RESEARCH PROGRESS IN MECHANICAL AND MANUFACTURING ENGINEERING
e-ISSN: 2773-4765

RPMME

Vol. 6 No. 1 (2025) 196-208
https://publisher.uthm.edu.my/periodicals/index.php/rpmme

Synthesis and Characterisation of Composite Starch / Chitosan / Sugarcane Fibre / Zinc Oxide (ZnO) Bioplastics

Muhammad Afzan Azmi[1], Lee Woon Kiow[1]*,

[1] *Faculty of Mechanical & Manufacturing Engineering,*
Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Batu Pahat, Johor, MALAYSIA

*Corresponding Author: wklee@uthm.edu.my
DOI: https://doi.org/10.30880/rpmme.2025.06.01.021

Article Info

Received: 31 January 2025
Accepted: 20 May 2025
Available online: 31 July 2025

Keywords

Bioplastic, sugarcane fibre, potato starch, glycerol, acetic acid, chitosan, ZnO, sulfuric acid, tensile, water resistance, water solubility, biodegradable, SEM, FTIR

Abstract

Starch-based bioplastics, optimised with the right additives, could be effective for industrial use, supporting environmental sustainability by mitigating plastic pollution and reducing greenhouse gas emissions. The objective was to investigate the mechanical, thermal, and biodegradable properties of starch-based bioplastics by incorporating sugarcane bagasse fibre at varying concentrations (0.5%, 0.75%, and 1%). The bioplastics were produced using a casting method and analysed through tensile, water solubility, water resistance, biodegradability tests, SEM, and FTIR analysis. Results revealed that the addition of sugarcane bagasse fibre significantly improved the tensile strength and biodegradability, with 1% fibre yielding the best overall performance. However, water resistance decreased with higher fibre content, highlighting a trade-off between mechanical and barrier properties. These findings demonstrate the potential of sugarcane bagasse fibre to enhance bioplastic performance, offering a sustainable solution to mitigate plastic pollution and reduce reliance on fossil fuel-based materials.

1. Introduction

Over the years, the production of polymers from renewable resources has grown significantly, driven by the need to replace fossil fuel-based plastics. Bioplastics, derived from renewable biomass sources like vegetable oils, corn starch, and microbial biomass, have gained attention as sustainable alternatives due to their renewable and biodegradable properties. Conventional plastics, derived from fossil fuels, contribute significantly to environmental issues, including plastic waste that takes hundreds to thousands of years to decompose and increased greenhouse gas emissions from incineration. The rising global demand for plastics, projected to account for 20% of fossil fuel extraction by 2050, underscores the urgency of transitioning to bio-based plastics to reduce dependency on non-renewable resources and mitigate their environmental impact [1].

Bioplastics, such as polylactic acid (PLA) and polyhydroxyalkanoates (PHA), offer a sustainable solution to global plastic pollution by reducing reliance on fossil fuels and providing biodegradable or compostable alternatives. These materials are used in diverse applications, from packaging and disposable items to medical devices and textiles. While they offer significant environmental benefits, including lower greenhouse gas emissions and reduced plastic waste in landfills, the production and disposal of bioplastics require careful management to ensure they deliver on their sustainability promise. By leveraging renewable resources and promoting a circular economy, bioplastics present a promising alternative to traditional plastics in addressing global environmental challenges.

This is an open access article under the CC BY-NC-SA 4.0 license.

Research Progress in Mechanical and Manufacturing Engineering Vol. 6 No. 1(2025) p.196-208

Plastic waste poses a significant threat to marine ecosystems, with an estimated 3% of the 415 million tons of plastic produced in 2019 leaking into oceans and marine habitats annually. This amounts to approximately 10 million tons of plastic waste each year, exacerbated by the 32% of single-use plastics that evade collection systems. Additionally, plastic waste in landfills contributes to leakage into water systems, ultimately reaching the oceans. This ongoing pollution highlights the urgent need for effective waste management and reduction strategies to address the growing environmental crisis. Simultaneously, the problem of greenhouse gas (GHG) emissions further drives climate change, causing rising global temperatures, severe weather events, and ecosystem disruptions. Addressing these challenges requires transitioning to renewable energy, protecting forests, and adopting sustainable practices to mitigate GHG emissions and reduce plastic waste.

Despite their potential, starch-based bioplastics face limitations that hinder their wide application. These include high water vapour and oxygen permeability, making them unsuitable for applications requiring strong barrier properties, such as food packaging [2]. Additionally, their fragility, low tensile strength, and poor thermal resistance restrict their durability and functionality in demanding environments. While their biodegradability is a benefit, it limits their long-term stability for applications requiring prolonged use. Furthermore, manufacturing starch-based bioplastics often requires specialised equipment due to limited processability. Addressing these challenges through innovation and research is essential to enhance the performance of starch-based bioplastics, making them viable for a broader range of industrial and consumer applications while supporting sustainable solutions to plastic pollution.

The objectives of this research are designed to evaluate the success of the experiments and address the problems stated. Firstly, the study aims to fabricate composite bioplastics by integrating potato starch with sugarcane bagasse fibre. Secondly, it seeks to investigate the impact of incorporating sugarcane bagasse fibre on key properties of potato starch-based bioplastics, including water permeability, water solubility, and tensile strength. Lastly, the research examines the biodegradability of potato starch-based films with varying concentrations of sugarcane bagasse fibre, providing insights into their potential as sustainable and eco-friendly materials.

The scope of this study focuses on developing bioplastics using potato starch as the primary component, combined with chitosan and sugarcane fibre. The sugarcane fibre content will be varied at concentrations of 0.5%, 0.75%, and 1% to examine its influence on the bioplastics. The chemical properties of the bioplastics will be analysed using FTIR, while their detailed microstructure will be observed through SEM. Additionally, the tensile strength of the bioplastics will be evaluated according to the ISO 527-2/1BB standard, ensuring a comprehensive assessment of their mechanical properties.

2. Methodology

The methods section, otherwise known as methodology, describes all the information required to obtain the study's results.

2.1 Sugarcane bagasse fibre extraction

Figure 1 shows that sugarcane bagasse was sourced locally, washed, and dried after juice extraction. It was soaked in 1M NaOH for 1 hour at room temperature, rinsed with water, and then heated at 70°C for 15 minutes. The fibres were then cut into 5 mm pieces for further use, as shown in Figure 2.

Fig. 1 *Fibres after treatment*

Fig. 2 *Fibers after cut into 5 mm length*

2.2 Sample preparation

The bioplastic films in this study were prepared using the casting method, as shown in Figure 3. A mixture of distilled water, acetic acid, glycerol, and potato starch in a 0.5:0.75:1 weight ratio was homogenised with 6% ZnO using a magnetic stirrer to form a gel. Separately, 8% chitosan (based on starch weight) was dissolved in sulfuric acid and added to the gel, then homogenised at 110°C for 20 minutes at 400 rpm. Sugarcane bagasse fibre was incorporated into the gel at concentrations of 0.5%, 0.75%, and 1%, then poured into moulds as shown in Figure 4 and left to dry at room temperature. The resulting bioplastic samples were categorised as A (pure), B (pure+ZnO+chitosan), C (with 0.5% fibre), D (with 0.75% fibre), and E (with 1% fibre) as shown in Table 1.

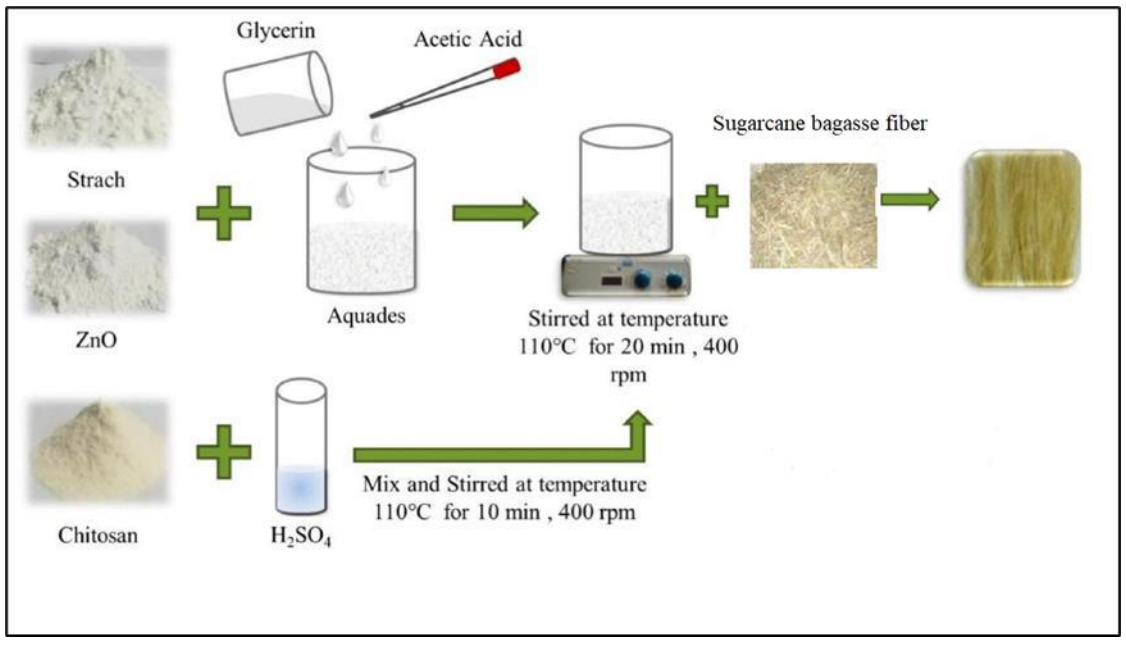

Fig. 3 *The potato starch/ZnO/chitosan/sugarcane bagasse bioplastic film preparation method*

Fig. 4 *Bioplastic gel in the mold*

Research Progress in Mechanical and Manufacturing Engineering Vol. 6 No. 1(2025) p.196-208

Table 1 *The composition of each sample*

Sample	A	B	C	D	E
Potato Starch (g)	10	10	10	10	10
Glycerol (g)	6.67	6.67	6.67	6.67	6.67
Acetic Acid (g)	3.3	3.3	3.3	3.3	3.3
Distilled Water (ml)	60	60	60	60	60
Zinc Oxide (g)	0	0.6	0.6	0.6	0.6
Chitosan (g)	0	0.8	0.8	0.8	0.8
Sulphuric Acid (g)	0	4	4	4	4
Sugarcane Fibre (g)	0	0	0.38	0.57	0.76

2.3 Thickness Measurement

The bioplastic samples must meet ASTM D638 standards, requiring a thickness of less than 1.0 mm. A vernier calliper measures thickness at five points, and the average is calculated. Surface roughness is assessed by checking if values deviate more than ±0.2 mm from the mean; samples exceeding this range are considered unsuccessful.

2.4 Tensile Test

Tensile tests were performed following ISO 527-2/1BB for the samples by using Universal Machine GT-7001- LS10 as shown in Figure 5. The sample was cut into a dumbbell shape according to ISO 527-2/1BB, as shown in Figure 6.

Fig. 5 *Tensile test machine*

Fig. 6 *Shape of dumbbell cut*

2.5 Water Resistance

Figure 7 shows that the water resistance (WR) of starch-based bio-composites was evaluated by measuring the weight change of 2 cm × 2 cm specimens. Samples were dried at 80°C for 48 hours, then placed in desiccators at 25°C with 100% humidity [3]. Weights were recorded every 24 hours until the increment was less than 0.001 g. WR was calculated using the Equation 1:

$$WS = \frac{w_i - w_f}{w_i} \times 100 \quad (1)$$

where **wi** is the initial weight, and **wf** is the weight after absorption.

Fig. 7 *Water resistance test of the samples*

2.6 Water Solubility

Figure 8 shows that the water solubility (WS) of bio-composites, an important factor for selecting packing materials, indicates their integrity in aqueous environments [3]. WS was calculated using Equation 2:

$$WS = \frac{w_i - w_f}{w_i} \times 100 \quad (2)$$

where: WS = water solubility, wi = initial weight of sample and wf = final weight of sample.

Fig. 8 *Water solubility test of the samples*

2.7 Biodegradable Test

Biodegradability tests assess a material's ability to break down naturally through microbial action into harmless byproducts. In this study, the biodegradability of potato starch-based bioplastic was tested using compost soil, following ASTM D6003-96 to measure weight loss. The test duration was limited to 20 days, during which the sample's decomposition was observed [4]. Figure 9 shows the bioplastic sample buried in compost soil.

Research Progress in Mechanical and Manufacturing Engineering Vol. 6 No. 1(2025) p.196-208

Fig. 9 *Bioplastic sample has been buried under compost soil*

2.8 Fourier Transform Infrared Spectroscopy (FTIR)

The spectrometer was used to perform Fourier transform infrared spectroscopy while it was in the attenuated total reflectance (ATR) mode as shown in Figure 10. Using 200 cumulative scans, the spectra in the 400 - 4000 cm^{-1} range were acquired [5].

Fig. 10 *FTIR machine*

2.9 Scanning Electron Microscopy (SEM)

The test is run on a Hitachi SU1510 SEM equipment as shown in Figure 11. SEM images were captured with a 5000x magnification using an electrical potential for acceleration that operated at 15kV. The calibration of the spot and the working distance (WD) are set at 10.8mm and 5.5mm, respectively [5].

Figure 11 *Hitachi Scanning Electron Microscope*

3. Results and Discussion

This presents the findings from various tests conducted to evaluate the tensile, water resistance, water solubility, degradation, SEM images, and FTIR images properties of potato starch-based bioplastic incorporated with different concentrations of sugarcane fibres at 0.5%, 0.75% and 1%. The objective is to understand how these additives affect the bioplastic mechanical properties and biodegradability, potentially enhancing their application and environmental benefits.

3.1 Tensile test

The tensile test results, shown in Figure 12, reveal varying maximum forces for the samples, indicating their tensile strength. Sample E exhibits the highest tensile force of approximately 0.9 N, suggesting superior mechanical stability, while Sample A has the lowest at 0.2 N. Samples B, C, and D show intermediate tensile forces, with progressively increasing strength. These differences are attributed to factors such as reinforcing fibres, antimicrobial agent dispersion, and material composition, which impact the tensile performance [6]. Sample E's high tensile force indicates it can withstand the most stress before failure, making it the most robust in terms of mechanical properties. In contrast, Sample A's low tensile force suggests weak intermolecular bonding and poor mechanical performance. Samples B, C, and D show moderate strength, with potential improvements needed in composition or fabrication. Overall, the results indicate that optimising the bioplastic formulation could significantly enhance tensile strength, with Sample E being the most promising for applications requiring higher mechanical strength.

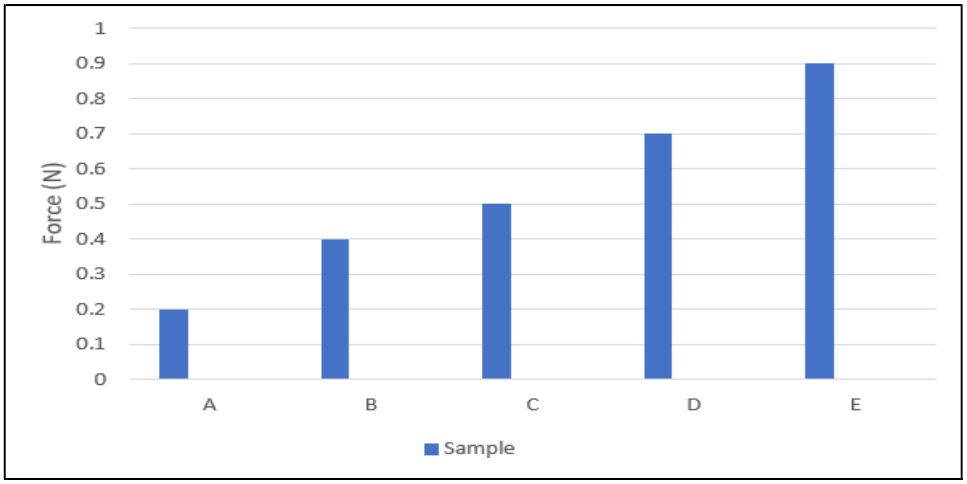

Fig. 12 *Tensile stress value for bioplastic*

Research Progress in Mechanical and Manufacturing Engineering Vol. 6 No. 1(2025) p.196-208

3.2 Water Resistance Test

The water resistance data in Figures 13 and 14 highlight significant performance differences among the bioplastic samples. Sample A shows the highest water resistance at approximately 18%, absorbing the least water relative to its weight, while Sample E has the lowest resistance at about 8%, making it more prone to water absorption. Samples B, C, and D demonstrate intermediate resistance, with a decreasing trend from B to E. This variation is linked to material composition, as the addition of rice husk fibres (10%–50%) has been shown to reduce moisture content significantly, as reported by [6]. Sample A's superior water resistance, likely due to hydrophobic components or a tighter polymer network, makes it ideal for applications requiring minimal water absorption, such as packaging in humid environments. Conversely, Sample E's poor water resistance suggests a more hydrophilic composition, limiting its suitability for moisture-sensitive applications despite its strong tensile properties. While Samples B and C offer a balance of water resistance and mechanical strength, the trade-offs between these properties highlight the importance of optimising bioplastic formulations for specific applications.

SAMPLE	BEFORE (g)	AVERAGE (g)	AFTER (g)	AVERAGE (g)
A	0.12	0.11	0.14	0.13
	0.11		0.13	
	0.1		0.11	
B	0.13	0.13	0.15	0.15
	0.14		0.14	
	0.13		0.17	
C	0.21	0.22	0.25	0.25
	0.23		0.24	
	0.22		0.25	
D	0.3	0.31	0.33	0.34
	0.32		0.35	
	0.33		0.33	
E	0.36	0.37	0.4	0.4
	0.4		0.41	
	0.35		0.38	

Fig. 13 *Water resistance test data*

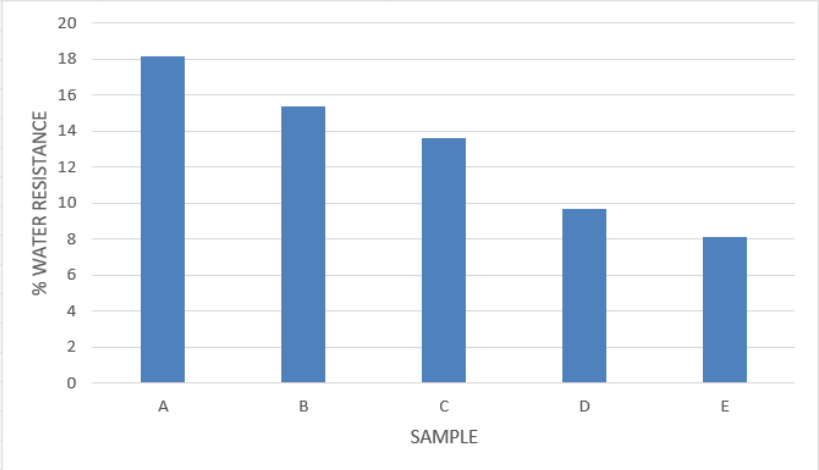

Fig. 14 *Water resistance percentage*

3.3 Water Solubility Test

The water solubility results in Figures 15 and 16 reveal significant differences among the bioplastic samples, influencing their suitability for various applications. Samples A and B have the highest water solubility at approximately 16% and 14%, respectively, indicating lower water resistance due to higher hydrophilic content or reduced crosslinking. In contrast, samples C, D, and E show lower solubility percentages, with Sample E exhibiting the least solubility at about 5%. These trends align with prior findings that adding fibres, such as rice

husk, reduces moisture content and improves water resistance [6]. Mass measurements after water immersion support these observations, as Samples A and B absorb more water, while Samples C, D, and E display minimal changes, reflecting greater stability. Sample E emerges as the most water-resistant bioplastic, ideal for applications requiring durability in moist environments, such as food packaging or agricultural films. Samples C and D also demonstrate good water resistance, making them suitable for moderate exposure. In contrast, Samples A and B, with their higher solubility, are better suited for applications like dissolvable films or products requiring controlled degradation in water. Overall, selecting the appropriate bioplastic depends on balancing water resistance with application-specific requirements, highlighting the need for tailored material formulations.

SAMPLE	BEFORE (g)	AVERAGE (g)	AFTER (g)	AVERAGE (g)	REMARKS
A	0.12	0.12	0.14	0.14	NOT SOLUBLE
	0.11		0.13		
	0.13		0.15		
B	0.14	0.14	0.17	0.16	NOT SOLUBLE
	0.15		0.17		
	0.14		0.15		
C	0.25	0.25	0.15	0.27	NOT SOLUBLE
	0.27		0.3		
	0.24		0.25		
D	0.33	0.32	0.34	0.34	NOT SOLUBLE
	0.32		0.33		
	0.32		0.34		
E	0.37	0.38	0.43	0.4	NOT SOLUBLE
	0.37		0.4		
	0.37		0.38		

Fig. 15 *Water solubility test data*

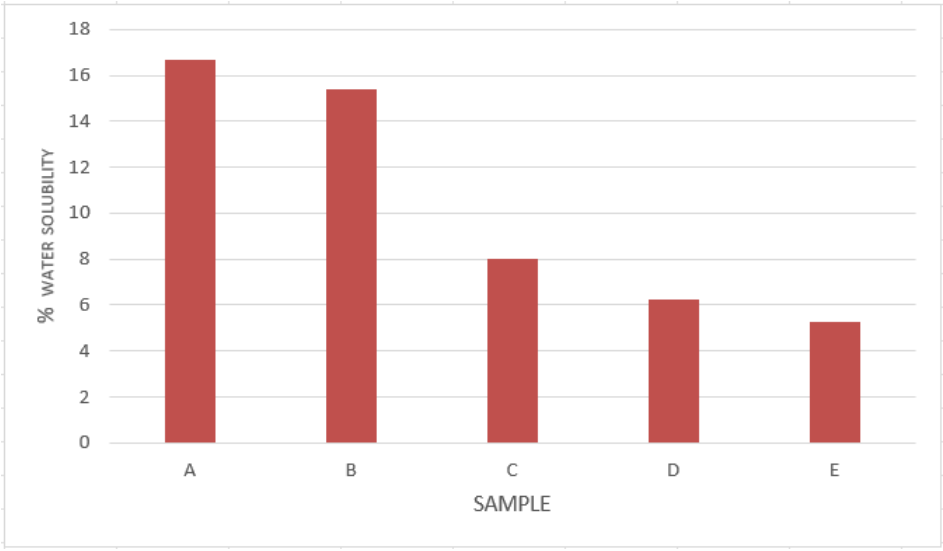

Fig. 16 *Water Solubility percentage*

3.4 Biodegradable Test

The biodegradability of bioplastic samples with varying fibre concentrations (Samples A to E) was evaluated over 23 days through weight loss data and visual observations (Table 2 and Fig.17). On Day 0, all samples appeared intact with consistent surfaces, while fibre-reinforced samples had higher initial weights. By Day 7, degradation was evident, with Sample E showing the most significant weight loss (0.12 g) due to its higher fibre content promoting microbial activity. In contrast, Sample A exhibited minimal weight loss (0.04 g), indicating slower biodegradability. Fragmentation and microbial activity, visible as black and white spots, were more pronounced in fibre-rich samples, while the control sample, made of starch and glycerol, degraded faster due to hydrolysis [6].

Research Progress in Mechanical and Manufacturing Engineering Vol. 6 No. 1(2025) p.196-208

By Day 23, Sample E displayed the highest biodegradability, with a cumulative weight loss of 0.29 g and complete disintegration into fragments. Sample D followed closely with significant degradation (0.23 g), while Sample C showed moderate breakdown. Samples A and B exhibited the least degradation, with weight losses of 0.01 g and 0.03 g, respectively. The results demonstrate that higher fibre concentrations enhance biodegradability, making Sample E the most environmentally friendly. However, slower-degrading samples like Sample A may be better suited for applications requiring longer durability.

Table 2 *Sample weight loss*

Day	Sample weigh loss (g)				
	A	B	C	D	E
Day 0	0.13	0.17	0.25	0.33	0.42
Day 7	0.09	0.10	0.19	0.23	0.30
Day 14	0.04	0.07	0.11	0.16	0.22
Day 23	0.01	0.03	0.06	0.10	0.13

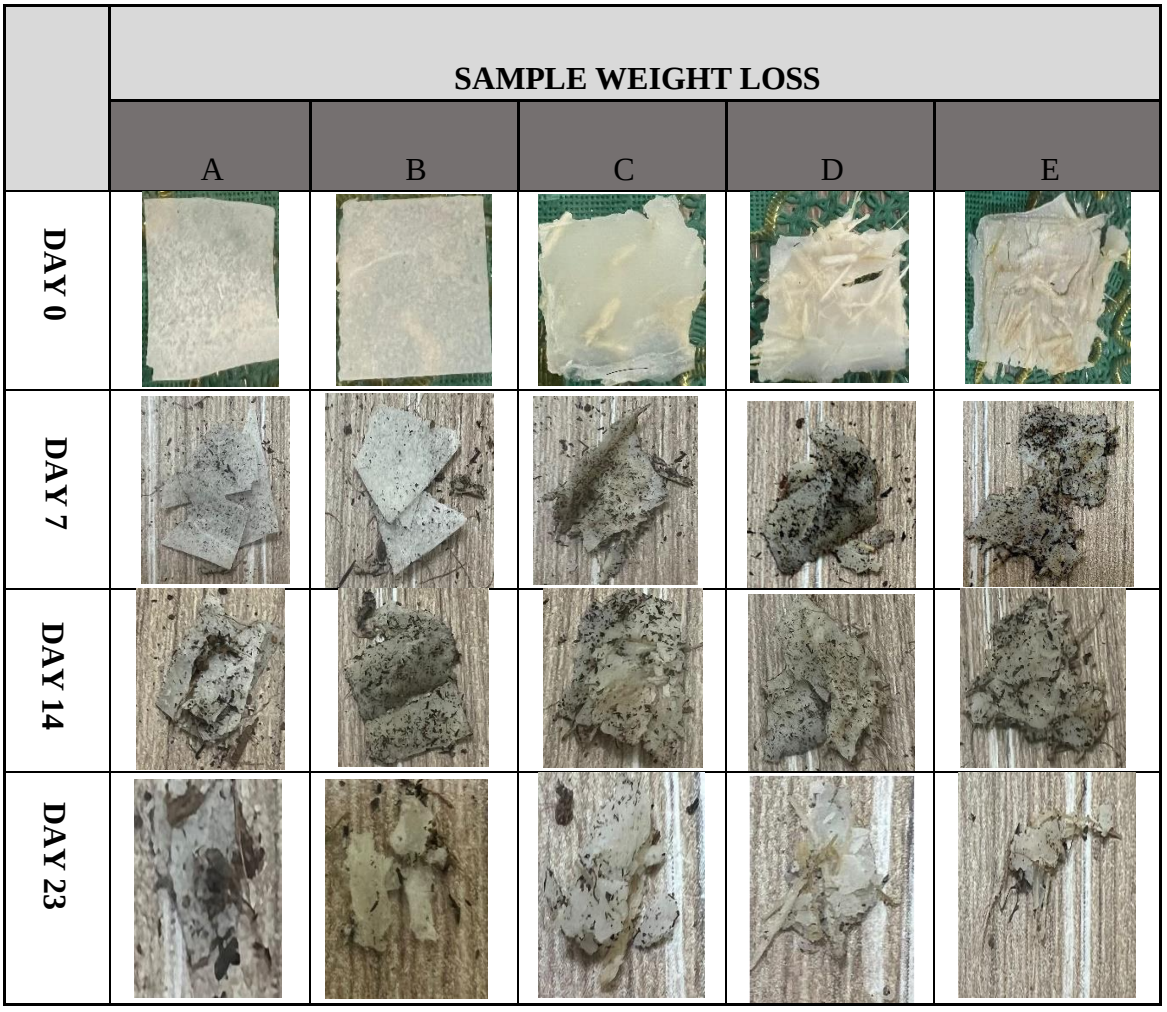

Fig. 17 *Images of samples' weight loss*

3.5 Morphology analysis

The SEM images in Figure 18 reveal how the structural morphology of bioplastic samples (A to E) is influenced by their compositions. Sample A, representing pure bioplastic, has a smooth, uniform surface with evenly distributed spherical particles, indicating a consistent but reinforcement-free structure. While its low porosity enhances moisture resistance, the lack of strengthening agents limits its mechanical durability. Sample B, with ZnO and chitosan added, shows a more complex structure with fibrous and irregular components, but uneven dispersion results in structural imperfections that could weaken its mechanical properties. Despite these flaws, the added antimicrobial and functional properties make Sample B more versatile than Sample A.

Samples C and D, with 0.5% and 0.75% fibre content, respectively, display denser matrices with fibres integrated into the bioplastic. Sample C shows improved mechanical reinforcement, but some pores and uneven dispersion. Sample D, with higher fibre content, has prominent porosity and void spaces, suggesting weakened

structural integrity due to disrupted bonding. Sample E, with 1% fibre, ZnO, and chitosan, demonstrates the most optimised structure, with well-integrated fibres, minimal porosity, and strong matrix adhesion. This combination results in enhanced tensile strength, flexibility, and durability, making Sample E the most multifunctional and structurally robust bioplastic among the samples.

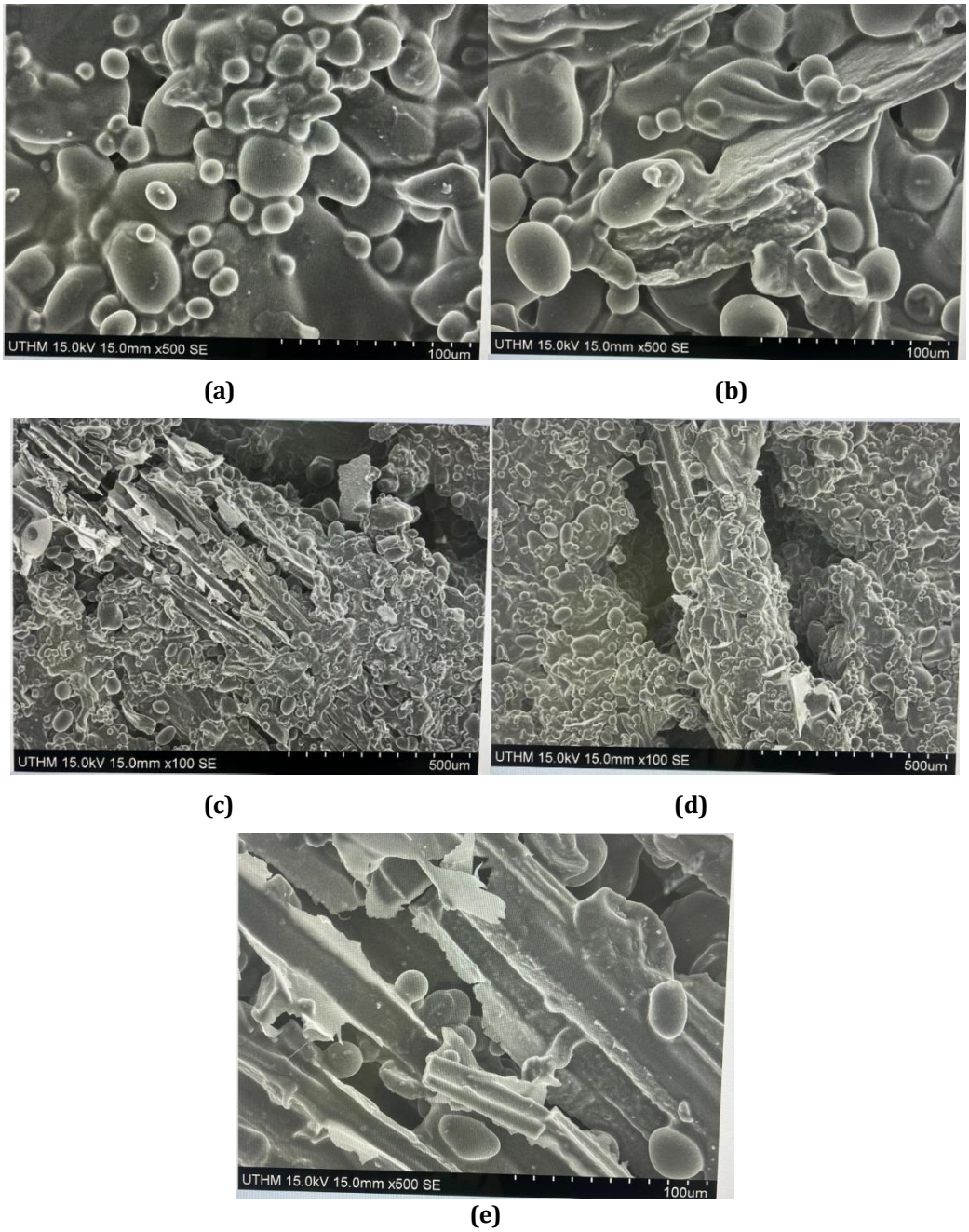

Fig. 18 *(a) SEM image of sample A (b) SEM image of sample B (c) SEM image of sample C (d) SEM image of sample D (e) SEM image of sample E*

3.6 FTIR Test

The FTIR spectra in Figure 19 highlight the chemical interactions within bioplastic samples (A to E) based on their compositions. Sample A (pure bioplastic) displays simple, well-defined peaks, indicating a uniform structure without additives. Sample B, containing ZnO and chitosan but no fibre, shows increased peak intensity in the hydroxyl and carbonyl regions, reflecting enhanced chemical interactions. However, the absence of fibre limits structural reinforcement, reducing its mechanical properties. The addition of fibre in Samples C (0.5%), D (0.75%), and E (1%) broadens and intensifies these peaks, signalling improved hydrogen bonding and fibre-matrix interactions.

Sample D (0.75% fibre) exhibits the strongest enhancement in the hydroxyl and carbonyl regions, suggesting optimal fibre-matrix compatibility and improved mechanical strength and water resistance. Sample C (0.5% fibre) shows moderate peak changes, indicating good but less pronounced reinforcement compared to Sample D. In contrast, Sample E (1% fibre) reveals excessive peak broadening and potential irregularities from fibre

agglomeration, reducing uniformity and performance. Overall, Sample D offers the best balance of fibre content and matrix compatibility, while Samples A and B, lacking fibre reinforcement, are less suited for applications requiring strength and durability.

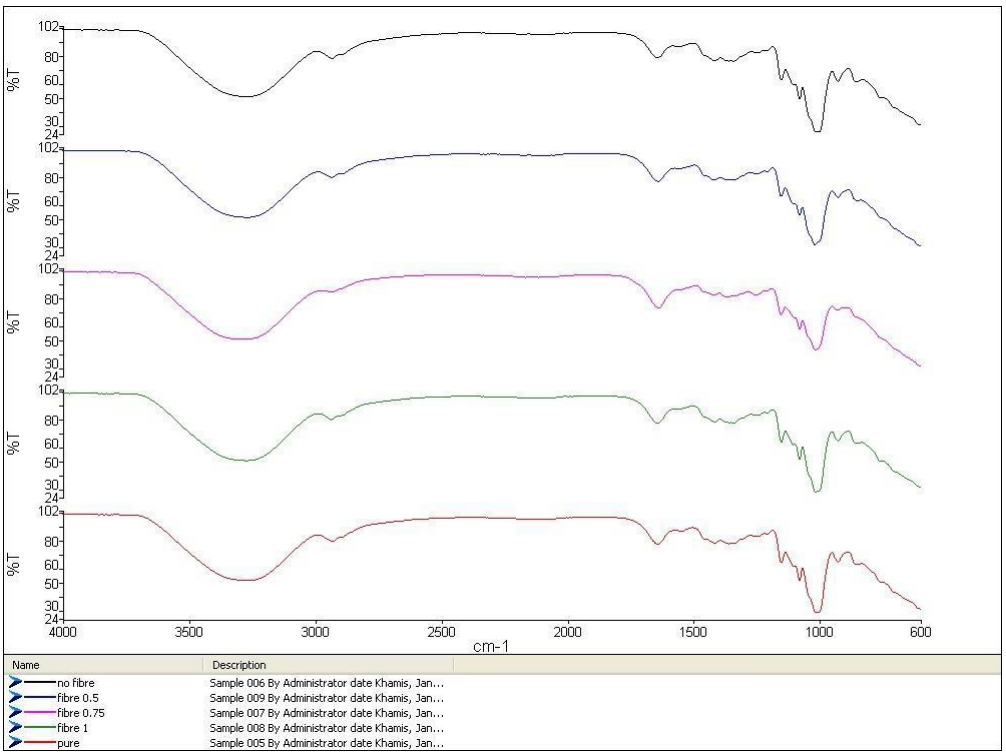

Fig. 19 *FTIR spectra*

4. Conclusion

The study successfully fabricated and evaluated composite bioplastics made from potato starch, sugarcane bagasse fibre, ZnO, and chitosan, achieving significant improvements in mechanical properties, thermal stability, and biodegradability. Sample E (1% fibre) demonstrated the best tensile strength and structural integrity, as confirmed by SEM analysis, though it exhibited reduced water resistance and the fastest degradation rate, making it ideal for environmentally friendly applications. The findings highlight the need for balancing fibre content to optimise water resistance and structural stability for broader use cases.

Acknowledgement

The authors wish to thank the Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia, who has supported the accomplishment of the research activity

Conflict of Interest

The authors declare no conflict of interest regarding the paper's publication.

References

[1] Rahardiyan, D., Moko, E. M., Tan, J. S., & Lee, C. K. (2023). Thermoplastic starch (TPS) bioplastic, the green solution for single-use petroleum plastic food packaging – A review. In *Enzyme and Microbial Technology* (Vol. 168). Elsevier Inc. https://doi.org/10.1016/j.enzmictec.2023.110260

[2] Abe, M. M., Martins, J. R., Sanvezzo, P. B., Macedo, J. V., Branciforti, M. C., Halley, P., Botaro, V. R., & Brienzo, M. (2021). Advantages and disadvantages of bioplastics production from starch and lignocellulosic components. In *Polymers* (Vol. 13, Issue 15). MDPI AG. https://doi.org/10.3390/polym13152484

[3] Fitch-Vargas, P. R., Camacho-Hernández, I. L., Martínez-Bustos, F., Islas-Rubio, A. R., Carrillo-Cañedo, K. I., Calderón-Castro, A., Jacobo-Valenzuela, N., Carrillo-López, A., Delgado-Nieblas, C. I., & Aguilar-Palazuelos, E. (2019). Mechanical, physical and microstructural properties of acetylated starch-based biocomposites reinforced with acetylated sugarcane fiber. *Carbohydrate Polymers*, *219*, 378–386. https://doi.org/10.1016/j.carbpol.2019.05.043

[4] Ismail, N., Mohd Tahir, S., Yahya, N., Wahid, M., Khairuddin, N., Hashim, I., Rosli, N., & Abdullah, M. (2016). Synthesis and Characterization of Biodegradable Starch-Based Bioplastics. *Materials Science Forum*, *846*, 673–678. https://doi.org/10.4028/www.scientific.net/MSF.846.673

[5] Sangian, H. F., Maneking, E., Tongkukut, S. H. J., Mosey, H. I. R., Suoth, V., Kolibu, H., Tanauma, A., Pasau, G., As'ari, A., Masinambow, V. A. J., Sadjab, B. A., Sangi, M. M., & Rondonuwu, S. B. (2021). Study of SEM, XRD, TGA, and DSC of Cassava Bioplastics Catalyzed by Ethanol. *IOP Conference Series: Materials Science and Engineering*, *1115*(1), 012052. https://doi.org/10.1088/1757-899x/1115/1/012052

[6] Srivastava, V., Singh, S., & Das, D. (2023). Rice husk fiber-reinforced starch antimicrobial biocomposite film for active food packaging. *Journal of Cleaner Production*, *421*. https://doi.org/10.1016/j.jclepro.2023.138525