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Bending Strength Analysis of Polymer Composite Reinforced With Dried Leaves Filler

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ABSTRACT

This study investigates the bending strength of polymer composite materials reinforced with crushed dried leaves as a natural filler, offering a sustainable alternative to synthetic fibres. Eight different composite specimens were fabricated using various combinations of cement, polyester resin, river sand, and dried leaves, with compositions guided by previous research. Specimens were tested according to ASTM C580 using a three-point bending setup to evaluate flexural properties. Results revealed that polyester resin-based composites (ROO and RSO) exhibited the highest flexural strength, with ROO reaching 26.84 MPa and demonstrating significant ductility, while RSO showed superior stiffness (modulus of elasticity: 2367.2 MPa). Composites containing dried leaves (especially RDS) showed moderate strength (14.05MPa) but improved strain (0.0724) characteristics, indicating potential for energy-absorbing applications. Failure modes ranged from brittle fractures to ductile deformations, revealing how different material compositions influence mechanical behaviour. The findings affirm the feasibility of incorporating minimally processed dried leaves in polymer composites for structural and semi-structural applications, promoting environmentally friendly material innovation.

1.0 Introduction

Polymer composites reinforced with natural fillers, such as dried leaves, are gaining attention due to their potential to replace synthetic fibres, offering environmental benefits and enhanced material properties such as bending strength. The bending strength of polymer composites reinforced with dried leaves filler is a topic of interest due to the potential of using renewable resources to enhance material properties especially for application with flexural loading. This potential has been reported through a review by Md Jaafar (2022) which suggested an experimental study to be made on polymer composite employing dried leaves as reinforcement in three variations: raw, shredded and pulverized. Based on other previous research articles, the application of organic solid waste such as dried leaves are recognized for their potential as a renewable resource in polymer composites, offering a sustainable alternative to synthetic fibres (Mohit & Selvan, 2015; Elsen et al., 2019, Shariffah et al, 2025, Huzaisham et al., 2020). They can enhance mechanical properties due to their cellulosic nature, which contributes to strong interfacial bonding within the polymer matrix (Mohit et al., 2023). Composites reinforced with dried leaves and other fillers like cobalt, nickel, and ferrous have shown improved mechanical stability. The presence of dried leaves contributes to higher mechanical and thermal stability, as observed in studies using artificial neural network techniques to predict these properties (Mohit et al., 2023).

In addition to dried leaves, other natural fillers such as wheat straw and pine leaves have shown similar potential. For instance, wheat straw increased bending strength up to 30 wt.% before a decline was observed (Cherkashina et al., 2023). Similarly, pine tree leaves in epoxy composites showed significant flexural strength improvements (Ayyanar et al., 2024). The combination of dried leaves with other fillers, such as eggshells, in hybrid composites has also been investigated. While lemon leaves alone showed lower mechanical properties, their combination with eggshells provided intermediate values, suggesting that hybridization can optimize performance (Hayajneh et al., 2021). Similarly, dried banana leaves fibre, when treated with sodium hydroxide, improved the tensile strength of recycled polypropylene composites by enhancing matrix-filler interaction (Narayanan et al., 2019). Natural fillers like dried leaves are often more cost-effective than synthetic alternatives, making them an attractive option for producing economically viable composites with desirable properties (Irudhayam et al., 2020).

Despite their advantages, the application of dried leaves in polymer composites remains limited due to the challenges associated with their pre-processing. As noted by Pokhriyal et al. (2014) and Kacem et al. (2024), natural fibre preparation typically involves multiple stages such as harvesting, retting, drying, extraction, and surface treatment, which increase complexity and production cost. To address this issue, the present study proposes a simplified approach using minimally processed dried leaves—dried under sunlight and manually crushed—to serve as reinforcement in polymer composite fabrication. The primary objective of this research is to evaluate the flexural performance of polymer composites containing crushed dried leaves as a filler. A series of composite specimens incorporating different matrix systems (cement and polyester resin) and filler combinations were fabricated and tested in accordance with ASTM C580. The experimental results provide insights into the mechanical behaviour and failure modes of these composites, supporting the development of sustainable materials suitable for structural and semi-structural applications.

2.0 Materials and Testing Program

In this study, eight variations of polymer composite specimens were fabricated, incorporating different combinations of raw materials, including both the matrix binder and reinforcement filler. The materials used were cement (C), polyester resin (R), river sand (S), and crushed dried leaves (D). The dried leaves were pre-processed by drying them for two hours under direct sunlight, followed by manual crushing to reduce the particle size. The matrix-to-reinforcement ratio was set at 30:70 for all specimens, following the guidelines from Manda et al. (2020). For specimens containing two types of reinforcement materials, the ratio was adjusted to 50:50. Each specimen was labelled according to its material composition, using the abbreviations of the raw materials. The wet mixture of each composite was cast into a 1' x 0.5' PVC mould and left to cure for 7 days at room temperature. Figure 1 provides an overview of the specimen preparation process, and Table 1 outlines the composition and specifications of each test specimen.

Figure 1. Process of test specimen preparation

Table 1. Specimen variations and composition specification

Bil	Specimen	Composition Specification	Weight
1	ROO	100% Polyester Resin (R)	58g
2	RSO	30% Polyester resin (R) + 70% River sands (S)	58g
3	COO	100% Cement (C)	123g
4	CSO	30% Cement (C) + 70% River sands (S)	89g
5	RDS	30% Polyester resin (R) + 35% crushed dry leaves (D) + 35% River sands (S)	84g
6	RDO	30% Polyester resin (R) + 70% Crushed dry leaves (D)	44g
7	CSD	30% Cement (C) + 35% River sands (S) +35% Crushed dry leaves (D)	75g
8	CDO	30% Cement (C) + 70% Crushed dry leaves (D)	75g

Figure 2 shows the overall testing setup for the experimental testing. The flexural properties of the specimens were assessed using a three-point bending test, conducted in accordance with ASTM C580— Standard Test Method for Flexural Strength and Modulus of Elasticity of Polymer Concretes. The specimens were tested using a Shimadzu 50 kN universal testing machine (Figure 2a), equipped with a three-point bending apparatus. The bottom jig provided two free supports, and the upper jig, featuring a cylindrical shape, applied the load. The span between the supports was set to 110 mm, and the specimen dimensions were 12 mm in depth and 27 mm in width (Figure 2c). The loading rate was set at 0.003 inches per minute, consistent with the ASTM C580 standard, ensuring a controlled and gradual application of load. The test was automated using Trapezium software, which was linked to the testing machine for real-time data acquisition (Figure 2b). After completing the tests, the raw data were analysed to determine the maximum load, displacement, strength, strain, and modulus of elasticity for each specimen. Additionally, failure modes were recorded and analysed to understand the material's behaviour under load.

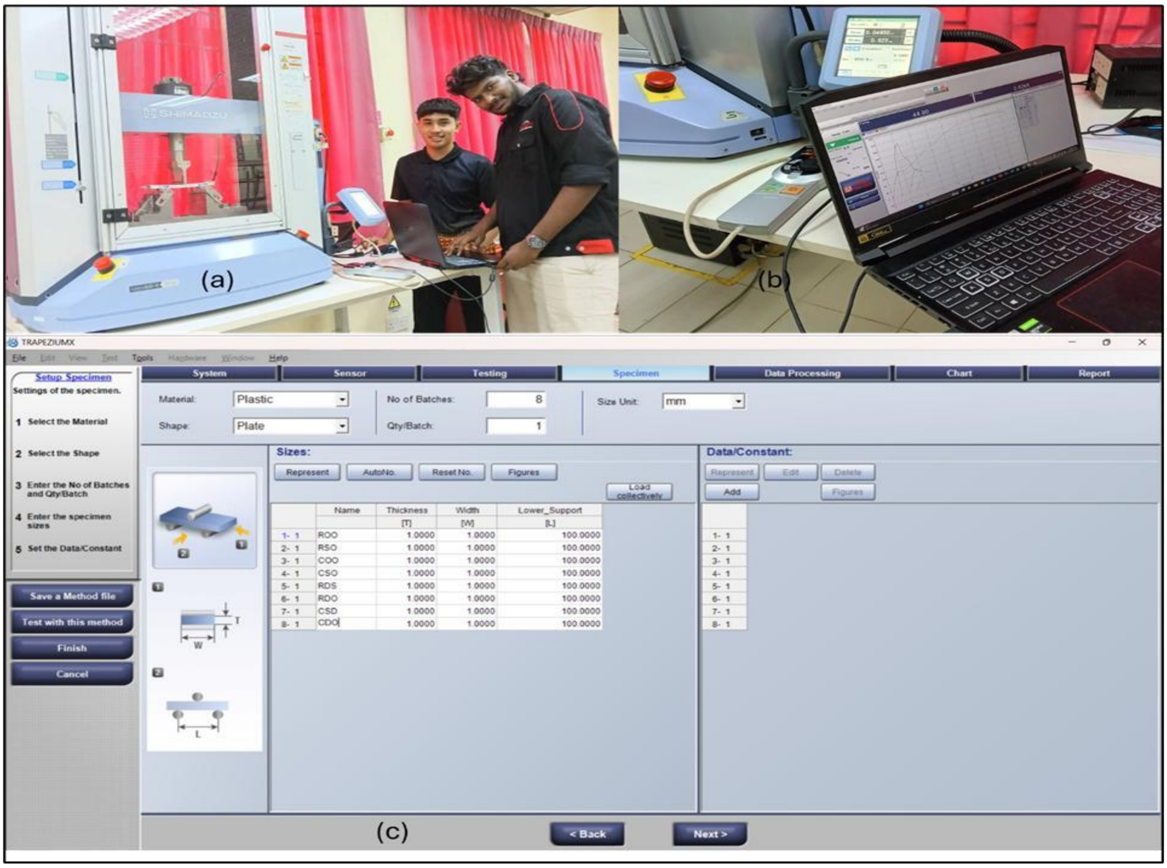

Figure 2. Mechanical test setup. (a) Shimadzu 50 kN universal testing machine, (b) linking Trapezium software to the testing machine, and (c) test specimens' specification setting.

3.0 Results and Discussion

3.1 Mechanical Properties

Define abbreviations and acronyms the first time they are used in the text, even after they have been defined in the abst The mechanical properties of the composite specimens were evaluated using the three-point bending test, and the key parameters—maximum load, maximum displacement, maximum strength, maximum strain, and modulus of elasticity—were recorded. Table 2 presents a summary of the test results, while Figure 3 displays the stress vs. strength curves for all the test specimens.

Table 2. Summary of mechanical test results

No	Specimen	Max. Load (N)	Max Displacement (mm)	Max Strength (MPa)	Max Strain	Modulus Elasticity (MPa)
1	ROO	316.26	27.39	26.84	0.1630	211.65
2	RSO	298.87	5.85	25.37	0.0348	2367.2
3	COO	119.23	5.65	10.12	0.0336	654.16
4	CSO	126.61	5.73	10.75	0.0341	719.91
5	RDS	165.55	12.16	14.05	0.0724	403.68
6	RDO	89.30	7.32	7.58	0.0435	400.63
7	CSD	125.72	4.69	10.67	0.0279	438.07
8	CDO	122.97	6.43	10.44	0.0383	365.44

The highest maximum load was recorded for the ROO specimen at 316.26 N, corresponding to a maximum strength of 26.84 MPa. The RSO specimen followed closely with a strength of 25.37 MPa at a slightly lower load of 298.87 N. On the other hand, the lowest maximum load was observed for RDO (89.30 N), which also exhibited the lowest strength at 7.58 MPa. The highest strain value was recorded for ROO at 0.1630, followed by RDS at 0.0724, indicating their ability to undergo significant deformation before failure. Conversely, CSD showed the least strain at 0.0279, suggesting higher rigidity. Maximum displacement values followed a similar trend, with ROO reaching 27.39 mm, while CSD exhibited the least displacement at 4.69 mm. The highest modulus of elasticity was observed in RSO (2367.2 MPa), signifying superior stiffness compared to other specimens. In contrast, CDO had the lowest modulus (365.44 MPa), indicating greater flexibility and lower resistance to deformation under load.

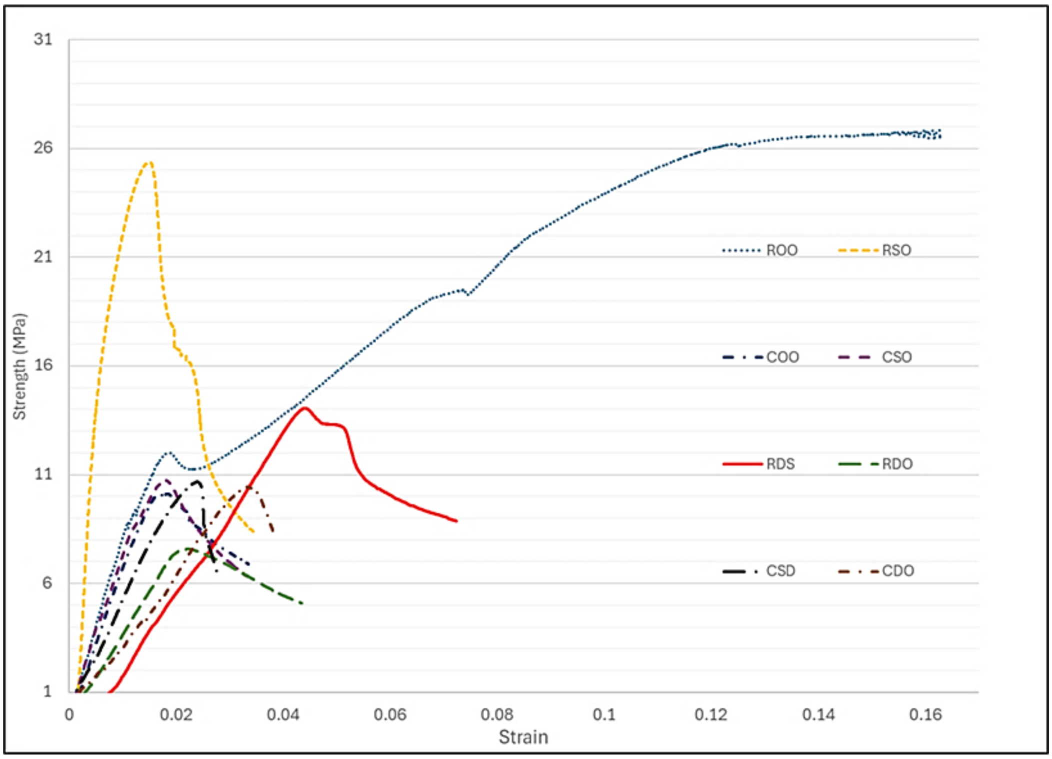

Figure 3. Stress versus strength curve for bending strength of all test specimens

The findings suggest that the ROO and RSO specimens demonstrate superior mechanical performance, particularly in terms of strength and stiffness. ROO, with the highest strain and displacement, exhibits ductile behaviour, making it suitable for applications requiring high deformation before failure. RSO, with its high modulus of elasticity, is ideal for structures requiring significant rigidity and minimal deformation under stress. Comparatively, COO and CSO exhibited moderate mechanical properties, with strength values around 10 MPa and strain values near 0.034. These materials may be suited for applications where moderate strength and stiffness are required. On the lower spectrum, RDO and CDO exhibited the weakest mechanical properties, with low strength and modulus of elasticity. These specimens may not be suitable for load-bearing applications but could be utilized where flexibility is prioritized.

The results also indicate that recycled materials (ROO, RSO, RDS) generally perform better than their composite counterparts (COO, CSO, CDO). This could be attributed to better bonding and load transfer mechanisms in the recycled samples. Further studies on microstructural analysis and failure mechanisms may provide deeper insights into these behaviours.

3.2 Failure Modes

Figure 4 and Figure 5 show the failure of each test specimen with behavioural curve to relate how the failure occurred. The failure modes observed in the specimens have provided crucial insights into their mechanical behaviours and potential applications. Specimen ROO has failed with exploding and scattered randomly. This failure mode indicates a brittle fracture with sudden energy release, signifying that the material could not undergo significant plastic deformation before failure. The high strain and displacement values further support its ductile nature before catastrophic failure. Then, specimen RSO failed with fracture in smooth cut which suggests a relatively brittle failure with minimal plastic deformation. This mode is typical for materials with high modulus of elasticity, as seen in RSO's 2367.2 MPa. Specimen COO showing fractured with multiple cracks and cuts. The presence of multiple cracks and cut-like fractures suggests a mixed brittle-ductile failure. These behaviours may arise due to microstructural inconsistencies or weak bonding in the material.

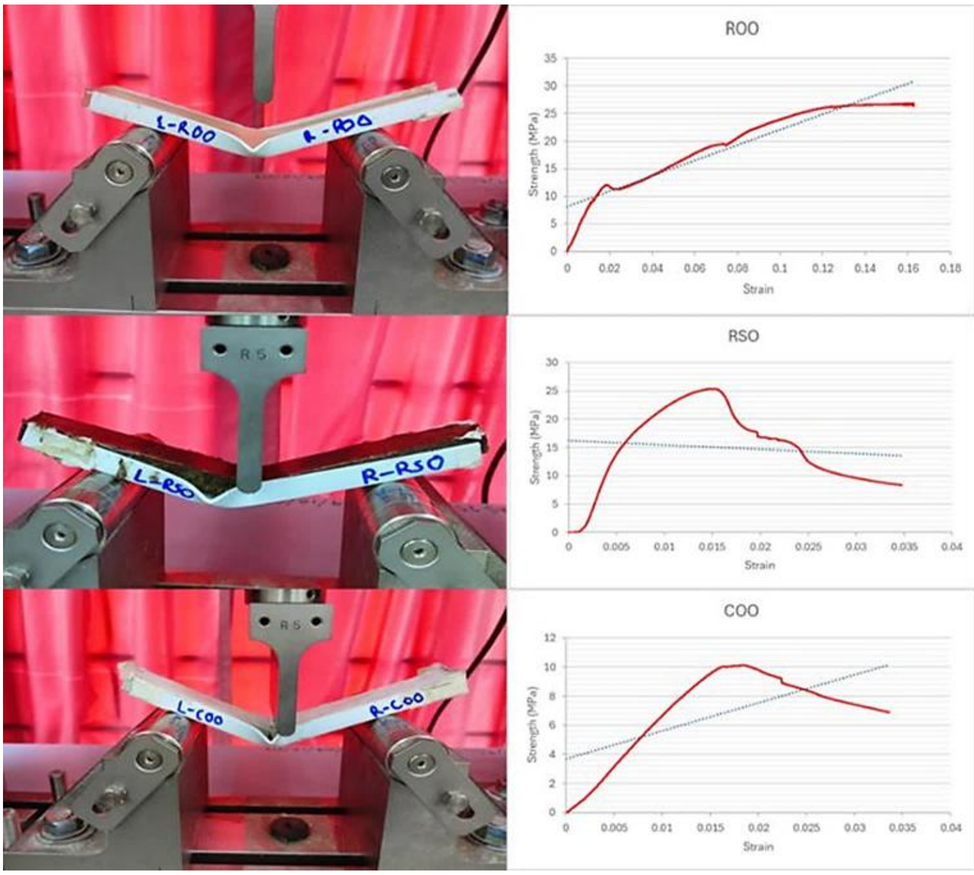

Figure 4. Failure modes and failure behaviour of specimen ROO, RSO and COO

Specimen CSO showing multiple fractures without cracking indicate a gradual failure process, possibly due to progressive microcrack propagation under load. Specimen RDS failed with internal cracks without sign of fracture. The internal crack formation without complete fracture suggests a strong material with good toughness, capable of withstanding stress without immediate catastrophic failure. Specimen RDO shows softened without crack or fracture reflecting ductile behaviour, where the material deforms significantly without breaking, likely due to a lower modulus of elasticity. Specimen CSD has softened and finishes with crushing failure. A combination of softening and crushing suggests a compressive failure mode, where the material deformed beyond its structural limit. Finally, specimen CDO fails with filler particles peeling out while showing major crushing signs. This failure mode indicates weak bonding between the filler and the matrix, causing disintegration under stress.

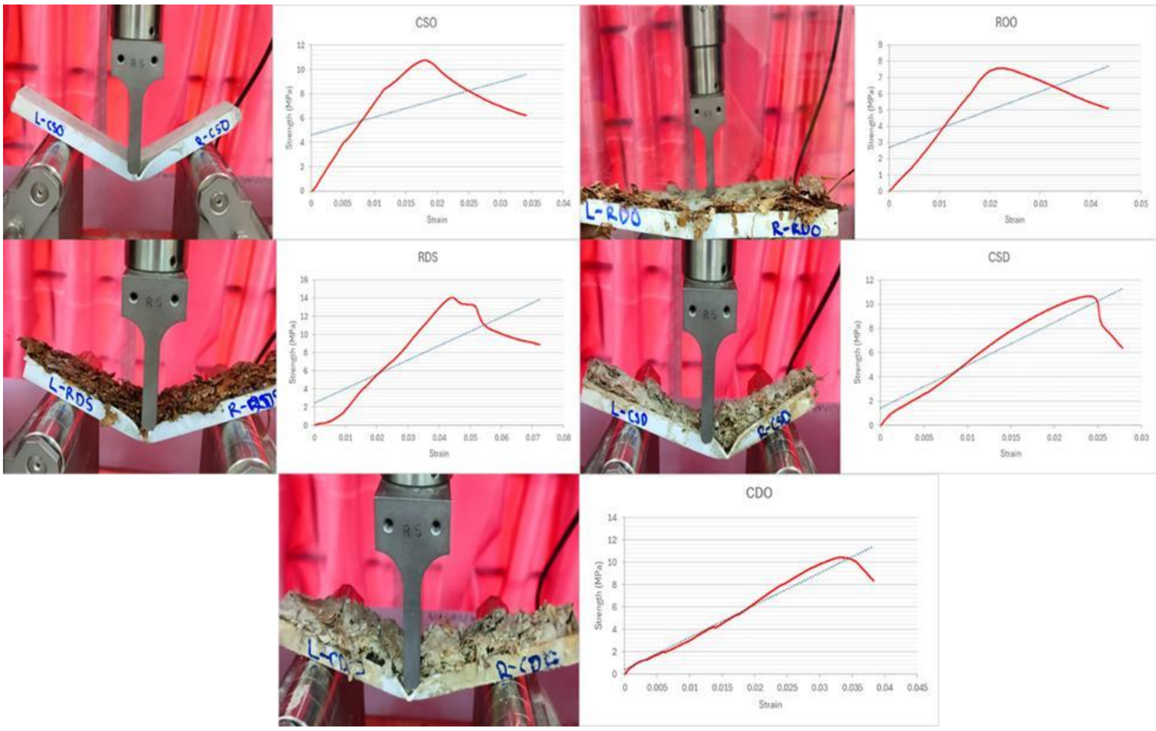

Figure 5. Failure modes and failure behaviour of specimen CSO, RDO, RDS, CSD and CDO

Table 3. Summary of failure modes of all test specimens

Specimen	Summary of Failure Modes
ROO	Exploded and scattered energy.
RSO	Fracture with smooth cut.
COO	Fracture with multiple cracks and cuts.
CSO	Multiple fractures without cracking.
RDS	Internal crack without sign of fracture.
RDO	Softened without crack or fracture.
CSD	Softened and crushing failure.
CDO	Filler particles peeling out and showing crushing signs.

4.0 Conclusion

This study investigated the mechanical behaviour of composite materials incorporating dried leaves as a sustainable filler in combination with polyester resin, cement, and river sand. The three-point bending test revealed significant variation in mechanical performance depending on the composition of the specimens. Among all the tested samples, ROO (100% polyester resin) and RSO (polyester resin and river sand) demonstrated the highest bending strength and stiffness, making them suitable candidates for structural applications that demand high mechanical performance. The high strain capacity of ROO also indicates its potential for applications requiring ductile behaviour. In contrast, specimens with a high proportion of dried leaves, such as RDO and CDO, exhibited lower mechanical strength and stiffness but showed greater flexibility and ductility. While these materials may not be ideal for load-bearing applications, they hold promise for non-structural uses or components where energy absorption, flexibility, or environmental sustainability is a priority. The experimental results also revealed that hybrid compositions, such as RDS and CSD, offer a balance between strength and ductility. This suggests that the mechanical performance of natural-fibre reinforced composites can be further optimized by adjusting the proportions of matrix and filler materials. Overall, the use of dried leaves as a filler in polymer and cement-based composites offers an eco-friendly approach to material development. Future work should explore the influence of filler particle size, chemical treatment, and hybrid reinforcement strategies on mechanical behaviour to enhance the performance and broaden the application potential of these sustainable composites.

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Author Contributions

Manda M. S.: Conceptualization, Methodology, Software, Writing- Original Draft Preparation, Supervision; **Md Jaafar N. S.**: Data Curation, Validation, Supervision; **Abd Manaf A. S. A.**: Software, Validation; **A.Gunalan V.:** Methodology, Software.

Conflicts of Interest

The manuscript has not been published elsewhere and is not being considered by other journals. All authors have approved the review, agree with its Submission and declare no conflict of interest in the manuscript.

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