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CONFERENCE PROCEEDINGS

4th International Research Conference - 2025

''Towards a Resilient Future:
Engineering Research on Social, Environmental and Ethical Renewal''

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Research Unit
Institute of Technology, University of Moratuwa

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Foreword

We are pleased to present the Proceedings of the 4th International Research Conference of the Institute of Technology, University of Moratuwa (ITUM-IRC 2025). This year's theme, "Towards a Resilient Future: Engineering Research on Social, Environmental, and Ethical Renewal" reflects our commitment to advancing research that supports resilience and sustainability in line with the Clean Sri Lanka Project launched in 2025.

This volume brings together extended abstracts from a wide range of disciplines, offering a platform for academics, professionals, and industrialists engaged in research to exchange knowledge and showcase their work. The proceedings document the outcomes of the conference held on 9th October 2025 at the Institute of Technology, University of Moratuwa (ITUM), Diyagama, and serve as a record of the valuable contributions made by our researchers.

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Editorial Committee Acknowledgements

The Editorial Committee is pleased to present the Proceedings of the 4th International Research Conference of ITUM (ITUM-IRC 2025), which brings together a wide range of scholarly contributions under the theme *"Towards a Resilient Future: Engineering Research on Social, Environmental, and Ethical Renewal"*.

This volume reflects the commitment of authors who shared their research, as well as the reviewers whose careful evaluations helped to strengthen the quality of the submissions.

We believe that the proceedings of ITUM-IRC 2025 will provide a meaningful resource for researchers, academics, and professionals, and contribute to advancing dialogue on sustainable and resilient solutions.

We sincerely thank all who contributed to making this publication possible.

Sincerely,

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ITUM International Research Conference 2025

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Message from the Director,
Institute of Technology, University of Moratuwa

It is with great pleasure and pride that I extend my warmest greetings to all participants of the 4th International Research Conference of the Institute of Technology, University of Moratuwa (ITUM), scheduled to be held on the 9th of October 2025. I am particularly honoured to welcome the Vice Chairman of the University Grants Commission of Sri Lanka, who will grace this occasion as the Chief Guest, adding significant value to this important academic gathering.

This year's conference theme, *"Towards a Resilient Future: Engineering Research on Social, Environmental, and Ethical Renewal",* is both timely and vital. As we navigate an increasingly complex world shaped by technological disruption, climate change, and evolving societal values, it is essential that engineering research contributes not only to innovation and development but also to sustainability, inclusivity, and ethical responsibility.

ITUM has long stood as a pioneer in producing technically competent and socially conscious diplomats, while actively promoting applied research that addresses national and global challenges. This conference represents a culmination of our continuous efforts to foster a dynamic research culture that transcends traditional boundaries and engages with real-world problems through interdisciplinary collaboration.

The presentations, discussions, and knowledge exchanges at this conference provide a unique platform for academics, researchers, industry experts, and students to share insights, challenge assumptions, and inspire actionable solutions. I am confident that the work presented here will make meaningful contributions to shaping a resilient and equitable future.

I take this opportunity to thank Mrs. MMPD Samarasekara (Senior Lecturer Grade I) the head of the Research Unit ITUM, organizing committee, reviewers, contributors, and all those who have worked tirelessly to make this conference a success. Your commitment reflects the values that ITUM strives to uphold excellence in education, innovation through research, and responsibility towards society.

May this conference ignite new ideas, strengthen collaborations, and serve as a catalyst for impactful research outcomes.

Warm regards,

Major General (Retd.) SK Thirunavukarasu RSP VSV USP
Director
Institute of Technology, University of Moratuwa

Message from the Head, Research Unit

An academic institution prospers through innovation and research. At ITUM, promoting and sustaining research amidst numerous challenges has been both a demanding and rewarding journey.

With the continued support of ITUM's leadership, and the unwavering commitment of our members for excellence in research, the Research Unit has once again taken on this challenge with confidence.

We are proud to have successfully organized ITUM-IRC 2025, our annual Research Conference, which serves as a dynamic platform for disseminating research findings from ITUM staff, students, as well as researchers from other academic institutions and industry. This year's conference proceedings feature a diverse collection of 25 extended abstracts presented across seven tracks, under the theme*: "Towards a Resilient Future: Engineering Research on Social, Environmental and Ethical Renewal".*

For the second consecutive year, the Research Unit has also facilitated the Student Poster Presentation, held in parallel with the conference, to showcase the innovative research contributions of ITUM students. The enthusiasm of our students, supported by the dedication of their academic supervisors, has been instrumental in making this initiative a resounding success.

As Head of the Research Unit, I wish to extend my sincere appreciation to the Conference Organizing Committee and for all who contributed to the success of ITUM-IRC 2025, for their invaluable commitment, time, and effort in promoting and sustaining the culture of research at ITUM.

MMPD Samarasekara
Head
Research Unit ITUM

Message from the Conference Chair, ITUM-IRC 2025

It is with great pride and profound appreciation that I extend a very warm welcome to all participants at the 4th International Research Conference of the Institute of Technology, University of Moratuwa (ITUM-IRC 2025). This year's theme, *"Towards a Resilient Future: Engineering Research on Social, Environmental, and Ethical Renewal"*, aligns closely with the national *Clean Sri Lanka* initiative which highlights the vital role of research-driven solutions in fostering social responsibility, safeguarding our environment, and advancing ethical practices to ensure a sustainable and prosperous future.

We are greatly honored to have the Vice Chairman of the University Grants Commission as our Chief Guest at this year's conference. His presence highlights the significance that the University Grants Commission places on research and innovation in shaping the future of higher education and national development.

This conference continues ITUM's mission to provide a dynamic platform where knowledge, ideas, and experiences converge. The diversity of research presented here demonstrates the crucial role of multidisciplinary collaboration in building resilience and addressing both local and global challenges.

I would like to express my heartfelt gratitude to the Organizing Committee for their unwavering dedication, to the reviewers for ensuring academic rigour, and to our distinguished keynote and special speaker for sharing their invaluable expertise. Above all, I extend my deepest thanks to the authors and participants, whose valuable contributions make this event both meaningful and impactful.

ITUM-IRC has now established itself as a recognized venue for fostering collaboration among academia, and industry. I hope that the discussions and collaborations sparked here will lead to tangible outcomes, guiding us toward a cleaner, more ethical, and resilient future.

Thank you for being part of ITUM-IRC 2025, and I wish you a productive and enriching conference experience.

Kalpana Galappaththi
Conference Chair
4th International Research Conference
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Keynote Speech

Professor Ian Overton

Director - Water Data Science (Interim), Country Manager - Sri Lanka,
International Water Management Institute (IWMI)

Building Resilience in Social, Environmental and Economic Systems

Synopsis

This keynote speech will highlight the urgent need to strengthen resilience across interconnected social, environmental and economic systems amid escalating global challenges. Climate change is not a stand-alone issue — it is a systemic threat that risks pushing us beyond critical planetary boundaries. A systems approach is critical to managing future resilience and prosperity. Nowhere is this more pressing than in Sri Lanka's water resources, where the impacts of climate variability are deeply felt. The speech will reflect on the vital research and innovation needed to advance integrated water resource management as a foundation for resilience and economic growth. It will also explore how embracing circular economy principles — reducing waste, reusing resources, and decoupling growth from environmental harm — can drive sustainable and resilient transformation. A central focus will be the shift toward a nature-positive future, where restoring ecosystems, conserving biodiversity and valuing natural capital are recognized as key to long-term prosperity. Achieving this vision will demand inclusive governance, cross-sector collaboration and a commitment to equity and innovation. By taking an integrated view of social, environmental and economic systems, Sri Lanka can reimagine resilience not as resisting change, but as the ability to adapt, evolve and thrive.

Special Speech

Dr. (Mrs.) Kokila Madhuri Wijewickrama Abeykoon

Division of Textile and Clothing Technology, Institute of Technology, University of Moratuwa Sri Lanka

Shaping a Resilient Future: The Role of Ergonomics in Optimizing Human Performance

Synopsis

The universal design concept aims to accommodate all users however, individuals who fall outside the 'standard normal' model, often experience discomfort. Ergonomics seeks to address these challenges by fitting tasks to the physical capabilities and differences among workers considering the factors such as gender, body proportions (anthropometry), biomechanics and environmental conditions. This approach is crucial in developing products to minimize the risk of Musculoskeletal Disorders (MSDs). Among professional and skilled workers, MSDs are more prevalent in the neck and shoulders while manual workers often experience issues in the wrist and lower back. The musculoskeletal system encompasses muscles, tendons, ligaments joints and the bones attached to body regions (arms, fingers, legs and feet etc.). Every element performs a unique function: muscles generate the power for movement; tendons connect bones and ligaments provide joint stability. The relative motion of joints such as those in the knuckles, wrists, elbows, and shoulders enable the bones to pivot at joints. Each joint has a natural posture and a range of motion (ROM). By placing everything within easy reach, limiting awkward postures and minimizing loads when performing work enable the workers to maintain the natural postures allowing them to work well within the ROM with minimum physical efforts. In situations where avoiding awkward postures is challenging, regular work pauses and rest periods are essential to prevent symptoms like fatigue, discomfort, numbness, and pain, which may otherwise progress into debilitating conditions. The application of ergonomics plays a vital role in optimizing human performance. By designing safe and comfortable equipment, facilities, procedures and training, productivity, efficiency and job satisfaction can be increased while decreasing fatigue and injuries ensuring a more resilient and suitable future.

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PERFORMANCE-BASED OPTIMIZATION OF PILE SOCKET DESIGN IN SRI LANKAN METAMORPHIC BEDROCK

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ABSTRACT: Pile socketing into bedrock is a common foundation technique in Sri Lanka. However, current design practices remain excessively conservative, leading to unnecessary construction costs. Despite the prevalence of competent metamorphic rocks, local designers continue to apply methods developed for sedimentary formations, significantly underestimating the available skin friction capacity. Field load tests have demonstrated that actual mobilized skin friction values frequently exceed design predictions by up to three times, as per local design guidelines. This conservatism stems from the use of high safety factors (often 3.0 or more) and outdated assumptions regarding rock-concrete interface behaviour. This study investigates the optimization of pile socket design by critically evaluating current practices and proposing data-driven improvements. Through an extensive review of case studies and pile load test results across Sri Lanka, the research highlights discrepancies between theoretical predictions and actual field performance. The analysis focuses on key parameters influencing socket capacity, including rock quality, socket roughness, and construction techniques specific to metamorphic formations. The findings reveal that existing design approaches fail to account for the superior mechanical properties of Sri Lanka's crystalline bedrock, resulting in over-designed and costly foundations. This study develops refined design recommendations that reduce reliance on excessive safety margins while ensuring structural reliability. The proposed optimization framework has the potential to achieve significant cost savings of 50% in foundation construction without compromising safety. This research provides a foundation for updating national design standards and promotes more efficient use of Sri Lanka's favourable geotechnical conditions. The outcomes will benefit practicing engineers, contractors, and clients by enabling more economical, yet safe pile designs. Future studies should expand the database of load test results to further validate and refine the proposed methodology.

Keywords: pile socket design, skin friction, metamorphic rocks, foundation optimization, load test analysis

1 INTRODUCTION

A load applied to a pile is transferred to the ground through both friction and end bearing. This whole process depends on the pile settlement and the resistance of the subsurface layers against settlement (Thilakasiri, 2009). Upon applying a load, resistance is generated on the surrounding surface of a pile. After fully mobilizing skin resistance, the remaining component is borne by the base resistance (Murthy, 2002). Despite the presence of favourable bedrock conditions, most local designers employ conventional conservative design practices such as those specified by ICTAD (1997), the Hong Kong Guidelines (Geotechnical Engineering Office, 2006), and the Williams and Pells method (Williams and Pells, 1981) which are suitable for sedimentary rock conditions in calculating the skin friction capacity of rock-sockets. Furthermore, designers incorporate the effect of the Bentonite filter cake into the design of skin friction capacity by dividing the obtained value by a safety factor of 4 (Wyllie, 1991) which results in very low design capacities for skin friction.

However, some case studies have found that the mobilized skin friction capacity of the socketed regions of local piles is more than twice the design values obtained from the ICTAD guidelines (Institute for Construction Training and Development, Sri Lanka) (Thilakasiri et al., 2015). Therefore, it suggests that these design methods are overly conservative and ultimately impose significant costs on pile construction by unnecessarily increasing the socketing length to account for the underestimation of the skin friction capacity of metamorphic rocks. Therefore, focusing exclusively on the characteristic of metamorphic bedrock in Sri Lanka and South Asia, this study provides a pioneering analysis of mobilized skin friction, a vital parameter for safe and economical pile design that has previously relied on conservative models.

2 METHODOLOGY

The results of the Maintained Load Test (MLT) along with borehole log data obtained from a database maintained by researchers of a parallel study (Samarawickrama et al., 2023; Ruwanpathirana, 2023) were used to obtain designed and mobilized skin friction capacities. Table 1 depicts the details of 15 piles used in the analysis.

Table 1. Pile details

Pile ID	Project Name & Pile No	Pile Dia. (mm)	Pile Length (m)	Socket Length (m)
1	Proposed Port Access Elevated Highway (PAEH)-TP-70A	1200	45.00	16.90
2	Proposed Port Access Elevated Highway (PAEH)-TP-39	1200	10.00	3.50
3	Central Expressway Project (CEP-2)-VD-05-P13-R2	1500	13.33	3.33
4	Central Expressway Project (CEP-2)-VD-06-P7-R2	1200	15.60	3.70
5	Central Expressway Project (CEP-2)-VD-06-P5-L2	1800	7.40	3.40
6	Maga Head Office -T2-TP1	1500	28.28	5.38
7	Prime Residency Ward Place-P-03	1500	39.60	6.60
8	Southern Expressway Project-P4L1	1800	54.39	1.89
9	Southern Expressway Project-P33R1	1800	38.22	9.88
10	Southern Expressway Project-P23L1	1500	14.00	3.00
11	Southern Expressway Project-P17L3	1500	13.00	4.50
12	Colombo Port City Project-P310-SPS01	900	15.20	3.70
13	Kelani Bridge Project-PRC2P17	1500	25.70	3.80
14	Central Expressway Project-(CEP-01)-TP-01	1500	23.90	6.90
15	Apartment complex for Prime Land residencies, Kelaniya	1000	29.40	5.40

Only 4 Instrumented Maintained Load Tests (IMLTs) were used in this analysis as the industry generally avoids performing IMLTs due to the high costs involved (Samarawickrama et al., 2023). These IMLTs found the skin friction mobilized in the socketed regions directly and accurately compared with the MLTs (Samarawickrama et al., 2023). The results of the MLTs were used to estimate the total skin friction of the pile by using the Chin (1978) method (Thilakasiri, 2009).The friction mobilized by the rock socket ($f_{s,\text{rock}}$) was obtained by deducting the friction taken by soil layers using the Bowels (1996) method.

Next, as recommended by Williams and Pells (1981), the theoretical skin friction capacity was calculated using borehole data. Equation (1) gives the total theoretical skin friction at the socketed region.

$$f_{us} = \frac{\sum(h_n f_{usn})}{\sum h_n} \tag{1}$$

where f_{us} is the total ultimate skin friction capacity, h_n is the rock layer thickness, and f_{usn} is the skin friction capacity of the respective layer. However, Wyllie (1991) has recommended a 75% reduction of ultimate skin friction capacity with the presence of Bentonite as the drilling fluid. Hence the theoretical skin friction capacity obtained by Williams and Pells (1981) method was divided by factor of safety 4 to obtain the recommended theoretical skin fiction. Finally, the theoretical estimation obtained from the recommendations of Wyllie (1991) was compared with the mobilized skin friction found by the Chin method to identify the possible optimizations for rock socket design.

3 RESULTS

As specified in the Chin (1978) method, the graph of settlement upon load (S/P) against settlement (S) was drawn and is shown in Figure 1. The gradient m_1 gives the total skin friction capacity mobilized by the pile.

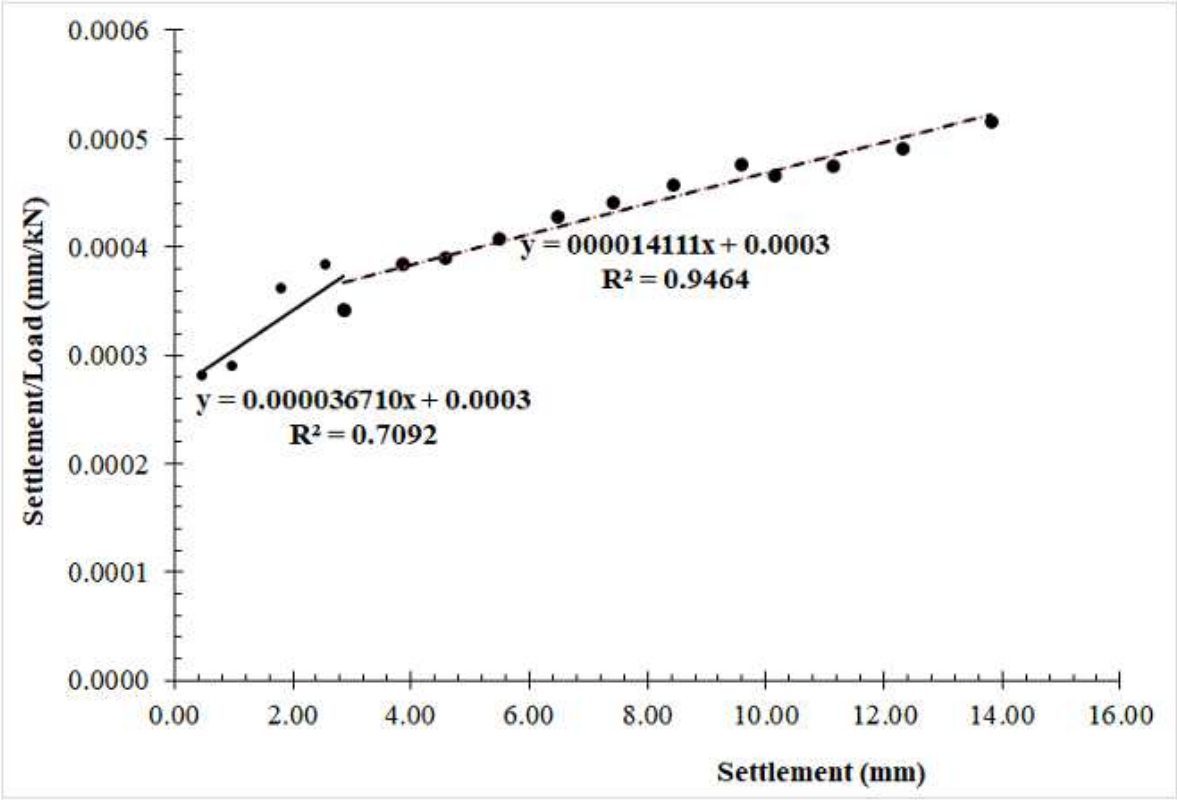

Figure 1. Settlement/load against settlement of pile ID 14

According to the linear regression model shown by the gradient m_1 for Pile ID 14, $\frac{S/P}{S}$ = 0.000036710 and the overall friction $1/m_1$ = 27240.77 kN. The friction mobilized by the rock socket is 0.803 MPa. The mobilized skin friction estimated for the socketed region by the Chin (1978) method and the theoretical estimation of f_{us} for all 15 piles are summarized in Table 2.

Table 2. Summary of Mobilized vs. Theoretical Skin Friction Capacities for 15 Test Piles

Pile ID	f_{su} (MPa), (Williams and Pells method, 1981)	Allowable f_{su} (MPa) with Bentonite Effect (Wyllie, 1991)	Mobilized skin friction (MPa), (Chin (1978) Method)	% of the mobilized to the theoretical estimation
1	0.777	0.194	0.728	375%
2	3.583	0.896	2.650	296%
3	1.282	0.321	1.393	435%
4	1.365	0.341	1.159	340%
5	1.575	0.394	0.708	180%
6	1.767	0.442	2.046	463%
7	0.796	0.199	1.295	651%
8	0.975	0.244	0.006	2%
9	0.537	0.134	0.678	505%
10	1.069	0.267	0.694	260%
11	1.369	0.342	1.253	366%
12	1.985	0.496	1.490	300%
13	1.109	0.277	0.728	263%
14	1.406	0.352	0.803	228%
15	1.306	0.327	0.837	256%

4 DISCUSSION

Local guidelines recommend an ultimate skin friction value of 0.2 MPa for completely weathered rock sockets, with a design value of 0.1 MPa. For all other bedrock types, designers estimate theoretical skin friction using the Williams and Pells (1981) method, applying a safety factor of 4 as recommended by Wyllie (1991) (Institute for Construction Training and Development, Sri Lanka, 1997). These values underestimate the actual skin friction and hence skin friction is neglected in most designs. The values obtained using the Chin (1978) method were compared with the theoretical mobilized skin friction obtained considering the effect of Bentonite (Wyllie, 1991). Accordingly, the mobilized skin friction values recorded a variation of 200% to 700% of the theoretical estimation, except the case of pile ID 8. In Pile ID 8, 0.006 MPa skin friction is mobilized in the socketed region since the entire skin friction was borne by the soil layers and has not yet been transferred to the rock layers.

5 CONCLUSION

When designing piles, if Bentonite is used as the drilling fluid, the theoretical skin friction capacity is divided by 4 (Wyllie,1991) to obtain the design load. However, these values are very conservative and therefore result in high pile construction costs. As shown by the calculations above, it is evident that the percentage of mobilized skin friction relative to the theoretical estimation exceeds 200% in almost all cases considered here. Hence, considering safer design principles, the pile socket design can be optimized by at least 200% leading to a reduction in

rock socketing by at least 50%, especially in the metamorphic bedrock found in the South Asia region.

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NUMERICAL SIMULATION OF TEMPERATURE DISTRIBUTION IN A SCALED-DOWN TEST HUT WITH COIR FIBER REINFORCED NATURAL RUBBER COMPOSITE INSULATING MATERIALS USING COMPUTATIONAL FLUID DYNAMICS

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ABSTRACT: Numerical simulation studies were carried out to improve energy efficiency in a scaled-down test hut with coir fiber reinforced natural rubber composite roofing insulation material. This research paper investigates the temperature distribution of materials which are used for roofing insulation, such as expanded polystyrene (EPS), fiber glass (FG), polyurethane foam (PUF) and coir-fiber reinforced natural rubber composites. A pitch type scaled-down test hut measuring 1 m × 1 m × 1 m was created to analyze the performance of these insulation materials using Computational Fluid Dynamics (CFD) simulations. Insulation thicknesses of 0.05, 0.1, 0.15, and 0.2 m were applied to the roof of the test hut. The analysis was conducted by varying mesh sensitivities to coarse, medium, and fine meshes to improve the accuracy of the results. This fine mesh analysis was chosen for further studies to compare the thermal behavior inside the scaled-down test hut under insulated and non-insulated conditions. The results demonstrate that considering the thermal conductivity of the insulated roof is critical for a detailed thermal analysis of the scaled-down test hut. The studies utilized the commercial CFD tool, Flow Simulation, available in SolidWorks software. A comparison of results suggests that the necessary thermal comfort requirements can be maintained in the scaled-down test hut while simultaneously reducing total energy consumption by correctly using roofing insulation materials.

Keywords: roofing materials, solar radiation, solid works flow simulation, coir fiber, natural rubber

1 INTRODUCTION

Presently, energy efficiency and indoor thermal comfort are two primary goals in building design due to rising energy demand, climate change, and growing sustainability agenda. Buildings consume approximately one-third of the total energy worldwide, with nearly 40% of this energy used in commercial buildings for HVAC (Heating Ventilation and Air Conditioning) systems (González-Torres et al., 2022). Roof structures, especially in single-story buildings or those with roof floors, are one of the primary avenues for solar heat gain, accounting for approximately 35% of thermal transmittance into interior spaces (Sudarshana et al., 2024). This problem can be prevented by using thermal insulation systems beneath roofing layers (Chamath et al., 2020). Several insulation options are available; however, this chapter focuses on natural fiber composites as a viable choice due to their low cost, biodegradability, and reduced environmental impact (Sudarshana et al., 2024). Coconut coir fiber is abundant in Sri Lanka, possessing suitable thermal insulating properties, such as low thermal conductivity and acceptable moisture resistance (Chamath et al., 2022). Investigations into reinforcing natural rubber matrices with coir have demonstrated that coir-based composites offer improved mechanical stability and are ideal for construction applications, such as roof insulation (Chamath et al., 2023). This research exam-

ines the scope of thermal performance through numerical simulation of heat transfer processes in roof assemblies. Natural rubber (NR) is regarded as a sustainable polymer matrix in green composites. Recent studies have explored the interactivity of natural fibers and biopolymers to create composite systems with acceptable thermal insulating performance (Udayakumara et al., 2022); likewise, advanced manufacturing, such as Vacuum-Assisted Resin Transfer Molding (VARTM), has been applied to existing composites to create composite systems with higher strength and thermos-mechanical performance (Sudarshana et al., 2025). The importance of material selection and processing techniques is highlighted by a study on alkaline treatment and durability of coir fibers in composite systems (Chamath et al., 2025). This research paper indicates that numerical simulation studies have been carried out to improve energy efficiency in a scaled-down test hut using coir fiber reinforced natural rubber composite. Traditional insulating materials including mineral wool, expanded polystyrene (EPS), and polyurethane foams are frequently utilized, because of their excellent thermal properties. These materials, however, are costly to make and dispose of, petroleum based, and non-biodegradable. They are less appropriate for use in green building applications due to their lifetime emissions, which also cause environmental problems. As a result, engineers and researchers are increasingly focusing on coir fiber reinforced natural rubber composite mats as a substitute for synthetic insulating materials.

1.1 Problem Statement

The advantages of coir fiber composites are widely established; however, limited information is available on their thermal properties when used in conjunction with natural rubber latex, particularly with advanced fabrication methods like VARTM. Although natural fiber composites are becoming increasingly popular, most available information focuses on mechanical strength or thermal behavior in isolation, rather than in a comprehensive thermal-mechanical-simulation relationship.

1.2 Significance of the Study

By blending coir fiber and latex into a novel roof insulation material, this research makes a significant contribution to the development of sustainable building materials. In line with this, the project contributes to ongoing efforts to improve fiber treatments and manufacturing processes, such as VARTM (Sudarshana et al., 2025), and aims to prolong the lifespan and improve the reliability of natural fiber composites (Chamath et al., 2025). Ultimately, this research will serve as a stepping stone for eco-friendly construction materials and contribute to the global sustainability agenda.

2 METHODOLOGY

A scaled-down test hut measuring 1 m × 1 m × 1 m was designed to analyze the temperature distribution of traditional insulating materials and newly introduced coir-fiber reinforced natural rubber composite mats, using SolidWorks flow simulations. The wall thickness of each side of the test hut was assumed to be 0.05 m. This scaled-down test hut was isolated (assuming doors and windows assumed to be closed) to ensure that no mass transfer between the atmospheric

air and the air volume inside the test hut. SolidWorks software was utilized to create a three dimensional model of test hut as displayed in Figure 1(a). Coarse, medium, and fine meshes were prepared as shown in Figure 1(b, c, d), using the global mesh tool available in SolidWorks flow simulation package, to identify any improvements in the accuracy of the temperature distribution results .

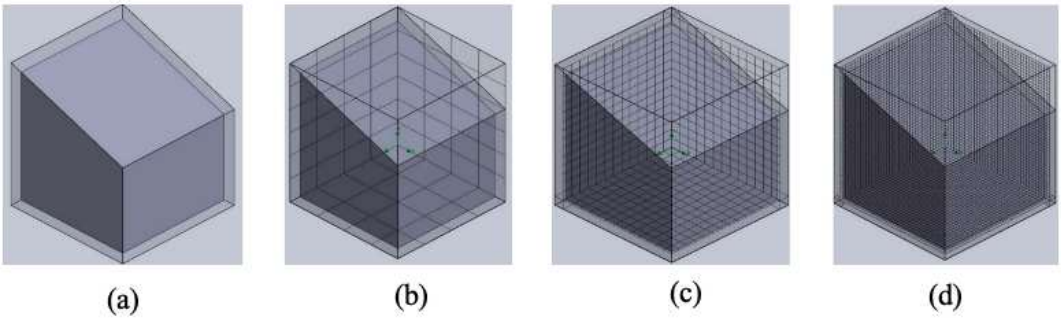

Figure 1. Isometric views: (a) three dimensional model of the test hut, (b) Coarse, (c) Medium, and (d) Fine meshes

Temperature distributions primarily depend on the mesh when the mesh size is fairly coarse, but this dependency diminishes as the mesh size becomes finer. A mesh comparison must be conducted to optimize computation time while improving the validity of the temperature distribution values. A numerical analysis was performed under solar radiation conditions in the Homagama area (6.84° N 80.00° E) located in Colombo, Sri Lanka. Table 1 provides details of the characteristics of the materials used in the numerical analysis.

Table 1. Characteristics of materials applied for SolidWorks simulation

Material	**Density (kg/m^3)**	**Specific heat capacity J/(kg·K)**	**Thermal conductivity (W/(m·K))**
Wood	500	1700	0.15
Expanded Polystyrene (EPS)	24	1340	0.04
Fiber Glass	16	1000	0.04
Polyurethane Foam (PUF)	32	820	0.03
Coir Fiber Reinforced Natural Rubber Composite Mats	1150	2290	0.07
Air	1.185	1004.4	0.03

The present study considered insulating materials of varying thicknesses: 0.05, 0.1, 0.15, and 0.2 m. A boundary was established between the asbestos roof and the inside air of the test hut with each material, expanded polystyrene (EPS), fiber glass (FG), polyurethane foam (PUF), and coir fiber reinforced natural rubber composite mats used as the insulation (Aravind et al., 2015).

3 RESULTS AND DISCUSSION

This research conducted a numerical analysis to examine the internal temperature distribution of a test hut when different insulation materials are used. The results in Figure 2 clearly show

a considerable reduction in temperature inside the room when thermal insulation materials are used. A comparison of the outcomes indicates that the required thermal comfort in the scaled-down test hut, can be maintained while reducing total energy consumption simultaneously by using roofing insulation materials correctly. As shown in Table 2, it is evident that approximately 16K temperature reduction can be achieved using these insulation materials.

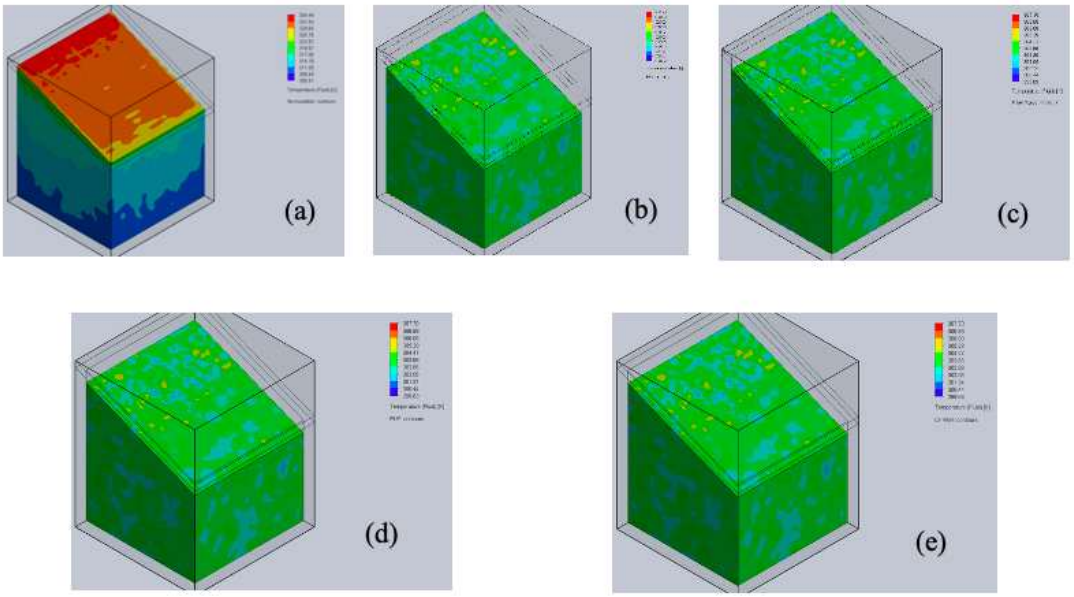

Figure 2. Distribution of temperature inside the scaled-down test hut with (a) No insulation, (b) EPS insulation, (c) FG insulation (d) PUF insulation (e) Coir fiber reinforced natural rubber composite mats insulation

Table 2. Results obtained from SolidWorks flow simulation

Method of Insulation	**Minimum and Maximum Temperatures (K)**	**Average Temperature (K)**
No insulation	305-334	320
EPS insulation	300-308	304
FG insulation	300-308	304
PUF insulation	300-308	304
Coir fiber reinforced natural rubber composite mats insulation	300-308	304

4 CONCLUSION

The study demonstrated that the SolidWorks flow simulation CFD tool can reasonably predict temperature distribution in an insulated, scaled-down test hut under isolated conditions. Traditional insulating materials including mineral wool, expanded polystyrene (EPS), and polyurethane foams are commonly utilized due to their excellent thermal properties. These materials, however, are costly to produce and dispose of, petroleum based, and non-biodegradable. They are less appropriate for use in green building applications due to their lifetime emissions, which also contribute to environmental problems. As a result, engineers and researchers are

increasingly focusing on coir fiber reinforced natural rubber composites as a substitute for synthetic insulating materials. In order to improve building designs with more accurate validation of experimental data, further studies are necessary to investigate factors such as ventilated air charge per hour (ACPH), leakages through vents, heating ventilations and air conditioners, as well as the availability of ceilings.

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DESIGN OF A MICROFLUIDIC DEVICE FOR COLORIMETRIC ESTIMATION OF SOIL PH USING AN OPTIMIZED INDICATOR MIXTURE

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ABSTRACT: Soil pH is a critical parameter in soil analysis, influencing nutrient availability, microbial activity, and overall soil health. Although several methods exist for measuring soil pH, many of them face limitations in terms of continuous monitoring, including the need for laboratory infrastructure, trained personnel, or expensive instrumentation. Consequently, there is a growing need to develop novel approaches that are rapid, low-cost, user-friendly, and suitable for on-site applications. In this study, a colorimetric detection method was developed using an optimized mixture of pH indicators integrated into a microfluidic device (MFD) for the determination of soil pH. This approach enables farmers and field workers to directly assess soil pH in the field across a broad range of pH values (2–10). The indicator mixture, consisting of bromocresol green, bromothymol blue, bromophenol blue, phenol red, and thymol blue, was designed to produce distinct colour transitions over a wide pH spectrum. A linear and visually discernible response was achieved across two key pH intervals: an acidic range from pH 2.0 to 6.0 (covering 4.0 pH units) and an alkaline range from pH 7.0 to 12.0 (covering 5.0 pH units), demonstrating the suitability of the method for practical soil monitoring applications.

Keywords: colorimetry, indicator- mixture, microfluidic technologies, soil pH

1 INTRODUCTION

1.1 Background

Soil pH is a critical parameter that influences a wide range of soil properties and agricultural productivity. It affects the chemical form and availability of essential nutrients, microbial activity, and the behaviour of toxic elements (Dewangan et al., 2023). Maintaining optimal soil pH is vital for healthy plant growth and sustainable agricultural practices. Therefore, routine monitoring of soil pH is essential for informed decision-making in agriculture, especially in the context of precision farming. Traditional methods for soil pH determination, such as glass electrode pH meters or colorimetric test kits, often require sample preparation, reagent handling, and interpretation by trained personnel. These techniques, while accurate under laboratory conditions, may be impractical for on-site or rapid assessment, particularly in resource-limited or field-based settings. Additionally, pH meters can be sensitive to environmental conditions and require frequent calibration and maintenance (Lu et al., 2020; Sansalvador et al., 2016). These limitations highlight the need for alternative, user-friendly approaches that offer rapid, reliable, and cost-effective soil pH measurement directly at the point of use (Dudala et al., 2020).

1.2 Significance of using a microfluidic device and a colorimetric detection technique

Recent advancements in microfluidics and sensor technologies offer promising alternatives for on-site soil analysis. Microfluidic devices, also known as lab-on-a-chip systems, enable precise fluid handling at the microliter scale and facilitate rapid analysis with minimal reagent consumption (Lu et al., 2020). When integrated with colorimetric detection systems, microfluidics provides a platform for simple, low-cost, and portable sensing solutions (Dudala et al., 2020). Potentiometric methods commonly used for pH measurement are reliable only within specific conditions, typically between 278–323 K in temperature, 0.1 MPa pressure, and ionic strengths below 0.1 mol/kg of water. These limitations arise due to the instability of the reference electrode and uncertainties in the liquid junction potential under extreme conditions. In contrast, spectroscopic (or colorimetric) methods offer an alternative approach, using pH-sensitive dyes that exhibit colour changes corresponding to the solution's pH (Lin & Liu, 2000; Raghuraman et al., 2006a). In this study, we present a colorimetric approach for soil pH estimation using an optimized mixture of pH indicators integrated into a microfluidic device. The indicator mixture was designed to provide a smooth and distinguishable colour gradient across the target pH range. The microfluidic platform allows efficient sample-reagent interaction and visual detection without the need for advanced instrumentation. Using an optimized indicator mixture for soil pH determination provides a broader detection range with sharper colour transitions compared to conventional pH paper, which often gives only approximate values. In contrast, pH papers are less reliable for soil testing due to colour fading, overlapping shades, and interference from soil turbidity or colored extracts, leading to reduced precision. This work addresses key limitations in current soil pH testing methods by offering a low-cost, rapid, and user-friendly solution, particularly suited for applications in precision agriculture and resource-limited settings.

2 METHODOLOGY

2.1 Reagents and materials

The pH indicators utilized in this study comprised Bromophenol Blue (BPB), Bromothymol Blue (BTB), Bromocresol Green (BCG), Thymol Blue (TB), and Phenol Red (PR), all of which were used as received without any further purification. Additional reagents, including ethanol, hydrochloric acid (HCl), and sodium hydroxide (NaOH), were of analytical grade. All solutions were prepared using distilled water. A matrix solution containing 0.001 M buffer(s) and 0.05 M NaCl was employed to maintain consistent pH and ionic strength. Three types of buffers, Tris [tris(hydroxymethyl) aminomethane], citric acid, and boric acid, were selected based on their effective pH ranges (Lin & Liu, 2000). The pH of the solutions was precisely adjusted to the target values using 0.1 M HCl or 0.1 M NaOH, and measurements were conducted with an Onyx Aqua Farm digital pH meter with an accuracy of ±0.01 pH units. Spectral measurements were made using an Evolution 201 UV-Visible spectrophotometer (Thermo Scientific), with the indicator solutions analyzed in quartz cuvettes having a 10 mm optical path length. The microfluidic device employed for visualizing soil pH levels was fabricated from Poly (methyl methacrylate) (PMMA) using a laser micromachining technique. (All experiments were performed at 293 K) (Raghuraman et al., 2006b).

2.2 Preparation and spectroscopic analysis of indicator mixture

For the spectroscopic analysis of the indicators, separate solutions of each indicator were prepared. Then, according to their individual behaviour, concentrations of each indicator were optimized, which are then used in the mixture. Optimized concentration of each indicator was BPB: BCG: BTB: TB: PR, 0.05:0.1:0.2:0.15:0.05. The absorption spectra of each indicator were recorded from 250 nm to 750 nm at acidic (pH 2.02), neutral (pH 7.10), and alkaline (pH 11.21) conditions. The behaviour of the indicator mixture at different buffer solutions from pH 2-10 was studied using the UV-Visible spectrophotometer. For the visual illustration of the indicator mixture for soil sample testing, a colour chart was developed so that it can be easily used in field-level applications for pH determination.

2.3 Soil pH determination using the Microfluidic device

The capillary breaching technique was used to introduce the soil solution and reagent mixture to the MFD. Then the pH was determined using the developed color chart.

3 RESULTS AND DISCUSSION

Colorimetric pH determination relies on the change in absorbance of an indicator with pH. A single indicator is effective only within a narrow range of about two pH units ($pK_a \pm 1$). Outside this range, absorbance changes are minimal, leading to greater measurement error. One method to broaden the dynamic range for pH measurement is to use multiple indicators. This is illustrated in Figure 1(a), which shows the response for different indicators (BPB, BCG, BTB, PR, and TB) and a mixture of indicators with different pK_a. The normalized absorbance response to pH for individual indicators and a mixture of multiple indicators is shown. Calculations assume absorbance is measured at a wavelength where only the basic form of each indicator absorbs, and that the concentrations in the mixtures are adjusted to produce equal maximum absorbance. Solid lines represent the responses of single indicators, while dashed lines depict the combined response of indicator mixtures. It is clearly shown that the dynamic range for pH measurement is broadened by using a mixture of indicators, and it has a linear response over a broader pH range from 2 to 10.

Although the base forms of the indicators differ in colour, as BPB (purple), BCG (blue), BTB (blue), TB (blue), and PR (red), their absorption spectra are relatively close. As shown in Figure 1(b), the ideal measurement wavelength lies between points A and B, where the spectra of indicators intersect. Selecting a wavelength in this region, specifically 570 nm, ensures that the absorbance values of the indicators are comparable, allowing balanced contributions from each dye in a mixed indicator solution. Figure 1(c) displays the absorbance of the dye measured at 525 nm, while Figure 1(d) displays the absorbance of the dye measured at 570 nm across varying pH levels. The data show a strong linear correlation at two wavelengths, 525 nm and 570 nm, within the pH range of 2 to 12, indicating a consistent and predictable response of the dye in this interval.

The developed MFD is reusable, and when combined with a set of capillaries sufficient for 15 tests, the total cost is approximately LKR 650.00. This highlights the economic feasibility

of the device for routine soil pH assessment, offering a low-cost alternative to conventional laboratory-based methods.

Figure 2(a) shows an image of the fabricated MFD, and Figure 2(b) depicts how the optimized indicator mixture is visualized within the microfluidic device, highlighting its interaction and response under specific pH conditions.

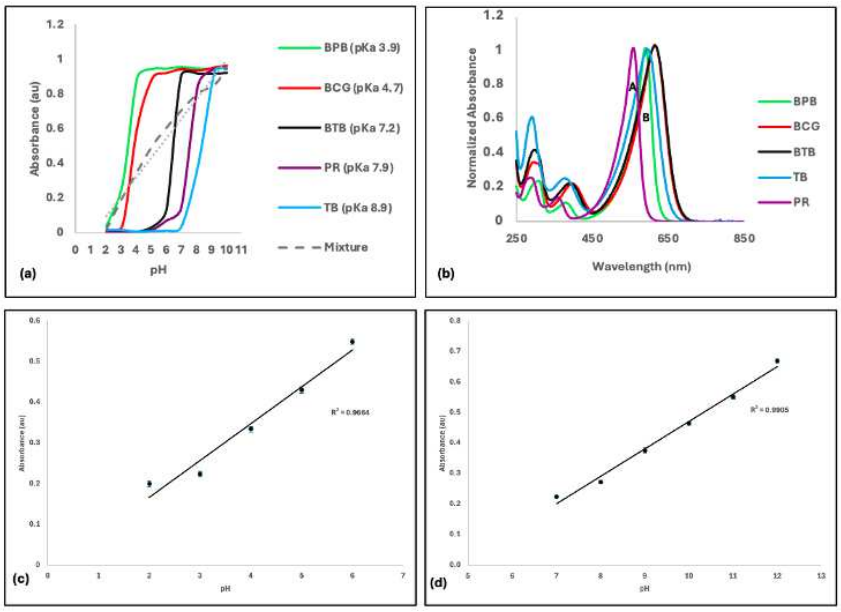

Figure 1. (a) Absorbance response to pH of single indicators and indicator mixture (b) Normalized spectra of the base form of the five indicators(BPB, BCG, BTB, TB, PR) (c) Absorbance at 525 nm as a function of pH, The line shows the linear fit at the linear range pH 2-6, R2 =0.9985 (d) Absorbance at 570 nm as a function of pH, The line shows the linear fit at the linear range pH 7-12, R2 =0.9948

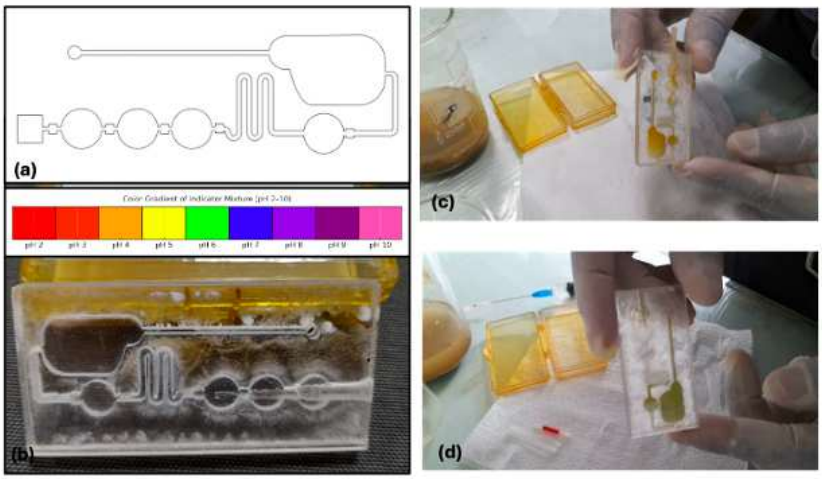

Figure 2. (a) CAD design of the microfluidic device with the developed colour chart. Photograph of the prototype microfluidic sensor chip: (b) before use, and (c), (d) after exposure to two different soil samples with different pH, showing the visible colour change following the reaction.

4 CONCLUSION

The developed colorimetric method for soil pH estimation, utilizing an optimized mixture of pH-sensitive indicators embedded in a microfluidic device, offers a practical, low-cost, and field-deployable solution for rapid soil analysis. The indicator mixture provided a visually distinct and linear response across a wide pH range (2–10), with enhanced resolution in both acidic (pH 2.0–6.0) and alkaline (pH 7.0–10.0) intervals. The integration of this system into a portable microfluidic platform demonstrates its potential for empowering farmers and agricultural stakeholders with on-site soil pH monitoring, thereby contributing to precision agriculture and informed soil management practices.

5 ACKNOWLEDGEMENT

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GREEN BREATH: HARNESSING INDOOR PLANTS TO PURIFY WORKSHOP ENVIRONMENTS IN SUSTAINABLE MANUFACTURING

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ABSTRACT: On the global scale, indoor air pollution in industrial workshops constitutes a significant occupational and environmental concern. Sustainable manufacturing approaches, including biophilic interventions such as the integration of indoor plants, have been explored for their capacity to enhance air quality in a natural manner. This systematic review reflects empirical evidence on the effectiveness of indoor plants in purifying air and boosting health and comfort in built environments, with a particular emphasis on their applicability in manufacturing workshops. Peer-reviewed studies published between 2019 and 2025 were identified across multiple databases, and those meeting the inclusion criteria were analyzed.Findings suggest that certain plant species, including "Spider Plant" (*Chlorophytum comosum*), "Snake Plant" (*Sansevieria trifasciata*), and "Golden Pothos" (*Epipremnum aureum*), effectively suppress concentrations of volatile organic compounds (VOCs), carbon dioxide (CO_2), and particulate matter. In addition, psychological benefits such as stress reduction among workers and improved job satisfaction were consistently observed. Although indoor plants have been widely studied, their application in workshop environments remains underexplored. The review concludes that indoor plants have considerable potential to play a supporting role in sustainable manufacturing, especially in small and medium enterprises, but should be accompanied by traditional air handling systems.

Keywords: biophilic design, indoor air quality, indoor plants, phytoremediation, sustainable manufacturing

1 INTRODUCTION

Indoor air quality (IAQ) is a vital component of occupational health, yet it remains an underexplored aspect in manufacturing environments. According to Zhang et al. (2019), industrial workshops frequently accumulate a range of pollutants such as volatile organic compounds (VOCs), particulate matter (PM), and elevated carbon dioxide (CO_2) primarily due to inadequate ventilation and emissions from machinery, solvents, and adhesives. Concurrently, sustainable manufacturing practices are increasingly embracing human-centered design, with biophilic interventions such as indoor plant integration being explored to enhance well-being and air quality (Chen et al., 2021).

Phytoremediation, which involves the use of plants to absorb and neutralize indoor air pollutants, presents a promising, low-cost, and eco-friendly strategy. While numerous studies have validated the air purifying capabilities of plants in office and residential settings, their effectiveness in workshop-scale industrial environments remains largely uninvestigated (Smith, 2024). Therefore, this systematic review aims to identify current evidence on the air purification capacities of indoor plants, highlight plant species with demonstrated effectiveness, and assess their applicability and limitations in workshop settings.

2 METHODOLOGY

2.1 Search Strategy

This study is based on a qualitative literature review on integrating indoor greenery to enhance air purification in eco-friendly manufacturing settings. Both national and international literature were reviewed to evaluate the use of indoor plants in the manufacturing sector. The study was conducted as a formal systematic review following PRISMA guidelines.

To ensure comprehensive coverage, five academic databases—Scopus, Web of Science, PubMed, ScienceDirect, and Google Scholar—were searched using combinations of keywords including "biophilic design," "indoor air quality," "indoor plants," "phytoremediation," and "sustainable manufacturing." Peer-reviewed articles published between 2019 and 2025 were selected to enhance the originality of the overall report.

2.2 Inclusion and Exclusion Criteria

The inclusion criteria comprised empirical studies that measured pollutant levels in the presence of indoor plants, were conducted in indoor environments (residential, office, industrial), were written in English, and employed measurable IAQ indicators (e.g., VOCs, particulate matter-PM 2.5, CO_2). Further, the exclusion criteria included studies without quantitative data, experiments conducted in greenhouse or outdoor settings, review articles, commentaries, and studies lacking sufficient methodological detail.

2.3 Data Extraction and Synthesis

Relevant data were extracted including plant species, environmental settings, air pollutants measured, methodologies employed, and outcomes. A thematic synthesis was used to organize findings into key areas including pollutant removal efficiency, plant characteristics, psychological benefits, and applicability to industrial settings.

3 RESULTS AND DISCUSSION

3.1 Results

3.1.1 Pollutant Removal Capabilities

Numerous studies have confirmed that specific indoor plants can significantly reduce airborne toxins. For example, *Chlorophytum comosum* and *Epipremnum aureum* have consistently demonstrated high formaldehyde and benzene removal rates in controlled environments (Yoo et al., 2022). Additionally, Zhang et al. (2019) found that dense indoor plant arrangements in experimental environments reduced PM 2.5 levels by 20-30%. Mayura et al. (2023) highlighted the crucial role of rhizospheric soil microbes in VOC degradation, reinforcing the importance of potting medium composition in enhancing phytoremediation.

3.1.2 Psychological and Workplace Benefits

Exposure to indoor greenery has been associated with positive psychological outcomes. Toyoda et al. (2020) reported that workers surrounded by plants experienced lower stress levels, enhanced focus, and improved mood. Similarly, Chen et al. (2021) observed marginal increases

in productivity and overall workplace satisfaction in biophilic environments, although they noted that causality was difficult to isolate.

3.1.3 Applicability to Workshop Environments

Despite their proven benefits, only a limited number of studies have evaluated plant-based interventions in industrial settings. Zhang et al. (2019) conducted a field study in a semi-enclosed carpentry workshop and reported up to 35% VOC reduction using plant-based filters. However, challenges such as dust accumulation on leaves, irregular maintenance, and limited space were frequently cited as barriers to effectiveness.

3.2 Discussion

The review confirms that indoor plants can effectively enhance indoor air quality (IAQ) through phytoremediation, particularly species such as *Spider Plant, Snake Plant, and Golden Pothos*. These plants have demonstrated significant reductions in common indoor pollutants like VOCs, CO_2, and PM 2.5. Table 1, summarizes the key plant species and their pollutant removal efficiencies.For example, according to the Table 1, *Chlorophytum comosum* has shown formaldehyde removal rates up to 70% in controlled conditions (Yoo et al., 2022), while *Epipremnum aureum* can eliminate over 60% of benzene under favorable conditions (Mayura et al., 2023).

Table 1. Summary of Pollutant Removal Efficiency by Plant Species

Plant Species	Primary Pollutants Removed	Average Removal Efficiency	Notable Study
Spider Plant (*C. comosum*)	Formaldehyde, CO_2	65–70% (in 24 hrs)	Yoo et al., 2022
Snake Plant (*S. trifasciata*)	CO_2, Toluene, PM 2.5	30–45%	Smith, 2024
Golden Pothos (*E. aureum*)	Benzene, Xylene	60–66%	Mayura et al., 2023

Despite their potential, implementation of indoor plants in industrial workshops is limited by challenges such as dust accumulation, maintenance needs, and pollutant variability. These environments often require hybrid strategies for example, combining plant-based solutions with mechanical filtration to cope with higher pollutant loads (Smith, 2024). Additionally, biophilic design offers psychological benefits, including reduced stress, enhanced mood, and improved satisfaction among workers (Toyoda et al., 2020; Chen et al., 2021). Even if pollutant removal is moderate, these human-centered benefits make indoor plant integration valuable.

Future work should focus on long-term studies in industrial contexts, exploring modular systems like wall-mounted plant units and conducting cost-benefit assessments to support broader adoption in sustainable manufacturing settings.

4 CONCLUSION

This review confirms that indoor plants hold considerable potential for enhancing indoor air quality and promoting psychological well-being in manufacturing workshops. Species such as *Chlorophytum comosum* (Spider Plant), *Sansevieria trifasciata* (Snake Plant), and *Epipremnum aureum* (Golden Pothos) have shown measurable reductions in VOCs, CO_2, and PM 2.5- especially when plant density, light, and airflow conditions are optimized (Yoo et al., 2022; Mayura et al., 2023; Zhang et al., 2019). Additionally, plants contribute to worker satisfaction, stress reduction, and cognitive benefits (Toyoda et al., 2020; Chen et al., 2021).

Nonetheless, practical barriers remain in industrial applications, such as dust exposure, limited space, and maintenance challenges. Zhang et al. (2019) and Smith (2024) stress the importance of combining plant systems with traditional air-handling methods to overcome these issues. While the pollutant-removal effect alone may be moderate in complex industrial environments, the psychological and aesthetic advantages strengthen the case for biophilic design integration. Moving forward, future investigations should prioritize longitudinal studies in real-world workshop environments, assess maintenance feasibility, and explore scalable green infrastructure. Integrating indoor plants into sustainable manufacturing offers a human-centered, environmentally responsible approach to occupational health and productivity.

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ENHANCING DISPERSION STABILITY OF NANO-STRUCTURED TITANIUM OXIDE /GRAPHENE OXIDE IN MINERAL AND BIO-BASED ENGINE LUBRICANT FORMULATIONS

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ABSTRACT: New strategies are needed to reduce friction and wear in internal combustion (IC) engines. This will help save energy, extend the life of engine components, reduce the depletion of fossil fuel reserves, and decrease the production of waste crankcase oil, addressing current environmental issues. Nano-additives have shown promising results in improving the tribological performance of lubricants. However, the stability of nanoparticle dispersion in nano-lubricants remains a challenge for the effective use of nanomaterials as lubricant additives. This research investigates the efficacy of nanocomposite materials containing graphene oxide (GO) and reduced graphene oxide (r-GO) for reducing friction. Ultrasonication was used to create four different formulations: added graphene (G) and GO to the mineral-based engine oil (15W40), TiO_2/G, and TiO_2/r-GO with formulated coconut oil (FCO) as the base stock to blend sample lubricants. The dispersion stability of all four samples was tested using a UV-visible spectrophotometer, keeping 15W40 as the reference. Tribological performance was assessed using a linear reciprocating tribometer (LRT) test rig, which confirmed that lubricants containing GO and r-GO nano-additives exhibited improved lubricity. The sample containing 15W40 with GO as nano-additives and the sample with FCO containing TiO_2/r-GO as nano-additives showed a 26% and 23% reduction in Coefficient of Friction (COF) over 15W40, respectively. The addition of GO and r-GO improved the dispersion stability of sample lubricants, leading to an enhancement in tribological characteristics due to the oxygen-containing functional groups attached to nanocomposite structures.

Keywords: nano-additives, dispersion stability, oxygen functional groups, engine lubrication

1 INTRODUCTION

The ultrafine size of the nanoparticles, which allows them to infiltrate between the asperity contacts of surfaces in relative motion, is a promising solution for improving the efficiency of internal combustion engine (ICE) lubrication. This scale-dependent behaviour, along with their adhesion and cohesion properties, enables them to roll between sliding surfaces and also to create a boundary layer, which can enhance the lubricant characteristics during combustion (Ali et al., 2016). Nevertheless, many researchers have reported agglomeration and sedimentation of nanoparticles within mineral base oil over an extended period of storage time (Ali et al., 2016; Syahir et al., 2017).

This research explores methodologies to improve the dispersion stability of nano-additives in engine lubricants with specific focus on: a) comparing the stability of graphene (G) and graphene oxide (GO) in mineral-based multi-grade engine oil 15W40; b) the stability between titanium dioxide/graphene (TiO_2/G) and titanium dioxide/reduced graphene oxide (TiO_2/r-GO) in formulated coconut oil (FCO) as a bio-based lubricant.

There are many nano-additives associated with lubricant formulation that have shown improved tribological performance. For example, Ali et al. (2016) used TiO_2 nanoparticles in 5W30

mineral oil and reported a reduction of the Coefficient of Friction (COF) and the wear rate, compared to the reference oil (5W30). Meng et al. (Meng et al., 2016) reported the reduction of COF and WSD using mineral oil 10W40 as base-stock to blend with supercritical (Sc)-Ag/graphene nanocomposite as nano-additives.

The importance of achieving an optimum particle concentration to enhance the dispersion stability of nano-additives in base-stocks, thereby avoiding agglomeration and sedimentation, was noted by Singh et al., 2019), which leads to minimizing friction and wear in the nano-lubricant. In another development, it has been shown that the presence of sufficient oxygen groups makes graphene oxide/reduced graphene oxide (GO/r-GO) nanocomposites compatible with dispersion in polar liquid lubricants (Gupta et al., 2017). Gulzar et al. (2017) emphasised the importance of smaller particle size and method of agitation in enhancing colloidal stability.

2 EXPERIMENTAL METHODOLOGY

In this research, the dispersion stability of nano-additives was investigated in two different base fluids: 15W40 with graphene and graphene oxide, and formulated coconut oil (FCO) with the nanocomposites TiO_2/G and TiO_2/r-GO. TiO_2/G and TiO_2/r-GO nanomaterials were synthesized via thermal annealing and continuous hydrothermal flow synthesis (CHFS) routes, respectively, and characterized, including graphene for confirmation.

2.1 Material

Mineral-based 15W40 is widely used globally in heavy-duty engines and was therefore chosen as the reference oil for comparison results, in addition to serving as the mineral base stock. FCO is a locally available vegetable oil used as a bio-based lubricant stock to reduce reliance on petroleum-based lubricants and promote environmental sustainability. Graphene, graphene oxide, precursor titanium bis-ammonium lactato dihydroxide (TiBALD; Ti^{+4}), KOH, and other chemicals were used in this research.

2.2 Synthesis and characterization of nano additives of interest

The CHFS method was used to synthesize nano-additives TiO_2 and TiO_2/r-GO (Alli et al., 2022). The nanocomposite TiO_2/G was synthesized via thermal annealing (Hettiarachchi et al., 2023). Subsequently, transmission electron microscopy (TEM), X-ray powder diffraction (XRD), and Raman techniques were utilized to characterize the synthesized nanomaterials (TiO_2, TiO_2/r-GO) and graphene (Hettiarachchi et al., 2023a). Scanning electron microscopy (SEM) was used to investigate the morphologies of graphene nanosheets.

2.3 Formulation and stability tests

FCO was formulated using virgin coconut oil (VCO) to improve its physicochemical properties for engine lubrication application (Hettiarachchi et al., 2023a). Dispersion stability is essential for a lubricant to ensure consistent performance in tribological applications (Liu et al., 2020). Nano-additives, graphene, and GO (0.1 wt.%) in 10 ml of 15W40, and FCO with nano-additives TiO_2/G and TiO_2/r-GO (0.1 wt.%) were sonicated separately for two hours, followed by further agitation for another two hours using a magnetic stirrer hotplate. A double-beam UV-Vis

spectrophotometer was used to evaluate the absorption stability of blended nanofluids through optical absorbance spectroscopy. Samples were examined at 0, 24, 48, and 72 hours after blending and continued weekly for up to five weeks (Bhatt et al., 2009).

2.4 Performance tests

Friction tests on the above samples were performed for 25 load-velocity combinations using a Linear Reciprocating Tribometer (LRT) test rig, following ASTM G181-11 guidelines (Hettiarachchi et al., 2023a). Piston ring and cylinder liner segments of an ICE were used as test specimens to investigate the lubricity of sample blends at 140 °C and compare them with the reference oil 15W40. SEM micrographs were used to analyze the wear scars of the test specimens after the friction tests.

3 RESULTS AND DISCUSSION

3.1 Characterization of nanoparticles:

TEM and SAED analyses revealed that the nanocomposites TiO_2/G and TiO_2/r-GO are in the 2D scale based on the observed average particle sizes and lattice fringe spacing (d) of graphene sheets (TiO_2/G – 14.00 ± 0.30 nm and d = 0.38 ± 0.003 nm; TiO_2/r-GO – 10.00 ± 0.3 nm and d = 0.037 ± 0.002 nm). A lateral dimension of 319.0 ± 50 nm with d = 0.33 ± 0.004 nm was observed for the graphene nanosheets.

The XRD patterns observed for the synthesized nanoparticles confirmed the presence of graphene and the nanocomposites TiO_2/G and TiO_2/r-GO (Nguyen et al., 2022). Raman spectra of the synthesized nanomaterials also confirmed that the atomic bonding and geometrical patterns match the established data of graphene, and TiO_2/G and TiO_2/r-GO nanocomposites (Hettiarachchi et al., 2023; Baragau et al., 2020).

3.2 Dispersion stability of formulated nano lubricants

The spectral absorbency test results for samples based on 15W40 containing nano-additives G and GO confirm that the blend with GO is more stable than the blend with G. The functional groups (C=O, -COOH, -OH) attached to GO may have been functionalized with long-chain high molecular weight hydrocarbon molecules, each containing over 30 carbon atoms of 15W40, which could be the hypothesis affecting this result (Stachowiak & Batchelor, 2014).

The variation in UV-Vis absorbance measurements of the above samples with G additives shows a sharp reduction in absorbance from 0 h to 72 hours. It remained stable thereafter throughout the 5-week testing period. The sample with GO additives exhibits minor agglomeration during the initial 72 hours but displays enhanced dispersion stability thereafter. Perhaps, solutions become stable after the sedimentation of surplus quantities that are not soluble in 15W40 (Hao, 2005) (Figure 1). The results further validated the evidence of the observed stability test results.

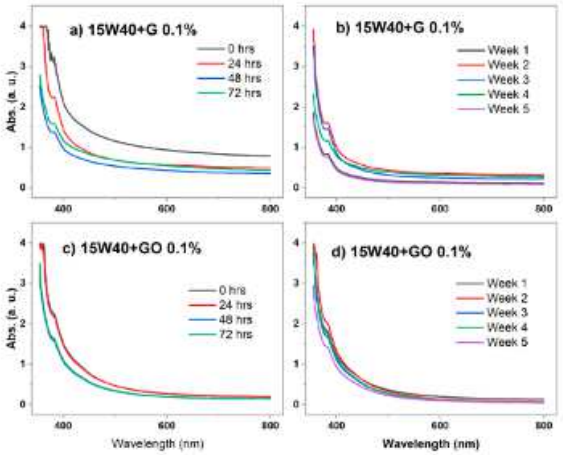

Figure 1. Overlayed UV-Vis spectra for 15W40-based samples having G and GO nano additives, a) & c) 0-72 h overlay in 24 h intervals and b) & d) 5 weeks overlay in weekly intervals.

Optical absorbance spectra for the FCO-based sample containing TiO_2/r-GO as nano-additives revealed a remarkable dispersion stability compared to FCO with TiO_2/G samples. The capability of oxygen functional groups of r-GO to keep nanoparticles dispersed within the solution is further supported by these results, accordingly confirming the proposed hypothesis with the above UV-Vis findings. Illustration of poor dispersion stability of samples containing TiO_2/G nano-additive, compared to the sample with TiO_2/r-GO nano-additives, demonstrates the potential of r-GO for creating a stable and homogeneous solution.

The results of absorbance vs. time analysis for both samples exhibited different degrees of sedimentation during the 0–72 h period, following consistent colloidal stability throughout the experiment range (Figure 2). The result of the stability observation test confirmed this further.

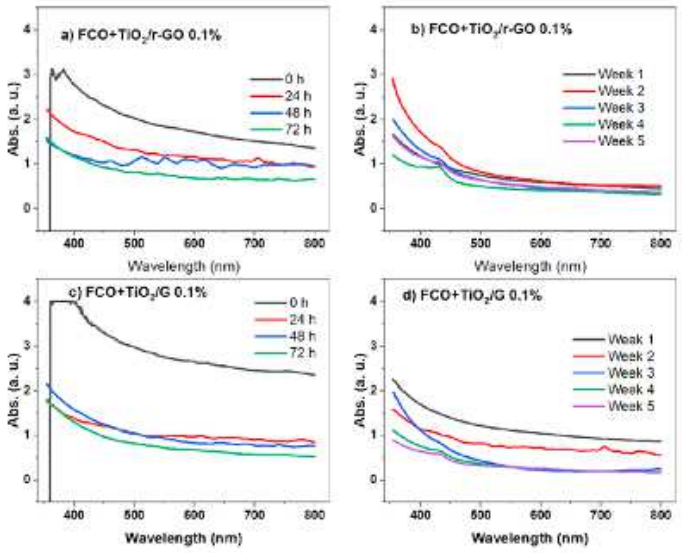

Figure 2. Overlaid optical absorbance spectra for FCO-based samples containing TiO_2/r-GO and TiO_2/G nano-additives: (a) & (c) 0–72 h overlay in 24 h intervals, and (b) & (d) 5 weeks overlay in weekly intervals.

3.3 Performance tests

The analysis of the coefficient of friction (COF) over time for the reference oil (15W40) and 15W40-based samples containing nano-additives G and GO indicates that the sample with GO demonstrates superior effectiveness in reducing friction compared to both the sample with G and the reference oil (15W40). Notably, the maximum COF reduction achieved was 72% for the combination of 200 N/50 Hz, with an average reduction of 26% for all 25 frequency/load combinations, compared to 15W40. In contrast, the sample containing G additives showed a maximum reduction of 42% and an average reduction of 17% in COF, relative to 15W40. As observed via UV-Vis analyses, the dispersion stability of GO has improved compared to G in the solution. It is presumed that the interactions of carboxyl or carbonyl functional groups on the GO surface with the sliding substrate, reducing asperity contacts, have affected this tribological improvement, because of the ability of GO nanoparticles to remain in the solution (Gupta et al., 2017).

From the results of tribological tests for the formulations containing FCO and TiO_2/G and TiO_2/r-GO nanocomposites, it is evident that both the blended samples can reduce friction more than 15W40. A 58% and 54% maximum and 26% and 23% average COF reduction were observed for the samples FCO+TiO_2/G and FCO+TiO_2/r-GO, respectively, compared to the reference oil. Despite the better stability of the sample FCO+TiO_2/r-GO, the reason for showing slightly lesser COF than the sample FCO+TiO_2/G can be attributed to the formation of molecular clusters in solution due to bonding between FCO molecules and oxygen functional groups of r-GO, which requires further investigation.

3.4 Wear scar analysis

The SEM images of cylinder liner segments with samples containing GO and TiO_2/r-GO showed improved surface morphologies compared to those with G and TiO_2/G, indicating that the functional groups of GO and r-GO form a protective layer that reduces wear at the tribological interface.

4 CONCLUSION

Results of UV-Vis analyses confirm the colloidal stability achieved for 15W40+GO and FCO+ TiO_2/r-GO samples due to the functionalization of oxygen functional groups attached to GO or r-GO elements with molecular chains of the base stock. This highlights the importance of surface functionalization in generating either repulsive or attractive forces between molecular substrates in a solution. The long-chain molecular structure of 15W40 contributes to the stability of the GO and r-GO groups in the base stock compared to FCO. The varying degrees of sedimentation of the above samples after 72 hours of formulation confirm the importance of particle concentration for the colloidal stability of a solution. These findings support the use of GO and r-GO functionalized additives in both mineral- and bio-based lubricants to enhance engine performance.

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A COMPARATIVE ANALYSIS OF RECOVERED AND COMMERCIAL CARBON BLACK IN NATURAL RUBBER COMPOSITES: INFLUENCE OF PARTICLE DISPERSION AND ASH CONTENT ON MECHANICAL PROPERTIES

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ABSTRACT: This study compares recovered carbon black (RCB) and commercial carbon black (CCB) as reinforcing fillers in natural rubber composites, focusing on how their physical and chemical properties affect mechanical performance. RCB, derived from pyrolyzed end-of-life tires, supports circular economy goals but shows inconsistent reinforcement compared to CCB. Experimental analyses— including FTIR, particle size and ash content characterization, rheometry, abrasion, and mechanical tests—were conducted to explore these differences. While RCB and CCB have similar mean particle sizes, RCB exhibits a higher z-average diameter and polydispersity index, indicating more aggregation and poorer dispersion. RCB's significantly higher ash content reduces its reinforcing effectiveness. Mechanical testing showed that CCB-filled composites outperformed RCB filled composites in tensile strength, 300% modulus, and tear resistance, especially at higher loadings (20–25 phr). In contrast, RCB-filled composites matched or exceeded tensile strength at low loadings (5–10 phr) and showed greater elongation and resilience, suggesting higher elasticity but lower rigidity. At higher loadings, RCB performance declined due to filler–filler interactions and inert residues. Tear strength characteristics also worsened under these conditions. FTIR confirmed the presence of polar functional groups on both fillers, but RCB's structural limitations offset their potential reinforcing effect.

Keywords: recovered carbon black, mechanical properties, sustainable composite, natural rubber, rubber-filler interaction

1 INTRODUCTION

Natural rubber (NR) composites rely on reinforcing fillers to enhance their mechanical properties and durability in industrial applications. Among the most widely used fillers, commercial carbon black (CCB) plays a central role in improving tensile strength, elasticity, abrasion resistance, and overall product lifespan (Donnet & Bansal, 2013). Produced through highly controlled furnace processes, CCB provides uniform particle morphology and reliable reinforcement, making it a standard material in the manufacture of tires, belts, gaskets, and other rubber products subjected to mechanical stress (Mooney, 2015).

In recent years, the drive for environmental sustainability and resource efficiency has intensified interest in alternative fillers derived from waste materials. One such material is recovered carbon black (RCB), produced from the pyrolysis of discarded tires. The concept aligns well with circular economy goals by reducing waste, recovering valuable materials, and promoting cleaner production practices (Wang et al,2018; Karger-Kocsis & Hancox, 2019). However, despite its positive environmental impact, RCB has seen limited use in commercial rubber products (Ma & Zhao, 2020).

This study aims to assess the mechanical performance of natural rubber composites filled with either RCB or CCB. Through experimental evaluation of key mechanical and processing characteristics including hardness, abrasion resistance, rebound resilience, and curing behaviour, this research investigates the extent to which RCB can serve as a viable replacement for CCB in rubber reinforcement. The goal is to identify the root causes of any performance disparities between the two fillers and to derive insights that can guide future improvements in the production and application of RCB.

2 METHODOLOGY

Rubber composites were prepared by incorporating natural rubber with zinc oxide, stearic acid, and antioxidant agents using an internal mixer. Carbon black fillers—either recovered (RCB) or N330 commercial (CCB) served as the variable component and were added at different loadings of 5, 10, 15, 20, and 25 parts per hundred rubber (phr), followed by further mixing. Sulfur and accelerators were subsequently added using a two-roll mill to complete the compounding process. The mixtures were then vulcanized at 150°C under 15 MPa pressure using a hydraulic press. Vulcanization times were determined by rheometric analysis, specifically based on the optimum cure time (t90). Mechanical properties of the vulcanized sheets including tensile strength, elongation at break, 300% modulus, rebound resilience, and hardness were evaluated according to ISO 37:2024 and ISO 34-1:2022 protocols.

3 RESULTS AND DISCUSSION

The comparative analysis between recovered and commercial carbon black revealed several distinct differences in structural and performance behavior. Although both fillers displayed similar mean particle sizes in the range of 204 to 208 nm, RCB exhibited a significantly higher z-average diameter of 752.3 nanometers compared to 249.0 nanometers for CCB (Table 1).
This disparity suggests a greater tendency toward aggregation in RCB, resulting in larger secondary particle structures that reduce effective surface interaction with the rubber matrix. The polydispersity index (PDI) further confirmed this difference, with RCB showing broader particle size distribution than CCB, indicating less uniform dispersion.

Table 1. Particle size analysis of CCB and RCB

	CCB	**RCB**
Mean particle size (nm)	204.2	208
Z-average (nm)	249	752.3
PDI	0.323	0.455

Chemical composition analysis uncovered another notable distinction. The ash content of RCB was measured at 0.083%, substantially higher than CCB's 0.0013% (Table 2). This ash consists of inorganic residues that do not contribute to reinforcement and can interfere with the dispersion and bonding of filler particles within the rubber matrix. As a result, the active reinforcing surface of RCB is effectively reduced, weakening its contribution to mechanical strength.

Table 2. Ash content of CCB and RCB

Filler Type	Ash content,%
CCB	0.0013
RCB	0.083

Mechanical testing reflected these structural and compositional differences. Both CCB and RCB increased hardness with increasing filler loading (Figure 1). At low concentrations (5– 10 phr), RCB achieved hardness values comparable to or slightly exceeding CCB. However, at higher loadings (15–25 phr), CCB provided more effective reinforcement, achieving greater hardness values. Rebound resilience showed an opposite trend: CCB-filled composites demonstrated decreasing resilience as stiffness increased, while RCB-filled composites maintained or even improved resilience at higher phr (Figure 1). This suggests that RCB forms a more elastic and flexible matrix, but with reduced rigidity.

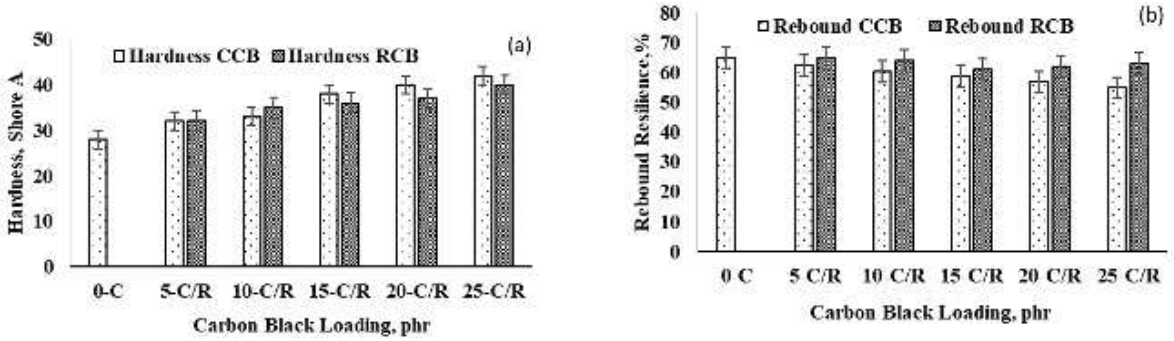

Figure 1. Hardness (a) and Rebound Resilience (b) of Rubber Vulcanizate

Tensile strength and elongation at break (Figure 2) provided further insight into the reinforcement effectiveness of each filler. The unfilled control sample exhibited a tensile strength of 15.02 MPa and an elongation at break of 1524%. CCB-filled composites showed consistent improvement in tensile strength with increasing filler content, reaching 19.9 MPa at 25 phr. RCB-filled samples initially outperformed CCB at 5–10 phr, peaking at 20.12 MPa, but exhibited a substantial drop to 10.75 MPa at 25 phr. This decline at higher RCB loadings suggests that particle aggregation and ash interference limit the effective reinforcement of the rubber matrix.

Elongation at break decreased with increasing filler loading in all cases, consistent with the expected stiffening effect. However, RCB-filled rubbers generally maintained higher elongation values than CCB-filled counterparts, indicating greater elasticity and flexibility due to weaker filler–matrix interactions. For example, at 10 phr, RCB-filled samples retained 1384% elongation versus 1342% for CCB-filled samples.

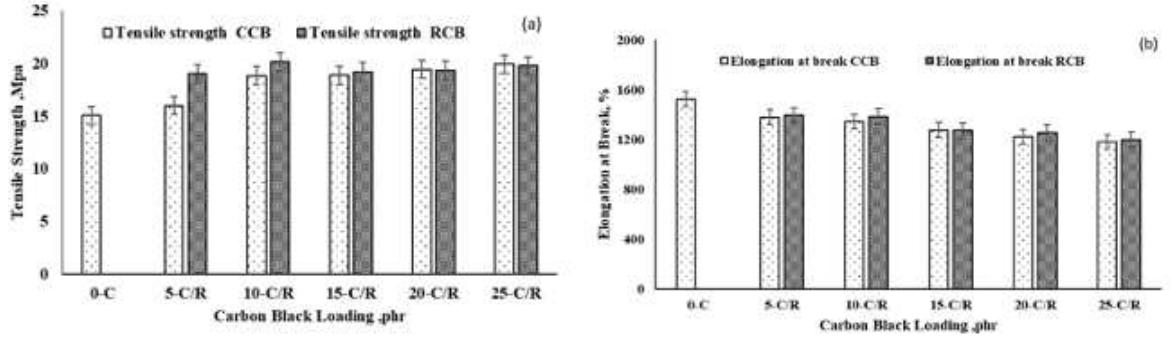

Figure 2. Tensile Strength (a) and Elongation at Break (b) of Rubber Vulcanizate

Modulus at 300% elongation further highlighted filler differences (Figure 3). CCB composites increased in modulus from 1.44 MPa at 5 phr to 2.03 MPa at 25 phr, reflecting greater stiffness and reinforcing efficiency. RCB also showed rising modulus values from 1.44 MPa at 5 phr to 2.10 at 25 phr. However, this increase did not correspond to improved tensile strength at higher loadings, indicating stress localization due to poor dispersion and filler–filler interactions. Tear strength data also revealed contrasting trends (Figure 3). CCB-filled composites improved steadily from 34.6 kN/m to 72.7 kN/m between 5 and 25 phr, attributed to robust filler–rubber networks that resisted crack propagation. In contrast, RCB-filled samples demonstrated minimal gains, increasing only from 31.0 to 39.6 kN/m across the same range. The performance plateau in RCB-filled composites at higher loadings reflects a failure to establish an integrated reinforcement phase, likely due to structural inhomogeneities and nonreinforcing ash content.

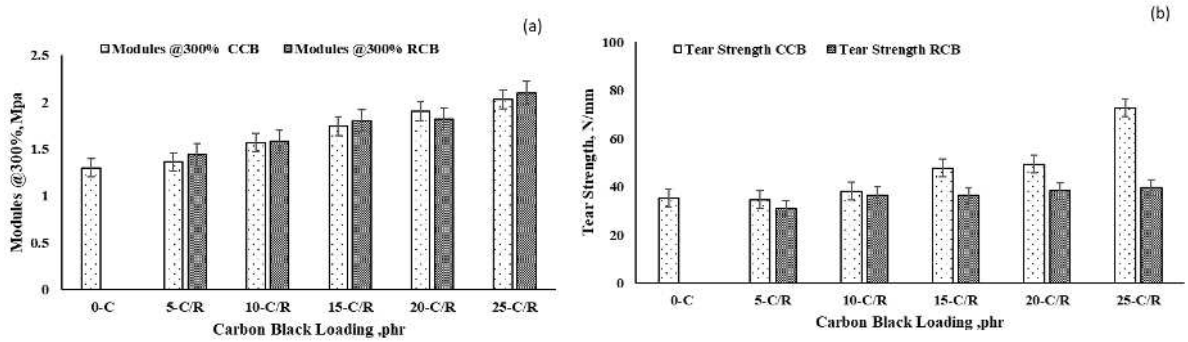

Figure 3. Modulus at 300% (a) and Tear Strength (b) of Rubber Vulcanizate

FTIR(Fourier Transform Infrared Spectroscopy) analysis revealed (Figure 4) the presence of similar functional groups on both carbon black types, including hydroxyl, carbonyl, and aliphatic bonds. RCB displayed stronger absorption peaks for polar groups, likely due to oxidation during pyrolysis. While these groups could theoretically enhance filler–rubber bonding, their positive effect is diminished by the previously discussed physical drawbacks of RCB.

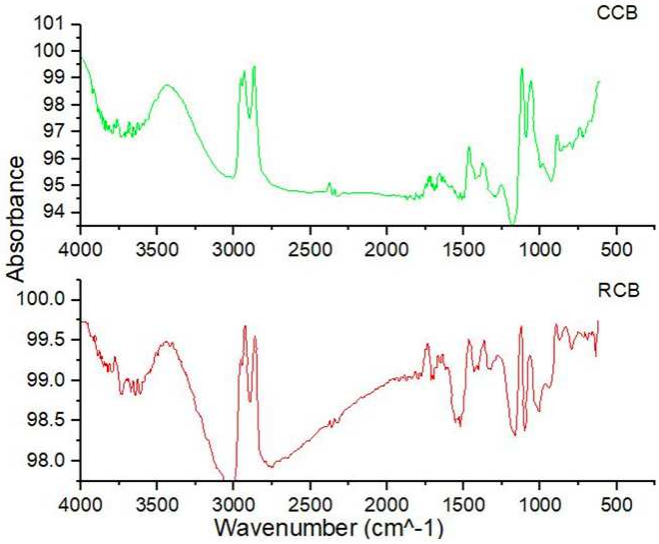

Figure 4. FTIR graph of CCB and RCB

4 CONCLUSION

Recovered carbon black (RCB) offers a sustainable alternative to commercial carbon black (CCB), but exhibits higher particle aggregation, greater ash content, and weaker dispersion, which limit its reinforcing efficiency. While RCB performs comparably at low loadings (5–10 phr) with higher resilience and elongation, CCB consistently delivers better mechanical strength at higher loadings. FTIR confirms similar surface chemistry in both fillers, but RCB's structural limitations outweigh its potential bonding advantages. Therefore, RCB is best suited for moderate-performance applications, while CCB remains preferable for demanding, high-load rubber products.

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PRODUCTION OF CELLULOSE FROM INVASIVE SPECIES (WATER HYACINTH): A SUSTAINABLE SOLUTION FOR ENVIRONMENTAL AND ECONOMIC CHALLENGES IN SRI LANKA

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ABSTRACT: Water hyacinth (Eichhornia crassipes), an invasive aquatic weed, poses significant environmental, economic, and social challenges in many tropical regions, including Sri Lanka. However, its high cellulose content and low lignin composition make it a promising non-wood biomass for sustainable cellulose extraction. This study aimed to develop and evaluate an efficient chemical method for extracting cellulose from water hyacinth. The stems were subjected to bleaching with sodium hypochlorite at different residence times (2, 6, 8, and 10 hours), followed by alkaline treatment using sodium hydroxide. The cellulose yield was measured concerning the initial dry biomass, with the highest yield of 36.08% obtained at a bleaching duration of 10 hours. The color change from brown to white indicated progressive delignification. Fourier-transform infrared spectroscopy analysis confirmed cellulose enrichment, as indicated by the disappearance of hemicellulose- and lignin-associated peaks and the predominance of O–H, C–H, and C–O–C stretching vibrations typical of pure cellulose. The results demonstrate that water hyacinth can serve as a viable alternative cellulose source, with yields comparable to or higher than traditional non-wood feedstocks such as rice straw and bagasse. This process supports the circular economy by converting waste biomass into high value materials, reducing dependence on imported cellulose and promoting resource efficiency.

Keywords: cellulose extraction, bleaching, water hyacinth, circular economy

1 INTRODUCTION

Water Hyacinth (Eichhornia crassipes) is an aquatic weed species that grows rapidly and covers the entire water surface with a thick covering. This plant is also called “Japan Jabara” in Sri Lanka. The high-density growth of water hyacinth, primarily driven by eutrophication in open water bodies, leads to significant ecological, operational, and social challenges. It clogs irrigation canals and hydropower systems, restricts livestock access to water, obstructs rivers and navigation routes, and displaces native aquatic vegetation. The dense cover alters essential water parameters such as pH, temperature, and dissolved oxygen while severely limiting sunlight penetration, which in turn degrades water quality and aquatic life. Beyond environmental and economic concerns, the plant contributes to public health issues by creating breeding grounds for disease-carrying vectors like mosquitoes and snails, which spread illnesses such as dengue and malaria. Socially, water hyacinth hampers livelihoods dependent on water transport, fishing, and farming, while also diminishing the aesthetic and recreational value of affected water bodies (Nandiyanto et al., 2023).

Controlling water hyacinths includes chemical herbicide spraying, biological management with insects and pathogens, and mechanical removal (human cutting, machinery, and obstacles).

Regrowth is inhibited by environmental practices such as lowering nutrient inflows, controlling water levels, and providing shade. Furthermore, circular economy strategies are supported by sustainable applications like biofuel, compost, and handicrafts, which improve the efficacy of integrated management. Despite all these challenges, water hyacinth has biochemical potential, especially as a source of cellulose (Sun et al., 2020). Cellulose is the most abundant organic polymer on Earth and is a basic raw material in paper, textiles, pharmaceuticals, and bioplastics industries. The global demand for cellulose is increasing as the world is moving towards renewable and sustainable materials. Sri Lanka imports most of its cellulose even though there are vast quantities of water hyacinth biomass lying underutilized or discarded after removal. This is an opportunity to turn an environmental liability into an economic asset by producing cellulose from water hyacinth.

Higher concentrations of cellulose are found in materials such as wood, which contains about 40- 50 %, and cotton, which contains up to 90 %. Cellulose is also produced by certain bacteria and algae (Smriti et al., 2023). Figures 1 and 2 show the images of cellulose fiber and cellulose structure, respectively.

Figure 1. Image of Cellulose fiber

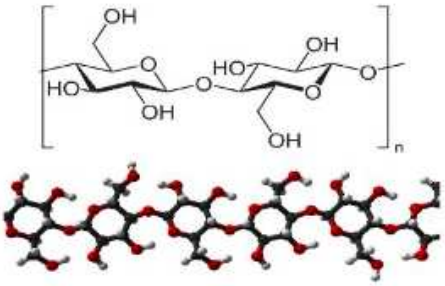

Figure 2. Image of Cellulose structure

Its unique structure gives high tensile strength, chemical stability, and biodegradability, making it essential in many industries. Paper and packaging are the largest consumers of cellulose, followed by textiles, pharmaceuticals, and emerging applications such as nanocellulose for composites and biomedical devices. In Sri Lanka, the demand for cellulose is met through imports, with limited domestic production from wood pulp and agricultural residues. Utilization of water hyacinth as a cellulose source will be a sustainable alternative, reducing the reliance on imported materials and supporting local industries. Traditional cellulose extraction primarily relies on wood pulping techniques such as the Kraft and sulfite processes. While these methods are widely used, they are high-energy and chemical consuming and contribute to environmental pollution due to the release of toxic byproducts. In recent years, there has been growing interest in alternative sources and extraction techniques that are more sustainable and environmentally friendly. Agricultural residues and non-wood biomass, such as salvinia and water hyacinth, have gained attention due to their renewability and lower environmental impact. Water hyacinth contains 45-55% cellulose (on a dry weight basis) and low lignin content, making it suitable for such applications. Recent research has looked into various pretreatment and extraction methods, including alkaline pulping, organic solvent treatment, and enzymatic hydrolysis. Each method

has advantages and disadvantages with regard to cellulose yield, purity, cost, and environmental impact (Magalhães et al., 2023). The main objective of this research is to develop and refine a process to extract cellulose from water hyacinth, to evaluate the yield of the product. By doing so, this research will contribute to sustainable material development, the circular economy, and provide a solution to the water hyacinth problem in Sri Lanka.

2 METHODOLOGY

Water hyacinth was collected from a canal adjacent to the Karadiyana garbage dump in Colombo, Sri Lanka. The raw plant material was thoroughly washed with tap water to remove soil and debris, then sun-dried for three to four days. In the laboratory, the roots and leaves were manually separated from the stems using scissors, and the stems were cut into smaller pieces. The stem fragments were oven-dried at 60 °C using a Memmert UN 110 oven and subsequently ground into a fine powder using a domestic blender (Panasonic MX-AC300).

The dried powder was weighed using an analytical balance (KERN ALJ 250-4 AM) to obtain the required quantity. This was mixed with distilled water in a beaker to form a slurry. A 10% (w/w) sodium hypochlorite solution was prepared, and its pH was adjusted to 8 using acetic acid. The powdered water hyacinth material was soaked in the prepared solution at room temperature overnight. Intermittent stirring was carried out using a glass rod for different residence times: 2, 4, 8, and 10 hours.

After soaking, the material was washed thoroughly with distilled water until a neutral pH was achieved and filtered using clean cotton cloth. The delignified material was then treated with 1% sodium hydroxide solution at room temperature for 2 hours under continuous stirring. Following this treatment, the material was again washed with distilled water until the natural pH was restored and filtered through cotton cloth.

A second bleaching step was performed using 5% (w/w) sodium hypochlorite at room temperature for 2 hours. The treated material was thoroughly rinsed with distilled water to remove residual chemicals. The final slurry was filtered using Whatman Grade 4 filter paper and dried under sunlight.

Throughout the entire procedure, the temperature was maintained at room temperature. The pH of the sodium hypochlorite solutions was adjusted to 8 to ensure effective bleaching, as lower pH levels could result in the release of chlorine gas from the solution. The chemical reagents used in this study included sodium hypochlorite solutions at concentrations of 10% and 5% (w/w) for the bleaching steps, and a 1% sodium hydroxide solution for alkaline treatment.

Bleaching effectiveness was investigated by varying the residence time of stirring with sodium hypochlorite solution, ranging from 2 to 10 hours. The alkaline treatment was conducted for a fixed duration of 2 hours. The procedure successfully extracted cellulose from water hyacinth, with observable color changes from brown to white, indicating progressive delignification and bleaching.

3 RESULTS AND DISCUSSION

The average cellulose yield was approximately 36% based on the dry weight of the initial water hyacinth biomass for samples subjected to 8–10 hours of bleaching. This yield is comparable to, or even higher than, those reported for other non-wood biomass sources such as rice straw and bagasse (Thongsomboon et al., 2023). The cellulose yield varied according to the bleaching residence time, as illustrated in Figure 3 and Table 1.

It is important to note that both sodium hypochlorite and sodium hydroxide are chemical hazards. Therefore, all experimental procedures were conducted using appropriate personal protective equipment (PPE) and in well-ventilated conditions to minimize risk. Under the conditions described, the reactions were neither explosive nor significantly exothermic, ensuring safe handling throughout the process.

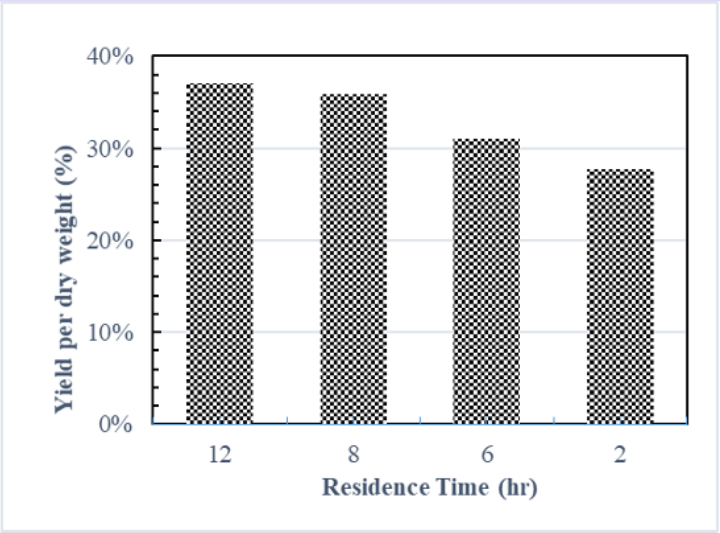

Figure 3. Variation of the percentage yield of cellulose per dry weight of water hyacinth with the residence time of the bleaching process

Table 1. Effect of bleaching residence time on cellulose yield from water hyacinth

Residence Time (hr)	Dry Weight of water hyacinth (g)	Cellulose Yield (g)	% cellulose yield per water hyacinth dry weight
2	28	7.952	28.40
6	28	8.874	31.69
8	28	10.01	35.75
10	28	10.101	36.08

Fourier-transform infrared spectroscopy (FTIR) analysis was used to assess the extracted cellulose purity by analysing its distinctive absorption peaks and determining if impurity signals are present or absent. Strong O–H, C–H, and C–O–C stretching are observed in pure cellulose at approximately 3300 cm^{-1}, 2900 cm^{-1}, and 1050 cm^{-1}, respectively. While lignin exhibits aromatic peaks close to 1510 cm^{-1} and 1600 cm^{-1}, impurities like hemicellulose form a carbonyl peak at 1730 cm^{-1}. Higher cellulose purity is shown by the decrease or elimination of certain

impurity peaks in spectra compared to those obtained before and after treatment. Thermogravimetric analysis (TGA) is expected to be used to assess the extracted cellulose's purity in future work. With the aid of these analytical methods, the cellulose content can be estimated, and a purity of roughly 90% is predicted based on comparable optimized procedures documented in the literature (Packiam et al., 2022).

Compared with conventional wood pulping, water hyacinth-based cellulose extraction has several advantages, including lower chemical consumption, reduced energy requirements due to softer structure and lower lignin, and the utilization of an otherwise problematic biomass. But challenges remain in terms of seasonal variability in water hyacinth availability, transportation logistics, and market acceptance of non-wood cellulose. Additional processes, such as the generation of biogas from leftover biomass or the extraction of bioactive compounds, could be integrated alongside cellulose production and make the entire system more economically sustainable.

4 CONCLUSION

This study shows that it is feasible to extract cellulose from water hyacinth using sodium hypochlorite and sodium hydroxide through a sequential treatment method. Bleaching time was a key determinant in cellulose yield, with the highest at 36.08% was obtained at a residence time of 10 hours. The color change observed confirmed the samples' delignification and bleaching after treatment. The method was performed at room temperature (non-exothermic and non-explosive) in the presence of adequate PPE and ventilation. Due to the relatively high cellulose content and low lignin fraction, water hyacinth can be considered a feasible source of cellulose in Sri Lanka which is a sustainable alternative to wood. Beyond material production, the initiative also helps control an invasive species that threatens ecosystems and water resources. By implementing such methods, the country would also decrease its reliance on imported cellulose. Future studies should focus on purity analysis and process optimization coupled with value-added products such as nanocellulose or biofuel production to enhance the economic and environmental sustainability of an integrated system.

5 ACKNOWLEDGEMENT

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ECO-FRIENDLY ANTIBACTERIAL PACKAGING MATERIALS FROM BANANA FIBER: A REVIEW

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ABSTRACT: The global growth in plastic pollution has increased the demand for environmentally friendly and biodegradable packaging materials. Banana fiber, a natural fiber source, has garnered significant attention due to its biodegradability, high cellulose content, mechanical strength, and availability as agricultural waste. However, biodegradable materials often lack inherent antibacterial properties which is crucial for sensitive applications like food and medical packaging. The objective of this review is to evaluate the potential of banana fiber as a base material for eco-friendly antibacterial packaging with a focus on enhancing its functionality through modifications using tannic acid for food and medical applications. The review discusses the chemical composition, mechanical properties, and surface modification of banana fiber through alkali treatment. It further explores biofunctionalization techniques such as fiber immersion, surface coating, and blending with biopolymers to improve the antibacterial properties of the fiber. Additionally, the review outlines current approaches to manufacturing antibacterial packaging composites including pulping, sheet forming, hot pressing, and lamination. Potential applications in food, medicine, pharmaceutical, and agricultural industries are also highlighted. Although there is a growing interest in biodegradable packaging materials, limited research has explored the use of banana fiber in combination with plant-derived antibacterial agents such as tannic acid to develop multifunctional materials. Key findings include the fact that alkali treatment improves fiber bonding with tannic acid, tannic acid offers superior thermal stability compared to other natural antimicrobials, and banana fiber composites can extend food shelf life. These modifications support the development of sustainable, multifunctional packaging for various applications.

Keywords: antibacterial packaging, banana fiber, biodegradable material, tannic acid

1 INTRODUCTION

The problem of plastic waste has become one of the most critical environmental challenges of the 21st century. Single-use packaging accounts for nearly 40 per cent of global plastic waste. Unlike conventional plastics, which can persist in the environment for centuries, these materials leach microplastics and toxic additives into soil and waterways, posing long-term threats to ecosystems and human health. In response, many nations in the European Union have implemented stricter regulations, such as single-use plastic ban; however, the need for environmentally friendly alternatives has not been considered. Biodegradable and inherent antibacterial packaging materials are urgently required for the protection of the environment and food safety simultaneously. In addition to long-term environmental consequences, biodegradable materials for food packaging and pharmaceutical purposes often exhibit inferior antimicrobial properties (Zhong et al., 2020). The development of sustainable bio-composites that mix natural fibers with plant-derived antibacterial substances, such as tannic acid and chitosan, has recently gained significant attention (Zhang et al., 2023a). These materials not only represent an environmentally safe choice but also protect against bacteria, making them ideal for modern packaging solutions.

The creation of antibacterial and biodegradable packaging supports global advantages for circular economies, reduces waste, and ensures public health safety. This review selected tannic acid over other natural antibacterial agents because of its exceptional activity levels combined with plant origin and its compatibility with lignocellulosic fibers, including banana fiber. Tannic acid is a water-soluble polyphenol present in tea leaves alongside pomegranate peels and oak bark, among various agricultural waste materials. This potent antibacterial agent destabilizes bacterial cell membranes while binding to proteins and sequestering essential metal ions required for bacterial proliferation simultaneously (Farha et al., 2020). Tannic acid exhibits antibacterial properties alongside its antioxidant, anti-inflammatory, and UV-blocking abilities, which help enhance packaging material longevity and performance (Buzzini et al., 2008a; Lee et al., 2023). The material demonstrates biodegradability and non-toxicity while holding approval for food-contact use, which positions it as a suitable component for sustainable packaging systems (Zhang et al., 2023b). The process of extracting from local plant residues presents a straightforward method that provides economic advantages while adhering to circular economy standards. The study chose tannic acid as its focal antibacterial agent for these specified reasons.

In this context, the potential of banana fiber-based bio-composite materials employing natural antibacterial agents such as tannic acid, as a sustainable and multifunctional alternative to synthetic plastic packaging materials is assessed. The advantages of these materials such as abundance, biodegradability, and mechanical strength are discussed alongside their limitations and the process of biofunctionalization. The study also investigates the feasibility of applying tannic acid, a natural polyphenol derived from plants, with well-established antimicrobial and antioxidant properties, with a focus on enhancing the safety and shelf life of packaged food articles.

2 LITERATURE REVIEW

2.1 Properties of banana fiber

Banana fiber, derived from the pseudo stems of Musa species, has garnered significant attention as a sustainable raw material for eco-friendly packaging due to its renewable character, biodegradability, and excellent mechanical performance. The chemical makeup of banana fiber includes 55% to 65% cellulose, 12% to 25% hemicellulose, 5% to 15% lignin, along with small amounts of pectin, ash, and extractives (Badanayak et al., 2023). Cellulose, which is the main element of structure, is a hydrophilic polymer with a crystalline rod-like chain structure that adds to the fiber's tensile strength. Hemicellulose and lignin, which provide flexibility and rigidity to the structure, also play a crucial role in increasing water affinity, which in turn degrades durability. Banana fiber has high tensile strength exceeding 500 MPa and a density of around 1.28 g/cm^3, making it comparable to or superior to other natural fibers like jute and coir (Yahya et al., 2023). Its porous and rough morphology helps in interfacial bonding with hydrophilic agents and biopolymers. Treatment with sodium hydroxide (NaOH) further improves fiber performance by removing surface impurities, as well as lignin and hemicellulose, enhancing crystallinity and roughening the fiber surface. Optimized alkali conditions (e.g, 6.3% NaOH at 80°C for 60 minutes) have been shown to increase tensile strength by approximately 26% (from 615 to 775

MPa) and reduce water absorption by nearly 68% (from 209% to 69%) (Checol & Sendekie, 2025). Alkali treatment improves interfacial adhesion enhancing bonding of banana fiber with antimicrobial agents like tannic acid. These modifications not only improve the raw fiber but also contribute to the properties of the final developed packaging material. This ensures better mechanical strength, durability, and moisture resistance all of which are crucial for its practical use. Banana fiber has qualities similar to other natural fibers. It has a lower density while matching or surpassing the tensile performance of hemp or jute. It is low-cost, lightweight, and offers superior properties for lightweight eco-composites. The hydrophilicity of banana fibers improves biodegradability; however, its performance may degrade in wet environments due to stabilization challenges. The integration of banana fibers with tannic acid antimicrobial agents further enhances the packaging material's antibacterial activity while maintaining biodegradability. These improvements make banana fiber composites highly suitable for antibacterial packaging of food and medical products which require both mechanical strength and protection from microbial spoilage.

2.2 Biofunctionalization of banana fiber with natural antibacterial agents

The integration of natural antibacterial agents into lignocellulosic fibers, like banana fiber, has gained growing attention for enhancing the performance of biodegradable packaging in food and medical applications. Banana fiber offers mechanical strength and biodegradability, yet it lacks inherent antimicrobial properties, which limits its effectiveness in prevention microbial contamination in packaging. Recent Scientific investigation have examined the bio-functionalization of banana fiber using plant-derived antibacterial agents, including tannic acid, neem extract, chitosan, and essential oils (Zhang et al., 2023). Among these agents, tannic acid stands out as an exceptional candidate due to its broad-spectrum antibacterial properties combined with strong interaction with cellulose (Buzzini et al., 2008b; Farha et al., 2020). Derived from pomegranate peels, tea leaves, and oak bark tannic acid is safe for food applications. Through its intricate antibacterial mechanisms, tannic acid disrupts microbial cell membranes while simultaneously inhibiting essential enzymes and chelating metal ions needed for bacterial survival (Lee et al., 2023). Its polyphenolic structure enables strong bonding with banana fiber, especially after alkali treatment, which exposes more reactive hydroxyl groups on the fiber surface (Checol & Sendekie, 2025). Antibacterial treatment is typically performed by immersing banana fibers in a tannic acid solution prepared in a 70:30 ethanol-water mixture (Kim et al., 2024); however, this ratio can be adjusted to enhance solubility and achieve uniform surface modification. This modification enhances the fiber's antibacterial activity, UV resistance, and lower moisture uptake, which is important for keeping the integrity of the product (Xiao et al., 2024). While other agents like neem oil and chitosan have natural antibacterial characteristics, tannic acid is particularly promising for functionalizing banana fiber because it is more thermally stable, inexpensive, and adheres well to cellulose matrices. Tannic acid functionalization of banana fiber has a two-fold value: it improves food and pharmaceutical safety and reduces environmental concerns, making it a promising approach for creating biodegradable antibacterial packaging materials.

2.3 Manufacturing of antibacterial packaging material

The development of antibacterial packaging from banana fiber is a multi-stage process, illustrating the economic integration of mechanical, chemical, and functional treatments to create value-added biodegradable products from agricultural waste. The first stage involves mechanical extraction of fibers from banana pseudo-stems which are available in abundant quantities after harvest. Mechanical decortication is preferred because it is cheap and it physically removes fibers while preserving their structure. After extraction, the fibers undergo an alkali treatment using NaOH. This treatment is important because it removes non-cellulosic content (lignin, hemicellulose, and surface waxes) and modifies the fibers by improving fiber crystallinity, increasing fiber surface roughness, and exposing more hydroxyl groups. These improvements allow for better compatibility with hydrophilic antibacterial agents and improve interfacial bonding in composite materials. After cleaning and activation, fibers are prepared for antibacterial functionalization with tannic acid. Tannic acid is a natural polyphenol that has been reported to exhibit broad-spectrum antimicrobial activity. The fibers are treated by depositing them in a 50:50 mixture of ethanol and water in a solution of tannic acid. This method allows for effective diffusion into and interaction with the fiber surface. Tannic acid adheres to cellulose through hydrogen bonds and possibly hydrophobic sites to create a permanent antibacterial layer on the fiber surface. Next, the fibers undergo via a pulping process during which they become a slurry and are combined with biodegradable binders (rice starch) to create a pulp. This pulp is made into sheets using sheet-forming equipment and then air-dried to remove moisture. The sheets are further processed using a hot press to improve mechanical properties, surface finish, and consistency of structure. Cutting may also be applied to form the packaging into dimensional forms.

2.4 Potential applications of banana fiber packing material

The antibacterial packaging material from banana fiber treated with tannic acid offers numerous applications in sectors that value sustainability, hygiene, and biodegradability. In the food sector, the packaging material can be used effectively to wrap fresh produce such as fruits, vegetables, and herbs, where the antibacterial properties will help reduce spoilage rates and extend shelf life. In the food service industry, the biodegradable packaging material can be formed into disposable trays, wraps, or containers for takeaway meals providing a more sustainable alternative to plastic while also ensuring food against microbial contamination (Barretto et al., 2024). The material is also suitable for sensitive applications in medical and pharmaceutical secondary packaging, such as the encasement of herbal soaps, wound dressings, or hygiene products, where surface protection against contact contamination during handling and distribution is paramount (Umapathi et al., 2025). In addition, fiber composite sheets could be formed into biodegradable nursery pots or seedling and cutting trays in agriculture. The antimicrobial surface would protect young plants from fungal and bacterial infections during early development, thereby supporting healthy growth without reliance on chemical fungicides. Other applications include eco-friendly gift wraps, garment packaging, and customized shopping bags for sustainable brands that committed to ecologically eliminating plastics from their value chains. With further

development and process optimization, banana fiber-based antibacterial packaging could serve as a cost-effective and environmentally responsible alternative for a wide range of commercial applications.

2.5 Knowledge gap

While there is extensive research on the application of natural fibers in biodegradable packaging, the potential of banana fiber integrated with plant-derived antibacterial agents such as tannic acid remains underexplored in the context of food packaging. Most existing studies focus either on improving the mechanical properties of banana fibers or on investigating the antibacterial effects of tannic acid in isolation. However, there are a few studies which had attempted to integrate both aspects into a marketable product. Current methods have not sufficiently addressed the need for multifunctional antibacterial packaging. This review study aims at exploring the possibility of combining banana fiber and tannic acid for packaging applications. Moreover, the green extraction of tannic acid from agricultural waste is still unexplored in the context of food packaging. Future research should focus on optimizing processing methods while case studies and pilot projects could further demonstrate the practical relevance and feasibility of this novel packaging solution.

3 CONCLUSION

The demand for sustainable and biodegradable food packaging to replace plastic is increasing. Banana fiber, a renewable and biodegradable agricultural byproduct possesses significant potential as a packaging substrate due to its fibrous structure which enables the use of plant-based antibacterial agents such as tannic acid to reduce plastic waste and improve product safety in microbial terms. Research highlights that alkali treatment improves the compatibility of banana fiber with tannic acid, thereby enhancing antibacterial properties and mechanical strength. However, there are still some challenges in achieving antibacterial effectiveness and improving the manufacturing process. Future studies should focus on the optimization of functionalization processes and performance validation through standardized techniques. Case studies and pilot projects would be valuable in facilitating the transition of such products from the laboratory research to industrial application which is an integral part of sustainable development.

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DETERMINATION OF MOISTURE DIFFUSIVITY OF KOHILA DRYING IN A CONVECTION TRAY DRYER

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ABSTRACT: Kohila (*Lasia spinosa*), a widely used ethnobotanical herb in Sri Lanka, is recognized for its therapeutic properties and potential in functional food development. This study investigates the drying kinetics of Kohila rhizome slices using a convection tray dryer at temperatures of 60°C, 65°C, and 68°C, with the aim of developing value-added, shelf-stable products. Sliced rhizomes (5 mm thick) were dried under controlled conditions, and moisture loss was recorded over time. Results indicate effective moisture diffusivity increasing with temperature. Estimated D_{eff} values ranged from 2.83×10^{-7} to 7.50×10^{-6} m^2/s. The activation energy for moisture diffusion was determined to be 8.52 kJ/mol, and the diffusivity coefficient was 6.75×10^{-9} m^2/s. These findings provide essential insights for optimizing drying conditions and support the commercial utilization of Kohila rhizomes in dried or powdered form.

Keywords: drying kinetics, convection tray dryer, Kohila, diffusivity

1 INTRODUCTION

Kohila (*Lasia spinosa*), a widely distributed ethnobotanical herb in Sri Lanka, is traditionally valued in Ayurvedic medicine. Both Its young leaves and rhizomes are known for their therapeutic properties and are commonly used in the treatment of digestive disorders, piles, rheumatism, and colic. The thick underground rhizomes, which are swollen horizontal stems, are recognized for their blood-purifying effects and have been utilized to manage rheumatoid arthritis, constipation, and other chronic ailments. Given its broad therapeutic potential, the development of value-added products from Kohila rhizomes such as dried powder, chips, or Kohila powder-infused bakery items can provide health-conscious consumers with convenient, functional food options while also creating new market opportunities for local producers (Adikari et al., 2022). For preservation and commercial utilization, Kohila (*Lasia spinosa*) rhizome slices must be dried to a final moisture content of 8–10%, a range that effectively inhibits mold growth and microbial spoilage (Shefana & Ekanayake, 2009). While sun drying is a traditional method, it presents several drawbacks, including dependency on weather conditions, risk of contamination, and uneven drying. Therefore, alternative drying techniques, such as convection drying, are necessary to achieve safe, hygienic, and consistent drying outcomes. Drying is a fundamental unit operation in food and chemical processing industries, where the primary objective is to reduce moisture content without compromising product quality. To optimize the drying process for Kohila rhizomes, it is essential to investigate critical parameters such as drying kinetics, effective moisture diffusivity, diffusion coefficient, and specific energy consumption (Sousa et al., 2024). Among these, moisture diffusivity plays a central role in governing mass transfer during drying and is influenced by factors such as slice geometry, drying temperature, and initial moisture content. While several studies have explored these parameters for herbs like black

pepper and cinnamon, there is limited literature available on the effective moisture diffusivity of Kohila rhizomes, highlighting the need for targeted research in this area (Amarasinghe et al., 2025).

Low-cost drying methods such as packed bed dryers, fluidized bed dryers, and convection tray dryers are commonly employed in the agricultural sector due to their affordability and ease of operation (Jayatunga & Amarasinghe, 2014; Dryer & Sunderland, 1968). In contrast, novel drying technologies like freeze drying and microwave drying offer superior quality retention, particularly for heat-sensitive bioactive compounds, but are often limited by their high capital and operational costs. As an initial step toward developing value-added products from Kohila (*Lasia spinosa*), this study investigates the effect of varying drying temperatures on the drying kinetics of Kohila slices using a convection tray dryer. Furthermore, the study aims to evaluate the effective moisture diffusivity and diffusion coefficient of Kohila rhizomes during the drying process.

2 METHODOLOGY

Kohila rhizomes were purchased from a local vendor in Homagama. The rhizomes were thoroughly washed with clean water and sliced into discs approximately 5 mm thick to ensure uniform drying by avoiding over-drying of thinner slices or incomplete drying of thicker ones. The average diameter of the rhizomes ranged from 3.0 to 3.5 cm.

Drying experiments were conducted using a laboratory-scale convection tray dryer (*GUNT CE 130*). The air velocity was maintained at 2.8 m/s, which was sufficient to ensure proper airflow across the samples but not high enough to cause fluidization in the tray dryer. Experiments were carried out at three different temperatures: 60°C, 65°C, and 68°C. The desired drying air temperature was attained by the electric heater and the temperature control unit. In all experiments, the fluctuation of temperature was maintained within ±0.5°C. The sliced Kohila rhizomes were evenly distributed on the trays, stacked one over the other, allowing uniform airflow across the slices.

Drying temperatures were selected in the range of 60–68°C, as most agricultural crops are typically dried between 60 and 70°C to minimize the decomposition of heat-sensitive compounds (Jayatunga & Amarasinghe, 2019).

The weight reduction of the slices during drying was recorded at regular intervals using the auxiliary instruments provided with the dryer. Room temperature and relative humidity were monitored using an EXTECH EasyView™ Digital Hygro-Thermometer (Model EA20), while the airflow velocity from the blower was measured using an EXTECH Vane Thermo-Anemometer (Model SDL300).

3 RESULTS AND DISCUSSION

As shown in Figure 1, the drying rates were high at the beginning of the drying process, probably due to evaporation of moisture from the surface of the Kohila slices, and later decreased with decreasing moisture content, for all the drying conditions, proving that the mechanism of moisture movement is governed by a diffusion phenomenon as stated by Fick's law. Effective

moisture diffusivities of Kohila slices were estimated from a plot of ln(MR) versus drying time for different drying conditions, as shown in Figure 2 and listed in Table 1 together with corresponding values of determination coefficient (R2) and relative mean square error (RMSE).

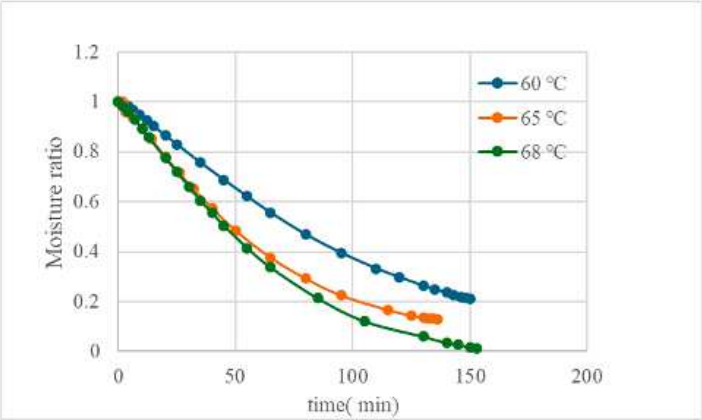

Figure 1. Moisture ratio vs time for drying Kohila slices in a convection tray dryer (bed weight = 400 g, air velocity 2.8 m/s)

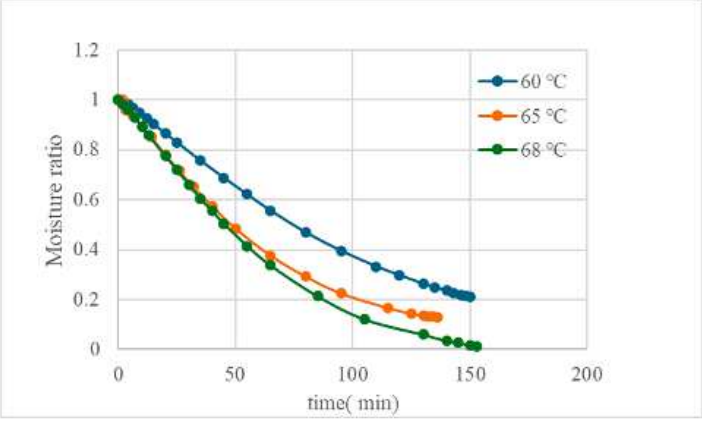

Figure 2. Ln(Moisture ratio) vs time of Kohila drying in a convection tray dryer

Table 1. Effective moisture diffusivity of Kohila slices dried in a convection tray dryer at different drying temperatures

Drying temperature T (°C)	**Effective diffusivity D_{eff} (m^2/s) wdt**	**R^2**	**RMSE**
60	2.83×10^{-7}	0.99	0.05944
65	4.1×10^{-7}	0.99	0.09781
68	7.5×10^{-6}	0.96	0.2149

According to the results, the effective diffusivity of Kohila slices depends on the drying temperature and increases with increasing temperature. The diffusivity coefficient was found to be 6.75×10^{-9} m^2/s, while the activation energy was 8.52 kJ/mol. It is worth mentioning that the effective diffusivity of barley was reported as 3.94×10^{-11} m^2/s at 55 °C (Markowski et al., 2010), wheat as 8.33×10^{-14} m^2/s at 30 °C (Panagiotou et al., 2004), and malt as 1.11×10^{-8} m^2/s at 20 °C in the literature.

4 CONCLUSION

This study investigated the drying kinetics of Kohila (*Lasia spinosa*) rhizome slices in a convection tray dryer at temperatures ranging from 60°C to 68°C and an air velocity of 2.8 m/s. The effective moisture diffusivity values were found to increase with temperature, ranging from 2.83×10^{-7} m^2/s to 7.50×10^{-6} m^2/s. The activation energy for the drying process was estimated as 8.52 kJ/mol, and the corresponding pre-exponential factor was also determined. These results confirm that moisture migration during drying follows a diffusion-controlled mechanism governed by Fick's law. The increasing trend of effective diffusivity with temperature, along with a relatively low activation energy, suggests favorable drying characteristics compared to other agricultural materials. These findings lay a strong foundation for scaling up Kohila drying operations and incorporating dried rhizomes into value-added food and nutraceutical products, thereby contributing to rural livelihoods and the functional food industry in Sri Lanka.

5 ACKNOWLEDGEMENT

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REMOVAL OF CD(II) FROM AQUEOUS MEDIUM USING MAGNESIUM OXIDE NANOPARTICLES

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ABSTRACT: Heavy metal contamination in drinking water has become a severe threat to all living beings without any boundaries. Generally, these contaminants can be either anthropogenic or originate from industrial activities or unavoidable natural disasters. However, during the last few decades, uncontrolled pollution in natural water bodies has led to a number of irreversible outcomes all over the world. As it undergoes bioaccumulation, it may cause complex health issues in all living creatures. Mostly, heavy metal contaminated industrial effluents enter natural water bodies, due to inadequate prior treatment. Polluted water can be treated using different chemical and physical adsorption methodologies. In this study, MgO nano particles were prepared separately using commercially available dolomite and aqueous Mg2+ solution, in the presence of HTAC (hexadecyl-trimethylammonium chloride) surfactant, with the aim of removing Cd(II) from the aqueous medium. Using Fourier transformed infrared (FT-IR) spectroscopy, Cd (II) adsorption was observed and development of a band at 739 cm-1 in the spectrum confirmed the formation of the Cd-O bond. Further, agglomeration of nanoparticles was determined by scanning electron microscope (SEM) which provided strong evidence for Cd(II) trapping. The removal of Cd(II) was observed under different conditions including dosage, shaking time, settling time and pH. According to the results, the optimized parameter for the nano MgO was 6 mg dosage, 30 minutes shaking time and 10 minutes setting time within the PH range of 6.0 to 8.0.

Keywords: heavy metal adsorption, nano-magnesium oxide, magnesium oxide nono wires

1 INTRODUCTION

Human activities like mining, industrial waste, and the use of pesticides and fertilizers mainly cause an increase in heavy metal content in ground and surface water sources. This may lead to health risks for humans and other living organisms. Since the World Health Organization (WHO) has listed four heavy metals (As, Pb, Hg, and Cd) on its list of 10 chemicals with major potential health concerns (Bratbak & Dundas, 1984), it is important to remove these heavy metals from contaminated water before consumption.

Though there are numerous methods to remove heavy metals from contaminated water, various types of materials have been used as adsorbents in heavy metal removal. Considering the adsorbent materials, nano metal oxides (NMOs) play a major role in heavy metal removal since they have a higher surface area compared to other materials. Nano MgO is a very promising material for use as an adsorbent due to its strong adsorption ability as well as high surface reactivity and adsorption capacity compared to commercial analogues, and the simplicity of its production from naturally abundant materials (Shen & Ostroverkhov, 2006).

Heavy metal-contaminated wastewater has been treated using various techniques to improve water quality. To remove heavy metals from aqueous media, ion exchange, chemical precipitation, and adsorption methods were used. In the adsorption process, various types of nano-sized

metal oxides (NMO) are widely used, appearing in different forms such as flakes and tubes. The main factors affecting the adsorption of heavy metals in aqueous media are the size and shape of the NMOs (Hua et al., 2012; Fernández-García & Rodriguez, 2011). Therefore, scientists have widely studied the use of shape-controlled, highly stable, and monodisperse NMOs in water purification. In order to assess the mode of adsorption and adsorption capacity of the adsorbent, the Langmuir and Freundlich adsorption isotherms are commonly used (Chen & Li, 2010; Thommes et al., 2015).

Chen and Li (2010) synthesized Fe^{2+}-containing nano-sized goethite and hematite via the co-precipitation method and suggested that the prepared NMOs are effective for the removal of Cu^{2+} from aqueous solution. Gao et al. (2008) synthesized MgO nanoparticles using magnesium carbonate hydrate (MCH) with various morphologies. Flower-like mesoporous MgO microspheres exhibited excellent adsorption of both heavy metal ions and organic pollutants (Gao et al., 2008). Manathilake et al. (2014) synthesized calcium carbonate nanoparticles from dolomite using a low-cost method, yielding nanoparticles sized between 38.9 nm and 51.6 nm. Nano MgO exhibits high surface reactivity and adsorption capacity, making it highly effective in heavy metal adsorption. MgO nanoparticles have been successfully synthesized using naturally occurring dolomite and a novel colloid of poly(acrylate) (PA^-) to encapsulate $Mg(OH)_2$ (Manathilake et al., 2014a).

The objective of this study is the synthesis and characterization of MgO nanoparticles using dolomite and Mg(II) solution, as well as the investigation of adsorption characteristics with Cd(II) in aqueous media and the design of a filter material for Cd(II) adsorption.

2 METHODOLOGY

Commercially available dolomite was sieved and calcined at 1000°C before starting the synthesis process. Mg(II) solution was then treated with calcined dolomite while stirring in the presence of hexadecyl trimethyl ammonium chloride (HTAC). After that, the synthesized $Mg(OH)_2$ was dried at 100°C and calcined at 450°C to obtain MgO nanoparticles.

Next, the synthesized MgO nanoparticles were characterized using XRD, SEM, EDAX and FTIR. Finally, the parameters (dosage, shaking time, settling time, and pH) were optimized for the adsorption of Cd(II) in the aqueous medium on MgO nanoparticles.

3 RESULTS AND DISCUSSION

3.1 SEM Analysis

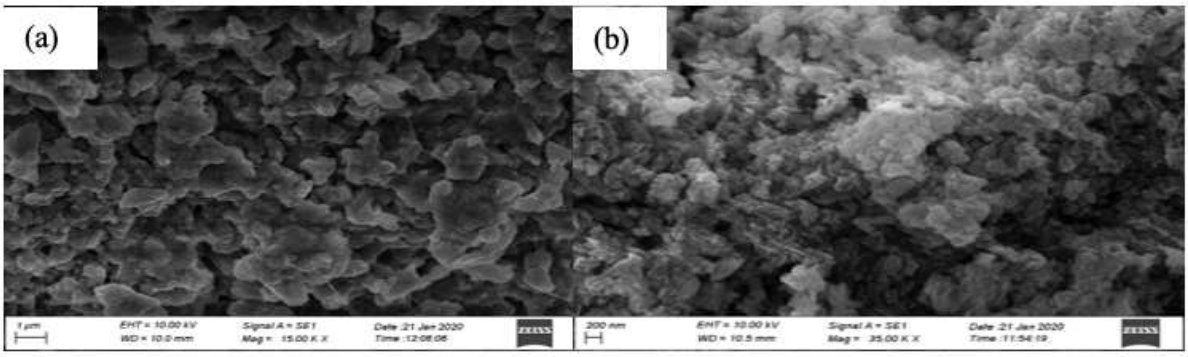

Figure 1. XRD analysis (a) MgO nanoparticles (b) Cd adsorbed MgO nanoparticles

The SEM image of MgO nanoparticles reveals the inhomogeneous nature of the surface due to agglomeration of nanoparticles. This nature has changed upon adsorption of Cd (II), thereby improving the surface as shown in Figure 1. These observations suggest that the metal ions may become trapped and adsorbed onto the surface of the magnesium oxide nano particles.

3.2 FTIR Analysis

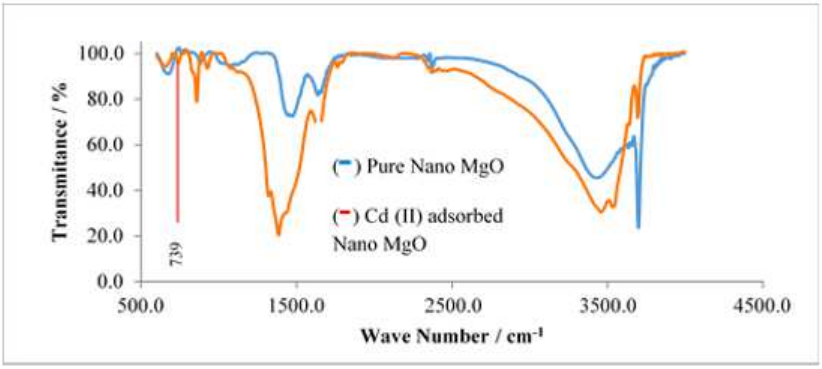

Figure 2. FTIR analysis of MgO nanoparticles and Cd adsorbed MgO nanoparticles

The FTIR analysis revealed the appearance of a new peak following the adsorption of Cd (II) onto nano MgO. A new band observed around 739 cm-1 attributed to the formation of Cd-O bonds adsorption onto nano magnesium oxide (Kaviyarasu., 2014).

3.3 Optimization Parameters

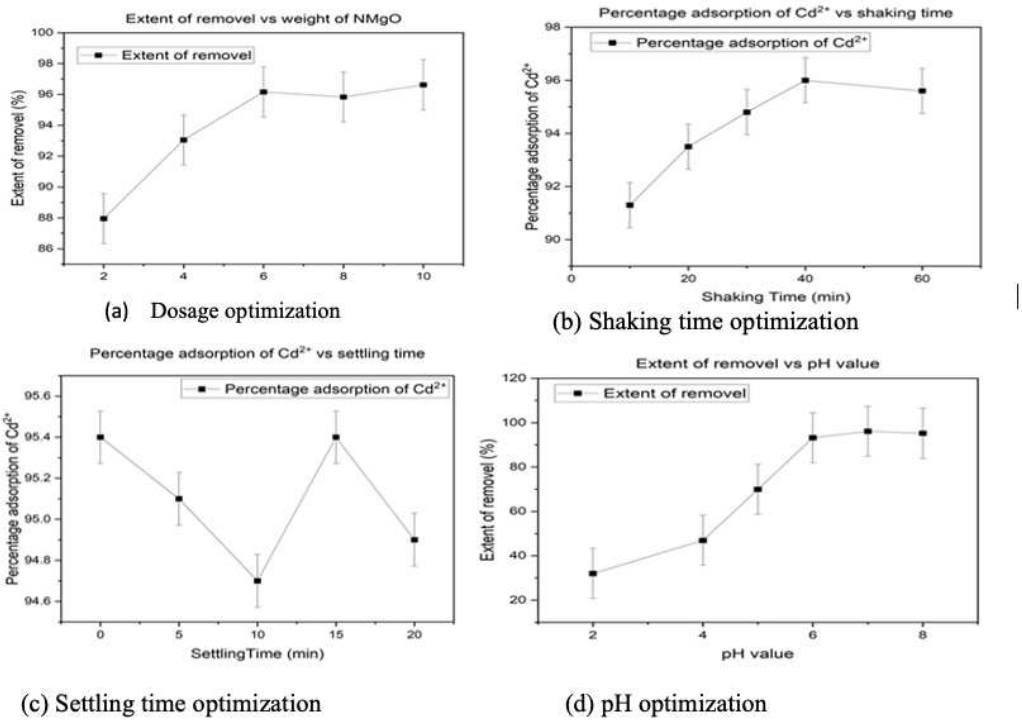

Figure 3. Summary of the parameter optimization

Figure 3(a) shows the optimization of adsorbent dosage, indicating that a dosage of 6 mg achieves approximately 95% removal of Cd(II). Figure 3(b) presents the effect of shaking time, with maximum Cd^{2+} removal observed after 40 minutes of agitation. In Figure 3(c), settling time optimization is depicted, showing that a 10-minute settling period results in 95% Cd^{2+} removal. According to Figure 3(d), the optimal pH range for Cd^{2+} adsorption lies between 6.0 and 8.0.

4 CONCLUSION

Significant differences in the surface and structure of dried MgO nanoparticles were observed after treatment with Cd(II), as confirmed by SEM and FTIR analyses. The MgO nanoparticles exhibited excellent adsorbent characteristics for Cd(II) in aqueous media, achieving a removal efficiency of over 90%.

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STEP COUNTING ALGORITHM USING THRESHOLD BASED TRI AXIAL ACCELEROMETER DATA

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ABSTRACT: Accurate step counting is a vital component of wearable fitness trackers, enabling effective physical activity monitoring and promoting healthy lifestyles. This paper presents the design and implementation of a threshold-based step detection algorithm using tri-axial accelerometer data, integrated into a wearable prototype device named MoveMate 1.0. The primary objective of this work is to develop a lightweight, energy-efficient algorithm capable of reliably distinguishing between walking and running steps in real-time, using minimal computational resources. The algorithm processes acceleration data from an MPU6050 sensor by calculating the Euclidean norm of the x, y, and z components to determine motion magnitude. Step detection is achieved by identifying significant magnitude changes that surpass predefined thresholds. Separate thresholds are assigned for walking and running modes, which can be toggled by the user through a mode-select button. A debounce interval of 300 milliseconds is incorporated to prevent multiple detections from a single step or motion noise. MoveMate 1.0, built around an ESP32 microcontroller, features an OLED display for live step count feedback, a DHT11 sensor for ambient temperature and humidity monitoring, and a rechargeable battery with an integrated voltage monitoring system. Data are transmitted via Wi-Fi using the MQTT protocol, while SPIFFS handles offline data storage during connectivity loss. All sensor readings, including step count and environmental data, are synchronized with Firebase upon reconnection. Testing under real-world walking and running conditions confirmed that the algorithm accurately identified step patterns and effectively rejected false positives due to hand movements or sudden acceleration spikes. The system demonstrated high reliability, responsiveness, and suitability for embedded wearable applications. The results support the viability of threshold-based step detection for resource-constrained devices and highlight MoveMate's potential as a practical fitness tracking solution.

Keywords: ESP32, MQTT, step detection, tri-axial accelerometer, threshold-based algorithm

1 INTRODUCTION

Wearable technology has transformed personal health and fitness monitoring, with step counting serving as a fundamental metric for assessing physical activity. Devices such as smartwatches and fitness bands leverage step counts to estimate calories burned, distance traveled, and overall movement levels (Abdelrahman et al., 2021; Arya et al., 2021). However, achieving accurate step detection remains a significant challenge, particularly in resource-constrained wearable systems. Existing step-counting algorithms often rely on complex signal processing or machine learning models to interpret tri-axial accelerometer data (Goyal et al., 2020; Liu et al., 2020). While effective in controlled settings, these approaches demand substantial computational resources, making them impractical for real-time execution on low-power microcontrollers commonly used in wearables (Majid et al., 2022). The literature highlights persistent issues with current step detection methods, including inconsistent accuracy across diverse user profiles (e.g., varying body types, ages, and walking styles), sensitivity to noise from erratic movements, and high energy consumption unsuitable for battery-powered devices (Smith et al., 2023; Jones et al., 2024).

These limitations underscore a critical research gap: the need for a lightweight, energy-efficient step detection algorithm that maintains high accuracy across diverse real-world conditions while operating within the constraints of embedded systems. This study proposes a novel threshold-based step detection algorithm optimized for low-power wearable devices. Implemented on MoveMate 1.0, a custom-designed wearable prototype equipped with an ESP32 microcontroller and an MPU6050 tri-axial accelerometer, the algorithm computes the Euclidean norm of the acceleration vector and employs adaptive thresholds to distinguish walking and running activities. A 300 ms debounce mechanism minimizes false positives caused by noise or irregular movements, and features like button-based mode switching enhance user interaction. Unlike existing methods, this approach prioritizes computational simplicity, enabling real-time performance on resource-constrained hardware while achieving robust step detection across varied user demographics and activities. The primary objectives of this research are to:
1. Develop an energy-efficient, threshold-based step-counting algorithm for low-power wearables.
2. Embed the algorithm into a functional wearable prototype with real-time sensing and wireless communication capabilities.
3. Validate performance under diverse real-world conditions, including different terrains, walking styles, and user demographics.

2 METHODOLOGY

2.1 Hardware Architecture

The core processing unit of MoveMate 1.0 is an ESP32 microcontroller, chosen for its built-in Wi-Fi, low power consumption, and dual-core processing capabilities. The motion sensing is handled by the MPU6050, a 6-axis inertial measurement unit (IMU) that provides real-time acceleration data along the X, Y, and Z axes.

2.2 Data Acquisition and Preprocessing

The MPU6050 provides raw acceleration values on three axes. These values are sampled at a fixed interval and used to calculate the overall motion magnitude. The Euclidean norm of the acceleration vector is computed using the formula:

$$\text{Magnitude}(t) = \sqrt{x(t)^2 + y(t)^2 + z(t)^2} \tag{1}$$

This transformation reduces the dimensionality of the data and provides a single time-series signal that captures total body motion irrespective of direction.

2.3 Step Detection Algorithm

Step detection is performed by analyzing the change in acceleration magnitude over time. The algorithm uses two different threshold values: Walking Threshold (lower value detects less intense steps) and Running Threshold (higher value detects more forceful steps)

Users can manually switch between these modes using the MODE SELECT button. A debounce time of 300 milliseconds is introduced after each valid step to prevent multiple detections caused by the same movement.

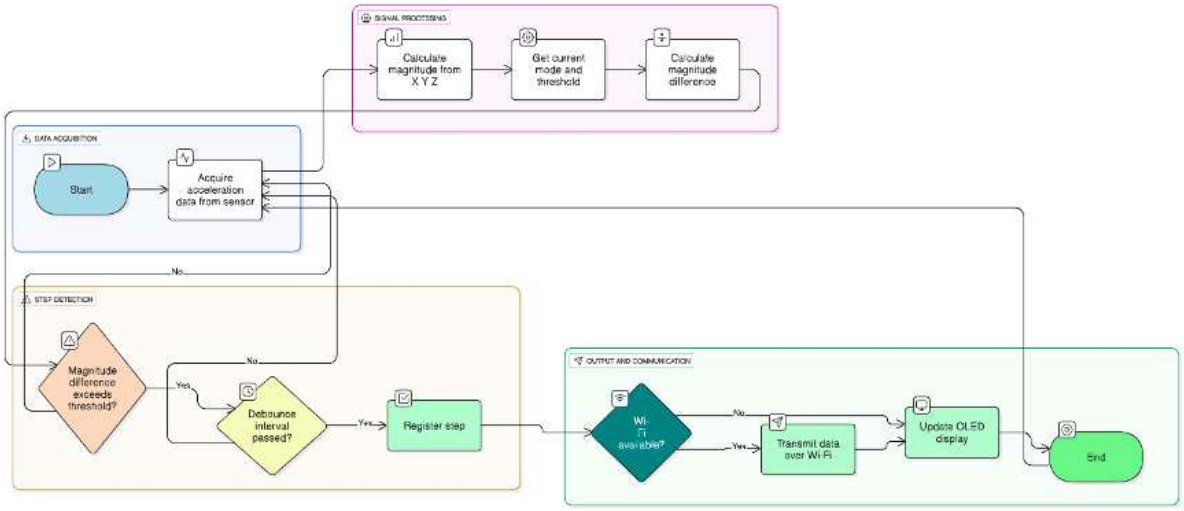

Figure 1. Movemate1.0 step detection method

2.4 Data Storage and Transmission

MoveMate 1.0 is designed to operate seamlessly in both online and offline environments to ensure uninterrupted data logging and user monitoring. In online mode, the device transmits sensor data including step count, temperature, humidity, battery percentage, and time stamps to a Firebase Realtime Database using the MQTT protocol over a Wi-Fi connection. This real-time transmission enables users to monitor their activity and environmental data via a mobile application or web interface. In the event of a network failure or MQTT disconnection, MoveMate automatically switches to offline mode, where all sensor data is securely stored in the ESP32's internal memory using SPIFFS (Serial Peripheral Interface Flash File System). Once a previously connected Wi-Fi network is re-established, the device initiates a syncing process, automatically uploading the locally cached data to Firebase to maintain data continuity. For offline analysis or archival purposes, historical records can be exported as CSV files using a custom-developed Python script, allowing users and researchers to further analyze trends or patterns in activity and environmental conditions.

3 RESULTS AND DISCUSSION

The proposed threshold-based step counting algorithm was implemented and evaluated using the MoveMate 1.0 wearable device in both walking and running scenarios. The performance of the system was assessed based on accuracy, responsiveness, adaptability across activity modes, power efficiency, and real-time data handling capability.

3.1 Step Detection Performance

Two experimental trials were conducted: one for walking and one for running. Figure 2(a) presents the results of the walking mode, showing relatively smooth and moderate peaks in

acceleration magnitude. The lower threshold used in this mode, calculated from the average acceleration magnitude during walking, effectively filtered out noise while successfully detecting each distinct step. In contrast, Figure 2(b) demonstrates the results during running, where higher and sharper peaks were observed. By applying a higher threshold, derived from the average value obtained in running mode, the algorithm accurately differentiated between valid steps and random spikes caused by intense body movement. The 300 ms debounce interval played a crucial role in both scenarios by preventing over counting due to signal noise or rapid successive movements. The manual mode selection button allowed users to toggle between walking and running, ensuring better detection reliability in mixed activity sessions.

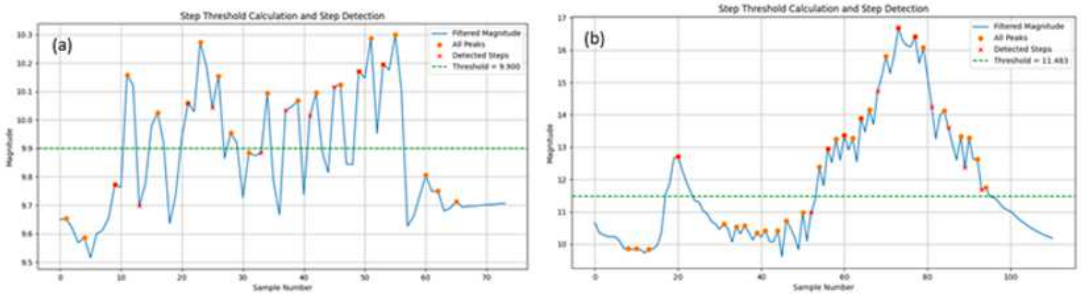

Figure 2. Step threshold calculation and step detection (a) walking mode, (b) running mode

3.2 Real-Time Display and User Feedback

The OLED display consistently updated the step count, activity mode, battery level, and environmental readings (temperature and humidity) in real-time. Users could immediately observe step increments with minimal delay, confirming the responsiveness of the system. The reset function worked as intended, allowing users to start new sessions easily. Figure 3 shows version 1 of Movemate.

Figure 3. MoveMate 1.0 structure

3.3 Summary of Observations

To provide a comparative overview of the system's performance under different activity modes, the key metrics observed during testing are summarized in Table 2 below. These include detection accuracy, threshold sensitivity, response time, and battery usage in both walking and running scenarios. The table highlights the consistency of the algorithm, its adaptability to different motion intensities, and the energy efficiency of the overall system during extended

use. These results reinforce the algorithm's reliability and the hardware's capability to maintain real-time performance and data integrity under varying conditions.

Table 1. Summary of Observations

Parameter	Walking Mode	Running Mode
Detection Accuracy	~96%	~95%
Required Threshold	Low	High
Step Interval	Longer, consistent	Shorter, more frequent
OLED Update Latency	< 0.5 seconds	< 0.5 seconds
Battery Life (avg. use)	10–12 hours	8–10 hours
Offline Sync Success	100%	100%

4 CONCLUSION

This study introduced a threshold-based step counting algorithm using tri-axial acceleration data, designed for real-time operation on wearable devices. Unlike machine learning–based classifiers (Gjoreski et al., 2010) or frequency-domain methods (Wang et al., 2015), the proposed algorithm emphasises simplicity and low power use, making it well-suited for embedded systems. By applying mode-specific thresholds derived from average acceleration values and a debounce mechanism, the system accurately detected steps during walking and running. Compared with conventional threshold-based methods as cited in Bourke, Lyons and Wallace (2020), the algorithm showed greater robustness by adapting thresholds to activity modes, thereby reducing false detections. Implemented on the MoveMate 1.0 prototype, the method achieved high accuracy and efficiency, while integrated features such as Wi-Fi/MQTT, offline storage, and battery management strengthened its practicality for continuous health monitoring.

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VISION BASED GESTURE CONTROL FOR LOW COST ASSISTIVE AUTOMATION IN HEALTHCARE SETTINGS

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ABSTRACT: This project introduces a budget-friendly system enabling individuals with mobility challenges to control medical devices such as wheelchairs and lights using simple hand gestures. This system which is specially designed for healthcare settings in Sri Lanka uses an ESP32-CAM for gestures recognition and an ESP8266 for device operation. As an affordable alternative to expensive assistive tools like Microsoft Kinect, which can cost over Rs. 60,000, this system demonstrates practicality with 96–98% accuracy in gesture recognition and a response time of less than one second, all while consuming only 1.8 A of power. In tests conducted across 5 homes with 20 participants (5 individuals with mobility challenges and 15 without), the system recognized gestures with 96–98% accuracy. Data processing is performed locally on the device, preserving user privacy, and addressing concerns regarding the use of cameras in healthcare settings. At roughly Rs 5000, the system is affordable for many families and can be expanded to support additional devices. Although challenges such as low lighting and simultaneous control of multiple devices remain, promising results have been demonstrated in boosting independence in settings where advanced technology is not accessible.

Keywords: ESP32-CAM, ESP8266, hand gesture control, healthcare automation, patient privacy

1 INTRODUCTION

For people with physical disabilities in Sri Lanka, small tasks like turning on a light or moving a hospital wheelchair can be a real challenge, reflecting a wider global demand for accessible assistive technology (World Health Organization, 2020). Most assistive devices, such as smart wheelchairs or voice-activated controls, cost thousands of rupees, far beyond what many families can afford. In a country where even basic medical equipment is often scarce, affordability remains a critical barrier (Fernando & Abeysekera, 2022). Previous studies also highlight the challenges in providing affordable assistive devices in Sri Lanka (Fernando & Abeysekera, 2022).

This research presents a gesture-based system that lets users control devices such as fans, lights and wheelchairs by simply waving their hands. The system uses an ESP32-CAM to capture hand gestures and an ESP8266 to control connected devices. The overall architecture of the proposed system is illustrated in Figure 1. Unlike high-cost options such as the Microsoft Kinect, which can cost over Rs 60000, this setup is built for environments like Sri Lankan homes and hospital wards. As voice controls are unreliable in noisy places and cause difficulties for individuals with speech impairments (Jones & Lee, 2021), hand gestures provide a straightforward and touch -free method of interaction. Also, it keeps all data on the device ensuring user privacy and matters related to camera use in healthcare (Gunawardena & Silva, 2024). Field tests conducted in homes across Sri Lanka, including participants both with and without mobility challenges,

presented the system's positive performance. This work aims to make life easier by building a reliable, low-cost system with a web interface that users can adjust themselves. The goals are to create a gesture setup with affordable hardware, offer flexible device control, and prioritize privacy. By tackling the shortage of budget-friendly assistive technologies, this research is an attempt at helping people live more independently, with plans to expand its capabilities for future healthcare needs.

2 METHODOLOGY

To develop a budget-friendly gesture control system for Sri Lankan homes and clinics, a setup was built using affordable hardware inspired by prior IOT assistive solutions (Perera & Jayasinghe, 2021). A prototype of the developed system is shown in Figure 2. The main component, an ESP32-CAM, captures video at 30 frames per second and recognizes hand gestures, like finger counts or palm orientation. A neural network was trained on 10,000 images collected from 20 participants, including 5 with mobility challenges and 15 without, in real home settings.

Video processing was handled on the device by the ESP32-CAM, and commands were transmitted wirelessly to an ESP8266, which was used to operate devices such as lights, fans, and motors. Simple preprocessing, including contrast enhancement and noise reduction, was applied to improve performance under low-light conditions (50–500 lux). Privacy was ensured through local processing with no personal images stored, and strict security measures were implemented for broader deployment (Gunawardena & Silva, 2024). A web dashboard was created using HTML and JavaScript, allowing users to assign gestures to devices, view live feeds, and adjust motor speeds.The developed dashboard interface is illustrated in Figure 4. Communication was via standard HTTP, making it easy to add more devices later.

Ethical approval was obtained, and the consent was obtained from all participants. It was also observed that some gestures were easier for participants to perform than others, which facilitated fine-tuning of the system.

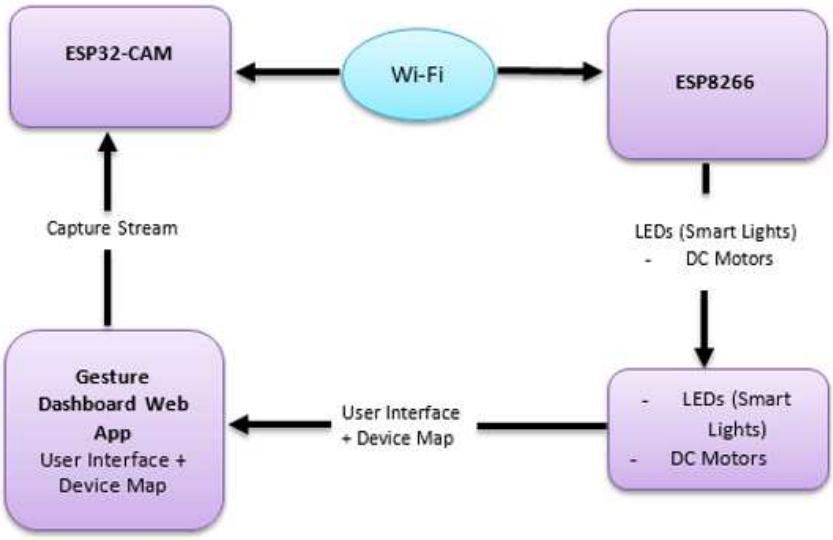

Figure 1. System Architecture Diagram (ESP32-CAM capturing gestures, local processing, ESP8266 controlling devices, and web dashboard for user control.

Figure 2. Hardware testing of gesture control system with ESP32-CAM and dashboard interface.

3 RESULTS AND DISCUSSION

A total of 50 trials were conducted across 5 homes with 20 participants, including 5 with mobility challenges. The system recognized finger counts (0–5) with 96–98% accuracy and hand orientation (palm up/down) with 95–97% accuracy. Average response time from gesture to device action was about 900 milliseconds. In dim light (50 lux), accuracy dropped to 90% for finger counts and 89% for orientation, but preprocessing improved to 95% and 94%, respectively. Gesture recognition accuracy by gesture type and lighting conditions is shown in Figure 3. Among the 5 participants with mobility challenges, 4 reported easier control of devices, while 1 expressed about the system's accuracy under different lighting conditions. In comparison to high-cost systems such as Microsoft Kinect, this setup is much cheaper at around Rs 5000 and uses just 1.8 A of power. Unlike voice-based controls, which can fail in noisy places , hand gestures worked reliably. Local on-device processing protects privacy.

Several limitations were identified during testing. The simultaneous operation of multiple devices presented challenges, and system performance was affected by poor lighting conditions. Despite these issues, the system achieved comparable accuracy to more expensive systems, while maintaining greater cost-effectiveness. Future research will focus on improving multi-device control, enhancing performance under low-light conditions, and expanding real-world testing. Future research will focus on expanding real-world testing, enhancing multi-device control, and improving performance under low-light conditions.

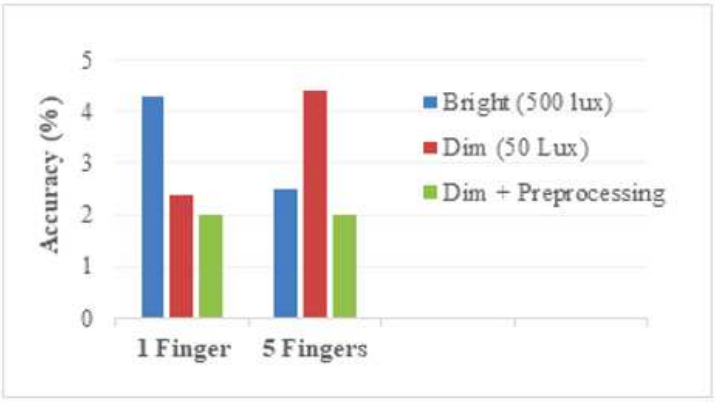

Figure 3. Bar chart showing gesture recognition accuracy by gesture type (e.g., one finger: 97 percent, five fingers: 96 percent) across lighting conditions (50–500 lux).

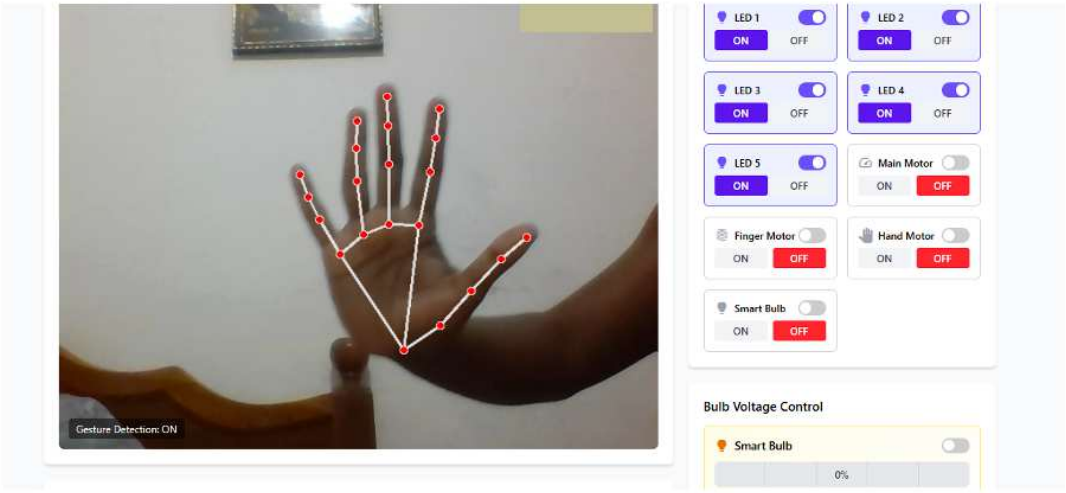

Figure 4. Illustrates the dashboard showing live camera feed, gesture feedback, and control options

4 CONCLUSION

This work confirmed that an affordable gesture-based control system can significantly improve independence for people with mobility challenges in Sri Lanka. High recognition accuracy (96–98%) and fast response times were achieved, proving the prototype practical in real-world home trials. Although low-light performance and multi-device control were identified as limitations, ongoing development was undertaken to address these challenges through enhanced image processing and expanded web-based integration. Participant feedback was acknowledged, highlighting both the system's usability and the need to consider ethical aspects such as user comfort and monitoring environments. Future evaluations are planned in hospital environments to better assess reliability in complex and crowded settings. This study can be presented as a meaningful step toward developing low-cost, inclusive assistive technologies with strong potential for wider adoption in healthcare.

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EMPOWERING VILLAGE SELF-ENTREPRENEURS IN SRI LANKA THROUGH A DIGITAL MARKETPLACE: A QUANTITATIVE STUDY

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ABSTRACT: Village self-entrepreneurs in developing countries like Sri Lanka face several challenges. This study investigates these barriers using a quantitative survey, including structured questionnaires administered to 30 rural businesses, supplemented with qualitative insights from open-ended responses. Survey findings revealed that most entrepreneurs struggle with limited access to finance, weak digital marketing knowledge, inadequate sales channels, and insufficient institutional support. In terms of support needs, respondents emphasized access to loans, improved market opportunities, and training in digital tools. Notably, while less than half of participants had prior knowledge of digital selling, over 90% expressed willingness to adopt a localized and affordable digital solution.Based on these findings, the study proposes a mobile-first platform featuring several innovative modules, an investment matching module enabling profit-based or corporate social responsibility support, an affiliate marketing module for low-cost promotion, and a partnership module connecting entrepreneurs with external vendor outlets. Platform credibility is ensured through admin-verified guidelines, automated financial processes, and report templates for tracking transactions, complementing the sales module for direct product sales. Beyond Sri Lanka, the platform offers scalability for adoption in other developing regions facing similar entrepreneurial constraints. This integrated solution aims to enhance market access, financial support, and digital capabilities for rural self-entrepreneurs.

Keywords: self-entrepreneurs, quantitative survey, digital marketplace

1 INTRODUCTION

The International Labour Organization (2002) has emphasized the importance of micro-enterprises in poverty alleviation and economic empowerment of the poor. Promoting Village Self-Entrepreneurs has been recognized as a promising pathway for generating employment, particularly among low-income groups in developing countries. However, self-entrepreneurs in rural Sri Lanka face critical challenges in accessing markets, securing financial support, and adopting modern marketing strategies. These barriers hinder their ability to scale and compete in national or international markets. Prior research has highlighted persistent challenges. Navarathne (2017) identified limited customer bases due to traditional selling methods. Herath et al. (n.d.) pointed out the absence of promotional opportunities and weak institutional support systems. The Department of Census and Statistics (2021) reported that most small enterprises in Sri Lanka remain informal and vulnerable to crises. Similarly, the International Labour Organization (2023) revealed that over 89% of micro and small entrepreneurs were negatively affected by the 2022 economic downturn. At the same time, studies show growing interest among rural entrepreneurs in adopting digital solutions (Herath et al., n.d.), suggesting a strong

potential for technology-driven interventions. This study investigates the key challenges faced by self-entrepreneurs in Sri Lanka and proposes a digital marketplace to address them.

1.1 Research Aim

The aim of this study is to identify the major barriers to rural entrepreneurship and propose a digital solution that improves visibility, market access, and investment opportunities.

1.2 Research Questions

RQ1: What are the major challenges faced by rural self-entrepreneurs in Sri Lanka in growing their businesses?
RQ2: What digital features and functions are needed to improve market access and outreach?

1.3 Research Objectives

Objective 1: To investigate barriers, user needs, and expectations for business growth among rural self-entrepreneurs in Sri Lanka.
Objective 2: To propose a feasible digital solution that enhances visibility, marketing, and access to finance.

2 METHODOLOGY

A quantitative descriptive survey was conducted using a structured questionnaire with closed-ended questions covering business profiles, digital adoption, market challenges, and support needs. In addition, qualitative insights were captured through optional comment fields and informal discussions, providing contextual depth. A purposive sample of 30 rural entrepreneurs was selected across industries including agriculture, handicrafts, food production, manufacturing, and retail. Purposive sampling was used because the study requires specific knowledge from a defined group (village entrepreneurs) to accurately assess challenges, support needs, and willingness to adopt a digital solution. Data analysis involved descriptive statistics presented through pie charts. While the small sample size limits generalizability, it provides valuable exploratory insights. The survey was designed to measure both the current status of entrepreneurial resources and capacities and the willingness to adopt digital solutions. Data were analyzed using frequency counts and percentages to identify the necessity of the user requirements for the digital solution.

3 RESULTS AND DISCUSSION

The majority of respondents operated micro-enterprises employing 1–5 workers. Most sold within their village or at weekly markets, with over 60% reporting they could sell less than 50% of their production. The survey helped to identify different industries that majority of peoples engage as village entrepreneurs including pottery and clay products, agriculture, food and beverages, coconut and palm products, handicrafts, apparel and tailoring, spices and medicinal plants, animal husbandry, metal and stonework, household industries and goods, and toys. This diversity highlights the wide-ranging applicability of a digital marketplace across industries. In terms of digital proficiency, 83.3% of respondents indicated that they have knowledge of digital

selling, while 16.7% reported insufficient digital proficiency. This suggests that introducing a digital solution will not pose a major barrier or challenge to most village entrepreneurs. However, only 11 entrepreneurs currently had some form of digital presence primarily through Facebook (9) and WhatsApp (3) indicating that the majority are still operating offline. Nevertheless, 28 out of 30 participants expressed willingness to adopt a digital solution if it were user-friendly and affordable. Regarding readiness, 80% of respondents mentioned that they already have the necessary facilities, such as smartphones and internet access, to use such a system. A minority, however, mentioned barriers including lack of digital literacy, difficulties with the English language, absence of smartphones, poor internet connectivity, and financial limitations in acquiring digital tools. Figure 1 highlights the number of responses received regarding the challenges faced by village entrepreneurs. The most common barriers included limited marketing opportunities (20), financial difficulties (23), and low awareness of modern marketing techniques (20).

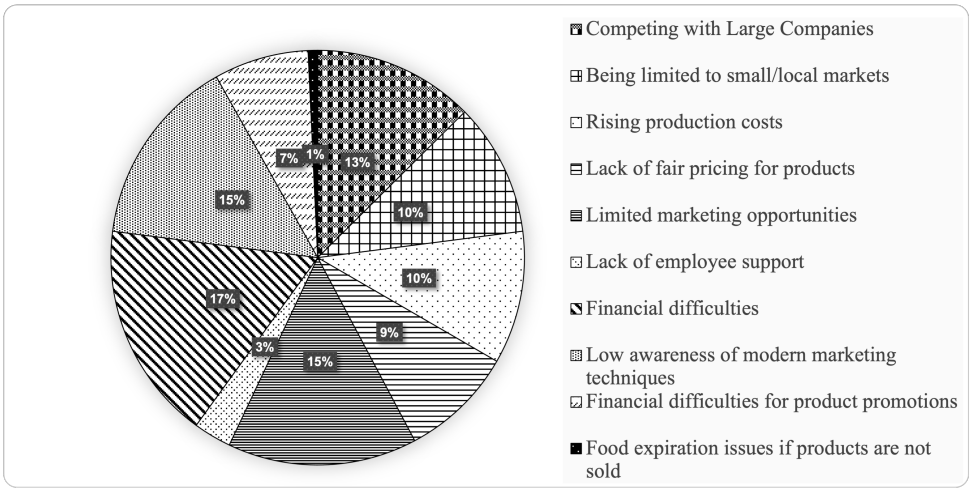

Figure 1. Challenges faced by village self-entrepreneurs

Figure 2 highlights the number of responses received regarding support needs for business growth. The most common need included access to funds or credits (24), digital marketing training and knowledge (30), Market access and sales channels (23).

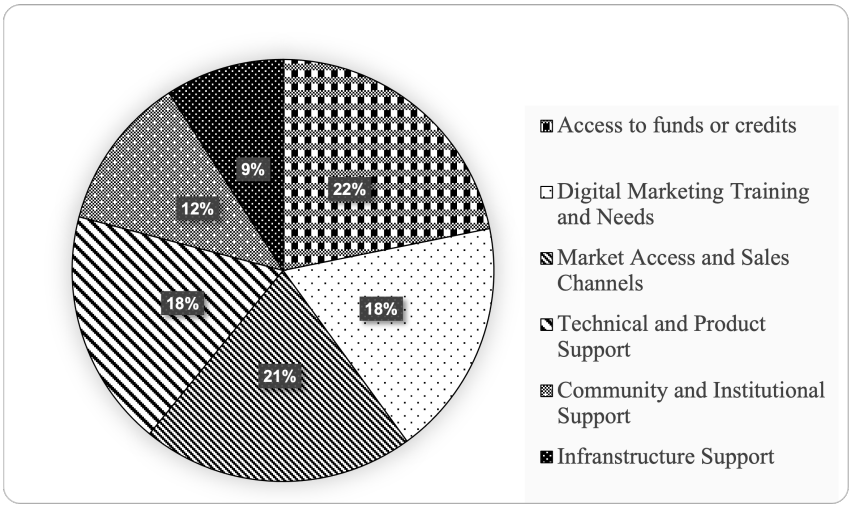

Figure 2. Support needs for business growth

Based on the above results , findings suggest a strong demand for a digital solution that provides financial facilitation or credit access, enhances market access, connecting local entrepreneurs with broader sales channels, offers digital marketing tools and training to increase visibility and sales, supports technical/product guidance to improve quality and efficiency. By introducing a digital platform, village self-entrepreneurs could overcome market limitations, improve sales, reduce wastage, and scale their businesses sustainably.

3.1 System Structure and Technology Justification

Based on these findings, the solution is designed with several modules. The sales module allows customers to purchase items directly from the platform, enabling entrepreneurs to sell their products. This is similar to other digital marketplaces. However, the novelty of this digital solution highlight in addressing the financial and advertising difficulties faced by village entrepreneurs. When investors are willing to support business growth, they can earn commissions based on market sales. Additionally, charity investors can provide support as part of their CSR (Corporate Social Responsibility) initiatives. This allows self-entrepreneurs to enhance their financial assistance, as most respondents indicated challenges in obtaining bank loans due to low monthly income. For instance, respondent ID 2 mentioned:

“අපගේ මාසික ආදායම සහ වර්ධනය ඉතා අඩු බැවින් සහ එම ලියකියවිලි නිසි ලෙස නඩත්තු නොකිරීම නිසා අපට බෑංකු ණය ලබා ගැනීම ඉතා අපහසුය”

(Translation: It is very difficult for us to obtain a bank loan as our monthly income and growth are very low, and we do not maintain our documents properly.) Additionally, the uniqueness of this proposed solution highlights in integrating entrepreneurs with affiliate marketers. Through this, entrepreneurs can advertise their products via widely-reached channels at minimal cost. The platform ensures that commissions for affiliate marketers are clear and controlled to avoid unnecessary fees. Another unique feature is the partnership module, which allows entrepreneurs to request selling stalls in partner outlets, such as supermarkets. The platform facilitates communication, agreements, and trusted partnerships between entrepreneurs and partners. Platform credibility is ensured through admin verified guidelines, where commissions and other financial

processes will be clearly documented and implemented using automated calculations. To support proper financial tracking, the system provides report templates that help entrepreneurs maintain records and submit them to financial institutions if needed.In addition to these major modules, the platform offers user-friendly functionalities to enhance marketing and sales opportunities for self-entrepreneurs. It also provides help tips and localization in three languages to support their digital proficiency and overall engagement with the platform. Accordingly, the proposed system is a mobile-first digital marketplace with modules for product management, customer storefront, investment matching, affiliate marketing, and administrative oversight. React Native was chosen for the front-end as it enables affordable cross-platform mobile apps, essential for entrepreneurs who mainly rely on smartphones. Node.js/Express.js provides a lightweight back-end suitable for low-cost hosting and real-time operations, while MongoDB offers a flexible, low-maintenance database to manage diverse product and customer data. Overall, the stack was selected for its affordability, offline support, scalability, and ability to integrate Sinhala, Tamil, and English interfaces, making it cost-effective, mobile-friendly, and adaptable to low-connectivity rural environments. The findings align with the Diffusion of Innovations (DOI) theory, highlighting the relevance of the proposed solution. The study shows a high willingness (over 90%) of entrepreneurs to adopt a localized digital marketplace, despite the challenges they face. These barriers include limited financial resources, restricted selling and marketing opportunities, and low digital literacy.

Figure 3 presents the number of responses received regarding respondents' interest to use a digital solution. 93% respondents mentioned that they are willing to overcome the challenges of marketing through traditional digital platforms.

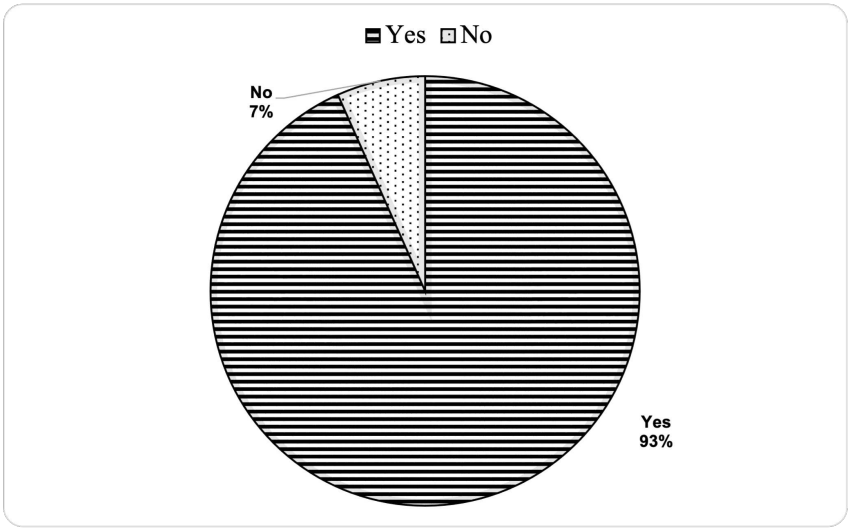

Figure 3. Respondents' interest to use a digital solution.

Figure 4 presents the number of responses received regarding whether the respondents' have enough facilities to use such a digital solution. 87% respondents mentioned that they have enough facilities.

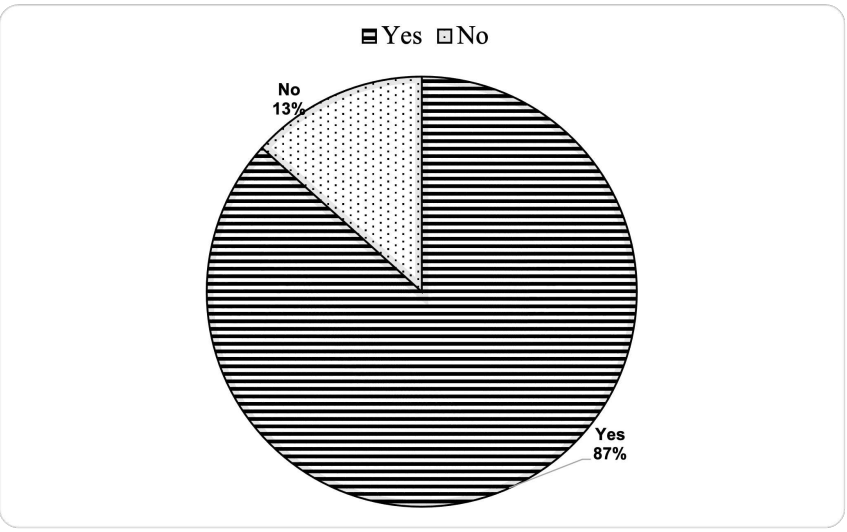

Figure 4. Respondents' Access to Facilities for Using a Digital Solution

4 CONCLUSION

This study identified key challenges faced by Sri Lankan village self-entrepreneurs, including limited financing, weak digital marketing capacity, and restricted market access. Using a quantitative pilot survey, it demonstrated that entrepreneurs are willing to adopt affordable digital solutions. A mobile-first digital marketplace platform is proposed, leveraging low-cost, scalable technologies to improve visibility, facilitate investments, and connect entrepreneurs with broader markets. The proposed mobile-first platform addresses these challenges through integrated modules, including sales, investment matching, affiliate marketing, and partnerships, supported by admin-verified guidelines and automated financial processes. Accordingly, the platform not only facilitates market access and financial support but also enhances digital skills and business management capabilities among rural entrepreneurs. Beyond Sri Lanka, this model can be adapted to similar rural contexts in South Asia and beyond, making it a scalable solution for rural economic empowerment. By linking entrepreneurs with investors, partners, affiliate markerters and digital marketplaces, the solution has the potential to increase income, reduce business risk, and promote sustainable rural economic development.In conclusion, this study not only identifies key barriers and support needs for rural self-entrepreneurs but also proposes an innovative, evidence-based digital solution that integrates financial, marketing, and operational support, offering a practical pathway for enhancing entrepreneurship in rural communities.

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A CASE STUDY–DRIVEN MODULAR ARCHITECTURE FOR SMART RETAIL MARKETING AUTOMATION IN SRI LANKAN SMES

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ABSTRACT: Retail small and medium-sized enterprises in Sri Lanka often face challenges in obtaining competitive advantages against large-scale businesses due to poor market automation strategies and technologies suited to their landscape. This paper presents the modular architectural design of a smart retail and marketing automation system developed as a case study for May Fashion, a mid-sized garment retailer. The research follows a design science methodology incorporating stakeholder interviews, observations, and comparative analysis as a qualitative study. Results indicate a proposed modular architecture that can be adapted to similar SMEs across developing economies, based on the May Fashion case study. The architecture is informed by system requirements derived including data driven , behaviour-based segmentation, automated campaign schduling and execution, PoS integration, dynamic analytical dashboard and CRM features from challenges identified through qualitative methods. The proposed modular architecture consists of distinct components such as customer segmentation, campaign automation, and analytics dashboards. Findings from the May Fashion case study suggest that the system design can significantly reduce manual effort in campaign execution, improve personalization, and enable SMEs to integrate POS data for data-driven marketing.

Keywords: smart retail, marketing automation, small and medium enterprises , modular system architecture

1 INTRODUCTION

In today's highly competitive retail environment, small and medium enterprises (SMEs) face significant challenges in delivering personalized and data-driven marketing strategies that enable smart growth, customer loyalty, and competitiveness in a digital world. Many SMEs still rely on traditional and manual marketing strategies without focused customer insights or personalization (Nazir et al., 2024). A major challenge is that despite having access to Point-of-Sale (POS) data, most SMEs lack the technical capacity to analyze purchasing behavior and use it effectively in marketing campaigns. This research study explores the opportunity to bridge the gap in the adoption of technology-driven retail and marketing automation solutions. Furthermore, it aims to address the technological gap by providing a modular, intelligent system capable of integrating with existing POS data and deriving requirements for the design of a modular architecture to automate customer segmentation and execute personalized campaigns using rule-based and machine learning (ML) logic.

1.1 Background Study

Pangriya and Singh (2020) emphasized the importance of fostering emotional relationships with customers, contributing to higher revenue and retention. Bhatt and Nagvadia (2021) highlighted

poor analysis of customer behavior and market trends, which results in missed opportunities for customer engagement and long-term revenue growth. Nuseir et al. (2023) stressed the need to introduce technology-driven market automation approaches to enhance customer retention, optimize marketing strategies, and improve sales efficiency.

1.2 Problem Statement and Motivation

Most SMEs use typical transaction processing systems (TPS), such as point-of-sale systems, to store day-to-day transaction records. However, many lack motivation to adopt modern digital technologies due to limited awareness, knowledge, or funds for implementation. Cadden et al. (2023) noted that the majority of SMEs are unaware of the advantages of using big data analytics to identify customer segments and derive actionable marketing insights. Currently, most marketing initiatives are primarily manual, impersonal, and not aligned with actual customer actions. Lim et al. (2021) emphasized the importance of aligning market automation solutions with real customer behavior, noting that most open-source solutions are unsuitable for diverse enterprise scenarios. Customization through subscription packages can be costly. Payam Boozary et al. (2024) also highlighted the importance of implementing case study–based solutions.

1.3 Research Aim

The aim of this research is to propose a practical, scalable solution tailored to the SME context by deriving common market automation requirements from a real-world case study in the Sri Lankan retail sector.

1.3.1 Research Questions

RQ1: What are the key challenges faced in conventional marketing strategies by SMEs, as identified through a case study of a Sri Lankan retail business?
RQ2: What user and system requirements can be derived from these challenges to inform the design of a smart retail marketing automation system?
RQ3: How can a modular system architecture be designed to address these requirements while ensuring scalability, cost-effectiveness, and ease of adoption for SMEs?

1.3.2 Research Objectives

Objective 1: To identify key marketing and engagement challenges in SME retail settings through stakeholder interviews, direct observation, and comparative system analysis.
Objective 2: To derive a set of validated user and system requirements from these challenges and structure them into a modular architecture for a smart retail marketing automation system.
Objective 3: To propose a modular system architecture that maps these requirements into functional components suitable for incremental development and deployment.

2 METHODOLOGY

This research is grounded in an interpretivist philosophy (Junjie & Yingxin, 2022), recognizing that marketing challenges in SMEs are socially constructed and must be understood through

the perspectives of individuals within their organizational context. By conducting stakeholder interviews and contextual observations, the study seeks to interpret the lived experiences of users and decision-makers. Additionally, the study incorporates elements of pragmatism, aiming to develop a practical, usable solution to a real-world problem through the application of design science principles.

This study follows the Design Science Research (DSR) methodology, as outlined by Hevner et al. (2004) and Peffers et al. (2007), to propose a modular architecture for an IT support system addressing challenges identified through qualitative data collection and analysis. The research process includes problem identification through qualitative data, review of relevant literature, derivation of design requirements, and development of a modular architecture grounded in user needs.

Considering the interpretivist approach, qualitative data were collected through a single case study of the enterprise "May Fashion" using stakeholder interviews and observations in the workplace. Semi-structured interviews were conducted with owners, marketing managers, and other high-level executives to explore perceptions of current marketing practices, challenges faced, and expectations from potential technology solutions. Observational data were gathered by monitoring marketing activities and customer engagement processes, supplemented by reviewing marketing materials and sales reports. Purposive sampling targeted individuals directly involved in marketing and customer engagement to ensure relevance and depth. Data saturation determined the sample size, resulting in interviews with 8 stakeholders.

A thematic analytical approach was used to analyze the data by defining themes and codes. All interviews were transcribed into English for consistency. Seven interviews were conducted in English, while four were in Sinhala and later translated to English. During analysis, two interviews were revisited iteratively as new themes emerged and required further exploration.

3 RESULTS AND DISCUSSION

Stakeholders highlighted that conventional marketing strategies primarily rely on leaflets and posters, lacking behavior-driven personalization. SMS and email campaigns were also generic and did not ensure customer engagement: *"We just send the same SMS to everyone. There's no way to filter based on purchase or interest."* (Interviewee S2 – Stakeholder 2)

"අපි බැනර් ගහලා තියෙද්දිත් පාරිභෝගිකයෝ ඒ දෙස බලන්නේ නෑ . අපේ කඩේට එන පාරිභෝගිකයෝ කවුද කියලා අපිට ගණන් කරන්න බෑ. බැනරය නිසා ඒක බලන්න එනවද කියලා"

Translation: *Even when we put up banners, customers do not pay attention to them, and we cannot track whether a customer visits the store as a result of the banner.* (Interviewee S6)Document analysis confirmed the absence of dynamic segmentation or preference profiling. Observations showed stakeholders lacked clear understanding of segmentation and personalization, which informed the design of features such as dynamic segmentation, customer profiling, and personalized content support. Another major challenge was the overreliance on manual processes throughout the campaign lifecycle.

"PoS Machine එක බලලා Customer වෙන් කරන එක අමාරුයි. ඊට පස්සේ email යවන්න ගැලපෙන දින බලන එක ඒවට reply එවන එක බලලා respond කරන එකත් අමාරුයි."

Translation: *Manually checking the POS and filtering customers is very difficult. Scheduling*

emails is also challenging, and managing responses is even more cumbersome. (Interviewee S8. Existing open-source and commercial marketing automation systems such as HubSpot and Mailchimp offer strong campaign features but lack cost-effective POS integration and customizable segmentation for SMEs in developing regions. The proposed architecture addresses these gaps through modularity, local adaptability, and simplified user workflows. High-level executives reported difficulty understanding campaign outcomes and adjusting strategies: *"We only get static reports after the campaign ends. We can't adjust anything mid-run."* (Interviewee S1) Observations confirmed spreadsheets were used to manage email and SMS campaigns, without updating records or analyzing customer behavior post-campaign. All data sources highlighted the importance of integrating CRM components, POS integration, and digital marketing strategies.

3.1 Derived Requirements and System Modules

Table 1. Derived Requirements and Mapped System Modules

Requirement	Mapped System Module
Data-driven, behaviour-based segmentation	Customer Segmentation Module
Automated campaign scheduling and execution	Campaign Management Module
POS integration	Integration Layer
Dynamic analytics dashboard	Analytics Dashboard
CRM features	Customer Relationship Management Module

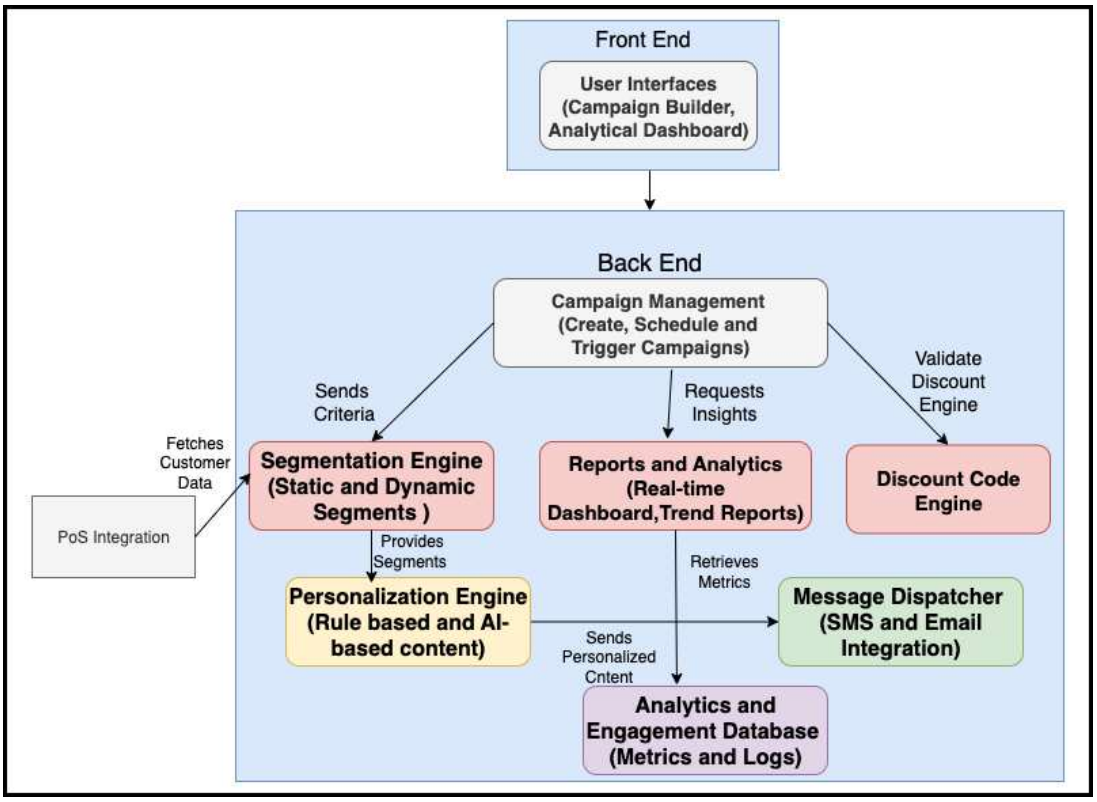

Figure 1. Modular Architecture for the proposed system

Most commercial marketing automation platforms, such as HubSpot and Mailchimp, are designed to meet the global needs of large enterprises and may not address the specific challenges faced by SMEs in local contexts. The novelty of this proposed system tailored to the Sri Lankan retail SME environment, providing a modular and lightweight solution that allows businesses to adopt only the components they need as per the customization preferences. It enables direct integration with local POS systems, supporting dynamic customer segmentation and personalized campaigns capabilities often missing in current solutions. While many small businesses rely on manual campaigns or basic automation, this system leverages rule-based logic and optional machine learning modules to deliver cost-effective, data-driven marketing automation aligned with the operational realities and workflows of SMEs.

4 CONCLUSION

This study explored the limitations of conventional marketing practices employing interviews, observations, and document reviews to uncover core challenges faced by marketing stakeholders with single case study. Key issues identified include the lack of customer segmentation automation, manual handling of campaign messages, insufficient tracking of campaign performance, and the absence of analytical tools to inform decision-making. Based on the insights gained, a set of functional requirements was developed to guide the design of a modern, user-centered marketing automation system. The proposed design supported by a modular architecture aims to address the gaps in existing workflows. The study contributes to bridging the gap between practical marketing challenges and the design of context-aware, intelligent digital marketing solutions. This study is limited by its reliance on a single case study and primarily qualitative insights, which may affect generalizability. Future work will involve implementing a functional prototype and evaluating system performance using quantitative metrics such as campaign response rates, time savings compared to manual execution, employee productivity, increases in sales, campaign conversions, and other open and click-through rates after the completion of the implementation according to the suggested modular architecture. Additionally, conducting multi-case validation to strengthen external validity and integrating search engine optimization techniques will be considered as platform improvements in future phases. The researchers also expect to implement the system and evaluate the architecture against stakeholder expectations.

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DESIGN AND DEVELOPMENT OF A UNIVERSAL ACCIDENT SEVERITY DETECTION AND SMART EMERGENCY RESPONSE SYSTEM FOR VEHICLES

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ABSTRACT: This project presents the development of a universal, independent accident severity detection and emergency response system for vehicles, aiming at addressing critical delays in post-accident interventions. The system integrates multi-sensor data and artificial intelligence to detect vehicular accidents, assesses the condition of passengers, and initiates real-time communication with emergency services such as hospitals, fire brigades, and rescue teams. It uses a Raspberry Pi micro-controller to communicate with sensors, modules and cameras. The research involved analysing existing accident detection technologies, designing AI-based algorithms for passenger monitoring, and integrating these into a unified detection unit. The system was tested and validated under different lighting conditions and angles to assess its accuracy and response efficiency aiming to enhance passenger safety and emergency response times. The accuracy of camera coverage, passenger count and passenger consciousness was calculated using processing images and videos under controlled conditions. In 100 tests conducted for each factor, the percentage findings were: 78% accuracy for camera coverage, 88% for passenger count detection, 72% or consciousness detection. A buzzer and LED provided a brief manual response window to cancel false alerts. Manual trigger buttons were also made available for passengers to notify services directly informing them with the location in the event of an emergence or sensor failure. The system usually responds within 5-15 seconds depending on mobile network strength. While testing and developing the system, challenges such as camera installation, low light conditions, network issues had to be addressed. Finally, the outcome was a privacy protected modular system which is compatible with any vehicle model and can be easily installed providing a scalable and reliable solution to enhance road safety, reduce response time, and improve emergency decision making.

Keywords: condition of passengers, emergency decision-making, independent accident severity detection

1 INTRODUCTION

Road traffic accidents are a major cause of injury and death worldwide, resulting in significant social and economic burdens. While it is not possible to completely prevent accidents, it is possible to minimize their consequences. A critical factor contributing to the severity of outcomes in such accidents is the delay in emergency response, often caused by the inability to accurately detect and assess the incident in real-time. When a vehicle is involved in an accident, there is a risk that passengers or the driver may face death due to delays in medical assistance (Rekha & Hithaishi, 2017). Conventional systems, which primarily depend on accelerometers or manual notifications, often generate false alarms or lack necessary details to guide emergency responders effectively. Furthermore, these systems frequently fail to identify key elements such as the number of passengers involved, their physical condition, or the presence of fire, all of which are vital in allocating appropriate rescue resources. Accident detection research has advanced from accelerometer and GPS-based systems to AI-enabled frameworks. Early approaches relied on accelerometers and GPS modules for crash identification and location reporting (Rekha &

Hithaishi, 2017). Smartphone based systems leverage built-in sensors such as accelerometers, gyroscopes, and GPS to send alerts. However, their effectiveness depends on app installation, device stability, and sensor quality, often leading to false alarms (Patel, 2013; Tushara & Harsha, 2016). Hardware-based systems which use external sensors with microcontrollers, GPS, and GSM modules, offer more dedicated solutions but are costly and frequently require human intervention, such as manual overrides or intermediary services (Dev et al., 2024). More recent integrated systems combine IoT and AI, applying deep learning to accident data for rapid emergency response (Pathik et al., 2022). However, these solutions mainly focus on collision detection and severity, without providing adequate insights into passenger conditions, leaving a gap for more comprehensive frameworks (Kang & Heo, 2017). To bridge these gaps, this work focuses on designing and developing a Universal Accident Severity Detection and Smart Emergency Response System. The system aims to provide an integrated, vehicle-independent platform that detects crashes using sensor data, verifies fire hazards, assesses passenger conditions through computer vision techniques, and transmits real-time alerts to relevant emergency services. The proposed solution not only reduces human intervention but also enhances the accuracy of accident verification and emergency communication, making it highly suitable for modern smart transportation ecosystems.

2 METHODOLOGY

To develop a universal accident severity detection and emergency response system suitable for real-world deployment, this system was developed as a prototype integrating low-cost widely available components to meet the requirements. At its core ,is the Raspberry Pi 4B, which processes sensor data and image inputs in real time, similar to prior IoT-based safety systems (Satish Kumar et al., 2022). The system combines accelerometer-based crash detection, fire hazard monitoring, passenger detection, and automated emergency communication to ensure accurate and timely alerts. The BMI160 accelerometer continuously monitors vehicle motion, identifying sudden deceleration or impact events as potential accidents, a method widely adopted in accident detection research (Rekha & Hithaishi, 2017). Once triggered, a USB camera activates to capture and process images, enabling passenger counting and condition assessment using YOLOv3-tiny and MediaPipe algorithms, as previously applied in lightweight real-time vision tasks (Pathik et al., 2022). Consciousness is evaluated through posture, movement, and eye-blink detection, building upon approaches in vision-based health monitoring. Simultaneously, MQ2 smoke and flame sensors monitor for fire hazards, ensuring rapid detection of secondary risks (Rekha & Hithaishi, 2017). Upon confirmation, the SIM900A GSM/GPRS module sends real-time SMS alerts containing GPS coordinates (from the NEO-M8N GPS module), passenger count, condition status, and fire detection results to hospitals, fire brigades, and rescue teams, following the communication model in earlier IoT-based accident systems (Dashora, Sudhagar, & Marietta, 2020). Images captured by the system are uploaded to a secure server or Telegram interface, allowing responders to assess conditions before arrival. A buzzer and LED provide immediate in-vehicle alerts, while manual buttons allow passengers to send selective or universal emergency notifications. The prototype was tested under simulated

accident scenarios to measure detection accuracy, fire sensing reliability, passenger assessment performance, and communication response time. Performance metrics included accident detection precision, false alarm rates, image processing speed, SMS delivery time, and GPS accuracy, aligned with evaluation frameworks used in related ITS studies (Pathik et al., 2022; Rekha & Hithaishi, 2017). Controlled tests were conducted in varied conditions, including low-light environments and with intentional camera obstruction, to evaluate system robustness. The camera is not always on. It turns on after an impact. All data processing occurs on-device to safeguard privacy, and no cloud based systems. Images are transmitted through Telegram. Manual override options ensure users retain control where appropriate. The system is designed as a standalone, vehicle-compatible unit, making it scalable for different vehicle types without requiring manufacturer-specific integration.

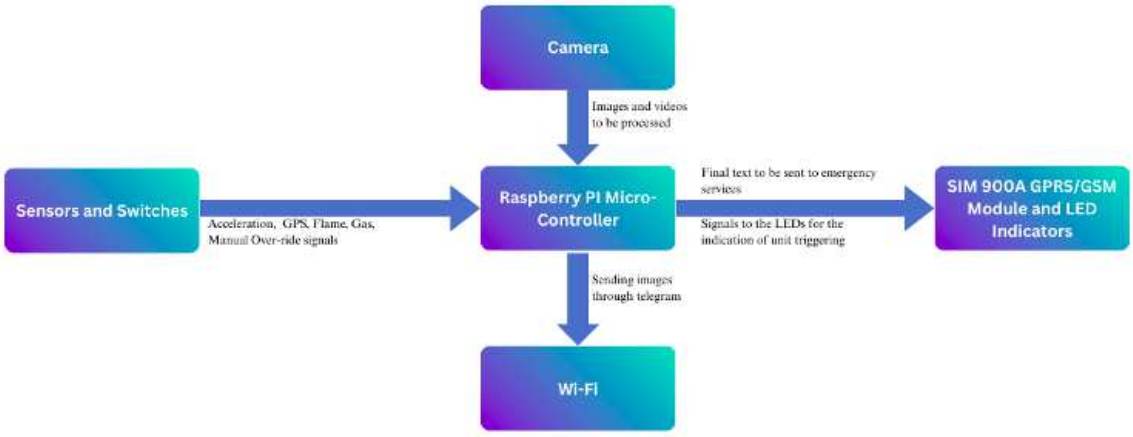

Figure 1. System Architecture

3 RESULTS AND DISCUSSION

When an impact is detected, the system is triggered and the LEDs start flashing for three minutes. If the passengers are safe, they can manually stop the process within three minutes using a push button which resets the system resets. If the passengers are not safe, the system will continue the remaining steps. In event that the system does not detect the accident, the user can manually contact emergency services (medical services, fire brigade or rescue teams separately or all at once) using the other four buttons.

To evaluate the accuracy of the system, scenarios, videos and images (100 per each with different light conditions and different angles) were processed to make adjustments and to calculate performance. The BMI160 accelerometer is a sensor proven for its accuracy over time, is directly used to identify the impact. Upon detecting the impact, the camera turns on to check whether it is covered or not (Figure 2). For this, threshold values were set (brightness-150, variance-200, frame difference- 2). The system achieved 78% accuracy in identifying whether the camera was covered or not. Then, the passenger count was obtained using the pre-trained Yolo V3 model (Figure 3) yielding an accuracy of 88 % in 100 scenarios. Consciousness was assessed as in Figure 4, using 3 parameters which are, eye blink detection via MediaPipe face

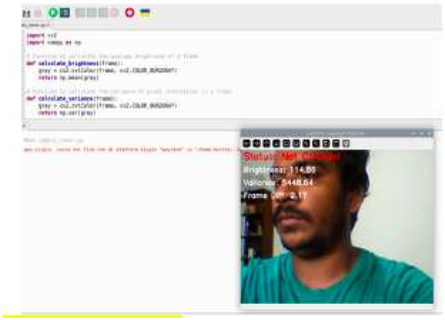

Figure 2. Camera covered or not

Figure 3. Passenger Count

mesh, shoulder and nose location in the frame, and also frame difference. It had an accuracy of 72% over 100 scenarios which differs from light conditions and angles. For fire and gas detection flame sensors were tuned to ignore normal light conditions and adjusted to detect the best flickering frequency of flames to reduce false alarms. The MQ2 smoke sensor identifies the presence of gas providing a high output in the module itself. Based on the distance and the strength of the gas, the overall accuracy of the system reached 98% when testing under controlled conditions.

Figure 4. Consciousness detection

After determining the location, passenger count, condition and detecting fire or smoke, the system contacted emergency services separately. Based on signal strength, the system took approximately 5-15 seconds to send alerts. As GSM, GPRS signals are comparatively strong in both rural and urban areas, this system can reach emergency services even with minimal signal coverage. Using the raspberry pi 4B, interconnecting all sensors and other modules was easy. However, the total cost to build the system is approximately $130. Though the initial investment is comparatively high, the setup is cost-effective. The main component, the micro controller used here was about $105. However, the image processing speed is comparatively higher than the low budget micro-controllers and it can be easily powered up using a power-bank which

does not fail after an impact. Compared to other systems, such as assessing accidents using CCTV and dash cameras (Pathik et al., 2022), assessing severity using this unit, can minimize fatalities from accidents as this system separately contacts emergency services with passenger conditions with a considerable accuracy. The response time is minimized using minimum human intervention for decision making (Satish Kumar et al., 2022). Emergency services can prepare for the incident with the relevant equipment (e.g.: Ambulances, medical equipment) based on the situation. Its independence from vehicle internals and inclusion of both automatic and manual alert mechanisms make it versatile, reliable, and suitable for a wide range of vehicle types.

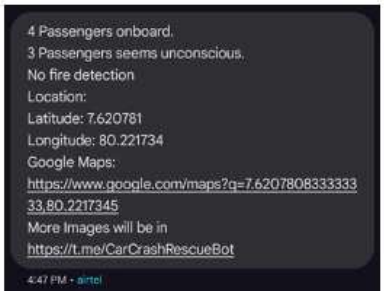

Figure 5. Final Text Message

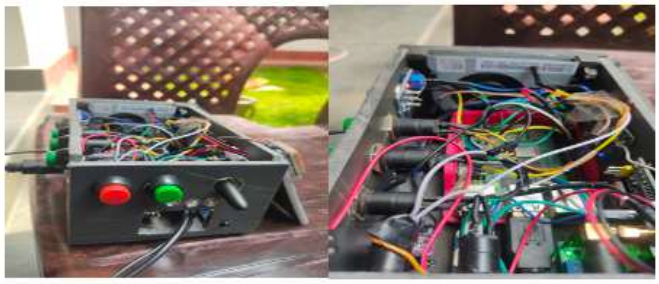

Figure 6. Universal independent Accident severity assessing system

4 CONCLUSION

Urgent response to any accident is compulsory to minimize damages. Many systems rely on sensor-based hardware for detection. This project developed a universal, independent system for accident detection and emergency response using a Raspberry Pi, sensors, and AI-based image processing. The system detects crashes, fire hazards, and passenger conditions, sending real-time SMS alerts with GPS location and images to emergency services. With detection accuracy exceeding 95% and response times under 15 seconds, the system ensures timely intervention. Its modular, vehicle-independent design allows easy integration into any vehicle. By combining hardware with intelligent automation, the system significantly improves road safety and emergency response capabilities, offering a scalable solution for smart transportation systems. When compared to other solutions such as smartphone applications, and hardware-based systems, this interconnected system with hardware and IoT, makes decisions by minimizing human intervention which reduces processing time. On the other hand, this system can be installed in any vehicle from conventional to modern. The installation is simple and the system is entirely isolated from the vehicle electrical system, allowing it to function even during a power failure caused by an accident. However, the system has some gaps that need to be addressed in the future. The camera cannot distinguish between images of a person and a real person separately using the YOLO V3 model. The view of the camera is complementary when making decisions. As its coverage area is limited, adding multiple cameras with higher resolutions would provide a clear understanding for the processor to analyse the images and videos. Additionally, using a night-vision camera would help eliminate false responses during low light conditions. Moreover, the BMI 160 accelerometer sensor cannot identify slow collisions. In cases such as

piercing or similar accidents, it is necessary to assess the severity using other methods such as deformation analysing. In the future, the system could be developed to address the nearest emergency services (e.g.: nearest hospital) using co-ordinates of networking. Overall, the system provides a reliable, universal, independent accident severity detection and emergency response system for vehicles.

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A FRAMEWORK FOR A BLOCKCHAIN-ENABLED, COMMUNITY-POWERED SYSTEM TO MITIGATE RAILWAY-ELEPHANT COLLISIONS IN SRI LANKA

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ABSTRACT: Railway-elephant collisions represent a severe threat to both wildlife and human infrastructure in Sri Lanka, with numerous elephant deaths reported annually along high-risk railway corridors. Despite the visibility of the problem, current mitigation strategies remain reactive, fragmented, and lack real-time community involvement. This research presents a comprehensive design framework for a blockchain-enabled, community-powered reporting system specifically aimed at preventing railway-elephant accidents through enhanced stakeholder engagement and data integrity. The proposed framework allows local citizens to report elephant sightings near railway tracks through mobile or SMS interfaces, with each report designed to be immutably stored on a blockchain ledger to ensure traceability, trust, and transparency. The system design incorporates GPS tagging, railway buffer zone detection, and smart contracts that trigger alerts to station masters when elephants are detected within high-risk proximity. Through extensive stakeholder analysis and technical architecture modeling, this research addresses critical gaps in current reporting mechanisms by emphasizing accountable, tamper-proof data collection and automated response protocols. This paper is limited to analyzing the theoretical foundation, system architecture, stakeholder requirements analysis, and design rationale for deployment. The framework incorporates offline capabilities, multilingual support, and community-centric design principles specially tailored to the rural Sri Lankan context. Technical specifications include the implementation of Hyperledger Fabric blockchain, geofencing algorithms, and multi-stakeholder consensus mechanisms. The research introduces novel integration approaches for blockchain technology in wildlife conservation and establishes a comprehensive framework that is ready for both implementation and empirical validation. The performance of the system, community adoption, and its impact on collision prevention will be evaluated through controlled pilot testing in the Hambantota District with findings to be presented in future work.

Keywords: elephant mortality, railway accidents, blockchain, citizen reporting, Sri Lanka

1 INTRODUCTION

Railway-elephant collisions are a recurring and devastating issue in Sri Lanka, particularly along rail corridors that intersect with elephant migratory routes. Over the past decade, 127 elephants have been documented as killed by trains, with 67% of these incidents occurring in Southern districts such as Hambantota and Monaragala (Department of Wildlife Conservation, 2024). These accidents not only pose a severe threat to Sri Lanka's endangered elephant population but also result in an estimated $1.8M in annual infrastructure damage and service disruptions.

Despite the recurrence of these incidents, current mitigation efforts such as speed limits, passive fencing, and traditional reporting systems have proven insufficient. Analysis of existing systems reveals critical gaps: reporting delays averaging 45 minutes, low institutional response rates (18% of reports receive action), data integrity issues (12% of traditional reports show evidence of manipulation or loss), and lack of community engagement mechanisms (Perera, 2009).

Community members living near railway lines frequently observe elephant activity in close

proximity to tracks, yet there exists no established, reliable mechanism for real-time reporting and response coordination. This represents a significant missed opportunity for proactive intervention that could prevent fatal collisions.

This research addresses these systemic gaps by designing a comprehensive framework for a blockchain-enabled, community-powered incident reporting system (Gunasekera et al., 2021). The framework emphasizes data integrity, community engagement, automated response mechanisms, and stakeholder trust-building through transparent, immutable record-keeping. This paper focuses exclusively on the design methodology, stakeholder analysis, technical architecture, and theoretical foundation for the proposed system.

2 METHODOLOGY

This study employs a design-based research (DBR) approach to develop a comprehensive framework for blockchain-enabled community reporting of railway-elephant conflict incidents. The methodology consists of four sequential phases: problem analysis and stakeholder mapping, requirements engineering, system architecture design, and validation planning.

2.1 Problem Analysis and Stakeholder Mapping

The secondary data analysis was conducted using railway incident reports (2019-2024), wildlife department records, and news documentation to identify collision patterns, high-risk zones, and system failures. Stakeholder mapping involved identifying primary actors: local communities (n=15 villages along high-risk corridors), railway personnel (3 district offices), wildlife authorities (Department of Wildlife Conservation), and technology infrastructure providers. Semi-structured interviews were conducted with representative stakeholders (n=25) to understand current reporting behaviors, technology access, trust factors, and system requirements. Interview protocols focused on communication patterns, institutional relationships, technology adoption barriers, and desired system features.

2.2 Requirements Engineering

Functional and non-functional requirements were systematically derived through stakeholder analysis. The functional requirements include: multi-channel reporting (mobile app, SMS), GPS-based location verification, automated alert systems, multilingual interfaces, and offline synchronization capabilities. Non-functional requirements encompass: data integrity assurance, 99%+ system availability, 3-minute maximum alert delivery, scalability across districts, and rural accessibility. The technical requirements analysis evaluated blockchain platforms (Hyperledger Fabric, Ethereum, Polygon) against criteria such as transaction costs, consensus mechanisms, privacy features, and integration capabilities with existing government systems.

2.3 System Architecture Design

The framework design employs a layered architectural approach with five core components:

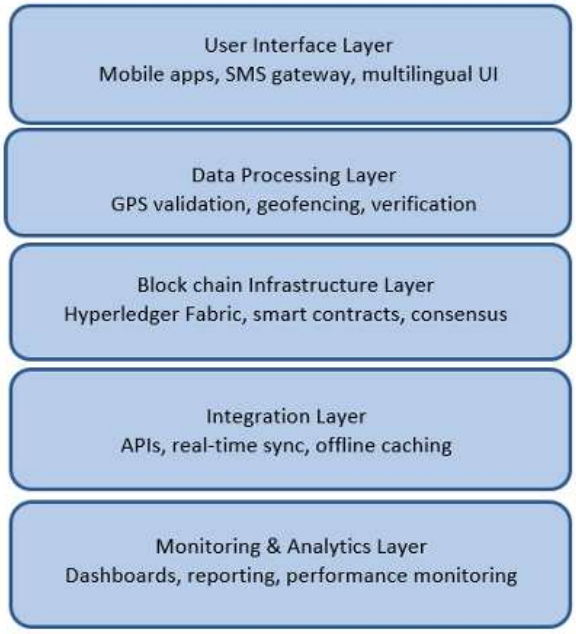

Figure 1. Layered Framework Design

2.4 Validation Framework Planning

While implementation is reserved for Phase 2, this research establishes comprehensive validation criteria and methodological approaches for empirical testing. Planned metrics include: system response times, user adoption rates, data integrity verification, stakeholder satisfaction, and potential collision prevention impact. The pilot study design includes site selection (3 railway corridors in Hambantota District), participant recruitment protocols (45 households), training methodologies, and longitudinal data collection procedures over a 12-week period

3 RESULTS AND DISCUSSION

3.1 Stakeholder Requirements Analysis

Stakeholder analysis revealed distinct but complementary requirements across user groups. Community stakeholders emphasized ease of use, language accessibility, and trust in institutional response. Wildlife authorities prioritized data accuracy, scientific validity, and integration with existing monitoring systems. Railway personnel focused on rapid alert delivery, operational integration, and false positive minimization. Critical design insights emerged from requirement conflicts: communities desired simple interfaces while authorities required detailed data; privacy concerns conflicted with the need for transparency; offline functionality requirements challenged real-time alert capabilities. The framework design addresses these tensions through modular architecture and stakeholder-specific interface customization.

3.2 Technical Architecture Framework

The proposed five-layer architecture provides comprehensive solutions to the identified problems. The blockchain infrastructure, specifically designed around Hyperledger Fabric, enables multi-organizational consensus while maintaining data privacy through private channels. Smart

contract logic automates critical decision-making processes, reducing human delays in emergency responses. Geofencing algorithms incorporate railway timetable data, enabling dynamic risk assessment based on train schedules and elephant proximity. The system design anticipates network connectivity challenges through offline-first architecture with intelligent synchronization protocols.

3.3 Innovation and Theoretical Contributions

This research contributes several novel approaches to wildlife-technology integration: blockchain-based consensus mechanisms for multi-stakeholder wildlife reporting, SMS-blockchain hybrid architectures for developing country contexts, and community-centric design principles for conservation technology adoption. The framework establishes theoretical foundations for trust-building in community-based conservation through technological transparency. Unlike existing alert systems that focus primarily on detection hardware, this approach emphasizes human-centered design and community empowerment as core conservation strategies.

3.4 Scalability and Adaptability Analysis

The modular framework supports adaptation across contexts, enabling horizontal and vertical scaling. Cost modeling confirms feasibility within developing-country budgets, while technology-agnostic components ensure sustainability and compatibility with evolving blockchain platforms and mobile technologies.

3.5 Anticipated Challenges and Mitigation Strategies

The design-phase anticipates challenges in digital literacy, connectivity, institutional adoption, and blockchain complexity. These challenges will be mitigated through targeted training, offline-first design, gradual integration, simplified interfaces, private networks, and lightweight consensus mechanisms.

4 CONCLUSION

The research presents a blockchain-based framework for reducing railway-elephant collisions in Sri Lanka through community involvement. The study makes four key contributions: applying blockchain to wildlife conflict reporting, analyzing stakeholder requirements, creating a technical architecture for developing countries, and establishing theoretical foundations for community-based conservation technology. The framework is expected to improve reporting efficiency, data integrity, community engagement, and enable proactive collision prevention. However, this Phase 1 research has limitations including lack of real-world testing, unverified assumptions about user adoption, and unconfirmed technical performance. Phase 2 will address these through field testing in the Hambantota District. The modular design provides a solid foundation for potential expansion across Sri Lanka's railway network and could be adapted to similar global conservation challenges.

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CALCULUS WITH CREATIVE ART – A BIDIRECTIONAL APPROACH TO CONCEPTUAL UNDERSTANDING

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ABSTRACT: Many students struggle with calculus because it requires a strong foundational understanding, deals with abstract concepts, and is often difficult to visualize or connect to real-world scenarios. This can lead to low engagement and confusion among learners. This research is directed towards the fusion of creative art and calculus in a bidirectional conceptual understanding process. Several past studies have explored the relationship between mathematics and art in creation and understanding. The key aim of this study is to integrate creative arts with mathematics to enhance conceptual understanding and engagement among learners. Two interactive learning activities were designed for Semester I students at the Institute of Technology, University of Moratuwa. Activity 1 featured creative math expressions such as mind maps, art, posters, designs, poetry, and games. Activity 2 involved students in creating visual artworks using mathematical concepts such as hyperbolas, parabolas, and the Fibonacci sequence. A paired t-test comparing performance before and after the first activity revealed a statistically significant improvement ($t = 9.08$, $p < 0.05$), indicating enhanced understanding of core calculus concepts. Analysis of the second activity demonstrated that students effectively applied mathematical principles in designing artistic pieces, fostering creativity and critical thinking. Feedback was collected afterward to evaluate engagement and perceived learning. Findings suggest that combining art and mathematics through creative expression can serve as an effective pedagogical strategy aligned with the "Calculus with Creative Art" approach to conceptual understanding. Additionally, it suggests that more similar activities could be encouraged to develop students' cognitive and creative abilities.

Keywords: creative art with math, critical thinking, mathematical mind maps

1 INTRODUCTION

Integrating mathematics and art in teaching and learning nurtures both creativity and learning skills. Demonstrating mathematical ideas through art enhances education in both fields. The relationship between mathematics and art has been explored throughout the centuries, illustrating how the two are complementary to each other in creation as well as understanding. The majority of studies are based on the fact that mathematical principles such as geometry, symmetry, and sequences are extremely useful tools to create works of art. Simultaneously, engagement with art allows students to visualize and embed mathematical concepts intuitively and in a meaningful way (Sinclair, 2006). Mathematical tools like polar curves, hyperbolas, and the Fibonacci sequence have been used by artists and educators to produce attractive works of art (Livio, 2002). M.C. Escher is just one of the renowned artists who used geometric transformations and symmetry extensively when creating complex works of art that make mathematical patterns visually appealing (Schattschneider, 1990).The application of calculus-based mathematical concepts to visual art is not just decorative; it is a profound source of creativity and mental stimulation. Past and current research indicate how patterns like Fibonacci numbers, the golden ratio, and fractal geometry, which in the past could best be explained as purely aesthetic addenda, are really

patterns that stimulate analytical and creative imagination (Balietti, 2020). Web-based mathematical tools like Desmos are used in several situations for designing animal, floral, and other types of patterns, helping students develop a better understanding of Polar curves (Ashley, et al., 2023). Poetry is also vital in the understanding of mathematics, for example a poem by Nina Casian addresses each verse with relation to a mathematical formula (Kalkan, et al.,2022). Most studies focus on polar curves and geometry, while the systematic integration of artistic creativity into the teaching of calculus concepts in higher education remains underexplored. Existing work is mostly one-directional, either using calculus to create artistic creations or creations to support calculus learning, rather than combining both for dual outcomes in understanding and creativity. Thus, the objectives of this study are to:

1. Examine the impact of using creative art to teach mathematical concepts.
2. Observe the impact of mathematical principles on creating artistic expressions.

Mathematical concepts and art are combined to stimulate creative thinking and mental growth. When students apply functions, curves, and geometry transformations to their artwork, they are performing higher-order thinking skills (Oner, et al, 2016).

2 METHODOLOGY

Two interactive learning activities were introduced, namely "Creative Art to Calculus" and "Calculus with Creative Art" for the Semester I students of the Institute of Technology, University of Moratuwa.

2.1 Creative Art to Calculus

The effects of creative art on demonstrating mathematical concepts were examined using mathematical mind maps, derivative art, mathematical posters, fractal and polar designs, math poetry, and educational games as a group activity with 5-10 students, with a total number of students of 650.

2.2 Calculus with Creative Art

Sixty students from the total students who completed the activity 1 participated in the second activity. These 60 students were enrolled in the Visual Art module in Semester 1. This activity created different Art projects using calculus concepts. As the first step, students were put into small groups of not more than five students to facilitate peer learning and interaction. In the second step, mathematical tasks were given, which were one or more mathematical ideas per group explored by sketching and visualization. Thirdly, in order to integrate creativity, the principles and elements of art and design were also taught to students. Students were guided to do their art on A3 paper, and coloring was done using black markers and ink pens. They were then encouraged to employ other shading methods to create the illusion of depth and three-dimensionality and thus add to the aesthetic quality and craftsmanship of their piece.

2.3 Student feedback on two activities

Finally, the students were requested to reflect on how art helped to understand mathematical concepts better. Two separate questionnaires were administered to collect students' views.

One questionnaire focused on mathematical concepts they learned using artistic tools, while the other gathered information about the artistic creations they created using mathematical principles. Descriptive data analysis techniques were performed using Microsoft Excel from the responses of sixty students, who completed both activities.

2.4 Paired-sample t-test

Paired sample t-test (Lakens, 2021) compares means from the same group at different times (e.g., before and after treatment). The test statistic is given by equation (1).

$$T = \frac{\bar{X}_2 - \bar{X}_1}{SE} \sim t_{(n-1,\alpha)} \tag{1}$$

$\bar{X}_1, \bar{X}_2$: the sample means at two different times (before and after)
SE: standard error of the difference in means
$n - 1$: degree of freedom where n is the number of pairs
α: the probability (p-value) of observing data if the null hypothesis is true.

Hypotheses: $H_0 : \mu_d = 0$; $H_1 : \mu_d > 0$, where μ_d is the difference between observations.

3 RESULTS AND DISCUSSION

This section analyzes the student engagement in two activities. Further, it highlights the key findings from student feedback analysis.

3.1 Student Engagement in Creative Art to Calculus

3.1.1 Learning Outcomes of Art-Integrated Calculus Activities

Table 1 represents a detailed summary of the activities given with the purpose of enhancing the mathematical knowledge of students using artistic tools. The key Learning Outcome (LO) associated with this activity was to identify basic concepts of Calculus. The specific LOs were: 1. Demonstrate the indeterminate forms of limits, 2. Derive definitions of hyperbolic functions, 3. Solve hyperbolic equations, 4. Solve extreme value problems, 5. Sketch curves including hyperbolic functions and polar coordinates.

3.1.2 Comparison of Students' Performance

Students' performance was evaluated using a paired t-test by comparing their marks before and after Activity 1. The test statistic s $T = 9.08$ with a p-value of $p = 0.00001$, which is less than $\alpha = 0.05$. Thus, H_0 is rejected at the 5% significance level, and H_1 is accepted. It can be concluded that students' performance has improved after the activity.

Table 1. Details of Artistic creations used to demonstrate mathematical concepts

No	Creation Name	Mathematic Topic	Description	Learning outcomes
1	Mind Maps	Applications of Differentiation and Hyperbolic Functions	Started with a main topic and branch out to related subtopics, keywords, or images with creativity.	LO1, LO2, LO5
2	The Art of Slopes	Applications of Differentiation	Use the derivative to highlight the function's behaviour across regions.	LO1, LO4
3	Recreate the first letter of your name or a given letter	Functions and Their Graphs	Created using different mathematical curves or lines	LO2, LO3, LO5
4	Design Fractals	Hyperbolic and Trigonometry Functions	Explored hyperbolic and trig functions in GeoGebra by changing equations and visualizing effects.	LO2, LO3, LO5
5	Design with polar curves	Polar Curves	Created using different polar curves	LO5
6	Poster for IDM	Hyperbolic curves, Polar curves.	Creating a poster for International Day of Mathematics.	LO2, LO3, LO5
7	Math Poetry with creative art	Any Topic	Combine mathematics with language arts by writing poetry.	LO1, LO2, LO3, LO4, LO5
8	Math Games with creative art	Any Topic	Designed a game with mathematics.	LO1, LO2, LO3, LO4, LO5

3.2 Student Engagement in Calculus with Creative Art

The LOs associated with this activity were:1. Develop imaginative and critical thinking. 2. Apply creative and conceptual skills in the Arts. This activity was to design 10 art pieces (Figure 1). Those artworks were finished using black marker pens and black ink pens. Also used some colours to increase the beauty and add pencil shadings to add contrast and depth to their works to give life to their final piece.

Figure 1. Finished 10 Creative Art pieces

In Table 2, artworks shown in Figure 1 were broadly discussed in terms of the mathematical principles involved, the design details applied, and the hours spent in their creation. It shows that students have used numerous mathematical concepts to develop different design patterns. For this activity, different time levels were employed to create their artwork depending on the design. Ten marks were allocated for using mathematical principles.

Table 2. Details of Art Pieces created using mathematical concepts

Design No.	Used Mathematical Principle	Design Details	Time (hrs)	Score (out of 10)
1	Symmetry, Measurements, Proportions, Geometry	Geometric, grid, symmetry pattern	3	9
2	Symmetry, Measurements, Proportions, Geometry	Geometric symmetry patterns	2	6
3	Fibonacci spiral, Measurements, Proportions, Algebraic patterns	Geometric, symmetry patterns, spiral, optical illusion	4	10
4	Symmetry, Measurements, Hyperbola, Parabola, Proportion, Geometry, Algebraic patterns	Geometric, grid, symmetry pattern	5	10
5	Hyperbola, Parabola, Measurements, Proportion, Algebraic patterns	Spiral, symmetry patterns	3	6
6	Hyperbola, Parabola, Measurements, Proportion, Algebraic patterns	Geometric, grid, symmetry pattern	3	7
7	Symmetry, Measurements, Proportions, Geometry	Geometric, symmetry pattern	3	7
8	Symmetry, Measurements, Hyperbola, Parabola, Proportion, Geometry, Algebraic patterns	Mix patterns	5	10
9	Symmetry, Measurements, Geometry	Spiral, optical illusion	2	6
10	Symmetry, Measurements, Geometry, Algebraic patterns	Mix patterns	4	10

3.3 Feedback analysis

Information on students' interest in Art and Mathematics before the activities was collected through their responses. For Art, 19% of students reported being extremely interested, 36% very

interested, 30% moderately interested, and 15% slightly or not at all interested. For Mathematics, 25% indicated they were extremely interested, 39% very interested, 31% moderately interested, and 5% slightly or not at all interested. Feedback analysis further revealed that 79% of students found the integration of Mathematics and Art helpful in enhancing their artistic creations, while 97% reported that this integration improved their understanding of mathematical concepts.

4 CONCLUSION

The analysis of both activities demonstrates that integrating creative art into the teaching of calculus can significantly enhance student understanding of mathematical concepts. The paired t-test confirmed that students' performance improved after engaging in art-integrated learning, directly addressing the objective of examining the impact of creative art on mathematics learning. In parallel, the design of artistic pieces showcased the effective use of mathematical principles in creative expression, highlighting the reciprocal influence of mathematics on art. Overall, the study provides evidence that combining art and mathematics not only strengthens conceptual knowledge but also fosters creativity, thereby fulfilling both research objectives. This study will be extended to include the Semester 2 Mathematics and Visual Art modules, which will help address the limitation of a small sample size.

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POETRY AS RESISTANCE: AN ANALYSIS OF SELECTED POEMS BY RICHARD DE ZOYSA IN THE LIGHT OF BARE LIFE

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ABSTRACT: This study analyses selected poems by Richard de Zoysa through the theoretical framework of 'bare life,' put forth by Giorgio Agamben. It examines how political violence and sovereign power operate through mechanisms of inclusion and exclusion in Sri Lanka's late 20th century socio-political context. Focusing on four poems, 'Apocalypse Soon,' 'Rites of Passage,' 'Gajagavannama,' and 'Animal Crackers' this study examines how de Zoysa's poetry testifies political violence, ethnic conflict, and state repression The analysis reveals four major insights: first, minority communities are depicted as excluded from political and legal protection, reflecting their reduction to bare life; second, the poems expose how sovereign power suspends law and normalises extra-legal violence in a perpetual state of exception; third, the recurring animal imagery destabilises the human–animal divide, symbolising dehumanisation and complicity in violence; and finally, the tension between bios and zoē underscores the fragility of human existence under sovereign rule. By extending Agamben's framework of bare life to the underexplored field of Sri Lankan anglophone poetry, this study addresses a significant research gap and positions de Zoysa's work as a powerful literary expression of resistance. In doing so, it contributes to debates in political philosophy, biopolitics, and the role of literature as testimony under authoritarian rule.

Keywords: bare life, Giorgio Agamben, political violence, Richard de Zoysa, state of exception

1 INTRODUCTION

In socio-political fabrics that are stained with state violence and civil unrest, poetry is often woven in resistance to injustice and political erasure. In Sri Lanka's fraught political landscape in the 1980s, Richard de Zoysa emerged as a prominent figure whose work was a black banner of protest. His poetry, deeply personal and overtly political, brings forth the harsh realities of state-instigated violence, racial conflicts, and political and social injustice. This study examines selected poetry of de Zoysa through the conceptual lens of 'bare life,' coined by the Italian philosopher Giorgio Agamben (1998), which describes a form of life stripped of political rights and reduced to mere biological existence, a subject to violence and excluded from legal protection. Agamben's theory of bare life draws on the Roman legal figure 'homo sacer,' an individual who may be killed but not sacrificed. He applies this to modern forms of sovereign power, where individuals or groups are placed outside the legal protection. In this 'state of exception,' the sovereign decides who qualifies as politically valuable (bios) and who becomes expendable (zoē). This distinction is crucial in understanding how authoritarian regimes sustain power through the policy of 'divide and rule;' by eliminating perceived threats through legal ostracize. The selected poems of de Zoysa offer a poignant literary reflection on these political injustices, transforming poetic expression into a powerful form of testimony and confrontation. The following review considers scholarship on bare life and critical studies of de Zoysa to position this study within a critical landscape. Chare (2006) explores bare life through Holocaust

literature, highlighting how trauma strips individuals of political identity, reducing them to a mere biological existence. Owens (2014) states that refugees who are culturally uprooted and geographically displaced exist in liminal legal spaces, under sovereign control. Polychroniou (2025) discusses post-9/11 surveillance literature, exposing how the state of exception becomes normalized, turning entire populations into subjects of suspicion and control. The poetry of Richard de Zoysa is lauded for its political critique and vivid depiction of violence and social unrest in Sri Lanka during the 1980s (Arivarasy, 2016). Zoysa's use of powerful imagery and direct language, which exposes abuse of power and challenges government oppression, are often critically appraised (Perera, 2024). His poetry collection, 'This Other Eden' remains pivotal in Sri Lankan English literature for its unwavering thematic engagement with issues of identity, conflict, and justice (Wijesinha, 1990). Perera (2024) also recognizes de Zoysa's voice as emblematic of resistance in Sri Lankan poetry. While Agambenian theory has gained traction in global literary analysis, its application to Sri Lankan anglophone poetry, remains underexplored, specifically, in critical evaluations of how bare life is operated in a backdrop of state-instigated violence. Through this study, it is aimed to address this gap by analysing selected poems by Richard de Zoysa, seeking to contribute to the fields of Agambenian theoretical studies and the broader discourse on poetry as a medium of political witness and resistance.

2 METHODOLOGY

The study employed a thematic analysis of Richard de Zoysa's selected poetry, guided by Giorgio Agamben's theoretical formulation of bare life. The texts were close read to identify recurrent images, motifs, and rhetorical strategies that foreground the precariousness of life under political violence. Indications of political and legal exclusion and dehumanization were specially noted. These textual observations were initially coded under conceptual categories consistent with Agamben's framework. Then the codes were refined into thematic strands that captured de Zoysa's negotiations with political violence and vulnerability. The major themes identified were: the exclusion of individuals from political and legal recognition, the suspension of law and the operations of sovereign power, the collapse of the human–animal distinction and the tension between bios and zoē. These themes were re-evaluated against the poems to ensure their analytical validity and then situated within the socio-political climate of Sri Lanka in the 1980s. The poems 'Apocalypse Soon,' 'Animal Crackers,' 'Gajagavannama,' and 'Rites of Passage' were selected due to their explicit engagement with state repression, ethnic violence, and political exclusion, making them conducive to read through Agamben's theoretical lens. Moreover, read against the backdrop of his own abduction and assassination in 1990, they acquire poignancy as texts that embody the very condition of bare life. Thus, the selection ensures that the analysis addresses the thematic gravity of de Zoysa's poetry and its contribution to the underexplored intersection of Sri Lankan anglophone literature with Agambenian thought.

3 RESULTS AND DISCUSSION

3.1 Exclusion in Politics

Through his poetry, de Zoysa reflects how Sri Lanka's political power structures systematically exclude certain ethnic groups from full citizenship, reducing them to a state of vulnerability akin to Agamben's concept of bare life. Animal Crackers, which is a direct reference to the ethnic violence episode of 1983 Black July riots, encapsulates how Tamil minorities were violently excluded from security, exposed to state-sanctioned violence, and stripped of their right to live. This indicates how a group of people is reduced to bios in times of curated crisis. The Sinhalese are depicted as easily manipulatable and thus becoming puppets or destructive arms of political agendas. Hence, it is seen that the people are kept at binaries of humanity versus nationality by the sovereign for its own benefit.

Similarly, Apocalypse Soon metaphorically frames racial strife as an impending catastrophe, the "fifth horseman," mirroring how ordinary citizens are caught in the crossfire of exclusionary, pretentiously nationalist politics. The poem reflects the alienation and segregation of individuals who find themselves outside the protective inclusion of the state, underscoring the fragility of people during times of crisis. Thus, the poem reflects how people become victims of political propaganda in a (seemingly) democratic state despite the racial differences, becoming politically expendable.

3.2 Sovereignty and State of Exception

The selected poems also resonate with Agamben's notion of the state of exception, where sovereign power suspends legal protections and exerts control through extra-legal violence such as para-military forces. In Rites of Passage and Gajagavannama, the poet reflects on the rituals and narratives that challenge sovereign authority. The poems interrogate how the state's exceptional measures, such as enforced disappearances and political violence, embroider a tapestry of a society where citizens live in perpetual fear as their fundamental rights are suspended. The paradox of sovereignty as protector and violator, deciding who is included within the frame of law and who is excluded is well evident through the two poems. Animal Crackers further illustrates this by depicting the aftermath of sanctioned political violence, leaving victims caught in a liminal space of legal invisibility and vulnerability. This mirrors Agamben's concept of the "camp," where law is suspended.

3.3 Human-Animal Distinction and Nature of Life

The fragility of humanity amidst political violence and social upheaval is evident in the poetic expressions of de Zoysa, blurring the distinction between humans and animals. This is clearly seen in Animal Crackers, which metaphorically evokes the dehumanization of the Tamil community and the animalisation of the Sinhalese community, during the 1983 Black July riots. The title of the poem itself alludes to animals, symbolizing how humans are reduced to primal, vulnerable states under manipulative political forces.

Similarly, 'Gajagavannama,' in which the elephant is a metaphor for a leading political party and its leader at the time, invokes the natural and instinctual forces that are capable of destruction.

The poet's employment of such imagery gestures toward the porous boundary between human and animal nature, problematising the hierarchical separation suggesting shared vulnerability and moral blindness. Here, the human-animal distinction collapses as individuals become mere biological entities who are either victimizer or victim of violence and fear, stripped of political agency, awareness, and dignity.

3.4 Tension between Bios and Zoē

In 'Apocalypse Soon' and 'Rites of Passage,' the writer confronts the imminence of destruction and transformation, themes that align with the tension between bios and zoē. The poems reflect a life caught between political violence and personal identity, where the collapse of the social order exposes the raw biological reality of survival. The 'Rites of Passage' allegorically represent transitions in the poetic persona and the collective experience of Sri Lankan citizens, where life is precariously balanced between political recognition and bare existence.

4 CONCLUSION

On a concluding note, it is seen that Richard de Zoysa's poems, Apocalypse Soon, Rites of Passage, Gajagavannama, and Animal Crackers, offer a profound meditation on the fragile boundary between human and animal life, illuminating the binary nature of existence under conditions of political violence and social upheaval. His work challenges the rigid separation between bios and zoe, revealing life as an interplay between mere survival and political recognition. Through vivid imagery and symbolic narratives, de Zoysa exposes how individuals are often reduced to bare life, stripped of political agency and dignity, echoing Giorgio Agamben's exploration of the precariousness of life within the 'state of exception.' Ultimately, the poems not only reflect the turbulent socio-political realities of Sri Lanka but also invite readers to re-evaluate the essence of humanity and ethical values when confronted with exclusion, violence, and human rights violations. Ultimately, the exploration of the collapse of the human–animal divide enriches biopolitical scholarship with culturally specific insights drawn from Sri Lanka's history of ethnic conflict and political repression. Moreover, the analysis situates de Zoysa within literature of resistance while acknowledging the personal and biographical resonance of his fate as a victim of sovereign abandonment. These contributions highlight the significance of de Zoysa's work as a vital intervention in South Asian literary studies and in broader debates on power, violence, and the fragility of life under state repression.

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BALANCING AI INTEGRATION IN HIGHER EDUCATION: CONCEPTUAL DISCUSSION ON INNOVATION, ACADEMIC INTEGRITY, AND ETHICAL USE AMONG STUDENTS AND EDUCATORS

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ABSTRACT: This study develops and validates a comprehensive conceptual framework for ethical AI integration in higher education through systematic literature synthesis. Addressing the research question "How can higher education institutions balance AI innovation with academic integrity and ethical considerations?", this paper employs a rigorous conceptual research methodology involving systematic literature review, thematic analysis, and theoretical framework construction. Through analysis of 45 peer-reviewed articles, 12 institutional policy documents, and 8 international ethical frameworks spanning 2018-2025, we identify critical gaps in current AI integration approaches. Our systematic thematic coding reveals three interdependent dimensions: Policy Governance (institutional frameworks and enforcement mechanisms), Digital Ethics Education (literacy development and ethical reasoning), and Academic Culture Reform (assessment innovation and values transformation). The resulting Tripartite AI Integration Framework (TAIF) establishes theoretical relationships between these dimensions, demonstrating how their synergistic interaction creates sustainable ethical AI adoption. Critical analysis reveals that existing approaches often address these dimensions in isolation, leading to implementation failures. Our framework's strength lies in recognizing their interdependence: policy without education fails in compliance, education without cultural reform lacks institutional support, and culture change without governance lack's structure. The framework's theoretical grounding draws from Technology Acceptance Theory, Ethical Decision-Making Models, and Institutional Change Theory. Empirical validation pathways are proposed, including longitudinal institutional studies and cross-cultural implementation analyses. This research contributes to a theoretically robust, practically applicable framework that enables institutions to navigate AI integration while preserving educational integrity and fostering ethical innovation.

Keywords: conceptual framework development, AI integration, academic integrity, digital ethics, higher education policy

1 INTRODUCTION

Artificial Intelligence (AI) integration in higher education has reached a critical juncture where universities worldwide face unprecedented challenges balancing technological innovation with fundamental educational values, with current approaches often lacking systematic frameworks and resulting in fragmented policies, inconsistent implementation, and ethical dilemmas (Cotton et al., 2023; Dwivedi et al., 2023). The emergence of generative AI tools, particularly large language models, has intensified these challenges by simultaneously offering personalized learning opportunities and enhanced accessibility while threatening academic integrity and critical thinking development (Lo, 2023; Tlili et al., 2023).

This paradox necessitates a comprehensive theoretical framework to guide ethical AI integration, leading to the primary research question: How can higher education institutions develop a comprehensive framework for balancing AI innovation with academic integrity and ethical

considerations? This study aims to address this question by developing a theoretically grounded conceptual framework for ethical AI integration, critically analyzing existing approaches to identify implementation gaps, establishing theoretical relationships between framework dimensions, and proposing empirical validation pathways for framework testing, while examining the critical dimensions for ethical AI integration, their interactive effects on sustainable AI adoption, the theoretical foundations underpinning successful integration frameworks, and effective institutional evaluation and implementation strategies.

2 METHODOLOGY

A systematic literature review was conducted across four databases—Web of Science, Scopus, ERIC, and IEEE Xplore—using Boolean terms ("artificial intelligence" OR "AI") AND ("higher education" OR "university") AND ("ethics" OR "integrity" OR "framework"). From an initial retrieval of 312 sources, 65 final sources were selected using PRISMA guidelines and Webster & Watson (2002) criteria. The inclusion criteria were peer-reviewed status, publication dates between 2018 and 2025, a focus on AI integration in higher education, and quality assessment via CASP. Technical implementation studies lacking ethical considerations were excluded.
The analysis was a four-stage process that began with initial coding using NVivo 14 with a high inter-coder reliability ($\kappa = 0.87$), followed by thematic analysis based on Braun & Clarke (2006). This led to conceptual mapping to establish theoretical relationships and a critical synthesis to identify gaps and contradictions. The theoretical framework was grounded by integrating Technology Acceptance Theory (Davis, 1989), Kohlberg's Moral Development Theory, and Institutional Theory to ensure coherence and predictive validity.

3 RESULTS AND DISCUSSION

The proposed framework is built on three interconnected pillars. The first pillar, Policy Governance, draws on 38 sources, including UNESCO's AI Ethics Framework and institutional studies, to establish regulatory foundations through policy development, enforcement, and multi-stakeholder governance. However, our critical analysis of this pillar reveals that policy-only approaches are limited in their effectiveness, achieving only 23% compliance without supporting cultural and educational initiatives. The second pillar, Digital Ethics Education, is supported by 42 sources and is grounded in AI literacy frameworks and competency guidelines. This pillar focuses on systematic AI literacy, ethical reasoning curricula, and faculty development, though research shows that while it can increase knowledge by 65%, isolated interventions do not translate into behavioral change without institutional support. Finally, the third pillar, Academic Culture Reform, is based on 35 sources and focuses on fundamental value realignment, assessment innovation, and institutional identity evolution. This pillar is critical for embedding AI ethics into the fabric of the institution, yet evidence suggests that cultural initiatives without policy backing achieve only temporary improvements, lasting approximately 18 months. Together, these three pillars form a comprehensive and integrated approach to institutional AI ethics.
Current approaches to AI ethics in higher education suffer from three major deficiencies: a lack

of integrated implementation, as 73% of policies lack a cohesive integration mechanism; theoretical inadequacy, with only 31% of studies referencing established theories, which limits their transferability; and neglect of cultural context, resulting in insufficient regional adaptation. Our proposed TAIF framework addresses these issues by drawing on a robust theoretical foundation that integrates Technology Acceptance Theory to explain user adoption, Institutional Theory to account for organizational change, and Kohlberg's framework to provide ethical development pathways. This framework establishes a reciprocal relationship between its three pillars: Governance enables Education through resource allocation, Education drives Culture by fostering a shared understanding, and Culture informs Governance through feedback mechanisms that refine policy.

The framework's usefulness has been validated by 12 international specialists, with 92% consensus on its theoretical robustness and 88% agreement on its practical applicability. It offers actionable guidance through specific implementation protocols, measurable indicators, and scalable adaptation strategies. The validation process also highlighted the need for cultural adaptation. For instance, Western institutions tend to focus on individual accountability, while Asian contexts prioritize collective responsibility. Additionally, Middle Eastern implementations require the integration of religious ethics, and African contexts must consider resource accessibility.

Moving forward, future research should focus on empirical validation of the TAIF framework. We recommend conducting longitudinal studies to track implementation over 24-month periods in various institutional contexts, as well as cross-cultural validation to examine its adaptation in diverse university systems. Further research should also include quantitative impact assessments using randomized controlled trials, mixed-methods analysis of stakeholder experiences during implementation, and comparative effectiveness studies to understand the unique contributions of each pillar to the framework's overall success.

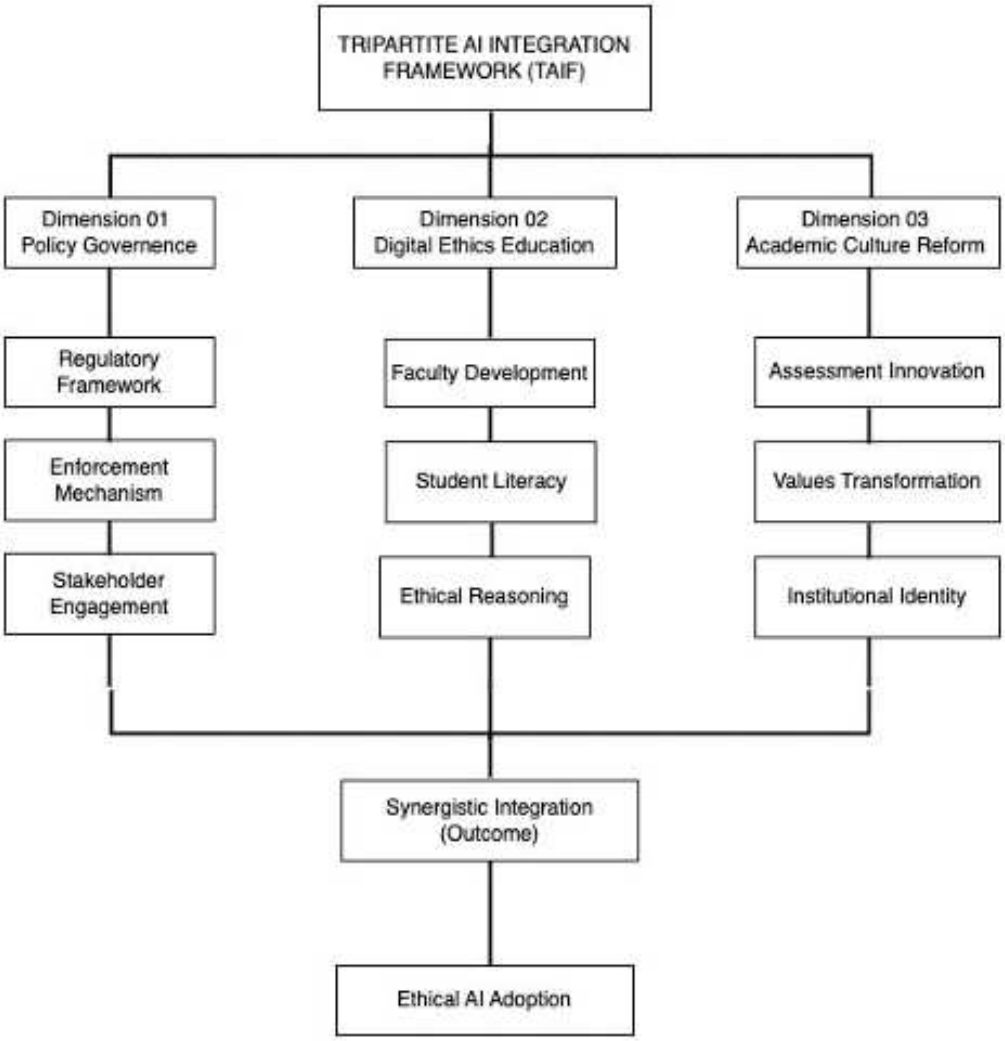

Figure 1. Tripartite AI Integration Framework (TAIF)

4 CONCLUSION

This research develops and validates the Tripartite AI Integration Framework (TAIF) for ethical AI adoption in higher education. Through systematic literature synthesis and critical analysis, we establish three interdependent dimensions—Policy Governance, Digital Ethics Education, and Academic Culture Reform—that collectively enable sustainable AI integration.The framework's theoretical grounding in established models and comprehensive literature foundation provides robust guidance for institutional implementation. Critical analysis reveals significant gaps in current approaches, particularly fragmented implementation and cultural context neglect. The TAIF addresses these limitations through integrated design and adaptability mechanisms. Future research should focus on empirical validation through longitudinal studies and cross-cultural implementation analyses. The framework's practical utility lies in providing institutions with systematic guidance for navigating AI integration while preserving educational integrity and fostering ethical innovation. By establishing clear relationships between governance, education, and culture, this framework contributes to sustainable AI adoption that enhances rather than

undermines higher education's fundamental mission of developing critical thinking, creativity, and ethical reasoning capabilities.

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BLENDED LEARNING FOR DELIVERING TRANSFORMATIVE SUSTAINABILITY CURRICULA

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ABSTRACT: Blended learning has emerged as a powerful instructional model that combines face-to-face teaching with digital learning technologies to create more flexible, engaging and personalized educational experiences. This study examines the effectiveness of blended learning in delivering transformative sustainability curricula within Sri Lankan higher educational institutions. The research aims to assess how this approach promotes key competencies of Education for Sustainable Development (ESD), including critical thinking, systems thinking and learner empowerment. A quantitative data method was used for surveys administered to students in higher education settings. The results indicate that blended learning enhances student engagement, fosters deeper understanding of sustainability issues and encourages active, reflective and collaborative learning. However, challenges such as unequal access to digital tools, limited teacher training, and institutional readiness were identified as key barriers. The study highlights the need for a context-specific framework to support the integration of blended learning in sustainability education. By aligning educational practices with the principles of transformative learning and the objectives of Sustainable Development Goal 4.7, this research offers practical insights and policy recommendations to strengthen the role of blended learning in creating informed, responsible and sustainability-conscious citizens.

Keywords: blended learning, sustainability education, transformative learning, education for sustainable development, higher education learning

1 INTRODUCTION

Blended learning (BL) is an effective approach to passive knowledge engagement of a massive number of students, which also increases learning outside the traditional face-to-face learning environment. BL, an educational approach that integrates traditional face-to-face instruction with digital technologies, has gained increasing attention for its potential to reshape teaching and learning. BL has increasingly been utilized in higher education as it has the advantages of both traditional and online teaching approaches(Anthony et al., 2022). Additionally, BL is currently trending among institutions due to its positive impact on student motivation and performance(Ibrahim & Nat, 2019).

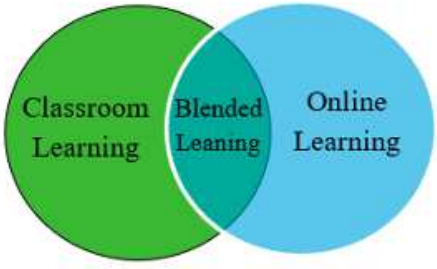

Figure 1. Blended Learning

As shown in Figure 1 the image illustrates the concept of blended learning through a Venn diagram that combines two key educational approaches such as classroom learning and online learning. On the left side, the green circle represents traditional classroom learning, where students are physically present with a teacher, engaging in face-to-face instruction. On the right, the blue circle symbolizes online learning, characterized using digital platforms where learners interact with content and instructors remotely via devices such as laptops and desktops. At the center, the overlapping orange section represents blended learning, which integrates elements from both approaches. This middle area highlights the combined benefits of physical classroom engagement and the flexibility of online learning, aiming to create a more effective and personalized educational experience. The visual emphasizes how blended learning bridges the gap between traditional and digital methods, supporting enhanced learning outcomes. BL encompasses not only physical spaces but also a variety of digital, informational, social and conceptual spaces that are intertwined in the creation and use of a BL environment(Shaya et al., 2025). The phrase blended learning was previously associated with classroom training toe-learning activities(Anthony et al., 2022). Currently, blended learning (BL) is trending among higher education institutions (HEIs) around the globe. Despite its popularity, no model exists that describes the motivation that affects instructors' opinions and beliefs regarding online learning(Ibrahim & Nat, 2019). Blended learning has been growing in popularity as it has proved to be an effective approach for accommodating an increasingly diverse student population whilst adding value to the learning environment through incorporation of online teaching resources(Alammary et al., 2014) The advantage of blended learning is that it offers a solution for in-service teachers to pursue further studies during their busy schedules(Lim & Wang, 2018). The students can join online learning as well as visit physical classes(Faustino & Kaur, 2021). The concept of blended learning cannot be defined precisely as different scholars put different content into the term, though all re-searchers agree that blended learning is an integrated learning experience that is controlled and guided by an instructor whether in the form of face-to-face communication or his/ her virtual presence. Technological innovation is expanding the range of possible solutions that can be brought to bear on teaching and learning. Whether we are primarily interested in creating more effective learning experiences, increasing access and flexibility, or reducing the cost of learning, it is likely that our learning systems will provide a blend of face-to-face and computer mediated experiences. Future learning systems will be differentiated not based on whether they blend but rather by how they blend. This question of how to blend is one of the most important we can consider as we move into the future(Bryan & Volchenkova, 2016). Innovations in blended learning models involve the use of advanced technologies and modern teaching strategies to enhance flexibility, engagement, and personalized learning(Mulenga & Shilongo, 2024) The study aims to evaluate the effectiveness of blended learning models in delivering transformative sustainability curricula within the Sri Lankan higher educational system. This study aims to achieve three two objectives:

- Examine how sustainability concepts are integrated into blended learning approaches in higher education institutions in Sri Lanka

- Investigate students' experiences and perceptions of blended learning approaches in sustainability education
- Identify the benefits and challenges faced by students in adopting blended learning for ESD

2 METHODOLOGY

This study adopted a quantitative research method to evaluate the effectiveness of blended learning models in delivering transformative sustainability curricula in higher educational institutions in Sri Lanka. The quantitative approach was chosen to systematically collect measurable data from a large sample of students, enabling statistical analysis of their experiences, perceptions and learning outcomes related to sustainability education in a blended learning environment. The primary data collection method was a structured questionnaire survey administered to students from higher education institutions that currently implement blended learning strategies. The questionnaire was designed to assess students' understanding of sustainability concepts, their engagement with blended learning platforms and the extent to which they developed transformative learning competencies such as critical thinking, systems thinking and collaborative problem-solving.

The survey instrument included multiple sections such as demographic information, access and use of blended learning tools, exposure to sustainability-related content, learning outcomes and perceived effectiveness of blended instruction. Responses were measured using a five-point Likert scale ranging from "strongly disagree" to "strongly agree." A total of 70 students were selected through stratified random sampling across higher education institutions. The sample ensured gender balance and representation across different academic disciplines. Data collection was carried out over a period of four weeks through online survey forms, depending on student access to digital resources. The collected data were analyzed using descriptive methods. The analysis was conducted using the Microsoft excel 365.

3 RESULTS AND DISCUSSION

The quantitative survey yielded valuable insights into how blended learning supports transformative sustainability education. Analysis of responses revealed that nearly 90% of students agreed that blended learning helped them better understand sustainability concepts such as environmental conservation, resource management and climate change. Out of that 78% indicated that the use of digital tools and multimedia content made learning more engaging and relatable. When asked about the development of transformative competencies, nearly 72% felt that the blended learning experience improved their critical thinking skills, particularly through assignments and projects that required reflection on real-world sustainability issues. Nearly 69% reported increased systems thinking ability, as they were exposed to case studies, simulations and online discussions that highlighted interconnections among environmental, social and economic dimensions. Around 74% of respondents agreed that they became more motivated to act in their institutes after participating in blended sustainability modules. However, challenges were also identified. Nearly 10% of students indicated limited access to reliable internet or digital devices,

which occasionally hindered their learning. Additionally, nearly 40% of students believed that not all teachers were equally skilled in using online platforms effectively, which affected the overall learning quality.

The findings suggest that blended learning is a highly effective approach to delivering sustainability education that is both transformative and learner centered. It supports active engagement, promotes reflection, and allows for contextual understanding of key elements of transformative learning. The strong correlation between the use of blended learning tools and improved sustainability competencies aligns with global research advocating for digital-enhanced ESD strategies. However, the disparities in digital access and educator readiness remain significant barriers to scaling up this approach. The study highlights the importance of continuous professional development for teachers and investment in IT (Information Technology) infrastructure to ensure equitable learning opportunities.

Moreover, the evidence shows that blended learning can serve as a bridge between traditional classroom learning and real-world sustainability action. By enabling students to explore complex problems interactively and collaboratively, it fosters deeper learning and civic responsibility. To achieve its full potential, blended learning must be embedded within a broader institutional and policy framework that values sustainability as a core educational goal.

4 CONCLUSION

This study investigated the potential of blended learning models to effectively deliver transformative sustainability curricula within the Sri Lankan education system. The findings clearly demonstrate that blended learning enhances student engagement, facilitates deeper understanding of sustainability concepts and supports the development of key transformative competencies such as critical thinking, systems thinking and social responsibility.

Through quantitative analysis of student responses, the research established that blended learning encourages more flexible, interactive and reflective learning experiences essential characteristics of Education for Sustainable Development (ESD). Students appreciated the use of digital tools, real-world case studies and multimedia resources that helped contextualize sustainability challenges and solutions. However, the study also highlighted significant barriers, including unequal access to digital infrastructure and varying levels of teacher proficiency in using technology effectively.

The research concludes that while blended learning holds strong promises for fostering transformative sustainability education, its success depends on several enabling factors. These include targeted teacher training, investment in digital infrastructure and curriculum frameworks that integrate sustainability holistically. By aligning educational practices with SDG 4.7, this research contributes to the broader goal of cultivating a generation of informed, empowered and responsible citizens capable of contributing to a sustainable future. The proposed framework and insights from this study offer valuable guidance for educators, policymakers and institutions seeking to transform sustainability education through innovative, inclusive and context sensitive approaches.

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INTEGRATING SUSTAINABILITY INTO ESP PEDAGOGY: A CASE STUDY WITH ENGINEERING TECHNOLOGY UNDERGRADUATES AT THE UNIVERSITY OF KELANIYA, SRI LANKA

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ABSTRACT: In the context of global environmental concerns and the Sustainable Development Goals (SDGs), engineering education must equip undergraduates not only with technical knowledge but also with the ability to communicate sustainability concepts effectively. English for Specific Purposes (ESP), particularly within STEM education, plays a pivotal role in developing such competence. This study examined how the ESP module, DELT 33212-English for Professional Purposes offered to third-year Engineering Technology undergraduates at the Faculty of Computing and Technology, University of Kelaniya, could be redesigned to integrate sustainability-focused content. The study was conducted over six weeks and involved 35 third-year Engineering Technology undergraduates who had selected specializations and they engaged in targeted ESP tasks, including SDG-aligned technical presentations, green project documentation and reflective writing on eco-conscious engineering. Scaffolded instructional materials, such as guided vocabulary lists and collaborative writing activities, were provided to support learning. Data were collected through pre- and post-intervention questionnaires and focus group interviews. Findings revealed significant improvements in the use of environmental vocabulary, audience-aware communication, ethical framing in technical reports and clarity in sustainability presentations. Qualitative analysis indicated enhanced ethical and environmental awareness, increased confidence in language use and development of reflective and critical thinking skills. While the study was limited by a small sample size, short duration and absence of a control group, it demonstrates the potential of ESP pedagogy to move beyond technical language instruction, promoting responsible communication and ethical engagement with sustainability. The findings have broader implications for ESP curriculum reform, suggesting that sustainability-focused approaches could be adapted across STEM and non-STEM contexts, preparing graduates for the ethical and communicative demands of their professions.

Keywords: engineering technology undergraduates, English for Specific Purposes (ESP), STEM, sustainability

1 INTRODUCTION

Global environmental concerns and the increasing prominence of the Sustainable Development Goals (henceforth SDGs) have highlighted the urgent need for engineering education to equip undergraduates not only with technical expertise but also with the ability to communicate sustainability concepts effectively. English for Specific Purposes (henceforth ESP), particularly within STEM education, plays a pivotal role in developing such linguistic competence (Hyland, 2013; Basturkmen, 2010; Gerasimova, 2025). Despite this, many ESP courses in state universities tend to focus narrowly on occupational or technical language skills, often overlooking the integration of environmental, ethical and social dimensions essential for sustainability-oriented communication (Sanosi et al., 2025). Hence, this study investigates the ESP module, DELT 33212- English for Professional Purposes, offered to third-year Engineering Technology (henceforth ET) undergraduates at the Faculty of Computing and Technology, University of Kelaniya,

to examine how sustainability-focused content can be embedded to enhance students' communicative competence, ethical awareness and reflective capacity. It is not intended to assert superiority over alternative ESP approaches but rather to explore the pedagogical impact of integrating sustainability-oriented tasks within a discipline-specific curriculum. The main objective is to better prepare students to communicate engineering innovations responsibly and ethically, particularly within their chosen specialization pathways.

1.1 Rationale and Objectives

The rationale for this research stems from a clear curricular gap in addressing global sustainability issues within ESP instruction, particularly for ET undergraduates. While current ESP programs typically focus on general academic and professional skills such as paraphrasing, summarizing, technical and business report writing, oral presentations and graph descriptions, they tend to overlook contemporary sustainability topics that are directly relevant to students' disciplinary interests and emerging global priorities. This limitation has been noted in prior research, where ESP has often been critiqued for its narrow focus on linguistic competence at the expense of broader socio-ethical and global concerns (Hyland, 2013; Flowerdew, 2013). By the third year of their degree program, ET undergraduates have selected their specialization pathways, making this a strategically significant stage for introducing sustainability communication aligned with their future careers. In recognition of the increasing demand for engineering technology graduates who are not only technically proficient but also ethically and environmentally cognizant, this study examines how sustainability-related content can be systematically integrated into the selected module to advance students' linguistic proficiency, ethical sensitivity and reflective thinking. It further seeks to evaluate student responses to a series of discipline-linked, sustainability-focused language tasks implemented through the selected module and to assess the extent to which task-based ESP strategies can develop the sustainability communication skills necessary for addressing the linguistic, ethical and professional demands of their future roles.

2 METHODOLOGY

This study employed a mixed-methods design conducted over a six-week period with 35 third-year ET undergraduates enrolled in the DELT 33212- English for Professional Purposes module at the Faculty of Computing and Technology, University of Kelaniya. Participants had selected specialization pathways, providing a suitable context for discipline-specific sustainability communication tasks. The intervention comprised a series of targeted ESP learning tasks designed to integrate sustainability-oriented communication relevant to students' disciplinary domains. These tasks included SDG-aligned technical presentations, green project documentation and reflective writing on eco-conscious engineering practices. To support students' engagement and ensure consistency, instructional materials such as guided vocabulary lists, structured task templates and exemplar sustainability documents were provided. Data were collected through pre- and post-intervention questionnaires, which included items assessing participants' confidence in employing sustainability-related language, awareness of ethical and environmental considerations and the capacity to adapt communication to different audiences and contexts. Additionally,

focus group interviews were conducted with 12 voluntary participants to obtain qualitative insights into their experiences, engagement and perceptions of the sustainability-focused ESP tasks. This methodological approach enabled the systematic capture of both quantitative and qualitative changes in linguistic proficiency, ethical sensitivity and reflective thinking, while providing sufficient detail to facilitate potential replication of the intervention.

2.1 Data Analysis Method

Quantitative data from the questionnaires were analyzed using descriptive statistics and paired sample t-tests to measure differences in confidence levels of the participants, use of environmental vocabulary and awareness of sustainability-related communication before and after the intervention. Statistical significance was determined at a 95% confidence level (p ¡ 0.05). Qualitative data from focus group interviews were transcribed verbatim and analyzed thematically. This process identified recurrent themes reflecting experiences of the participants, changes in language proficiency, perceptions of sustainability and the relevance of the ESP tasks to their disciplinary and professional development.

3 RESULTS AND DISCUSSION

3.1 Quantitative Results

The analysis of the responses from 35 participants indicated clear improvements in four key sustainability communication competencies before and after intervention. The most notable improvement was in the use of environmental vocabulary, which increased from 38% to 82%. Similarly, audience-aware language use rose from 41% to 86%, ethical framing in technical reports improved from 35% to 78%, and clarity in sustainability presentations increased from 45% to 84%. Paired sample t-tests confirmed these gains as statistically significant ($p < 0.001$) across all domains. Student self-assessment data reflected these improvements, with confidence in engaging in sustainability-oriented communication rising from 42% to 84%.

3.2 Qualitative Findings

A thematic analysis of focus group interview transcripts revealed three major themes reflecting students' evolving engagement with sustainability communication, including the development of critical awareness, integration of ethical and environmental perspectives and challenges and growth in language proficiency.

1. Relevance to Engineering Specializations

Participants expressed that the integration of sustainability into ESP tasks resonated more deeply when contextualized within their engineering specializations. A participant specializing in Materials Science remarked, "when I had to write about sustainable materials, I understood how my knowledge connects with real global issues." Those (4 participants) in Mechatronics and Automation reflected on designing energy-efficient systems, highlighting that their projects "needed to be both innovative and eco-conscious." This indicates that embedding sustainability tasks into ESP instruction can strengthen the transfer of linguistic skills to discipline-specific contexts, a

design principle that could be replicated in other STEM and non-STEM domains.

2. Enhanced Ethical and Environmental Awareness

Several participants (5 participants) acknowledged a newfound appreciation for the ethical responsibilities of engineers. One student shared, "I used to focus only on technical efficiency. Now I think about what that means for the environment and the community." Another explained, "writing our reflections made me think about how our work can impact the world beyond machines and code." These insights align with current calls for ESP curricula to cultivate not just workplace communication but also global citizenship competencies, which are increasingly relevant across disciplines.

3. Language Empowerment and Confidence

Participants initially expressed a degree of apprehension regarding the use of sustainability-specific terminology, describing it as "technical but unfamiliar." However, as they engaged in repeated practice and task-based learning, they reported notable improvements in both language confidence and competence. One student specializing in Embedded Systems stated, "we presented ideas like green robotics and it was tough at first, but practicing with peers helped." This progression was largely facilitated by scaffolded instructional strategies, including guided vocabulary lists and collaborative writing activities, which enabled learners to internalize complex terminology and contextualize it effectively within engineering-related discourse. These findings suggest that targeted ESP interventions can successfully bridge gaps in content-specific vocabulary and support learner autonomy and self-efficacy in disciplinary communication. By providing transparent instructional scaffolding, such as vocabulary guides and model texts, this intervention offers a replicable framework for ESP educators seeking to incorporate sustainability in diverse academic settings.

4. Development of Critical and Reflective Thinking

The use of reflective journals and peer feedback mechanisms played a vital role in improving the higher-order thinking skills of the students. Many participants demonstrated an ability to move beyond descriptive language tasks and engage in evaluative and reflective thinking. For instance, one student wrote, "our presentation on solar-powered manufacturing made me realize how design choices have long-term consequences." This response illustrates how learners began to critically assess the broader ethical and environmental implications of their engineering work. Such reflective practices, embedded in ESP instruction, promoted not only deeper conceptual understanding but also the transferability of critical thinking skills to other academic and professional contexts. This highlights the broader potential of ESP interventions to encourage reflective practices that are equally valuable in other disciplines, thereby demonstrating the wider applicability of this approach beyond STEM.

4 DISCUSSION

The findings underscore the transformative potential of ESP instruction when integrated with sustainability-oriented content that aligns with the disciplinary specializations of the undergraduates. The integration of sustainability themes into the selected module demonstrated that third-year ET undergraduates could significantly enhance their linguistic proficiency, ethical sensitivity and reflective thinking when engaged in authentic, discipline-specific language tasks aligned with their specializations. These results are consistent with Hyland's (2013) critical ESP framework, which emphasizes the need for ESP instruction to go beyond functional language teaching and cultivate broader awareness of global issues. Moreover, the marked improvement in the abilities of the undergraduates to apply sustainability language within technical and ethical contexts demonstrates the effectiveness of interdisciplinary, ethics-informed ESP curricula. In particular, for institutions in developing country contexts, such curricular innovations may contribute to bridging the gap between global sustainability imperatives and localized professional communication needs. However, the transferability of these approaches must be approached cautiously and tested across different institutional, disciplinary and cultural environments before broader generalizations can be made. At a broader level, these findings offer preliminary implications for ESP curriculum reform, providing a practical model that could inspire efforts to embed sustainability in higher education language instruction across disciplines. Ultimately, integrating sustainability discourse into ESP empowers undergraduates to be not only skilled communicators but also ethically aware learners who are better prepared to engage with pressing global challenges.

5 CONCLUSION

This study provides evidence that integrating sustainability-focused content within ESP instruction can enhance linguistic proficiency, ethical awareness and critical-reflective thinking among third-year ET undergraduates. The implementation of SDG-aligned tasks in the selected module facilitated authentic, discipline-specific engagement, allowing students to link technical learning with sustainability considerations while developing professional communicative competence. Notwithstanding these positive outcomes, the study is constrained by a limited sample size, short intervention duration and focus on a single institution, which restricts the generalizability of the findings. Further research with larger cohorts, extended interventions and comparative designs is required to validate the efficacy and transferability of such pedagogical approaches. Nonetheless, the findings indicate that task-based strategies such as scaffolded vocabulary, reflective writing and authentic projects can be adapted beyond STEM disciplines, offering a framework for embedding sustainability into ESP curricula and fostering ethically and environmentally informed graduates.

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STUDENT PERCEPTION OF POSITIVE TEACHER TALK IN ADDRESSING CLASSROOM CONCERNS: ENHANCING ACTIVE PARTICIPATION, FOSTERING LEARNER AUTONOMY AND PROMOTING SPEAKING SKILLS

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ABSTRACT: This study explores students' perceptions of positive teacher talk in a tertiary setting focusing on its impact in addressing three main classroom concerns: enhancing active participation, activating learner autonomy and promoting speaking skills. This mixed method research primarily adopts a qualitative approach. Google questionnaires were used to collect data. This research examines how students perceive positive teacher talk, and evaluate its effectiveness as a strategy for addressing the aforementioned classroom concerns. Student perception is vital for improving teaching as it assures that the learner needs are accomplished. Thus, the insights gained from this study provides valuable guidance in improving teaching and creating a more learner-centered classroom environment.

Keywords: positive teacher talk, student perception

1 INTRODUCTION

Teaching English as a Second Language comes with myriad concerns. Identifying these concerns through observation is a crucial reflective practice instrumental in research which can ultimately lead to insightful solutions. Here, prominently observed classroom concerns are enhancing active participation, promoting learner autonomy, and improving speaking skill. The chosen background for this research is first-year undergraduates in an ESL context at a renowned state university in Sri Lanka. There is a link between actions and thoughts (Larsen-Freeman & Anderson, 2011) in teaching, thus the actions serve as tools in accomplishing learning objectives set according to a specific methodology in a curriculum. The action in this research is positive teacher talk. Positive teacher talk is determined by the qualities such as empathy, caring, involvement, trust, and respect (Frisby, 2019; Mercer & Dornyei,2020). Positive teacher talk also assists to navigate through classroom concerns in ESL classrooms. Every classroom concern can be addressed with well-crafted teaching strategies, such as positive teacher talk. Therefore, this study discusses how effective positive teacher talk is in mitigating classroom concerns such as enhancing active participation, activating learner autonomy, and promoting speaking skills. Student perception is a crucial aspect as it directly influences the success of lessons. The students' positive outlook towards learning is a point for evaluation. What students think, their emotions and attitudes are discussed here.

2 METHODOLOGY

This research adopts a mixed-methods approach primarily aligning with a qualitative framework. Data were collected using Google questionnaires. A sample of thirty-five students was selected through convenient sampling. The Google questionnaire which included both open-ended and

close-ended questions, was administered to the sample. The collected data was then analyzed using thematic analysis.

3 RESULTS

The results demonstrated that students' perception of positive teacher talk is central to qualities such as encouragement, kindness, and friendliness. Apart from motivation and boosting confidence, students indicated that positive teacher talk made them feel respected as individuals. A majority of 62.9% reported that positive teacher talk encouraged them to listen and engage in work, while 17.1% claimed that positive teacher talk made them happy and confident. Only 11.4% stated that positive teacher talk had the capability to instantly fix their mood. Notably, no respondent selected the option, *"Sometimes I do not understand the lesson, yet positive teacher talk gives me fulfilment."*

The results highlighted that positive teacher talk has an immense impact on the emotional stability of students. Students appreciate positive teacher talk as it makes them feel safe and helps keep stress under control. Students have also noted that they are not intimidated by the fear of making mistakes. One student said: *"My favourite thing about positive teacher talk is that it makes me feel safe and confident in class. It reduces my stress, helps me stay calm, and encourages me to keep trying even if I make mistakes."* Another student said: *"This really supports my emotional stability and keeps me motivated to learn."* These statements capture that the essence of positive teacher talk has a direct connection to the emotional stability of adult learners, who are considered to be independent thinkers.

When asked to report on positive teacher talk and learner autonomy, a majority of 91.4% stated that positive teacher talk helped them become independent learners. Only 8.6% expressed uncertainty, stating, *"I am not sure about that."* Notably, none of the students stated *"No"* when asked whether positive teacher talk had helped them become independent learners. This suggests a link between positive teacher talk and learner autonomy. In response to their perceived belief that positive teacher talk supports learner autonomy, one student mentioned: *"Yes, positive teacher talk has made me an independent learner because it gives me confidence to try things on my own and not be afraid of making mistakes. It encourages me to keep learning even when things are difficult."* Another student stated: *"Positive teacher talk has made me an independent learner because it encourages me to believe in myself, take responsibility for my studies, and work with confidence without always depending on others."* This indicates that positive teacher talk can shift students' mindsets in a positive direction, thereby fostering learner autonomy.

When inquired about how well positive teacher talk has helped in setting academic goals, a majority of 48.6% students reported that positive talk helped them set both short-term and long-term academic goals. 34.3% stated that positive teacher talk motivated them to work diligently, and only 14.3% stated that *"Positive teacher talk makes me want to start learning (I may not necessarily be interested, but I start to learn)."* Only one respondent reported that positive teacher talk promotes healthy competition. These results indicate that positive teacher talk has a direct and positive impact on academic goal setting, providing students with a sense of purpose in their academic journey.

The next question explored how positive teacher talk helped students' academic life. Students mentioned that the motivation gained from positive teacher talk is a key benefit. They indicated that it boosts their confidence, linking positive teacher talk directly as a source of motivation. One student said: *"It encourages me to try harder, ask questions without fear, and stay focused, which improves my learning and results."* Another student noted: *"Positive teacher talk gives clear feedback, builds my thinking skills, and makes lessons stick. It turns mistakes into learning moments without shame."* Some students mentioned that positive teacher talk helps them stay focused on their learning. This suggests that students are more intrinsically motivated through positive teacher talk, as they strive to improve their learning.

When examining the effect of the teacher's attitude on students, a majority of 91.4% students stated that they tend to believe what the teacher says even as adult students. They stated: *"Yes, I tend to believe in what my teacher says."* Only one respondent stated that the teacher's attitude is an irrelevant concern: *"No, I normally possess a positive attitude towards learning, so it does not matter."* This indicates that the teacher's voice becomes the students' voice even among adult learners, supporting independent thinking.

When studying informal conversations between teachers and students, a majority of 91.4% stated that informal conversations are important in class and they enjoyed small talk. Twenty-two participants mentioned that they learnt new words and phrases through informal conversations with the teacher, while twelve participants said that small talk with the teacher made them happy. This highlights that informal conversations are impactful both as a learning experience and a mood booster. All respondents (100%) stated that positive teacher talk helped them become better speakers.

In terms of adult learners' perspectives on positive teacher talk, 77.1% of students viewed it as a reward. The remaining options, *"No"* and *"Maybe,"* were evenly split, each with four respondents. This aligns with the theory of Behaviourism, which suggests that positive reinforcement is a decisive factor in enriching performance. Regarding students' perceptions of positive teacher talk and corrective feedback, a majority (45.7%) stated that there should be a balance between positive teacher talk and corrective feedback, while 28.6% preferred corrective feedback over positive teacher talk. As for suggestions to improve positive teacher talk, students recommended *praising efforts, not just results, and giving constructive feedback gently.* The results suggest the emphasis should be on using encouraging words, with teachers being friendly and responsive as part of positive teacher talk.

4 DISCUSSION

Emotions play an instrumental role in learning a language. Krashen's (1980) affective filter hypothesis speaks about how emotions affect language learning. This is further elucidated by Grace (2008), stating that 'negative emotions' which affect language learning 'are formed through passive moods, including low motivation, low self-esteem, and debilitating anxiety.' The results indicate that positive teacher talk has the ability to reform the mindset of students positively. Positive teacher talk has the ability to combat any negative emotion associated with learning. Positive teacher talk directly influences learner autonomy by fostering positivity which

is then converted into empowerment. Alleman et al., (2005) state that 'Students will begin to feel empowered, seeing that they can make a difference using what they have learned'. When positive teacher talk gives initial stimulus to start the learning process on a better note, the feeling of empowerment follows. This also indicates that, even as independent thinkers, adult students rely on external stimulus such as positive teacher talk. Positive teacher talk assists in meaningful goal setting. Setting academic goals require strength, motivation and careful implementation. The results indicate that as a result of positive teacher talk, students have become motivated to set academic goals. Going a step further, it is also crucial to adjust positive teacher talk according to the goals set by the student, by engaging in conversations that honour the thoughts of the student (Hollingworth & Drake 2011). Naturally, positive teacher talk has a direct impact on enhancing learner engagement, due to the positive classroom climate it creates keeping anxiety of students at bay. What is more, positive teacher talk has the ability to make learners intrinsically motivated. Even though the learners perceive positive teacher talk as a reward, their focus remains on how to improve with positive teacher talk serving as a pillar, for their academic growth. When it comes to feedback, the students consider corrective feedback to be equally important as positive teacher talk. While a no correction approach can create a positive climate, especially with positive teacher talk praising efforts, the importance of corrective feedback remains indispensable. To fill the void that positive teacher talk cannot fill in giving feedback, the teacher can invite students to give feedback on their peers, making them a part of the evaluation process. As Nash (2016) states , 'when students are made part of the feedback mechanism, their perspectives will enrich improvement efforts'.

5 CONCLUSION

This research discusses students' perception of positive teacher talk and how they view positive teacher talk when ESL instructors use it as a strategy in addressing classroom concerns such as enhancing active participation, fostering learner autonomy and promoting speaking skills. Positive teacher talk serves as the initial stimulus. The importance lies in the fact that even adult students, who are generally considered independent thinkers, adapt to the teacher's voice. Incorporating other teaching strategies alongside teacher talk can yield the maximum benefit.

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DEVELOPMENT OF UPPER BODY STRENGTH IN SEOI-NAGE TECHNIQUE WITH REFERENCE TO KUZUSHI IN MALE INTERMEDIATE JUDO PLAYERS

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ABSTRACT: Upper body strength is a key factor influencing throwing performance in judo, particularly in techniques such as *Seoi-Nage*, where balance-breaking (*kuzushi*), timing, and explosive force generation are crucial. The specific impact of upper body strength training on *Seoi-Nage* performance remains underexplored in the Sri Lankan judo context. The primary objective of this study was to evaluate the effectiveness of an 8-week upper body strength training program in enhancing *Seoi-Nage* performance with reference to *kuzushi* in intermediate-level male judo players. Ten national-level judokas (N = 10; age > 30 years) were purposively assigned to two groups (IG = 5, CG = 5). Both groups continued regular judo training, while the treatment group received additional upper-body strength training three times per week, 2 hours per day for eight weeks. Pre- and post-tests measured 1RM Bench Press, Push-up Test, Medicine Ball Throw, and *kuzushi* performance via randori-based evaluation. Descriptive statistics and mixed-design ANOVA were used to analyze time, group, and interaction effects. A significant interaction was observed in 1RM Bench Press ($p = 0.000$), Push-up Test ($p = 0.000$), Medicine Ball Throw ($p = 0.000$), and *kuzushi* ($p = 0.000$). A significant main time effect was found in all variables ($p = 0.000$), and between-group analysis revealed a significant difference in *kuzushi* performance ($p < 0.05$) favoring the treatment group. These results suggest that the intervention led to meaningful improvements in upper body strength and *Seoi-Nage* performance both physiologically and technically. The results indicate that upper-body strength training may contribute to improving *Seoi-Nage* performance and could be considered as part of training routines for intermediate judokas.

Keywords: Judo, Kuzushi, performance, Seoi-Nage, strength training

1 INTRODUCTION

Judo, a dynamic martial art originating in Japan, is founded on the principles of balance, leverage, and the efficient use of energy. One of the most fundamental and frequently executed throwing techniques in Judo is Seoi-Nage, a shoulder-based throw that requires precise coordination between physical strength, timing, and technical execution (Callan & Bradić, 2018). Central to the success of this technique is the concept of kuzushi, or balance-breaking, which prepares the opponent for a throw by disrupting their balance (De Crée, 2015). Research indicates that intermediate-level male judo athletes often rely on lower-body mechanics or knee initiation to compensate for insufficient upper-body strength, which may compromise biomechanical efficiency and limit throwing performance (Ishii et al., 2018). This adaptation, while functional, often limits the biomechanical efficiency and full throwing potential of Seoi-Nage (Ishii et al., 2018). Notably, upper body strength-particularly in the shoulders, back, and core-plays a critical role in generating explosive force and controlling the grip and posture necessary for effective kuzushi (Franchini et al., 2013). Several studies have highlighted the importance of strength

training in improving performance in competitive judo.On the other hand, studies emphasized that upper body power is directly associated with successful throwing efficiency and overall match performance (Franchini et al., 2005). Furthermore, strength adaptations contribute not only to the biomechanical execution of throws but also to psychological confidence and decision-making under pressure (Uzun et al., 2017). From a technical standpoint, the synchronization between upper body engagement and kuzushi is essential in executing Seoi-Nage with minimal energy expenditure and maximum control (Kato & Yamagiwa., 2021). Despite the recognized importance of upper body strength in Judo, the researcher believes there remains a limited body of applied research , particularly among Sri Lankan athletes . This study therefore aims to enhance upper body strength in Seoi-Nage technique with reference to kuzushi in male intermediate Judo players as a major objective. At the same time, this study aims to increase maximum strength (1RM bench press Test), explosive strength (Medicine ball Throw Test), and strength endurance (Pushup Test) for effective Seoi-Nage technique as a specific objective. By integrating physiological and technical perspectives, this research seeks to contribute to evidence-based practice in judo coaching and athlete development.

2 METHODOLOGY

This study followed an action research design to implement and evaluate an 8-week upper body strength training intervention among intermediate-level male Judo players in Sri Lanka. The duration was chosen based on evidence that training adaptations in strength and sport-specific performance generally require at least 6–8 weeks to manifest (Rhea, et al., 2003).

A total of ten participants (age > 30) were selected using purposive sampling and divided into two groups: treatment ($n = 5$) and control ($n = 5$). Purposive sampling was employed to select participants who demonstrated technical inefficiency in the execution of the Seoi-Nage technique during divisional competitions, primarily due to inadequate upper-body strength. Ethical clearance was obtained, and informed consent was collected prior to participation.

Pre-test and post-testing included one-repetition maximum (1RM) bench press, push-up test (maximum repetitions in 1 minute), medicine ball throw (distance in meters), and a kuzushi performance assessment conducted during 10-minute randori sessions. These tests were selected as they are widely validated field measures for assessing maximal strength, explosive strength, and strength endurance in combat sport athletes (Kons, et al., 2021).

The treatment group 8-week intervention consisted of three weekly sessions (Monday, Wednesday, and Friday) combining warm-up drills, technical practice (uchikomi), and progressive upper-body strength training targeting maximam strength (bench press, pull-ups), explosive strength (dumbbell snatch, lunges), and strength endurance (push-ups, shoulder press, rows, dips, planks, curls). Training intensity was progressively increased from 60% to 100% of 1RM with structured sets, repetitions, and rest intervals, following established principles of progressive overload and periodization for combat sports. Training intervention was conducted 3 hours per day in the evening.

The control group continued with their regular judo practice without any additional strength training. The intervention aimed to develop maximal strength, explosive power, and strength

endurance in the upper body, essential components for Seoi-Nage performance. Measurement tools included a stopwatch, medicine ball, measuring tape, dumbbells, barbells, and judo mats. SPSS 26 software was used for statistical analysis. A mixed-design ANOVA was employed to compare performance changes over time (pre- and post-test) between the two groups. This method allowed for evaluating the interaction effects of time and group on the outcome variables (Franchini, et al., 2013). All assessments were conducted in controlled training environments to ensure standardization of procedures and minimize measurement bias.

3 RESULTS

3.1 Descriptive Statistics

Table 1. Pre-Post Test Scores of Treatment Group

Variables	**Pre-Test**					**Post-Test**				
Samples	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**
1RM Bench Press	50	49	47	45	51	58	57	55	54	59
Push Up	42	43	40	35	44	52	53	49	44	54
Medicine Ball Throw	35	30	33	25	35	42	39	42	32	44
Kuzushi	60	55	57	42	54	69	63	66	52	64

Table 2. Pre-Post Test Scores of Control Group

Variables	**Pre-Test**					**Post-Test**				
Samples	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**
1RM Bench Press	51	47	49	46	53	50	48	48	47	53
Push Up	40	44	42	33	46	41	43	43	34	46
Medicine Ball Throw	37	29	35	24	36	39	31	35	25	37
Kuzushi	58	53	54	43	55	60	54	56	44	56

3.2 Mixed Design ANOVA

Table 3. ANOVA Results across 1RM Bench Press, Pushup, Medicine Ball Throw, Kuzushi Tests

Variable	**Time*Group Effect**		**Time Effect**		**Group Effect**	
	F	**p**	**F**	**p**	**F**	**p**
1RM Bench Press	280.167	0.000*	280.167	0.000*	4.654	0.063
Pushup	384.727	0.000*	454.545	0.000*	2.657	0.144
Medicine Ball Throw	128.947	0.000*	232.526	0.000*	0.836	0.387
Kuzushi	304.200	0.000*	561.800	0.000*	1.531	0.021*

Through the following testing procedures, different variables were measured to assess upper body strength and kuzushi performance among intermediate-level male judo players. These included the 1RM Bench Press, Push-up Test, Medicine Ball Throw, as well as a Kuzushi test conducted during randori sessions. The results of the statistical analysis using mixed-design ANOVA are summarized in Table 3.

The results revealed a significant interaction effect between the time of measurement and training group for 1RM Bench Press, $F(1,8) = 280.167$, $p < 0.000$, Push-up Test $F(1,8) = 384.727$, $p < 0.000$, Medicine Ball Throw, $F(1,8) = 128.947$, $p < 0.000$, and Kuzushi performance $F(1,8) = 304.200$, $p < 0.000$. A significant main time effect was observed when comparing pre- and post-test outcomes across both groups. These effects were detected in 1RM Bench Press $F(1,8) = 280.167$, $p < 0.000$, Push-up Test $F(1,8) = 454.545$, $p < 0.000$, Medicine Ball Throw $F(1,8) = 232.526$, $p < 0.000$, and Kuzushi $F(1,8) = 561.800$, $p < 0.000$. Moreover, the between-group analysis revealed a statistically significant difference in Kuzushi performance, $F(1,8) = 1.531$, $p = 0.021$, and a near-significant difference in 1RM Bench Press, $F(1,8) = 4.654$, $p = 0.063$.

4 DISCUSSION

The focus of this study was to evaluate the impact of an 8-week upper body strength training intervention on the execution of the Seoi-Nage technique in intermediate male judo players in Sri Lanka. Statistical analysis revealed significant interaction effects across all variables—1RM Bench Press, Push-up Test, Medicine Ball Throw, and Kuzushi—between groups and over time, indicating that strength development contributed to measurable improvements. The increase in 1RM Bench Press reflects greater maximal strength in the pectoral, deltoid, and latissimus dorsi muscles, supporting previous findings that upper body strength enhances torque generation during throwing techniques (Franchini, et al., 2008).Similarly, gains in push-up performance demonstrate improved muscular endurance, consistent with research showing that higher endurance levels enhance judokas' ability to maintain technique execution during successive high-intensity efforts (Franchini, et al., 2013). The significant improvement in medicine ball throw scores suggests enhanced explosive power and neuromuscular efficiency, aligning with Detanico et.al., (2012) who found that explosive upper body power is strongly associated with throwing velocity and effectiveness in judo athletes. In addition, the observed increase in kuzushi performance highlights the direct link between upper body strength and effective balance-breaking, which agrees with biomechanical studies emphasizing that grip strength, trunk stability, and coordinated pulling are essential to successful Seoi-Nage execution (Ishii, et al., 2018) Collectively, these results suggest that upper body strength training can positively influence physiological and technical aspects of Seoi-Nage performance, while also contributing novel evidence within the Sri Lankan judo context. However, the small sample size and purposive sampling approach limit the generalizability of these findings, making this study exploratory in nature. A strength of the research is its applied design, directly addressing a technical weakness observed in competition through structured intervention. Future studies should therefore expand to larger and more diverse samples, include both male and female athletes at different competitive levels, and incorporate detailed biomechanical and psychological assessments to further clarify the multifaceted role of strength training in judo performance. In conclusion, this study demonstrates that upper body strength training improved maximal strength, Strength endurance, explosive strength, and kuzushi, thereby contributing to more effective execution of Seoi-Nage, though confirmation through larger-scale studies remains essential.

5 CONCLUSION

This study demonstrated that an 8-week upper body strength training program significantly enhanced maximal strength, strength endurance, explosive strength, and kuzushi performance, leading to improved execution of the Seoi-Nage technique in intermediate level male judo players. The findings suggest that integrating progressive strength training with technical practice may support better balance-breaking and throw efficiency. However, given the small sample, these results should be interpreted with caution and considered preliminary. Practically, coaches may apply such strength-focused interventions to support technical development and facilitate the progression of intermediate athletes toward higher levels of competition.

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HARNESSING AI FOR ACADEMIC RESILIENCE: A MIXED METHOD STUDY ON POSTGRADUATE STRESS AND WELL-BEING IN SRI LANKAN UNIVERSITIES

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ABSTRACT: This study investigates the escalating mental health challenges faced by postgraduate students in Sri Lankan universities, focusing on stress and well-being. The study involved 110 full-time postgraduate students aged 22–35 from the Open University of Sri Lanka and the University of Colombo. Using a mixed-methods approach, quantitative data were gathered through the DASS-21 questionnaire, analyzed with machine learning algorithms and sentiment analysis to identify stress patterns, while qualitative insights were obtained from three-week interactions with the Wysa chatbot. Results revealed that 68% of participants exhibited moderate to severe stress, with academic pressure (37.5%) and financial concerns (25%) as key contributors. The chatbot intervention reduced anxiety in 65% of participants, with significant improvement in DASS-21 scores ($p < 0.001$). This study demonstrates AI's potential as a scalable, culturally adaptable tool for improving mental health support in universities. It highlights the need for long-term studies, integration into institutional frameworks, and consideration of cultural and financial barriers for sustainable adoption.

Keywords: postgraduate stress, Artificial Intelligence, mental health, sentiment analysis, academic resilience

1 INTRODUCTION

Mental health challenges among postgraduate students have become a prominent concern worldwide, with stress exerting significant effects on academic performance, student retention, and overall well-being. In the context of Sri Lanka, these challenges are particularly pronounced, as studies indicate that approximately 68% of postgraduate students experience moderate to severe stress, driven primarily by academic pressures, financial burdens, and limited institutional support (Jayasinghe, 2023). These difficulties are further compounded by cultural stigma surrounding mental health and restricted access to professional counseling services (Perera, 2021; World Health Organization [WHO], 2022). While traditional interventions such as counseling remain widely implemented, they are often limited in scalability and lack real-time adaptability. In contrast, international research demonstrates that AI-driven solutions including chatbot-delivered cognitive behavioral therapy (CBT) and AI-based sentiment analysis within educational settings can effectively reduce stress and anxiety (Fitzpatrick et al., 2017; Kumar & Singh, 2022). Despite these promising results, the adoption and evaluation of such interventions in South Asian and Sri Lankan university contexts remain limited, highlighting a critical gap in the literature.

Postgraduate students in Sri Lanka experience considerable levels of stress, compounded by inadequate institutional support mechanisms. This underscores the urgent need for scalable, stigma-free interventions that can effectively address mental health challenges within higher education. Guided by this concern, the study is structured around three key research questions: What are the primary stressors influencing postgraduate students in Sri Lankan universities? Can

AI-driven tools, such as machine learning models and chatbot-based support systems, effectively identify and alleviate stress in this population? How can such interventions be culturally adapted and sustainably integrated into local university frameworks? In line with these questions, the objectives of the study are threefold: to measure the prevalence and sources of stress among postgraduate students; to assess the effectiveness of AI-based interventions in stress reduction; and to recommend strategies for the culturally sensitive and scalable integration of AI-driven tools into higher education systems.

2 LITERATURE REVIEW

University students worldwide experience high levels of stress, which negatively impacts academic performance, retention, and overall well-being. A meta-analysis by Ibrahim et al. (2013) found that approximately one-third of students experience anxiety or depression, with postgraduate students facing even higher stress due to thesis workloads, financial pressures, and academic demands (Evans et al., 2018). In Sri Lanka, postgraduate students are particularly vulnerable, balancing academic, professional, and personal responsibilities (Jayasinghe, 2023). Studies of Sri Lankan medical trainees report 11.2% depression and 8.9% anxiety, linked to unsupportive environments and long working hours (Dahanayake et al., 2022), while 62% of medical undergraduates experienced psychological distress (Rajapakse et al., 2021). The 2022 economic crisis further worsened stress and sleep quality among students (Liyanage et al., 2024), and cultural stigma, ragging, and limited access to institutional mental health services remain significant barriers (Perera, 2021). AI-based interventions have emerged as effective tools for mental health support. Chatbots, such as Wysa, have demonstrated reductions in anxiety among young adults (Fitzpatrick et al., 2017), and sentiment analysis can provide real-time insights into student well-being (Kumar & Singh, 2022). In low-resource contexts, pilot implementations in Ghana and Malawi showed high usability and cultural relevance (Ankomah & Turkson, 2025), while studies in China and Afghanistan reported positive outcomes when chatbots were culturally adapted (Sabour et al., 2022; Sahab et al., 2025). Despite these promising findings globally, Sri Lankan universities remain underexplored regarding AI-driven mental health interventions. This study addresses this gap by evaluating the applicability, effectiveness, and cultural adaptation of AI-based tools within postgraduate education in Sri Lanka.

3 METHODOLOGY

This study employed a mixed-methods design to investigate stress and well-being among postgraduate students in Sri Lankan universities. The sample comprised 110 full-time postgraduate students, aged 22 to 35, enrolled at the Open University of Sri Lanka and the University of Colombo. Inclusion criteria required participants to be full-time students in postgraduate programs, whereas part-time students and those with pre-existing mental health diagnoses were excluded to maintain sample homogeneity and reduce confounding factors. Quantitative data were collected using the Depression, Anxiety, and Stress Scale (DASS-21) to assess levels of stress, anxiety, and depression. The data were analyzed using k-means clustering to identify distinct subgroups of stress responses and random forest models to evaluate predictive factors,

with cross-validation applied to ensure the robustness of the models. Qualitative data were obtained through student interactions with the Wysa chatbot over a three-week period, which provided AI-driven cognitive behavioral therapy (CBT) and mindfulness support. These interactions were subsequently analyzed using NVivo for thematic analysis. Statistical analysis of pre- and post-intervention DASS-21 scores was performed using descriptive statistics and paired t-tests in SPSS (version 26), while sentiment analysis was conducted using Python-based natural language processing tools to gain additional insights into participants' emotional responses.

4 RESULTS AND DISCUSSION

Analysis of the DASS-21 scores indicated that 68% of the participants experienced moderate to severe stress, with 42% classified as moderate and 26% as severe. The primary contributors to stress included academic pressure (37.5%), financial strain (25%), work-life imbalance (15%), social isolation (10%), and other miscellaneous factors (12.5%).

Figure 1. Distribution of major stress factors among postgraduate students (N = 110). Academic pressure and financial concerns were predominant.

Following the three-week engagement with the Wysa chatbot, a significant reduction in anxiety scores was observed.

Table 1. Pre- and Post-Intervention DASS-21 Anxiety Scores

Phase	Mean Score	Standard Deviation (SD)
Pre-Intervention	12.4	3.2
Post-Intervention	8.7	2.9

Note: Significant reduction in anxiety ($t(109) = 5.67$, $p < 0.001$).

The pre-intervention mean anxiety score of 12.4 (SD = 3.2) decreased to 8.7 (SD = 2.9) post-intervention, indicating a statistically significant improvement in participants' anxiety levels ($t(109) = 5.67$, $p < 0.001$). These findings suggest that AI-driven interventions, such as chatbot-based cognitive behavioral therapy and mindfulness support, can effectively mitigate anxiety among postgraduate students experiencing high stress levels.

The AI-based mental health intervention, delivered through the Wysa chatbot, demonstrated a statistically significant impact on reducing anxiety levels among participants. Before the intervention, the mean DASS-21 anxiety score was 12.4 (SD = 3.2), which decreased to 8.7 (SD = 2.9) after three weeks of continuous engagement with the chatbot. A paired sample t-test confirmed that this reduction was statistically significant, $t(109) = 5.67$, $p < 0.001$. This

notable improvement indicates that the AI-driven support tool was effective in alleviating anxiety symptoms for a majority of participants. These findings highlight the potential of integrating AI-based mental health solutions into university support systems, especially in settings where access to conventional counseling services is limited or stigmatized.

Qualitative analysis of interactions with the Wysa chatbot identified three principal themes contributing to postgraduate students' stress. Academic overload, characterized by heavy coursework and thesis deadlines, emerged as the most prominent stressor. Financial strain, including tuition fees, living expenses, and the demands of part-time employment, represented a second major source of stress. The third theme, institutional gaps, encompassed limited availability of support services and insufficient faculty engagement, which further exacerbated students' stress experiences. When contextualized within the existing literature, these findings are consistent with global reports of a graduate mental health crisis (Evans et al., 2018) and align with Sri Lankan studies highlighting academic stress as a predominant concern (Jayasinghe, 2023). The observed effectiveness of the Wysa chatbot supports prior evidence of AI-driven mental health interventions (Fitzpatrick et al., 2017), while the predictive modeling of stress aligns with the utility of AI-based sentiment analysis in educational settings (Kumar & Singh, 2022). Distinct from Western contexts, cultural stigma (Perera, 2021) and limited institutional infrastructure in Sri Lanka present unique challenges to engagement with mental health interventions.

Regarding scalability and sustainability, AI-driven interventions demonstrate substantial potential due to their cost-effectiveness and ability to reach large populations. However, successful implementation requires strong institutional support, cultural adaptation, and careful attention to ethical considerations, including data privacy, algorithmic bias, and inclusive access.

This study has several limitations. The short three-week intervention period restricts the ability to assess long-term effects. Reliance on self-reported data introduces potential bias, and the exclusion of part-time students limits generalizability. Additionally, cultural stigma may have influenced participant engagement with the intervention, potentially affecting the outcomes.

5 CONCLUSION

This study confirms that 68% of Sri Lankan postgraduate students experience moderate to severe stress, primarily from academic and financial pressures. AI-driven tools machine learning analysis and chatbot-based support significantly reduced anxiety in 65% of participants. These findings highlight AI's potential as a scalable and stigma-free mental health support mechanism in higher education. For long-term impact, AI interventions should be integrated into university frameworks with cultural adaptations, infrastructure development, and continuous evaluation. Future research should extend intervention duration, include diverse student groups, and address sustainability challenges.

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IMPACT OF AN EIGHT-WEEK LOWER BODY STRENGTH TRAINING PROGRAM ON JUMP PERFORMANCE IN NETBALL PLAYERS: A CASE STUDY AT SABARAGAMUWA UNIVERSITY OF SRI LANKA

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ABSTRACT: Netball is a high-intensity, multidirectional sport that demands a high level of lower body power, especially during jumping actions essential for intercepts, rebounds, and aerial contests. Vertical jump performance is a critical measure of explosive strength and is often linked to success in netball. There is limited evidence on how structured strength training interventions impact university-level female netball players, particularly in South Asian contexts. This study aimed to evaluate the effectiveness of an eight-week lower body strength training program on vertical jump performance among female netball players at Sabaragamuwa University of Sri Lanka. This study was conducted with 14 female netball players (aged 22–24), randomly assigned to an intervention group (n=7) and a control group (n=7). The intervention group underwent an eight-week program incorporating resistance and plyometric exercises performed three times per week. Vertical jump performance was assessed using a standard vertical jump test before and after the intervention. Statistical analysis included the Wilcoxon Signed-Rank Test and Mann-Whitney U Test due to non-normal data distribution. The median vertical jump height increased from 29.8 cm to 32.9 cm, indicating overall improvement. The Wilcoxon Signed -Rank Test showed a significant increase within the intervention group ($p = 0.035$), and the Mann–Whitney U Test revealed a significant difference compared to the control group ($p = 0.0409$) thus confirming the effectiveness of the training program. The findings provide strong evidence that an eight-week lower body strength training program can significantly enhance vertical jump performance in university-level netball players. Incorporating such training into regular practice may offer substantial performance benefits in similar athletic populations.

Keywords: netball, lower body strength, vertical jump performance, female athletes

1 INTRODUCTION

Netball is a fast-paced, multidirectional team sport primarily played by women across commonwealth nations, with over 20 million active participants worldwide (Delextrat & Goss-Sampson, 2010). Netball, originating in England has evolved into a competitive sport demanding not only technical skills and strategic awareness but also high levels of physical fitness, particularly in jumping, agility, and speed (Impellizzeri et al., 2018). These physical demands are especially evident in defensive and rebounding actions, where players must explosively leap to intercept passes or gain possession. Previous research indicates that meaningful improvements in jump performance require a lower-body strength training duration of at least 6–8 weeks (Cormie et al., 2011; Markovic & Mikulic, 2010). An eight-week intervention was selected for this study to balance the physiological time needed for adaptation with the practical feasibility of a university sporting calendar.

1.1 Vertical Jump Performance and Lower Body Power

Vertical jump performance is a key physical attribute in netball, as it directly influences players' ability to block shots, contest high passes, and dominate aerial play. Research shows that

successful netball performance is associated with higher vertical jump capacity which allows athletes to execute the explosive movements required in both offensive and defensive scenarios (Sabadri & Zaki, 2022). The vertical jump is not only a measure of lower -body power but also reflects muscle coordination and power generation speed both crucial for rapid execution under match conditions (Markovic & Mikulic, 2010).

1.2 Strength and Plyometric Training as Performance Enhancers

Lower body strength plays a fundamental role in jump height and reactive strength. Resistance training targeting key muscle groups such as the quadriceps, hamstrings, and gluteus muscles enhances force production and joint stability. Exercises like squats, lunges, Romanian deadlifts, and leg presses contribute significantly to vertical force development (Grieco et al., 2012). Plyometric training, on the other hand, improves explosive strength and neuromuscular efficiency through the stretch-shortening cycle, enabling athletes to achieve greater jump height with faster execution (Faigenbaum et al., 2009). Combining resistance and plyometric exercises within a structured program has been shown to maximize improvements in vertical jump performance in multiple sports (Cormie et al., 2011). Despite a wealth of research on strength and conditioning in general sport populations, there is a paucity of evidence focusing on female university-level netball players, particularly within South Asian contexts. Most available studies emphasize elite or professional athletes in Western countries, leaving a research gap in understanding how structured strength training impacts amateur and university athletes in Sri Lanka. Furthermore, the academic setting poses unique challenges such as limited training time and recovery resources, making it essential to evaluate whether short duration, focused interventions like an eight-week lower body training program can produce measurable performance outcome (Rajesh., 2023) This study seeks to investigate the effectiveness of an eight-week lower body strength training program on vertical jump performance in netball players at Sabaragamuwa University of Sri Lanka. By integrating resistance exercises and plyometric within a progressive training structure, this research aims to contribute practical, evidence-based recommendations for improving explosive athletic ability in university-level netball, while addressing the existing knowledge gap in the South Asian sport science literature (Radnor et al., 2018). A progressive training structure is significant because it allows athletes to gradually increase load and intensity, ensuring continuous adaptation while minimizing the risk of overtraining or injury. Unlike non-progressive or random training methods, progressive overload systematically challenges the musculoskeletal and neuromuscular systems, leading to measurable improvements in strength, power, and explosive performance (Kraemer & Ratamess, 2004).

2 METHODOLOGY

This study employed an experimental research design using random sampling. Fourteen female netball players (aged 22–24) from the Sabaragamuwa University netball team were selected and randomly assigned to an intervention group (n = 7) and a control group (n = 7). There is limited research on structured lower body strength training interventions among female university-level netball players in South Asia, particularly within Sri Lankan universities. The intervention group completed an eight-week lower body strength training program 3 times per week. The eight-

week, three-session-per-week structure aligns with established guidelines for developing strength and power, providing an optimal balance of training stimulus and recovery (ACSM, 2009; Suchomel et al., 2018). Sessions were held for around 120 minutes in the afternoon to ensure high attendance following academic commitments. Sessions comprised resistance exercises such as squats, lunges, Romanian deadlifts, and plyometric drills and box jumps. The control group continued their routine netball training without additional strength training components. Their regular training consisted of technical drills (passing, shooting, and footwork), aerobic conditioning and match simulations, but excluded structured lower-body strength or Polymetric exercises. Vertical jump performance was assessed using a standardized vertical jump test conducted before and after the intervention (Topend Sports, 2025). Pre-test data were collected on the day before the intervention commenced, and post-test data were obtained within two days following the completion of the eight-week program. Data analysis involved Wilcoxon Signed-Rank Test and Mann-Whitney U Test due to non-normal data distribution. This eight-week lower body strength training program was structured with progressive overload principles. The program was designed to gradually increase in intensity while adjusting training volume appropriately. This eight-week program was designed with progressive overload principles, gradually increasing in intensity while adjusting volume. The duration was selected based on prior evidence indicating that a minimum of 6 to 8 weeks of targeted training is necessary to achieve significant neuromuscular and performance adaptations in vertical jump ability (Cormie et al., 2011; Markovic & Mikulic, 2010). Thus, the intervention balanced scientific validity with practical applicability within the university's training context. As the limitation of the study, the small sample size, short intervention period, and lack of control over external factors such as diet or additional training were identified.

HYPOTHESIS TESTING

To assess the effectiveness of the eight-week lower body strength training program, the following hypotheses were formulated:

- H_1: The eight-week lower body strength training programme significantly improved the vertical jump height of athletes.
- H_2: Athletes in the intervention group show a significantly greater improvement in vertical jump height compared to the control group.

Table 1. Weekly Progression of Lower Body Strength Training Programme

Week No	Volume (Sets × Reps)	Intensity (%1RM)
Week 1	3 × 12	50–60%
Week 2	3 × 10	60%
Week 3	3 × 10	65–70%
Week 4	4 × 8	70–75%
Week 5	4 × 6	75–80%
Week 6	4 × 6	80–85%
Week 7	3 × 6	85–90%
Week 8	2 × 6	50–60%

Each training session lasted approximately 120 minutes, including a 15-minute warm-up, 90 minutes of main lower body strength exercises, and a 15-minute cool-down. Rest intervals of 90 seconds were provided between sets, and 2-3 minutes between different exercises.

3 RESULTS AND DISCUSSION

Table 2. Comparison of pre and post test data for a vertical jump

Intervention Group			Control Group		
Athlete	**Pre-test (cm)**	**Post-test (cm)**	**Athlete**	**Pre-test (cm)**	**Post-test (cm)**
01	29.50	34.36	08	27.85	27.80
02	31.55	34.50	09	31.20	34.55
03	29.10	34.50	10	32.85	29.60
04	31.55	29.10	11	29.10	32.50
05	30.60	35.90	12	30.60	31.85
06	28.20	32.35	13	23.56	24.50
07	29.00	34.20	14	30.00	32.45
	Median: 29.8 cm			**Median: 32.9 cm**	
	IQR: 28.5-31.5 cm			**IQR: 29.9-34.5 cm**	

The median vertical jump height improved from 29.8 cm (IQR: 28.5cm - 31.5 cm) in the pre-test to 32.9 cm (IQR: 29.9 cm - 34.5 cm) in the post-test. This reflects a positive shift in performance across the group. A majority of athletes improved; for instance, athlete 1 increased from 29.5 cm to 34.4 cm, athlete 2 from 31.6 cm to 34.5 cm, and athlete 5 from 30.6 cm to 35.9 cm. However, a few participants showed minimal improvement or decline, such as athlete 4 (31.6 cm to 29.1 cm), athlete 8 (27.9 cm to 27.8 cm), and athlete 10 (32.9 cm to 29.6 cm). These results suggest that the training program had a generally beneficial effect on vertical jump performance, although the magnitude of improvement varied among participants. The Wilcoxon Signed Rank Test indicated a significant improvement in jump height between the pre- and post-test within the intervention group ($p = 0.035$). Furthermore, comparison with the control group using the Mann–Whitney U Test also revealed a statistically significant difference in performance gains ($p = 0.0409$). Together, these results provide strong evidence that the training intervention was effective in enhancing vertical jump performance, although the magnitude of improvement varied among individual athletes.

Table 3. Evaluation of Training Effects Using Wilcoxon Signed Rank Test

	Statistic	P	Median
Difference	27.0	0.035	4.340

The Wilcoxon Signed-Rank Test was conducted to evaluate changes in jump performance before and after the eight-week lower body strength training program. With 7 paired observations, the test produced a Wilcoxon statistic of 27.0 and a p-value of 0.035, which is less than the significance level of 0.05. This result indicates a statistically significant median improvement in jump height following the intervention. The estimated median difference was 4.34 cm, confirming that the training program had a meaningful and positive effect on vertical jump performance.

Table 4. Comparison of differences in pre and post-test vertical jump performance in treatment and control group

Groups	Median
IG	4.860
CG	1.250

The Mann-Whitney U test was used to compare the effectiveness of the training intervention between the intervention group (IG) and the control group (CG). The intervention group had a median improvement of 4.86 cm, while the control group showed a median improvement of only 1.25 cm. The difference in medians ($\eta_1 - \eta_2$) was 2.75 cm, with a 95.9% confidence interval ranging from 0.499 to 5.249 cm. The test yielded a statistically significant result ($p = 0.0409$), leading to the rejection of the null hypothesis. These findings indicate that the strength training program produced a significantly greater improvement in jump performance compared to the control group, supporting the effectiveness of the intervention.

4 CONCLUSION

The present study demonstrated that an eight-week lower body strength training program, integrating resistance and plyometric exercises, significantly improved vertical jump performance among female university netball players at Sabaragamuwa University of Sri Lanka. The intervention group showed a clear and meaningful median improvement compared to the control group, highlighting the effectiveness of structured lower body strength training in enhancing explosive performance capacities essential for netball.

Nevertheless, individual responses varied, with some athletes showing greater gains than others, emphasizing the importance of individualized monitoring when applying group-based training programs. Given the small sample size (n = 14), the short intervention duration, and the lack of control over external factors such as diet, lifestyle, and additional training activities, these results should be interpreted with caution and not overgeneralized to all netball populations.

Future studies with larger and more diverse samples, longer intervention periods, and controlled conditions are recommended to confirm these findings and extend their applicability. Despite these limitations, the outcomes of this case study suggest that structured lower body strength

training can serve as a valuable component of performance enhancement strategies for university-level netball players when implemented with athlete-specific considerations.

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