside fiber composites by directly observing the failure composites' surface area. This technique is particularly useful for examining the interface between the matrix and fiber. The scanning electron microscopy (SEM) pictures depicted in Figure 6 illustrate the comparison of the interface between PALF-TBP under 90× magnification for the DG0, DG10, DG20, DG30, and DG40 samples. Figure 6A shows that the interfacial bonding between the PALF fiber and the TBP matrix in the DG0 sample is poor, as evidenced by the gap and fiber pull-out from the matrix. This behavior could be explained by the low adherence of the fiber surfaces to the TBP resin. As a result, compared to the PALF-TBP sample with DG application, the tensile strength of the aforementioned composite is low.

The SEM picture of sample DG10, depicted in Figure 6B, reveals enhanced bonding between the fiber and matrix. This is evident from the reduced number of visible gaps and instances of fiber pullout. In addition, SEM micrographs reveal more distinct fractures and the fragmentation of fibers into smaller diameter fibrils, indicating robust adhesion. Furthermore, there are fewer gaps or voids observed at the interface between the fibers and the matrix. Furthermore, it is often feasible to observe the regular distribution of DG throughout the composite, guaranteeing a consistent and robust connection along the entire length of the fiber.[54,55] The combination of these visual indications suggests that DG has a role in improving the fracture behavior of the composites and maybe increasing their overall strength by strengthening the adhesion between PALF and the TBP matrix.

This phenomenon indicates that DG10 sample has significant improvement on interfacial adhesion where the stress is suspected well transfer from matrix to fiber. The anticipated outcome of this study is predicted to be a significant contributing factor in yielding improved mechanical properties for DG10 samples. The study has also documented comparable behavior in the examination of the impacts of chemical treatment and the application of coupling agents on the composites of roselle fiber-reinforced vinyl ester.[56]

Meanwhile, SEM image on DG20 sample show the combination between fiber breakage and fiber pull-out. This finding consistent with the mechanical test result where sample DG20 produce the higher result compared with DG0. In other hand, DG 30 and DG40 shows the 100% fiber pull-out phenomenon and without fiber breakage phenomenon. In addition, the gap between fiber and matrix was increased compared with DG10 and DG20 sample. This finding shows that the stress transfer from the matrix to the fiber does not occur efficiently compared with sample DG10. It was parallel with mechanical test results where the results of DG30 and DG40 are lower compared to DG10 sample. Therefore, the finding deduces that the interfacial bonding and mechanical properties of PALF and TBP with 10% of DG application is markedly better than other samples.[30]

3.3 | FTIR analysis

The FTIR technique is significant in the analysis of functional groups found in natural fibers and biopolymers, with a specific focus on hydroxyl and carbonyl groups. Furthermore, the understanding of the interplay among the constituent elements of composite materials can be attained by detecting shifts in band positions or the appearance of novel peaks in FTIR spectra. The comparison of the FTIR spectra of samples DG0 and DG10 is illustrated in Figure 7. Both samples exhibit the characteristic of the O—H group between 3331 and 3339 cm^{-1}. The band observed in the study was attributed to the presence of a hydrogen-bonded hydroxyl group (O—H). This observation was made based on the complex vibrational stretching associated with the presence of free hydroxyl groups, as well as those attached both intermolecularly and intramolecularly. This finding is consistent with previous research.[57]

Furthermore, it is worth noting that both samples demonstrate characteristic bands at 3336 cm^{-1}, which can be attributed to the O—H bonds stretching. Additionally, the presence of bands at 2917 cm^{-1} indicates the stretching of —CH bonds. Moreover, the occurrence of a band at 1740 cm^{-1} suggests the symmetric stretching of C═O bonds. Furthermore, the presence of a peak at 1461 cm^{-1} can be attributed to the deformation of —CH bonds in lignin. Finally, a peak within the range of 1000 to 1600 cm^{-1} indicates the concentration of O—H hydrogen bonds. Notably, the peaks of both samples did not differ significantly, indicating that no significant new interaction occurred between PALF-TBP-DG. It is believed to be caused by the TBP and DG, which are both

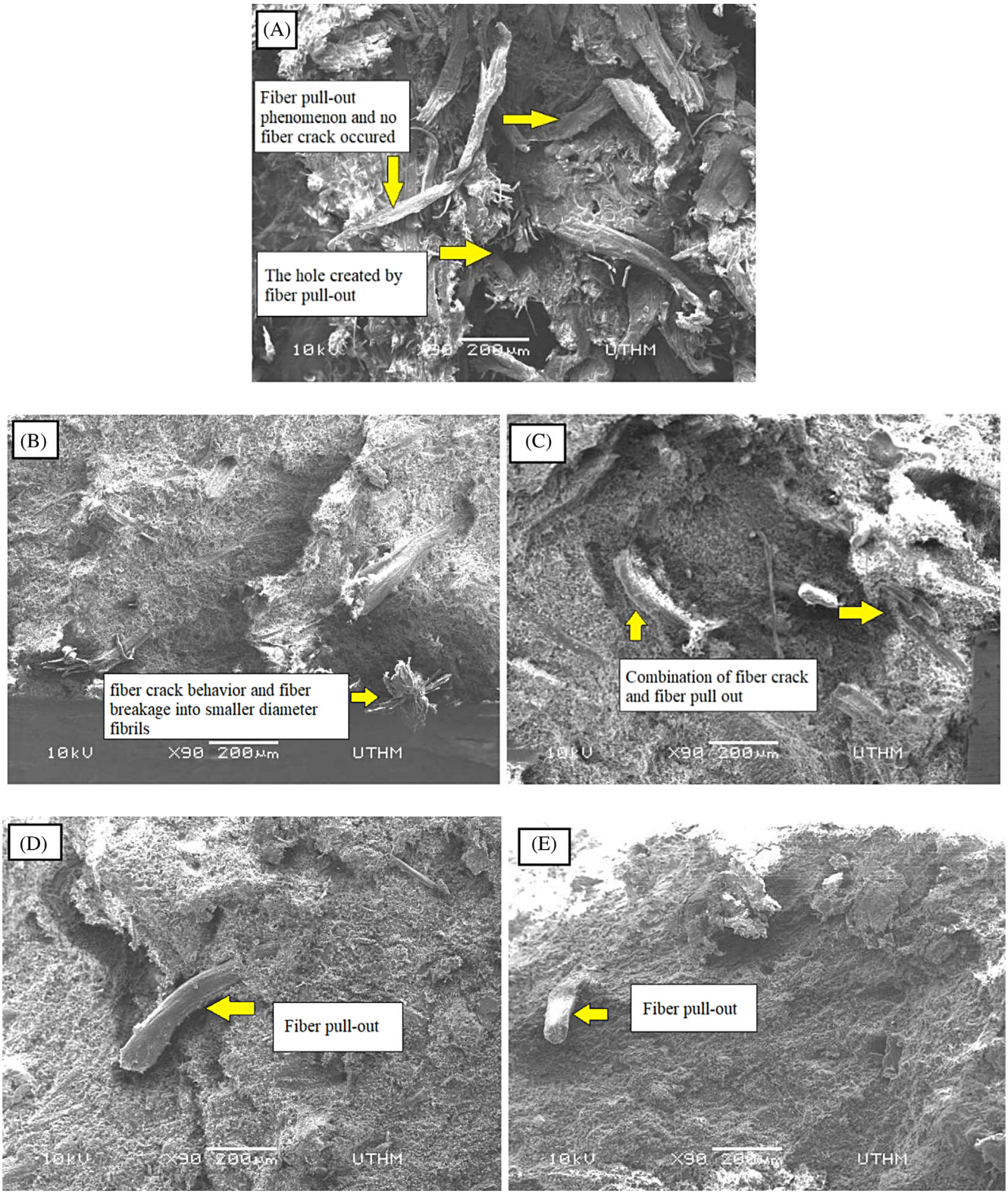

FIGURE 6 SEM image of PALF reinforced TBP composites subjected to DG percentage (A) DG0; (B) DG10; (C) DG20; (D) DG30; (E) DG40.

of natural origin and share similar properties. Nevertheless, the intensity of each peak decreases significantly between DG10 and DG0 samples.

As commonly seen, the prominent absorption peak with a wavenumber of 3336 $cm^{-1}$is evident. The utilization of 10% DG in PALF-TBP composite was observed to

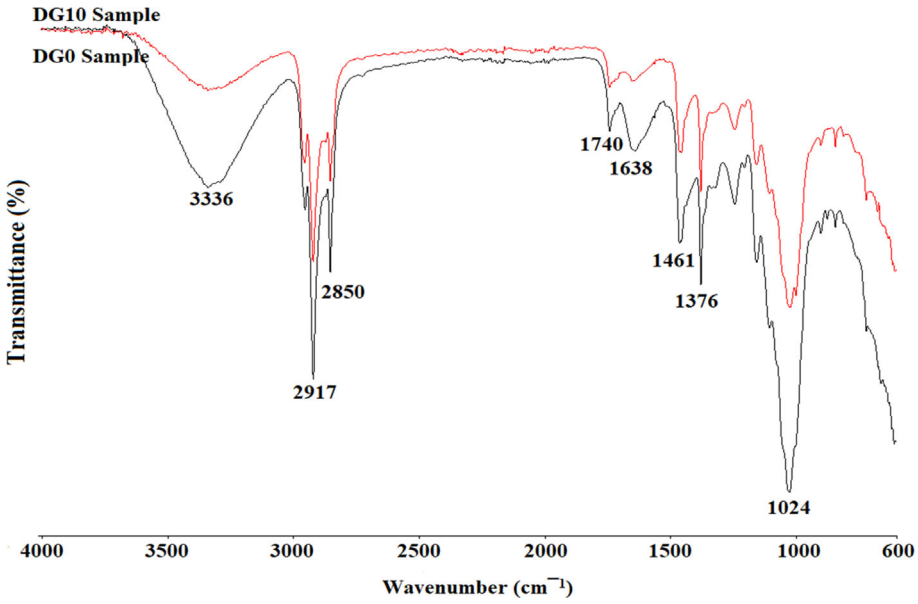

FIGURE 7 Comparison of FTIR results between DG0 and DG10.

reduce the intensity of hydroxyl groups. It is likely due to the interaction between DG and PALF fiber surface. The chemical surface of PALF may also be altered by the use of DG, which also affects the way the hydroxyl groups interact and affects their FTIR spectra. However, the hydroxyl group's rise experienced a decrease in the presence of DG, suggesting that esterification took place.[29] As a consequence of the reaction with the element in DG, adding DG to the PALF-TBP decreased the hydroxyl group.

The main implication of the decrease in the intensity of hydroxyl groups in the FTIR study of PALF-TBP-DG composites is suspected that the hydrophilic spots on the surface of PALF fibers are fewer, and their capacity to connect with water is reduced. In addition, the ability of the fibers to adhere to the polymer matrix may vary as a result. However, the decrease of these hydroxyl groups indicates a modification to the interaction and chemical composition of the composite, which may have an effect on its properties. The phenomenon could perhaps contribute for the notable increase in tensile and flexural strength measurements observed in the PALF-TBP-DG sample, specifically when the DG concentration reaches 10%.

4 | CONCLUSION

The incorporation of DG into PALF-TBP composites is undertaken to enhance the composites' mechanical characteristics, while also striving to create a sustainable and environmentally friendly polymer material that can effectively compete in the market. Therefore, this study aimed to examine the effects of utilizing DG as reinforcement for tapioca resin, a starch-based matrix, on short PALF. The results obtained from the mechanical properties analysis suggest that PALF-TBP with 10% DG had the highest mechanical properties compared with other DG concentration with tensile strength, flexural strength, and impact strength of 19.49 MPa, 18.53 MPa and 13.79 KJ/m^2, respectively. Moreover, the scanning electron microscopy (SEM) images of the fracture samples reveal a high degree of interfacial adhesion between the fibers and matrix, as well as an effective transmission of stress from the matrix to the fibers. In addition, the utilization of Fourier transforms infrared spectroscopy (FTIR) analysis provided insights into the effect of DG on the compatibility between PALF and TBP matrix. The results indicated that DG enhances the polarity of the PALF-TBP system, leading to improved adhesion of PALF to the TBP matrix. The observed phenomena elucidate the notable augmentation in the mechanical properties of the DG10 sample. To summarize, the results of the current investigation suggest that the utilization of DG exhibits considerable promise in augmenting the mechanical characteristics of short PALF-TBP composites. Furthermore, it is anticipated that DG could serve as a feasible substitute for petroleum-derived polymers across several domains in forthcoming applications especially for engineering application such as automotive and packaging industries.

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DATA AVAILABILITY STATEMENT

Data sharing not applicable to this article as no datasets were generated or analysed during the current study.

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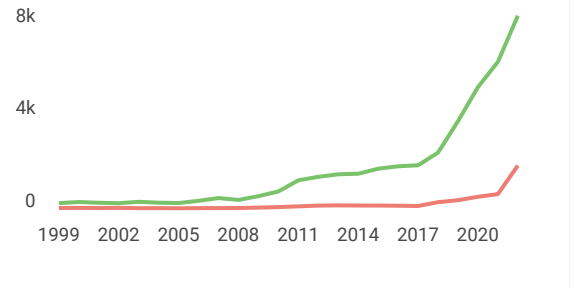

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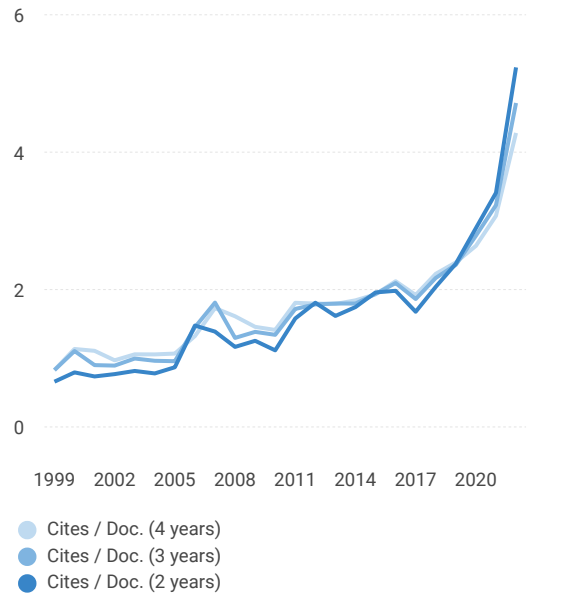

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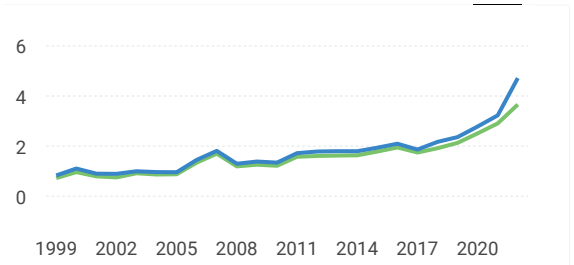

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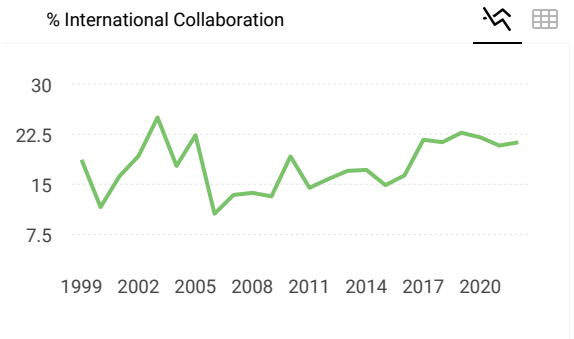

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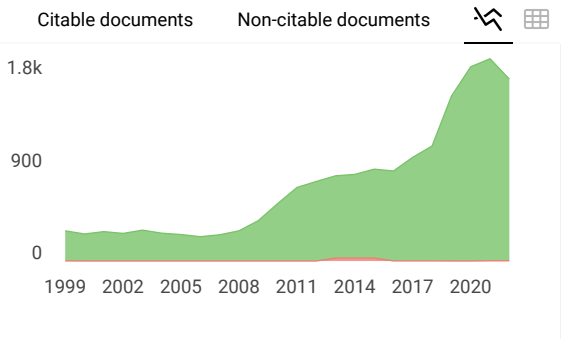

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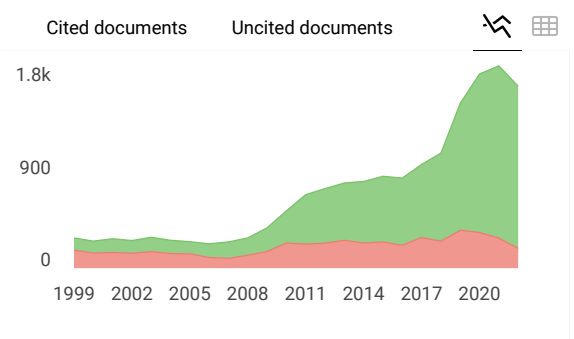

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