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Water Affinity and Environmental Characteristics of Thermoplastic Cassava Starch/ Beeswax Reinforced with Sugarcane Bagasse Fibre

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ABSTRACT

This study examines the effects of sugarcane bagasse on the properties of thermoplastic cassava starch (TPCS)/ beeswax (BW) composites. Composites containing sugarcane bagasse at varying ratios (10–30 wt.%) were prepared using dry mixing and hot pressing at 145°C. The environmental performance of TPCS/BW/sugarcane bagasse composites was assessed through key indicators such as water solubility and soil biodegradability. In addition, their water affinity characteristics including moisture content, moisture uptake, water absorption, thickness swelling,

and morphological features were systematically evaluated to understand their interaction with humid environments. Results demonstrated that the inclusion of sugarcane bagasse reduced the weight loss of the composites during soil burial and water solubility testing, indicating a reduced degradation rate. Water and moisture absorption tests revealed that increasing the sugarcane bagasse ratio decreased the water and moisture absorption percentages, suggesting enhanced hydrophobicity of the materials. However, the overall moisture content increased with higher fibre loading due to the hydrophilic nature of sugarcane bagasse. Thickness swelling analysis showed that adding fibre from 0 to 30 wt.% increased the swelling percentage from 41.1% to 54.1% following two hours of immersion. Morphological examination supported these findings by revealing the composite's internal structure and fiber-matrix interaction. This suggests that while sugarcane bagasse enhances moisture retention, it also increases expansion upon water exposure. Overall, sugarcane bagasse reduced the water affinity of thermoplastic starch (TPS) while increasing swelling and moisture content, demonstrating its significant influence on the composite's structural and environmental performance.

Keywords: Cassava starch; thermoplastic starch; beeswax; natural fibre; sugarcane bagasse fibre

INTRODUCTION

The widespread use of petroleum-derived plastics in the packaging sector is primarily driven by their superior multifunctionality, mechanical robustness, and exceptional barrier properties. Nevertheless, despite these advantages, such plastics pose a major environmental concern due to their non-biodegradable nature, contributing significantly to long-term pollution (Hafila et al. 2022; Ibrahim et al. 2019; Ilyas et al. 2018). Due to their extreme resistance to microbial degradation, non-biodegradable polymers used in packaging persist in the environment for several decades following disposal. Non-biodegradable plastics have been identified as major contributors to various global environmental issues, including water contamination and persistent accumulation in landfills due to their resistance to degradation. (Kamaruddin et al. 2023; Sanyang et al. 2016; Taharuddin et al. 2022). These environmental challenges have drawn significant attention to the development of novel biodegradable materials, such as thermoplastics derived from natural resources. The advancement of green materials is now being driven by the growing demand for solutions that are safe for both consumers and the environment (Shi et al. 2024).

Recent scientific interest in materials development has increasingly focused on the formulation of starch-based biopolymers. Starch, being one of the most prevalent materials, is used to produce thermoplastic by employing plasticiser and reinforcing material (Diyana et al. 2021; Hazrati et al. 2021; Kamaruddin et al. 2023). The chemical properties of the materials commonly come from the carbon chain, making them degrade and incorporate with the carbon in the soil and environment. The reinforcements used in the biopolymers are the fibres originating from plants and animals, as they offer adequate reinforcement to the materials while maintaining their environmental qualities (Rahmadiawan et al. 2025). The development of biodegradable materials is expected to mitigate the environmental impact associated with conventional thermoplastics, while offering safer alternatives for both consumer use and ecological sustainability. However, native starch remains inherently fragile and exhibits poor resistance to humidity, limiting its direct application. In recent years, increasing scientific interest has been directed toward the advancement of starch-based materials, owing to their intrinsic biodegradability, cost-effectiveness, and abundant availability in nature.

Starch can be converted into thermoplastic starch (TPS) by disrupting its granular structure and incorporating a plasticizer. Under elevated temperature and shear conditions, the plasticized starch undergoes transformation into TPS, which can then be processed using conventional thermoplastic equipment commonly employed for synthetic polymers, such as extrusion, compression moulding, and injection moulding. However, TPS exhibit inferior water barrier properties and mechanical performance relative to synthetic polymers, attributable to their high water affinity and hydrophilicity, which significantly limits their broader application. Consequently, numerous investigations have been undertaken by researchers in composite materials to improve the mechanical properties and water barrier qualities of thermoplastic starch-based materials while maintaining their biodegradability. Numerous modification methods, for instance, blending, plasticisation, derivation, and graft copolymerisation, have been researched to improve starch properties. As a result, numerous modification methods have been adopted. Apart from that, an intriguing approach to mitigate these drawbacks is the consumption of natural fibers as reinforcement for TPS. The mechanical capabilities of TPS are significantly enhanced when combined with natural fiber, attributable to the chemical resemblance between starch and plant fibers (Hafila et al. 2022). The incorporation of several natural fibers, including eucalyptus, wood pulp, flax, and jute, into starch/cellulose derivative blends resulted in enhanced tensile strength and Young's modulus, alongside a reduction in elongation with

higher fiber content (Asyraf et al. 2022; Kamaruddin et al. 2022a; Mohd Nurazzi et al. 2020). The use of cellulose fibers resulted in a notable enhancement in water resistance (Syazalee et al. 2023). This tendency is associated with the greater hydrophobic characteristics of natural fibers compared to the hydrophilic properties of starch. Furthermore, the thermal stability of TPS was noted to enhance due to the increased heat resistance of cellulose fibers (Mohamed et al. 2025).

Waxes serve as superior water vapor barriers relative to other lipids owing to their elevated fatty alcohol and long-chain alkane concentrations, resulting in enhanced hydrophobicity. Beeswax is excreted from the wax glands of honey bees. It is comparatively soft, yellow-hued, and possesses a low melting point of 62–64 °C. The chemical constituents comprise esters, hydrocarbons and free fatty acids, predominantly including palmitate, palmitoleate, and oleate esters of long-chain alcohols (Zhang et al. 2018). Beeswax is a naturally occurring substance that is hydrophobic in nature and is created by honeybees within their hive during the course of their life cycle. One of the components of a honeycomb is beeswax, which can be extracted from the honeycomb through centrifugation. There are a broad variety of applications for beeswax, including producing candles, casting metal, cosmetic items, food processing, textiles, and polishes (Diyana et al. 2021). Beeswax is the natural wax that experiences the greatest commercial use (Pervaiz et al. 2014). Apart from that, beeswax was selected as the hydrophobic agent because it is a biodegradable, food-grade wax with a relatively low melting point that enables incorporation into biopolymer matrices at moderate processing temperatures, provides effective moisture-barrier properties while maintaining film flexibility, and offers favorable regulatory and consumer-acceptance profiles compared with petroleum-derived paraffin or the harder, higher-melting carnauba wax.

Although previous studies have explored the blending of thermoplastic starch with beeswax, limited research has investigated the use of this polymer blend as a matrix for composite materials. Therefore, the objective of this study is to evaluate the influence of sugarcane bagasse fibre on the water affinity and environmental performance of thermoplastic starch/beeswax composites.

MATERIALS AND METHODS

MATERIALS

Cassava starch was sourced from Antik Sempurna Sdn. Bhd., Malaysia, whereas glycerol, serving as the plasticizer in this study, was acquired from QReC(Asia) Sdn. Bhd. Beeswax (BW) was supplied by Aldrich Chemistry Industries Sdn. Bhd. (Selangor, Malaysia). The sugarcane bagasse was collected as a residual byproduct following juice extraction by a local vendor. The material underwent a water-retting process for three weeks, followed by sun-drying for five hours. It was then ground into smaller particle sizes and subsequently oven-dried at 100 °C for five hours to remove moisture.

PREPARATION OF SAMPLES

The characteristics of the TPCS/BW matrix were modified by incorporating sugarcane bagasse fibre at varying loadings ranging from 0 to 30 wt.%, as outlined in Table 1. Initially, starch and glycerol were manually premixed, followed by blending with beeswax and sugarcane bagasse using a mechanical blender. The resulting mixture was then transferred into a mould and subjected to hot compression moulding at 145°C under a 10-tonne load for 60 minutes.

TABLE 1. Composite Formulation

Composite	Modified TPCS mixture (%)	Sugarcane Fibre Loading (wt%)
0 %	100	-
10%	90	10
20%	80	20
30%	70	30

MOISTURE CONTENT

Moisture content was assessed by subjecting the samples to oven-drying at 105 °C for 24 hours to eliminate any remaining moisture. To determine the initial moisture content, the specimens were cut into dimensions of 10 × 10 × 3 mm and weighed prior to drying (Wi) and after drying (Wf). The moisture content was then calculated using Equation (1):

$$\text{Moisture content (\%)} = \frac{W_i - W_f}{W_i} \times 100 \quad (1)$$

WATER ABSORPTION

The water absorption test was performed on three specimens of each formulation, measuring 10 × 10 × 3 mm, in accordance with ASTM D570-98, with minor modifications The specimens were subsequently dried in an air-circulating oven at 105 °C ± 2 °C for a duration of 24 hours. The weights of the specimen before, W_i, and after, W_f, the testing were recorded, and the amount of water absorbed was determined using the following equation.

$$\text{Water absorption (\%)} = \frac{Wi-Wf}{Wi} \times 100 \quad (2)$$

MOISTURE ABSORPTION

Moisture absorption testing was conducted with reference to ASTM D5229, incorporating minor modifications to accommodate the specific test conditions. For each formulation, three specimens were prepared and cut to dimensions of 10 × 10 × 3 mm to ensure consistency and suitability for the evaluation. The weight of the samples was recorded before, W_i, and after, W_f, the testing, and the moisture absorption was computed using Equation (3).

$$\text{Moisture absorption (\%)} = \frac{Wi-Wf}{Wi} \times 100 \quad (3)$$

THICKNESS SWELLING

Thickness swelling was evaluated in accordance with ASTM D570-98, using three specimens per formulation, each with dimensions of 10 × 10 × 3 mm. To remove residual moisture, the samples were oven-dried for 24 hours at 105 ± 2 °C using an air-circulating system. Following this, the dried specimens were submerged in water maintained at room temperature (23 ± 1 °C) for immersion periods of 0.5 and 2 hours. Their thicknesses were measured prior to immersion (Ti) and following the test (Tf), with the swelling calculated using Equation (4).

$$\text{Thickness swelling (\%)} = \frac{Ti-Tf}{Ti} \times 100 \quad (4)$$

FOURIER-TRANSFORM INFRARED SPECTROSCOPY (FTIR)

FT-IR analysis was conducted to detect and identify the functional groups within the sample. The analysis was conducted using a JASCO FT/IR-6100 IR spectrometer. Measurements were obtained in the range from 4000 cm^{-1} to 600 cm^{-1}.

SCANNING ELECTRON MICROSCOPE (SEM)

Morphological analysis was performed using a Zeiss EVO 18 Research SEM (Jena, Germany) under an acceleration voltage of 10 kV to investigate the microstructural features of the samples.

SOIL BURIAL

Soil burial testing was conducted by preparing three specimens of each formulation, with dimensions of 40 × 8 × 2 mm. The specimens were embedded approximately 10 cm beneath the surface and enclosed in a net containing soil of identical composition to the surrounding burial medium. The procedure was performed with reference to a modified method by (Ibrahim et al. 2014). The soil mixture consisted of 50% sand and 50% soil, with the temperature maintained at 30 ± 2 °C. To sustain the water content within the 30–40% range, 400 ml of water was added every three days to each 1250 g portion of the soil-sand mixture. Two experimental setups were established, with durations of 2 and 4 weeks. The initial weight of the specimen (Wi) and the final weight after testing (Wf) were recorded, and the water absorption was subsequently calculated using Equation (5), as specified in ASTM D6003-96.

$$\text{Weight loss (\%)} = \frac{W_i-W_f}{W_i} \times 100 \quad (5)$$

WATER SOLUBILITY

The samples were prepared by cutting a section measuring 10 × 10 × 3 mm, then subjected to drying at 105 °C ± 2 for 24 hours and weighing. The specimens were immersed in 30 ml of distilled water and gently agitated. After 24 hours, they were retrieved from the container, and any remaining surface moisture was blotted using filter paper, followed by oven drying at 105 °C for 24 hours and reweighed to determine the final weight. The weight reduction was calculated using Equation (6).

$$\text{Water solubility (\%)} = \frac{Wi-Wf}{Wi} \times 100 \quad (6)$$

STATISTICAL ANALYSIS

Statistical evaluation was performed using one-way analysis of variance (ANOVA) to determine differences among the tested groups. Duncan's multiple range test was subsequently applied to identify significant differences between mean property values at a confidence level of $p < 0.05$.

RESULTS AND DISCUSSION

MOISTURE CONTENT

Figure 1 illustrates that the moisture content of the composite materials reached its maximum at 10 wt.% fibre loading, while the lowest value was observed in the specimen without fibre (0 wt.%). This trend suggests that the incorporation of sugarcane bagasse fibre contributes to slight increased in moisture retention within the composite. The elevated moisture content is likely attributable to the hydrophilic nature of the lignocellulosic fibre, which inherently contains bound water and exhibits greater affinity for atmospheric moisture compared to the relatively hydrophobic polymer matrix (Edhirej et al. 2017a). Similar finding were also reported in the fabrication of sugarcana bagasse composites with pure cassava starch matrix (Edhirej et al. 2017a). However, although a visible rise in moisture content was observed, statistical analysis via ANOVA revealed no significant variation between the samples, as evidenced by the consistent group classifications.

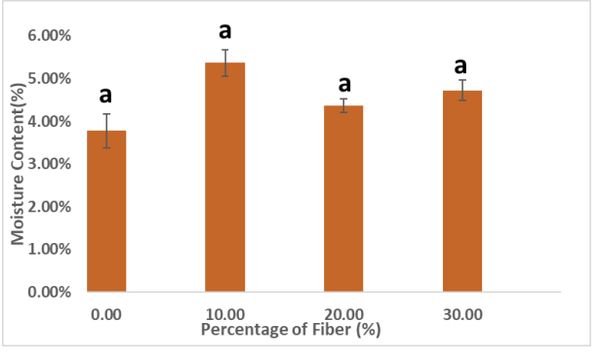

FIGURE 1. Moisture Content for TPCS/BW/sugarcane bagasse fibre composites

WATER ABSORPTION

Water absorption testing was conducted to assess the rate and extent of water uptake by the specimens, providing insight into their hydrophilic behaviour and potential suitability for applications requiring moisture resistance. Figure 2 presents the water absorption ability of the TPCS matrix and its composite when immersed in water for 0.5 and 2 h. For most specimens, the water absorption for 0.5 h water immersion resulted in absorption within the 41 to 49% range, indicating no significant variation. As for the specimens immersed in water for 2 h, it was found that the specimen with 0 wt.% fibre had the highest percentage of water absorbed, which value at 100.42%, and the least was the specimen with 30 wt.% fibre with the amount of water absorbed of 64.27%.

The reduction of water absorption mainly depended on the affinity of the matrix to the fibre compared to the water, yielding better fibre-matrix interfacial bonding. Also, the bonding formed from the higher fibre loading prevented the water from diffusing into the matrix (Lomelí Ramírez, Satyanarayana, Iwakiri, De Muniz, Tanobe, & Flores-Sahagun, 2011). Nevertheless, the decrease in absorption rate when sugarcane bagasse fibre was present may be linked to the fibres' capacity to create strong interfacial bonding, which hinders water infiltration into the matrix (Ibrahim et al. 2019). The presence of statistically significant differences in water absorption, as shown by ANOVA and group categorization, highlights the influence of formulation on water absorption behavior.

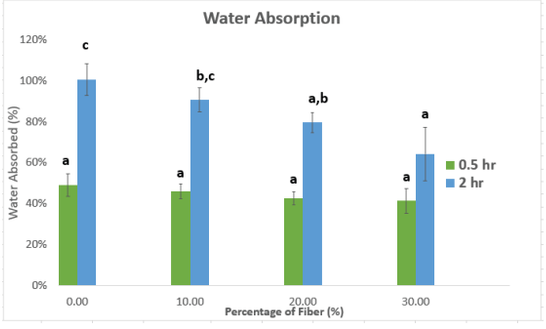

FIGURE 2. Water Absorption of TPCS/BW/sugarcane bagasse fibre composites

MOISTURE ABSORPTION

The moisture absorption testing was carried out to determine the rate of moisture absorption. According to a study, the rate of moisture absorption is the rate of transport of water molecules into the molecules that can be influenced by certain factors, such as the coefficient of diffusion, the environmental or equilibrium condition, and also the dimension of the material itself (Al-Maharma & Al-Huniti, 2019).

Figure 3 was obtained as a result of moisture absorption testing. Figure 3 shows that the specimens had fully absorbed the moisture to their capacity on day 5, indicating the specimen was highly hygroscopic. However, in terms of the fibre loading, the specimen with 0 wt.% fibre had the highest moisture uptake, and the specimen with 30 wt.% fibre had the least moisture uptake within 5 days. It was found that compared to specimens of 0 wt.% fibre, the composites with 10, 20, and 30 wt.% fibre reduced the percentage of moisture uptake by 0.07%, 1.16%, and 5.06%, correspondingly. This could be owing to the higher hydrophobicity of starch than cellulose, which was decreased with the presence of fibre (Curvelo et al. 2001). As can be seen, beeswax had a significant and favorable

effect on the enhancement of the water vapor permeability of the samples, and this favorable effect had a direct connection to the amount of beeswax that was loaded into the material. This result illustrates the effectiveness of beeswax, attributed to its hydrophobicity, as an enhancer of water resistance in bio-composite materials. This can be linked to the characteristics of the typical wax composition, which include the existence of long-chain alkanes and fatty alcohols. A comparable finding was reported in a prior investigation wherein sugar palm fibre-reinforced starch demonstrated reduced moisture absorption in comparison to the neat starch matrix (Sahari et al. 2013).

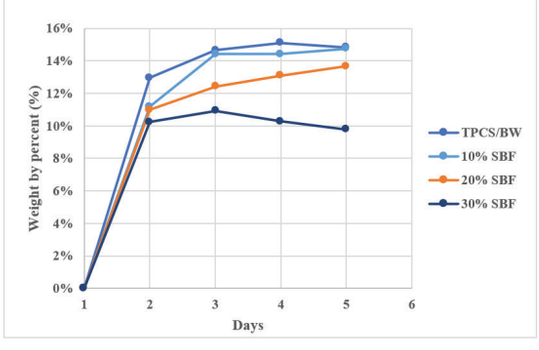

FIGURE 3. Moisture Absorption of TPCS/BW/sugarcane basgasse fibre composites

THICKNESS SWELLING

Thickness swelling assessment serves as one of the key evaluations for determining the dimensional stability of the specimens. It is a vital parameter in natural composite study, as it represents the capability of the material to tolerate certain conditions, for instance, indoor and outdoor uses as well as to ascertain its shelf life (Kamaruddin et al. 2022b).

The pattern for 0.5 and 2 h was similar, as shown in Figure 4. It was found that the specimen with a higher fibre percentage swelled the most. The percentages of thickness swelling of the 0 wt.% fibre specimens for the duration of 0.5 and 2 h were 27.83% and 41.08%, respectively, and for 30 wt.% fibre specimens were 32.93% and 54.12%, respectively. For 0.5 h and 2 h, the percentage of increments were 5.10% and 13.04%, respectively. Based on the ANOVA test, variations in swelling between samples were statistically significant, which was further validated through group letter differentiation. This result inferred that due to the presence of voids in the specimen, the swelling of the specimen increased with the increments of the fibre loading percentage. It was also recorded that the presence of voids in the composite affected the dimensional stability of the specimen (Sawpan et al. 2012). Apart from that, during the testing, it could be observed that the specimen began to delaminate as it absorbed water. From Figures 5(a) and 5(b), the delamination occurrence due to the presence of void was compared before and after the testing. The voids promoted water into the specimen; however, it caused delamination and water not being stored in the specimen.

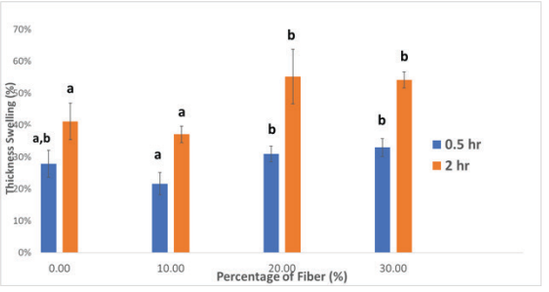

FIGURE 4. Thickness Swelling of TPCS/BW/sugarcane bagasse fibre composites

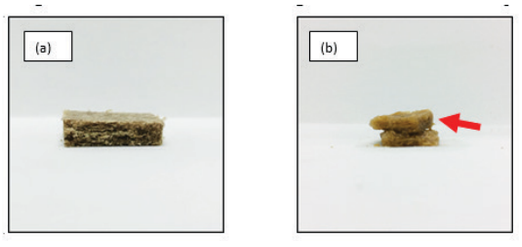

FIGURE 5. (a) Sample before and (b) sample after thickness swelling test (Arrow indicates the delamination of the specimen)

FTIR ANALYSIS

FT-IR testing is employed to characterise the chemical bonding of TPCS to cassava starch (Lomelí Ramírez, Satyanarayana, Iwakiri, De Muniz, Tanobe, Flores-Sahagun, et al. 2011). Figure 6 shows the FT-IR analysis of TPCS/BW and its composite. The presence of hydrogen-bonded hydroxyl group, O-H located in the range of 3100–3700 cm^{-1} was contributed by the starch and sugarcane bagasse fibre (Sarifuddin et al. 2016). However, the movement of the O-H bands as the percentage of the fibre loading increased was observed. Specimen with 0 wt.% fibre revealed a peak located at 3301 cm^{-1}. As the fibre percentage increased, the peak shifted to lower wavenumber as seen in specimen with 30 wt.% fibre at 3291 cm^{-1}. This was due to the increasing interaction of intermolecular hydrogen bonding which affect the O-H band peaks (Taharuddin et al. 2024)

The C-H stretch of aliphatic groups from hydrocarbon located in the range of 2850–2975 cm^{-1} was also seen to be present in the spectra of the specimens. A peak located at 1648 cm^{-1} was found in all specimens. This value signifies water or moisture, which indicates the moisture or water absorbed into the specimen (Jumaidin et al. 2020).

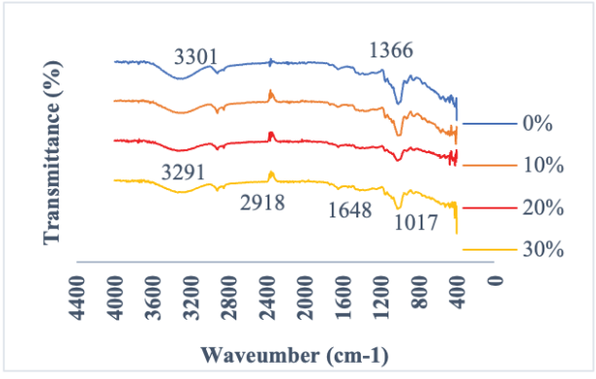

FIGURE 6. FT-IR result for TPCS/BW/sugarcane bagasse fibre composites

SCANNING ELECTRON MICROSCOPY (SEM)

From the SEM micrograph, the adhesion of the matrix and reinforcement can be assessed qualitatively from the image obtained. They can aid in the determination of the compatibility of the combination of the materials (Edhirej et al. 2017b). Aside from that, the dispersion of the fibre and matrix could also be observed through the SEM micrographs (Ma et al. 2005). Figures 7(a), (b), (c), and (d) show the microstructure of the TPCS/Beeswax surface and its composites obtained through SEM micrograph. The microstructures of the specimens were found to be varied according to the percentage of fibre present in the specimens.

The 0 wt.% fibre specimens acted as the control for the comparison of specimens with fibre loading from 10 to 30 wt.%. However, in the micrograph, it could be seen that the presence of beeswax altered the structure of the starch as the surface of the specimen was found to be in shiny granular-like shapes. Apart from that, it could be observed that cervices were formed between the surface as there was no reinforcement in the specimen. In relation to the finding, Sarifuddin et al. (2016) found a similar trend in the incorporation of LDPE with sago starch. Based on the findings, the inference could be made due to the agglomeration of the starch and weak interfacial bonding, as the materials were unable to create a homogenous mixture.

For the specimen with 10 wt.% fibre, no phase separation of the matrix and the fibre was observed as the fibre was combined into the matrix. This indicated good fibre wetting to the matrix and proved that the TPCS/Beeswax was able to form a homogenous surface when mixed with sugarcane bagasse. In contrast to the specimen with 20 and 30 wt.% fibre contents, the increase in fibre content was found to exert a notable influence on the composite's overall properties. The observation found small openings of phase separations when the fibre percentage increased. Apart from that, due to the phase separation, the specimens were found to develop porous surfaces as the phase separation occured.

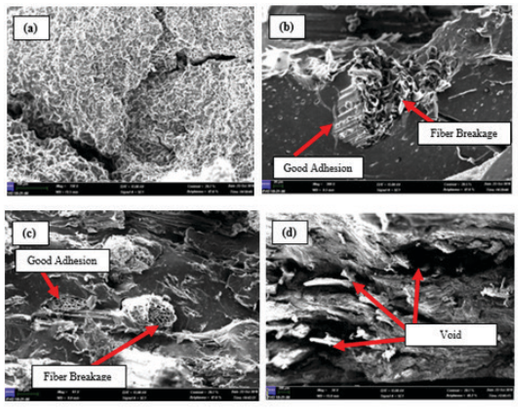

FIGURE 7. SEM Micrograph of TPCS/BW/Sugarcane bagasse fibre composites (a) 0 wt.% fibre (b) 10 wt.% fibre (c) 20 wt.% fibre (d) 30 wt.% fibre

SOIL BURIAL

The degradation process of TPS will significantly aid in reducing conventional thermoplastic waste. One of the main purposes of creating a biodegradable material is that the material should be able to decompose in the natural environment. The environmental degradation of TPS will alter the structure and properties of TPS before it disintegrates, and it would be able to function as a fertiliser to the soil with the carbon component previously existing in the TPS material (Amin et al. 2017). In general, using starch promotes water absorption, which will promote the degradation by natural causes (Wattanakornsiri & Tongnunui, 2012). However, the degradation rate of the material would differ based on environmental factors, i.e., humidity, temperature, pH of the soil, microorganisms present in the soil, as well as the characteristics of the material, including the composition, crystallinity, and synthesis method (Vasile et al. 2018).

Figure 8 shows the results obtained for 2 and 4 weeks of soil burial. After two weeks of soil burial testing, the specimen containing 30 wt.% fibre exhibited the highest mass reduction. The higher mass reduction observed for

30wt% fibre can be associated with the presence of voids within the samples. Typically, the presence of voids facilitates water uptake, thereby increasing the biodegradation of composites. However, this expectation appears to contradict the reported water absorption results, which showed no significant increase. This discrepancy suggests a more complex relationship between the internal structure of the composites, their water interaction properties, and degradation behavior. Addressing this interplay provides a more nuanced understanding of the material characteristics and highlights the need for further investigation into how voids influence both moisture dynamics and biodegradation processes. In a previous study, it was inferred that the voids mainly influence soil burial testing in the specimen, causing microbial organisms to enter the specimen and degrading the specimen. Maran et al. (2014) reported the availability of water opening will promote microbial organisms entering the specimen and increase the rate of degradation of the material.

However, after four weeks of soil burial, a decreasing trend in mass reduction was observed with increasing fibre loading, indicating improved structural integrity and resistance to biodegradation at higher fibre contents. These results demonstrate that the incorporation of sugarcane bagasse effectively reduced the mass loss of the samples. Consequently, the rate of biodegradation was prolonged with increasing fibre loading. This phenomenon can be attributed to the inherent characteristics of thermoplastic cassava starch (TPCS), which is more susceptible to biodegradation than the fibre. Therefore, the reduced starch content in composites with higher fibre loading contributed to the slower degradation rate. Analysis of variance (ANOVA) revealed statistically significant differences in mass reduction across the sample groups, as denoted by the use of different group letters in the post hoc comparison.

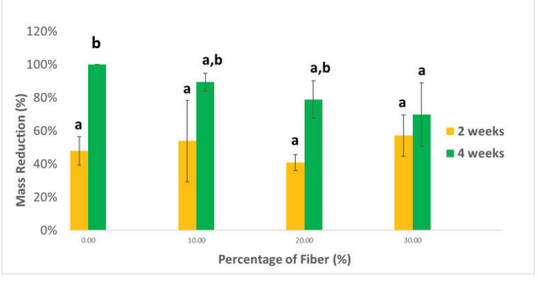

FIGURE 8. Mass loss of from TPCS/BW/Sugarcane bagasse fibre composites

WATER SOLUBILITY

Figure 9 presents the water solubility results of TPCS/BW and its fibre-reinforced composites. The specimen without fibre exhibited the highest weight loss, whereas the composite containing 30 wt.% fibre showed the lowest.

A declining trend in water solubility was observed with increasing fibre loading, indicating an inverse relationship between fibre content and solubility behavior. Analysis of variance (ANOVA) revealed statistically significant differences in weight loss across the sample groups, as denoted by the use of different group letters in the post hoc comparison. This result corelated to the finding of the water absorption and moisture absorption tests. Correspondingly to the result obtained from moisture absorption testing, the interfacial bonding of the matrix and fibre is possibly better with the higher percentage of fibre (Borges et al. 2015). This finding might be aattributed to the high networking of fibre that existed in high fibre content samples.

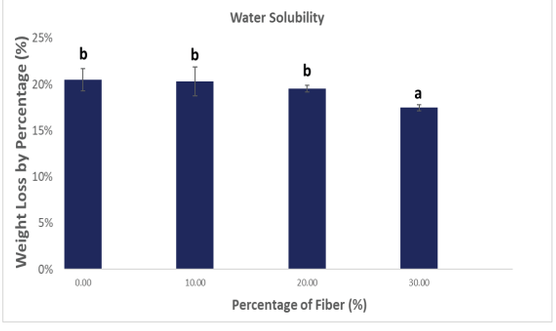

FIGURE 9. Water Solubility for TPCS/BW/Sugarcane bagasse fibre composites

CONCLUSION

Thermoplastic starch reinforced with sugarcane bagasse has been produced at various fibre contents, and their physical and environmental properties were investigated. Incorporating sugarcane bagasse into TPCS/BW has reduced the hydrophilicity characteristics of TPCS. This was indicated by the lower moisture absorption, water absorption, and water solubility values of the composites. These findings were accompanied by an increased thickness swelling of the composites. After 4 weeks of burial, increase in fibre content results to decrease in mass loss which was associated with more hydrophobic characteristic of sugarcane fiber and beeswax. Hence, a more comprehensive analysis is required to fully understand the degradation mechanisms, considering the complex interplay between void content, water absorption, and environmental factors affecting biodegradation rates. Future work should focus on elucidating these interactions to better predict the soil degradation performance of such composites. Overall, these results showed that sugarcane

bagasse is a promising reinforcement for TPCS, which is able to reduce the hydrophilicity of TPCS for wider potential application of this environmentally-friendly material.

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DECLARATION OF COMPETING INTEREST

None.

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