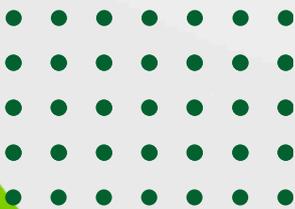# PROCEEDINGS OF PAPERS

5TH INTERNATIONAL CONFERENCE ON SCIENCE AND TECHNOLOGY

"Innovative Approaches for A Sustainable Future: Connecting Science and Technology for Global Challenges"

16TH OCTOBER 2025

In Collabration with

SLAAS (Eastern Chapter)

Faculty of Technology

South Eastern University of Sri Lanka

ICST 2025

Proceedings of Papers

**5th International Conference on Science
and Technology 2025**

October 16th, 2025

*"INNOVATIVE APPROACHES FOR A SUSTAINABLE FUTURE:
CONNECTING SCIENCE AND TECHNOLOGY FOR GLOBAL
CHALLENGES"*

**Faculty of Technology
South Eastern University of Sri Lanka
Sri Lanka**

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5TH INTERNATIONAL CONFERENCE ON SCIENCE AND TECHNOLOGY
SOUTH EASTERN UNIVERSITY OF SRI LANKA - OCTOBER 16, 2025

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MESSAGE FROM THE VICE CHANCELLOR

It gives me immense pleasure to extend my warm greetings to all participants of the 5th International Conference on Science and Technology (ICST 2025), organized by the Faculty of Technology, South Eastern University of Sri Lanka (SEUSL). The continued success of this prestigious event is a testament to the dedication, scholarly excellence, and collaborative spirit of the university community and its partners.

The theme of this year's conference, "Innovative Approaches for a Sustainable Future: Connecting Science and Technology for Global Challenges," is both timely and inspiring. In an era marked by rapid technological advancement and complex global challenges ranging from climate change to food security, integrating scientific knowledge with technological innovation is vital for developing sustainable solutions.

This conference provides an excellent platform for researchers, academics, industry professionals, and students to exchange ideas, share research findings, and explore interdisciplinary collaborations. It also reflects our university's commitment to fostering innovation, promoting sustainability, and contributing to national and global development goals.

I commend the Faculty of Technology for its unwavering efforts in organizing this academic forum and creating opportunities for productive engagement and knowledge dissemination. I am confident that ICST 2025 will inspire new perspectives, strengthen networks, and pave the way for impactful research and technological advancement.

I wish all participants a successful and enriching conference experience.

Prof. S.M. Junaideen
The Vice Chancellor,
South Eastern University of Sri Lanka
Sri Lanka.

MESSAGE FROM THE CHAIRMAN

As the Dean of the Faculty of Technology, I am proud and delighted to forward this message to the Fifth International Conference on Science & Technology (ICST 2025), themed "Innovative Approaches for a Sustainable Future: Connecting Science and Technology for Global Challenges". This theme is timely, addressing the indispensability of innovative approaches to mitigate the pressing global challenges faced by the entire globe today. The science and technology have an ample potential to develop constructive innovative approaches to maintain sustainability so that to handover the sustainable and peaceful world for the generations to come. The world faces multifaceted challenges such as global warming, natural disasters, manmade disasters, famine, war etc. Innovative approaches with changing mindset of world population is the only available option to the world to face the challenges successfully and to secure and maintain sustainability.

The Faculty of Technology is the youngest faculty in the history of South Eastern University of Sri Lanka and has achieved main milestones in its shortest period of life. Accordingly, this is the fifth consecutive international conference organized by it. I am quite sure that this ICST 2025 would serve as a vital platform for researchers, academicians, professionals, industrialists, research students, and policy makers to exchange their ideas, views, information and knowledge and discuss further advancements to meaningfully contribute to the challenges faced by the world and to find the ways and means to mitigate the challenges and to maintain the sustainable growth and development. The ICST 2025 has collaborated with the Eastern Chapter of the Sri Lanka Association for the Advancement of Science (SLAAS) so that to enrich the conference by way of broadening the contribution from the world scientist and technologists.

I extend my heartfelt gratitude and thanks to Vice Chancellor, coordinator, secretary, treasurer, track coordinators, keynote speakers, sponsors, authors, presenters, scholars, faculty members, the organizing committee, administrative staff, and the students for their fullest cooperation and enormous support extended to make this historic event a success. I also wish to extend my thanks for all who directly and indirectly supported during the different stages of this conference to make it a very success.

Dr. U. L. Abdul Majeed
Chairman/ICST2025
Dean, Faculty of Technology
South Eastern University of Sri Lanka
Sri Lanka.

MESSAGE FROM THE COORDINATOR

As the Coordinator of the Fifth International Conference on Science and Technology (ICST 2025), it is with great pride and enthusiasm that, I extend my warm greetings to all participants, presenters, and distinguished guests joining this prestigious event. The Faculty of Technology, South Eastern University of Sri Lanka, is once again privileged to host this significant annual academic gathering, which will be held on 16th October 2025. The theme of ICST 2025, "Innovative Approaches for a Sustainable Future: Connecting Science and Technology for Global Challenges," reflects our collective determination to advance research and innovation that address the pressing issues of our time. This theme emphasizes the indispensable role of science and technology in shaping a resilient, sustainable, and inclusive world.

In an era marked by climate change, rapid digital transformation, and evolving societal needs, innovation stands as the key to unlocking sustainable solutions. ICST 2025 provides a vibrant platform for scientists, technologists, engineers, researchers, and industrial experts to share their findings, exchange ideas, and build collaborations that transcend disciplinary and geographic boundaries. This year's conference is further enriched by the participation of two eminent keynote speakers Prof. P. Abdul Salam from Asian Institute of Technology, Thailand and Prof. (Mrs.) Huda Bt Haji Ibrahim from Institute for Advance and Smart Digital Opportunities, School of Technology, UUM, Malaysia whose insights and expertise will undoubtedly inspire new perspectives and ignite meaningful discussions on global sustainability through science and technology.

As the Faculty of Technology continues its mission to nurture innovation and excellence, ICST 2025 serves as a catalyst for promoting interdisciplinary research and fostering partnerships among academia, industry, and policy-makers. The knowledge shared here will not only empower our research community but also contribute to Sri Lanka's journey towards the Sustainable Development. I take this opportunity to express my heartfelt appreciation to all authors, reviewers, keynote speakers, session chairs, organizing committee members, Track Coordinators, Editor in Chief, Editorial Team, Editorial Assistants, other staff members and sponsors for their valuable contributions and unwavering support in making ICST 2025 a success.

Let us continue to inspire innovation, embrace collaboration, and lead the way in creating a sustainable future through science and technology.

Prof. A.D.N.T. Kumara
Coordinator/ICST2025
Faculty of Technology
South Eastern University of Sri Lanka
Sri Lanka.

MESSAGE FROM THE KEYNOTE SPEAKER

It gives me immense pleasure to extend my greetings to everyone participating in the International Conference on Science and Technology (ICST 2025), organized under the theme "Innovative Approaches for a Sustainable Future: Connecting Science and Technology for Global Challenges." This conference takes place at a critical juncture when the global community is seeking integrated solutions to complex challenges, ranging from climate change and energy security to sustainable infrastructure, digital transformation, and equitable growth.

The theme of this conference highlights the crucial role of science and technology in shaping a sustainable future. Scientific knowledge, when applied through innovative engineering practices, has the potential to transform industries, empower communities, and enhance the quality of life for future generations. What makes this conference particularly unique is that it offers an invaluable forum for academics, researchers, industry experts, practitioners, and students to share ideas, showcase innovations, and build partnerships that transcend traditional boundaries.

As the keynote speaker, I am deeply honored to share this platform with distinguished scholars and industry professionals. The sharing of ideas in forums like this not only enhances our knowledge but also ignites the passion of young researchers to explore new frontiers. Conferences such as ICST 2025 play a crucial role in nurturing innovation, fostering interdisciplinary research, and inspiring solutions that are both technologically feasible and socially responsible.

I offer my heartfelt congratulations to the organizers for their vision and commitment in uniting this vibrant and diverse group of thought leaders. I wish the conference great success and hope that the discussions and deliberations emerging from this conference will inspire actionable pathways toward a more sustainable and equitable future. I look forward to engaging with participants and learning from the diverse perspectives shared here.

Prof. P. Abdul Salam

Dean
School of Environment, Resources and Development,
Asian Institute of Technology, Thailand.

MESSAGE FROM THE KEYNOTE SPEAKER

I extend my heartfelt congratulations to the ICST2025 Organizing Committee for the successful organizing the conference, which provided an 'intellectual crossroad' for presenting and deliberating research and technological advancements anchored in transformative innovation—toward shaping a more sustainable future. In an era defined by complexity and disruption, the pursuit of sustainability is no longer a choice—it is a necessity. From climate volatility to economic fragility, the global landscape is shaped by risks that are increasingly systemic, interconnected, and unpredictable. Disasters—whether natural, technological, or socio-economic—are not isolated events. They are stress tests for our institutions, our communities, and our shared vision for the future. To build resilience, we must move beyond reactive responses toward proactive, integrated strategies. This is where innovation becomes indispensable. Innovation is not merely about new technologies—it is about reimagining systems, empowering communities, and translating knowledge into impact. Whether through predictive analytics for early warning, nature-based solutions for climate adaptation, or inclusive digital platforms for disaster response, innovation must be context-sensitive, ethically grounded, and aligned with the Sustainable Development Goals.

The SDGs provide a universal framework for action—linking disaster risk reduction to poverty alleviation, climate action, quality education, and institutional strength. They remind us that sustainability cannot thrive in isolation. It is a collective responsibility, powered by the insights of science and the tools of technology. To achieve it, we must foster collaboration across disciplines, sectors, and borders. We must invest in education that cultivates systems thinkers, policy shapers, and resilience architects. Let us innovate not for novelty, but for necessity. Let us prepare not only for the next crisis, but for a future that is inclusive, adaptive, and just. In connecting sustainability, disaster resilience, and innovation, we do more than respond—we reimagine what is possible.

I wish all participants fruitful exchanges, new partnerships, and the kind of collaboration that transcends disciplines and borders. Let us seize this opportunity to forge connections that not only advance academic inquiry, but also contribute meaningfully to global resilience and sustainable development.

Prof. Huda Ibrahim
Professor in Information System
Universiti Utara Malaysia
Malaysia.

MESSAGE FROM THE GENERAL PRESIDENT SLAAS (EASTERN CHAPTER)

It gives me great pleasure to extend my warmest greetings to the organizers and all participants of the 5th International Conference in Science and Technology, organized under the inspiring theme, "Innovative Approaches for a Sustainable Future: Connecting Science and Technology for Global Challenges."

This conference provides a valuable platform for scientists, technologists, and innovators from diverse disciplines to share knowledge, foster collaboration, and generate creative solutions to some of the most pressing global issues. In an era marked by rapid technological advancement, climate change, and complex socio-economic transformations, the integration of science and technology is more crucial than ever to ensure a sustainable and equitable future for all.

As the premier scientific body in Sri Lanka, SLAAS remains committed to advancing scientific knowledge, promoting innovation, and encouraging interdisciplinary research that contributes to national development and global sustainability goals. I am confident that the ideas and partnerships emerging from this conference will inspire transformative actions and lead to impactful outcomes in science, technology, and innovation.

I commend the organizers for their dedication and vision in creating this dynamic forum, and I wish all participants fruitful discussions and every success in their future endeavors.

Prof. K. Prasannath
President
Sri Lanka Association for the Advancement of Science -SLAAS (Eastern Chapter)

ABSTRACT OF KEYNOTE SPEECH

Science and Technology in Driving a Sustainable Future: Global Challenges and Innovative Approaches

Prof. P. Abdul Salam

Dean, School of Environment, Resources and Development,
Asian Institute of Technology, Thailand

The current global landscape is marked by pressing challenges that threaten ecological balance, environmental stability, economic growth, and human well-being. Climate change, rapid urbanization, rising energy demand, and resource scarcity are no longer distant concerns but urgent realities. To address these interconnected issues, the United Nations adopted the Sustainable Development Goals (SDGs) as a universal framework for achieving peace, prosperity, and sustainability by 2030. However, progress across many SDGs remains uneven. Innovative approaches that integrate science, technology, and policy hold the potential to accelerate progress toward these goals, transforming ambitious targets into achievable milestones. This presentation examines how emerging scientific insights and technological advances can catalyze transformative change, with a focus on three critical SDGs: SDG 7 (Affordable and Clean Energy), SDG 11 (Sustainable Cities and Communities), and SDG 13 (Climate Action). These goals are particularly pivotal as they address the interdependent challenges of energy transition, urban sustainability, and climate resilience. The presentation is structured into three sections. The first highlights global challenges and introduces the SDGs, emphasizing the current status and persistent gaps. The second explores the interconnections among the three selected SDGs, showing how progress in one domain supports the others. The third examines the enabling role of science and technology, including renewable energy systems, smart urban infrastructure, big data analytics, artificial intelligence, and climate modeling, in advancing sustainability and resilience. While science and technology provide powerful tools, the discussion emphasizes that global collaboration, supportive policy frameworks, and active public engagement are equally essential to achieving meaningful transformation. Ultimately, the presentation underscores that the path to a sustainable future lies in integrating scientific innovation with societal needs, fostering a culture of responsible consumption, and building resilience against climate change. By harnessing the power of technology, humanity can move closer to addressing the planet's most pressing challenges and ensuring a livable, equitable, and sustainable future for all.

ABSTRACT OF KEYNOTE SPEECH

Science and Technology as Catalysts for Sustainable Resilience: From Policy to Practice

Prof. Huda Ibrahim

Universiti Utara Malaysia, Malaysia

Sustainability is no longer a siloed ambition—it is a systems-level imperative that demands interdisciplinary thinking, ethical governance, and evidence-based action. This keynote explores how institutions can embed sustainability across infrastructure, pedagogy, and digital ecosystems, aligning their efforts with the 17 Sustainable Development Goals (SDGs). It emphasizes the need to move beyond fragmented interventions toward integrated frameworks that reflect local realities, global benchmarks, and shared accountability. Science is positioned as the foundation for resilience, enabling risk anticipation, complex systems modeling, and context-sensitive interventions. Malaysia's alignment with national instruments such as the MySDG Roadmap, Green Technology Master Plan (GTMP), NADMA, and the Malaysian Qualifications Framework (MQF) demonstrates how academic outputs can inform policy and institutional transformation. Technology is presented as a tool for inclusive governance, supporting digital literacy, ethical data stewardship, and equitable access to services—while confronting the digital divide. The keynote highlights curriculum innovation as a strategic lever for change, showcasing transnational collaborations such as the ERASMUS+ SDG Journalism for Reporting Project and the M.Sc. in Geomatics for Disaster Risk Reduction. These initiatives exemplify how Malaysian universities like UUM, UM and USM can co-create educational resources that integrate SDG literacy, disaster resilience, and digital ethics into teaching and research. By bridging academic inquiry with policy implementation, institutions can translate knowledge into scalable models and measurable impact. Ultimately, the keynote calls for collaborative futures—where universities, ministries, and industries co-develop responsive curricula, joint research agendas, and innovation platforms. It advocates for sustainability to be institutionalized across sectors, ensuring that Malaysia's education system not only prepares graduates for the workforce, but equips them to lead with conscience, competence, and a commitment to long-term resilience.

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TRACK – ANIMAL SCIENCE AND AQUACULTURE TECHNOLOGY

Ecological Niche Differentiation and Mixed-Schooling Behavior of Auxis thazard and *Auxis rochei* in the Indian Ocean

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Abstract

Understanding the behavioral and ecological dynamics of sympatric tuna species is vital for sustainable marine resource management. This study investigates the mixed-schooling behavior and environmental niche differentiation between Auxis thazard (frigate tuna) and Auxis rochei (bullet tuna) in the Indian Ocean. Despite frequent observations of mixed-species schools, driven by their phylogenetic proximity and ecological similarities, these species demonstrate notable differences in habitat preferences. A multidisciplinary approach integrating environmental data, and statistical modeling was employed. Key ecological drivers —including sea surface and bottom temperatures, salinity, primary productivity, dissolved oxygen, and distance to land—were analyzed across A. thazard and A. rochei occurrence points from 2020 to 2024. Generalized Additive Models (GAMs) revealed significant environmental predictors for both species, with A. thazard occupying a broader ecological niche, particularly in offshore, cooler, and well-oxygenated waters. In contrast, A. rochei was more associated with warmer, saline, nearshore environments. Habitat Suitability Predictions using Environmental Niches (HSPEN) and spatial probability mapping confirmed these distinctions, while Schoener's D index (0.62) and Principal Component Analysis indicated moderate niche overlap. Mixed-schooling is thus interpreted as a function of behavioral plasticity and opportunistic overlap during foraging and reproduction, rather than complete ecological equivalence. Generalized Additive Models revealed that A. thazard occupies deeper, cooler offshore waters (mean depth 316.5 m, SST 26.29°C), while A. rochei prefers shallow, warmer nearshore environments (mean depth 22.5 m, SST 28.16°C). Schoener's D index of 0.62 indicated moderate niche overlap, suggesting that mixed schooling represents opportunistic behavioral plasticity rather than complete ecological equivalence. The findings highlight the complex interplay between shared behaviors and environmental partitioning in pelagic tunas and underscore the value of integrating spatial analysis and ecological modeling to inform ecosystem-based fisheries management. This study contributes to a nuanced understanding of species interactions in tropical marine ecosystems, with implications for biodiversity conservation and sustainable exploitation.

Keywords: Auxis thazard, Auxis rochei, mixed-schooling behavior, environmental niche differentiation, Indian Ocean pelagic ecosystems.

I. INTRODUCTION

Species belonging to the genus *Auxis*, specifically *Auxis thazard* (frigate tuna) and *Auxis rochei* (bullet tuna), are small pelagic scombrids widely distributed across tropical and subtropical oceans, including the Indian Ocean. These species are ecologically important as mid-trophic level predators, playing a key role in marine food webs, and they are of considerable economic value to artisanal and small-scale fisheries across the Indo-Pacific region. Despite their size, their ecological impact is significant, particularly due to their abundance and foraging behavior.

Numerous studies from other parts of the world have reported that *A. thazard* and *A. rochei* often form mixed-species schools. This behavior is largely attributed to their close taxonomic relationship, overlapping habitats, similar feeding habits, and synchronized reproductive cycles. For example, Yoshida and Nakamura (1965) documented frequent observations of mixed schools in Hawaiian waters, noting that both species shared similar surface-oriented foraging strategies and diel activity patterns. Genetic and morphological studies have also confirmed their

close evolutionary relationship, reinforcing the basis for their behavioral compatibility (Collette and Nauen, 1983).

In the Indian Ocean, particularly in the western and central regions, these two species are known to co-occur in various pelagic ecosystems. Kumaran (1964) and later studies by Potier et al. (2007) observed spatial and trophic overlaps among small tunas, including *Auxis* spp., indicating potential for both resource competition and coexistence through niche partitioning. Their co-occurrence in fisheries catches, especially in countries like India, Maldives, and Seychelles, further supports the hypothesis of mixed schooling behavior.

However, around Sri Lanka—despite being situated centrally within the Indian Ocean and supporting a robust pelagic fishery—there is a noticeable gap in scientific literature specifically addressing the ecological relationship between *A. thazard* and *A. rochei*. While a recent molecular study by Herath et al. (2024) confirmed the presence of both species in coastal waters through stomach content DNA barcoding, detailed ecological assessments of their distribution patterns and environmental preferences remain lacking.

Given this context, the present study was conducted to investigate the spatial distribution of *Auxis thazard* and *Auxis rochei* in the Indian Ocean region surrounding Sri Lanka. The specific objectives were to identify the physicochemical parameters associated with the presence of each species, and to determine whether these environmental variables and distribution patterns overlap, thereby assessing whether the ecological compatibility reported in global studies holds true in this region as well.

This research also serves to evaluate past findings regarding mixed schooling behavior by examining if both species share similar environmental preferences around Sri Lanka. The insights gained will not only fill existing knowledge gaps in regional marine ecology but will also contribute valuable data for sustainable fisheries management and biodiversity conservation in the face of changing oceanographic conditions.

II.   METHODOLOGY

This study was designed to analyze the spatial distribution patterns of *Auxis thazard* (frigate tuna) and *Auxis rochei* (bullet tuna) in the Indian Ocean surrounding Sri Lanka and to examine their association with key physicochemical parameters. The methodology adopted involved the use of geospatial analysis, statistical modeling, and ecological data synthesis to identify environmental preferences and potential overlap between the two species.

A.   Data Collection

1)   Species Distribution Data:

Distribution data for *Auxis thazard* and *Auxis rochei* were primarily obtained from:

Indian Ocean Tuna Commission (IOTC) datasets, which provided species-specific catch and effort data in the Indian Ocean, including spatio-temporal resolution by gear type, vessel flag, and season.

Sri Lankan national fisheries databases, including data from the Department of Fisheries and Aquatic Resources (DFAR), which offered localized fisheries data, landings, and effort distribution by coastal districts.

AquaMaps (www.aquamaps.org), which contributed species-specific predicted distribution layers based on environmental suitability models.

These datasets were harmonized and filtered to extract records related specifically to the two *Auxis* species within the study region and time frame (2015–2023).

2)   Environmental (Physicochemical) Parameters

Key environmental variables known to influence pelagic fish distribution were collected for the Indian Ocean region surrounding Sri Lanka. These included:

- Sea surface temperature (SST)
- Sea surface salinity (SSS)
- Chlorophyll-a concentration
- Dissolved oxygen
- Bathymetry (depth)

Monthly and seasonal oceanographic data were extracted from Copernicus Marine Environment Monitoring Service (CMEMS) and NOAA data portals. All environmental layers were reprojected to a uniform spatial resolution and clipped to the Sri Lankan EEZ using ArcGIS Pro.

B. Spatial Analysis Using ArcGIS

ArcGIS Pro (version 3.1) was used to process and visualize spatial datasets. The steps included:

Georeferencing fisheries and environmental data layers.

Creating distribution maps of *A. thazard* and *A. rochei* using point and density-based mapping techniques.

Overlay analysis to examine spatial co-occurrence between the species and their environmental variables.

Zonal statistics and raster extraction methods to link environmental data with occurrence points.

The spatial distribution of catch records was visualized using Kernel Density Estimation (KDE), and hotspot analysis was performed using the Getis-Ord Gi* statistic to identify areas of high catch intensity and species overlap.

C. Statistical Analysis

R (version 4.3.1) was used for all statistical analyses to explore the relationship between species occurrence and environmental conditions.

1) Modeling Environmental Preferences:

A Generalized Additive Model (GAM) approach was employed using the mgcv package in R to identify the influence of environmental variables on species presence and abundance.

Predictor variables included SST, salinity, chlorophyll-a, dissolved oxygen, and depth.

Models were assessed using AIC values, deviance explained, and residual diagnostics.

2) Preference Range Identification:

For each species, preferred ranges of physicochemical parameters were identified using response curves generated from the GAM models.

Comparative plots were created using *ggplot2* and *plotly* to visually analyze overlap in environmental preferences.

3) Similarity Assessment:

A Mantel test and Principal Component Analysis (PCA) were used to assess similarity in environmental niches between the two species.

Schoener's D index was calculated to quantify niche overlap (values close to 1 indicate strong similarity).

D. Validation and Literature Comparison

The analysis framework was informed by previous studies that employed similar methodologies for tuna species, including:

Potier et al. (2007), who used GAMs to study the ecological partitioning of tuna species in the western Indian Ocean.

Ménard et al. (2000), who integrated fisheries and oceanographic data to assess small tuna distribution.

Booth et al. (2020), who applied niche modeling to examine the spatial ecology of tuna species in the Indian Ocean using remote sensing data and R-based modeling tools.

These studies validated the use of GAMs and GIS-based mapping for ecological modeling of pelagic fish, supporting the robustness of this study's methodological approach.

III. RESULTS AND DISCUSSION

A. Environmental Preferences and Species Distribution

A comprehensive analysis of 1,247 occurrence records (673 *A. thazard*, 574 *A. rochei*) revealed significant differences in environmental associations between the two species. The comparative analysis of key environmental parameters showed notable differences in multiple habitat characteristics, indicating distinct ecological niches within the Indian Ocean pelagic system (Table 01).

Table 01: Preferred Environmental Ranges of *Auxis thazard* and *Auxis rochei*

Parameter	Auxis thazard		Auxis rochei	
	Pref Min	Pref Max	Pref Min	Pref Max
Depth (m)	170	463	14	31
Temperature (°C)	21.63	28.7	17.92	28.35
Salinity (psu)	33.05	35.89	32.32	36.76
Primary Production (PP) (mgC·m-3·day-1)	1.6	23.18	0.86	26.76
Dissolved Bottom Oxygen (DBO) (mmol·m-3)	119.94	243.21	130.77	249.02
Distance to Land (km)	17	668	14	420

Statistical comparison of environmental characteristics at occurrence sites demonstrated

significant differences across most parameters examined (Table 02), providing strong evidence for niche partitioning between these closely related species.

1) Bathymetric Distribution and Vertical Habitat Use

The most striking difference between the species was their bathymetric distribution (Table 02).

Table 02: Environmental characteristics at occurrence sites (mean ± SD)

Parameter	A. thazard	A. rochei	t-statistic	p-value
Depth (m)	316.5 ± 126.4	22.5 ± 8.9	34.7	<0.001
SST (°C)	26.29 ± 3.21	28.16 ± 0.90	-8.9	<0.001
Bottom Temp (BT) (°C)	8.18 ± 9.59	18.04 ± 10.70	-12.4	<0.001
Surface Salinity (SS) (psu)	34.67 ± 1.78	34.90 ± 1.40	-1.8	0.067
Bottom Salinity (BS) (psu)	34.95 ± 0.91	35.19 ± 0.66	-3.7	<0.001
Primary Production	10.50 ± 13.20	13.04 ± 9.60	-2.8	0.005
Dissolved O$_2$ (mmol·m^{-3})	186.62 ± 51.62	137.91 ± 79.77	9.1	<0.001
Distance to Land (km)	256.33 ± 167.84	150.89 ± 125.47	8.9	<0.001

A. thazard demonstrated clear preferences for deeper, offshore environments with mean occurrence depth of 316.5 m compared to 22.5 m for *A. rochei*, representing a 14-fold difference. This bathymetric separation likely reflects different foraging strategies, with *A.thazard* accessing mesopelagic prey through vertical migrations while *A. rochei* remains in the epipelagic zone. The predicted depth ranges suggest broader vertical niche utilization by *A. thazard* (1–1000 m) compared to *A. rochei* (10–50 m), indicating the former's capability to exploit deeper and thermally stratified waters (Table 01). This aligns with the findings of Collette and Nauen (1983), who reported that *A. thazard* exhibits more oceanic behavior and can perform deeper vertical migrations than *A. rochei*. The broader depth envelope may provide *A. thazard* with an advantage in accessing diel vertically migrating prey and avoiding surface thermal stress, a hypothesis supported by Dagorn et al.

(2000) in their examination of tuna vertical movements.

2) Thermal Preferences and Tolerance

Temperature preferences differed markedly between species (Table 02). *A. rochei* occurred in waters averaging 1.87°C warmer at the surface and 9.86°C warmer at depth. These thermal preferences align with their bathymetric distributions, as *A. rochei* 's shallow habitat experiences less thermal stratification. The temperature tolerance range for *A. thazard* (11.53°C–32.9°C) is wider than that of *A. rochei* (2.66°C–32.55°C), although the preferred temperature envelopes are somewhat similar (Table 01). This implies a degree of eurythermy in both species but more pronounced in *A. thazard*. Muhling et al. (2011) demonstrated that such wide thermal tolerance allows pelagic fish to maintain broader distribution and resilience to seasonal changes, which is evident in *A. thazard*'s more expansive predicted habitat. Auxis rochei appears to prefer slightly warmer waters, both at the surface and bottom, which aligns with prior findings that *A. rochei* is more frequently encountered in warmer, more tropical regions (Ménard et al., 2000; Mohri et al., 1998). In contrast, *A. thazard* is distributed more widely and tolerates broader temperature ranges, often extending into subtropical zones (Booth et al., 2020).

3) Spatial Distribution and Distance from Shore

A. thazard occurrences were recorded farther offshore (mean 256.33 km), whereas *A. rochei* was found relatively closer to the coast (mean 150.89 km) (Table 02). The primary productivity range is broader for *A. thazard* (0.11–195.85 mg C·m^{-3}·day^{-1}), but both species show a preference for high productivity zones, typical of mesopelagic food chains. This corroborates with Olson et al. (1994), who showed that tuna aggregations are strongly influenced by areas of enhanced primary production, often near upwelling zones or eddies. *A. rochei* appears more coastal in nature with a preferred distance to land of 14–420 km, compared to *A. thazard*'s broader range extending up to 668 km (Table 01). This coastal-offshore gradient supports earlier conclusions by Zainuddin et al. (2006) regarding spatial trophic partitioning among sympatric tunas in the Indian Ocean. The significant difference in offshore distance supports niche separation, with *A. rochei* favoring more coastal habitats and *A.*

thazard being predominantly offshore (Zudaire et al., 2015). This spatial separation could reduce direct competition, allowing both species to coexist even when resources overlap.

4) Salinity Tolerance and Chemical Environment

The minor differences in salinity are consistent with the pelagic, oceanic nature of both species (Table 02). However, *A. rochei* 's slightly higher salinity association may reflect its presence in more saline surface layers closer to land or semi-enclosed basins, as observed in the western Indian Ocean (Pillai et al., 2007). Salinity ranges reflect adaptability in both species, with *A. thazard* showing a preference for salinities between 33.05 and 35.89 PSU, while *A. rochei* tolerates from 32.32 to 36.76 PSU (Table 01). These ranges fall within typical oceanic values but show that *A. rochei* might be slightly more tolerant to fluctuations, possibly due to its more coastal affinities as indicated by Potier et al. (2007).

5) Productivity and Oxygen Relationships

Higher primary productivity near *A. rochei* habitats (Table 02) suggests that it may favor nutrient-rich coastal upwelling zones, where food resources like zooplankton and small pelagics are more abundant (Menon et al., 2016). *A. thazard*'s broader offshore distribution includes oligotrophic regions with lower productivity, but it is known for high mobility that allows it to exploit scattered food patches (Logan et al., 2011).

The dissolved oxygen gradient was particularly pronounced, with *A. thazard* associated with oxygen levels 48.7 mmol·m^{-3} higher than *A. rochei* (Table 02). This difference may reflect *A. thazard*'s presence in well-ventilated offshore waters versus *A. rochei* 's tolerance for lower-oxygen nearshore conditions. Auxis thazard is associated with higher bottom oxygen levels, potentially indicating a preference for more ventilated offshore environments. Meanwhile, the lower oxygen levels for *A. rochei* may reflect adaptation to nearshore hypoxic conditions or mesopelagic incursions, a behavior noted in other scombrids (Stramma et al., 2012).

B. GAM Results and Habitat Suitability

GAM analysis revealed significant non-linear relationships between environmental variables and species occurrence, explaining substantial portions of variance in species distribution patterns (Table 03).

Table 03: GAM model summary

Species	Deviance Explained	AIC	Significant Terms
A. thazard	68.3%	542.1	Depth, SST, BT, DBO, Distance
A. rochei	71.2%	489.7	Depth, SST, PP, Distance

For *A. thazard*, optimal conditions were: depth 170-463 m, SST 21.6-28.7°C, and distance 17-668 km from shore. *A. rochei* showed preferences for: depth 14-31 m, slightly narrower temperature range 17.9-28.4°C, and closer proximity to shore (14-420 km). Response curves indicated *A. thazard*'s broader environmental tolerance, particularly for temperature and depth. This eurythermy likely enables its more extensive oceanic distribution, consistent with observations by Booth et al. (2020) of greater habitat plasticity in this species.

C. Spatial Probability Mapping

Habitat suitability maps revealed high probability zones for *A. thazard* in offshore waters west and south of Sri Lanka, while *A. rochei* showed peak suitability near the continental shelf and coastal upwelling areas (Figure 01). The spatial prediction probabilities reinforce the environmental preferences identified in the statistical analysis. *A. thazard* had high suitability values (>0.9) widely distributed across the western and central Indian Ocean, especially around 6°–10°N and 76°–82°E, coinciding with zones of dynamic productivity and eddy activity. *A. rochei*, on the other hand, showed clustering of high probabilities near coastal margins and continental shelves, suggesting a stronger affinity to neritic environments.
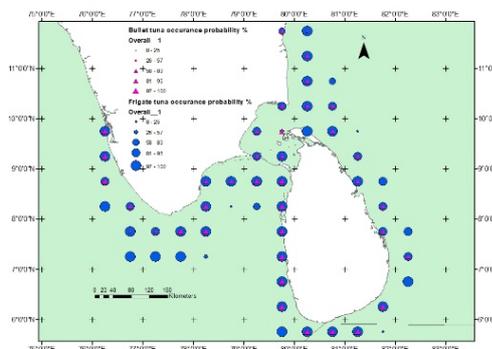

Figure 01: Probability of the occurrence of *A. thazard* and *A. rochei*

High-probability occurrences for *A. thazard* were observed in grid squares such as 1007:477:2 and 1007:476:4 with probabilities of 1.0, indicating ideal environmental alignment. Meanwhile, *A. rochei* also exhibited maximum probability in overlapping regions (e.g., 1007:477:4 and 1007:478:3), confirming sympatric distribution but likely with resource partitioning via vertical or temporal segregation.

D. Niche Overlap Analysis

Schoener's D index of 0.62 indicated moderate environmental niche overlap between the species. PCA revealed that the first two components explained 73.4% of environmental variance, with species clustering along depth and temperature gradients.

A. thazard occurrences aligned with deeper, cooler water masses, while *A. rochei* associated with shallow, warmer conditions. However, substantial overlap in the intermediate environmental space suggests opportunities for interspecific encounters during foraging or reproductive activities. The moderate overlap supports observations of mixed schooling while confirming distinct core habitats. This pattern resembles findings by Zudaire et al. (2015), who documented similar niche partitioning among sympatric tunas in the Indian Ocean.

E. Ecological Implications and Comparative Insights

The observed environmental preferences of *A. thazard* and *A. rochei* around Sri Lanka indicate distinct, though overlapping, ecological niches within the Indian Ocean pelagic system. The Habitat Suitability Predictions using Environmental Niches (HSPEN) for both species reveal niche partitioning among closely related tuna species, potentially driven by evolutionary and ecological constraints. The environmental envelope and spatial probability data highlight how abiotic variables shape the ecological distribution of these pelagic predators in the Indian Ocean.

Such habitat partitioning is ecologically important to minimize interspecific competition, a concept supported by Bertrand et al. (2002) who found depth stratification in tuna species linked to prey specialization and thermal preferences. Moreover, the co-occurrence patterns with partial niche overlap observed here align with the findings of Ménard et al. (2000), who noted that *A. rochei* tends to dominate nearshore waters, while *A. thazard* is more abundant offshore.

Furthermore, Tanimoto et al. (2012) used satellite telemetry and confirmed that *A. thazard* exhibits diel vertical migration, an adaptive trait absent or less pronounced in *A. rochei* . This may explain the former's broader depth and temperature envelope and its presence in deeper, more oligotrophic zones. These behavioral studies enhance our understanding of how *A. thazard*'s access to offshore mesopelagic prey layers contributes to its broader ecological niche, while *A. rochei* shows more constrained vertical movement patterns.

The observed differences suggest that although both species may school together, particularly during feeding or migration, they likely exhibit distinct habitat preferences during other life history stages. This niche partitioning enhances species coexistence and may be a key reason for their frequent, but non-exclusive, association. These findings align with past studies that suggest spatial and temporal partitioning among sympatric tunas (Bertrand et al., 2002; Zainuddin et al., 2006), demonstrating how closely related species can coexist through resource partitioning strategies in marine pelagic ecosystems.

IV. CONCLUSION

This study provides a comprehensive analysis of the mixed-schooling behavior and ecological differentiation between *Auxis thazard* and *Auxis rochei* in the Indian Ocean. Despite frequent co-occurrence and behavioral synchrony—largely driven by their close phylogenetic relationship and shared foraging strategies—these two species exhibit clear ecological separation, particularly in terms of habitat preferences, environmental tolerances, and spatial distribution.

Environmental parameter comparisons and niche modeling revealed that *A. thazard* favors more offshore, cooler, and oxygen-rich waters with greater vertical mobility, while *A. rochei* shows stronger associations with warmer, more saline, and productive nearshore environments. These differences are further supported by GAMs and habitat suitability mapping, which demonstrate distinct yet partially overlapping ecological envelopes.

The findings underscore the adaptive behavioral plasticity of *Auxis* spp. and highlight the

importance of integrating ecological, genetic, and spatial modeling approaches to understand species interactions and distribution in pelagic ecosystems. Such insights are valuable for ecosystem-based fisheries management, particularly in regions where small tunas contribute significantly to coastal livelihoods and marine biodiversity.

Future studies should aim to increase sampling of *A. rochei* and explore temporal dynamics in schooling behavior, which would further refine understanding of species coexistence mechanisms and inform conservation strategies amid changing oceanographic conditions.

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Evaluating the Growth and Production Performance of Indian River Layer Parent Stock Across Key Life Phases

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Abstract

This study evaluates the production performance of Indian River layer parent stock across brooder (0-6 weeks), grower (7-15 weeks), and layer (35-61 weeks) stages under Sri Lankan farm conditions. Key parameter - body weight (BW), weight gain (WG), feed intake (FI), feed conversion ratio (FCR), and mortality-were monitored. Results indicated significant sexual dimorphism, with males achieving higher BW at all stages, while females exhibited higher FI during lay. FCR increased with age, reflecting greater maintenance and reproductive demands. A critical finding was the strong negative correlation between the Temperature-Humidity Index (THI) and performance metrics (BW, WG, FI, FCR), while THI was positively correlated with mortality. Furthermore, early-life performance profoundly influenced later productivity; higher WG and FI during the brooder stage were negatively correlated with subsequent egg production and egg weight, whereas a better brooder-stage FCR was positively correlated. The study concludes that optimizing early-growth management and mitigating heat stress are essential for maximizing the reproductive performance and sustainability of Indian River parent stock in tropical climates.

Keywords: Brooder, Grower, Growth performance, Indian River parent stock, Layer, Temperature-Humidity Index

I. INTRODUCTION

Poultry is one of the most progressive livestock sub-sectors in Sri Lanka, having shown remarkable growth over the past thirty years. The poultry sector in Sri Lanka has recently gained prominence due to its significant contribution to the national gross domestic product (GDP). In 2023, the poultry sector contributed Rs. 21.9 bn (1.1% of GDP), accounting for 79% of the total livestock GDP (DAPH, 2024). The poultry industry in Sri Lanka plays an important role in the nation's protein supply, thereby helping to address malnutrition among vulnerable populations (Nisamiya et al., 2023).

The Indian River offers a high-performance line of poultry breeds to meet the modern demands of commercial poultry production. Known for its efficiency, adaptability, and strong health profile (Aviagen, 2024). Body weight management during the growing phase is a crucial factor in successful parent stock production, influencing sexual maturity, reproductive efficiency and subsequent performance of progeny (Rahman et al., 2015). Growth performance in poultry is routinely assessed using body weight (BW), weight gain (WG), feed intake (FI) and feed conversion ratio (FCR) (Leeson and Summers, 2005; Quintana-Ospina et al., 2023). These parameters are influenced by bird sex and genetics (England et al., 2023), as well as feeding management and diet composition, which determine feed intake and nutrient availability, and environmental conditions such as ambient temperature and humidity (Quintana-Ospina et al., 2023). The FCR is a key indicator of feed efficiency; a lower FCR value indicates that birds require less feed to produce a unit of body mass or output, reflecting greater efficiency (Quintana-Ospina et al., 2023).

The environment in poultry production refers to the external physical and climatic conditions in which birds are reared. Key environmental parameters include temperature, relative humidity, ventilation, air quality, lighting, and stocking density. Environmental conditions also influence production performance, animal welfare, and the yield of parent stock (Bist et al., 2024). Ambient temperature and humidity are

often expressed as the temperature-humidity index (THI). High THI can have adverse effects, including reduced feed intake, slower growth rate, and decreased feed efficiency, while also increasing mortality (Ferreira et al., 2024). Additionally, the performance of commercial chicks mainly depends on the quality of chicks obtained from parent stocks (Rahman et al., 2015). Selecting high-quality day-old chicks from a broiler breeder can help enhance the flock performance, underlining the importance of early-stage management for future production outcomes (Siagian and Nugraheni, 2021).

Considering the importance of optimised production performance for the sustainability of the poultry industry, it is vital to evaluate how Indian River parent stock performs across its different life stages. While existing studies emphasise factors such as feed efficiency, weight gain, and environmental conditions in poultry production, a gap remains in comprehensive data tracking performance from brooding to the laying period under Sri Lankan conditions. Moreover, the link between early chick performance and later reproductive outcomes in parent stock is not fully explored. The present study addresses this gap by assessing growth and production performance at the brooder, grower, and layer stages, examining the impact of temperature-humidity index on productivity, and clarifying how early-life performance shapes egg production and egg quality. The findings underscore the significance of optimising brooder management and mitigating heat stress to improve long-term reproductive efficiency and sustainability in Indian River parent stock.

II. MATERIALS AND METHODS

The study was conducted at a commercial poultry breeder farm located in the Western Province of Sri Lanka, which lies in the wet zone and is characterised by a tropical monsoonal climate with high relative humidity. The farm operates under an open-sided housing system and follows standard commercial management practices for broiler parent stock (Aviagen, 2024).

A. Experimental design and Birds

This study was conducted in an open-sided poultry house across three growing stages: brooder (0-6 weeks), grower (7-15 weeks), and layer (35, 42, 56, and 61 weeks). Table 01 presents the experimental layout. The male-to-female ratio was adopted in accordance with the standard farm practice where the study was conducted. This ratio reflects the farm's established management protocol for broiler parent stock, specifically for monitoring body weight, allocating feed, and evaluating performance. Data were collected separately for males and females, although birds were housed together under uniform management conditions. These ages were selected to represent critical growth and production milestones. The brooder stage encompasses early growth and immune development, while the grower stage ensures proper pre-pubertal growth and body weight management. The selected layer weeks correspond to key points in the reproductive cycle, including peak and late production, allowing for the assessment of growth, reproductive performance, and environmental effects.

Table 01. Layout of the experiment

Stages	Age (week)	No. of birds	
		Male	Female
Brooder	0 - 6	50	100
Grower	7 - 15	50	100
Layer	35	25	50
	42	25	50
	56	25	50
	61	25	50

The equipment and poultry house were thoroughly cleaned and disinfected before the placement of chicks. Fresh wood shavings were used as litter material. A 100 W bulb was used as a light source in combination with three heating coils, which provided the main source of heat during brooding. The temperature is adjusted according to the chick's behaviour. Standardised feeding practices were followed across all stages. Birds were provided with commercial diets formulated for each stage (brooder, grower, and layer) according to the nutrient requirements of Indian River parent stock. Although water consumption was not measured quantitatively, birds had continuous access to clean drinking water throughout the trial, ensuring no limitation to feed intake or feed conversion. Environmental conditions were

regularly monitored to ensure consistency across all experimental units.

During the first two weeks, feed was provided ad libitum. After two weeks, quantitative feed restriction was implemented to meet body weight targets. Adjustments were made by increasing the feed allocation by 1 g for every 50 g of underweight compared to the target standard. During the grower stage, feed adjustments ensured uniform body weight (±10% of the standard). Layer birds were supplied with breeder layer feed using an automatic chain feeder system, with allocations adjusted weekly based on body weight. Feed intake was recorded daily, and weekly averages were calculated.

The environmental temperature and relative humidity inside the poultry house were measured daily in each cage using a wet-dry bulb thermometer. The temperature-humidity index (THI) (Marai et al., 2001; Thom, 1959) was calculated as:

$$THI = 0.85 \times T + 0.15 \times RH - 0.15$$

where T= ambient temperature (^0C), RH = relative humidity

Body weight (BW), weight gain (WG), feed intake, feed conversion ratio (FCR), egg production (hen-housed percentage), and mortality were recorded throughout the study. BW was measured using a UWE HS Series digital hanging scale. In the first week, chicks were weighed in groups of five; from the second week onward, individual birds were weighed.

$$Weight\ Gain = Final\ Body\ Weight - Initial\ Body\ Weight$$

The FCR was calculated weekly as the ratio of feed intake to body weight gain, providing a measure of feed efficiency (Martinez et al., 2022).

$$FCR = \frac{Total\ Feed\ Intake\ (kg)}{Total\ Body\ Weight\ Gain\ (kg)}$$

B.   *Statistical Analysis*

Microsoft Excel and SPSS (Statistical Package for the Social Sciences) version 26.0 were used to analyse the data. Descriptive statistics were applied to summarise performance parameters. Correlation analyses were performed to assess the relationship between production performance and the Temperature-Humidity Index (THI) at four specific layer production ages: 35, 42, 56, and 61 weeks. Statistical significance was considered at $p < 0.05$.

III.   RESULTS AND DISCUSSIONS

A.   *Growth Performance*

The growth and feed utilisation performance of Indian River broiler parent stock were monitored across the brooder, grower, and layer stages. Key parameters assessed included BW, WG, FI, and FCR. Separate evaluations for male and female birds are summarised in Table 02, which highlights the differences between sexes and growth stages. Male birds consistently exhibited higher BW than females. At the brooder stage, males had an average BW of 517 g, while females averaged 331 g. During the grower stage, the average BW of males was 1931 g, while that of females was 1324 g. By the layer stage, males and females reached an average BW of 4806 g and 4195 g, respectively. These findings align with England et al. (2023), who attributed sex differences in body weight to competition for feed, social dominance, hormonal differences, and metabolic demands. The findings indicate that males consistently outperform females in terms of growth at every stage of production. Weight gain peaked during the brooder stage. Female chicks gained 95 g, while males gained 183 g. Weight gain patterns stabilised during the grower and layer stages, with males continuing to gain more than females. This reflects the rapid early growth phase in poultry, as noted by Siagian and Nugraheni (2021).

Feed intake increased with age for both males and females. During the brooder and growth stages, males consumed more feed than females. However, females consumed more feed (1127 g) than males (975 g) during the layer stage, due to the additional energy demand for egg formation. These changes highlight the evolving dietary needs associated with female reproduction. The FCR was lowest during the brooder stage (1.2 in males and 0.8 in females), indicating the highest feed efficiency at early growth. As birds grow, FCR increased substantially, reaching 5.0 for

males and 5.7 for females at lay. A Higher FCR in later stages reflects the increased nutritional

Table 02: Body weight, weight gain, feed intake, and feed conversion ratio of Indian River parent stock across brooder, grower, and layer stages

Performance of broiler parent stock	Gender	Age (Stage)		
		Brooder	Grower	Layer
Body weight (g/bird)	Male	517.19±329.74	1931.19±307.78	4806.41±494.05
	Female	330.82±173.08	1324.42±328.74	4194.89±569.84
Weight Gain (g/bird)	Male	183.45±158.74	121.43±39.74	193.74±9.12
	Female	94.62±100.50	122.37±37.16	193.47±17.87
Feed Consumption (g)	Male	389.31±172.45	567.86±15.62	975.30±24.57
	Female	263.78±93.63	469.62±59.16	1126.79±25.84
Feed Conversion Ratio	Male	1.2±1.17	5.2±1.89	5.0±0.27
	Female	0.8±1.86	4.2±1.66	5.7±0.82
Mortality (%)	Male	2.57%±1.90%	0.67%±1.00%	2.50%±2.97%
	Female	2.57%±1.51%	1.44%2±1.13%	3.00%±2.13%

requirements to support their maintenance and reproduction. Furthermore, both genetic and environmental factors contribute to the increase in FCR (Quintana-Ospina et al., 2023). Mortality rates remained within acceptable commercial limits across all stages (<3.5%). Rates were slightly higher in females during the layer stages, possibly due to reproductive stress.

B. Effect of Temperature-Humidity Index (THI)

The correlation analysis revealed a significant negative relationship between THI and BW (r = -0.62), WG (r = -0.65), FI (r = - 0.61), and FCR (r = - 0.56), all $p<0.001$ (Table 03). Higher THI adversely affect birds' growth performance and feed efficiency. Vandana et al. (2021) also reported that heat stress increases maintenance energy requirements and compromises productivity. In contrast, THI was positively correlated with mortality rate (r = 0.44, $p<0.01$). Given that the death rate rises in tandem with THI, this implies that rising temperatures and humidity levels have a negative impact on bird survival (Kang et al., 2020).

C. Brooder Performance on Layer Productivity

Tables 04 and 05 present the results of correlation analysis, illustrating the relationships between brooder stage growth performance and its impact on subsequent egg production and egg weight.

Table 03: Relationship between THI levels and key performance parameters

	BW	WG	FI	FCR	THI
BW	1				
WG	0.53**	1			
FI	0.94**	0.55**	1		
FCR	0.55**	0.33*	0.55**	1	-
THI	-0.62**	-0.65**	-0.61**	-0.56**	1
M	-	-	-	-	0.44

BW = Body weight, WG= Weight gain, FI= Feed intake, FCR= Feed conversion ratio, THI= Temperature humidity index, M=Mortality

* Correlation is significant at the 0.05 level (2-tailed).

** Correlation is significant at the 0.01 level (2-tailed).

Table 04: Correlation of brooder growth performance with egg production

Growth Parameters	35th Week	42nd Week	56th Week	61st Week
BW	-0.18*	-0.25*	-0.32**	-0.28*
WG	-0.68**	-0.75**	-0.78**	-0.72**
FC	-0.79**	-0.82**	-0.85**	-0.79**
FCR	0.54**	0.62**	0.63**	0.58**

BW = Body weight, WG= Weight gain, FC= Feed consumption, FCR= Feed conversion ratio, EP = Egg production, EW= Egg weight
* Correlation is significant at the 0.05 level,
 ** Correlation is significant at the 0.01 level

The BW at the brooder stage was negatively associated with egg weight (r = -0.23 to -0.26) and egg production (r = -0.18 to -0.32) at p<0.05. indicating that rapid development during the brooder phase was linked to adverse effects on subsequent production performance. WG and FI during the brooder phase also showed strong negative correlations with egg production and egg weight at 35, 42, 56, and 61 weeks. These results suggested that rapid early growth and overfeeding may compromise production performance, aligning with findings of Rahman et al. (2015). Confirming the relationship between increased early feed consumption and decreased reproductive performance, similar adverse patterns were observed at 42, 56, and 61 weeks of age.

Table 05: Correlation of brooder growth performance with egg weight

Growth Parameters	35th Week	42nd Week	56th Week	61st Week
BW	-0.25*	-0.25*	-0.26*	-0.23*
WG	-0.88**	-0.89**	-0.89**	-0.89**
FC	-0.99**	-0.99**	-0.99**	-0.99**
FCR	0.70**	0.72**	0.73**	0.73**

BW = Body weight, WG= Weight gain, FC= Feed consumption, FCR= Feed conversion ratio, EP = Egg production, EW= Egg weight

* Correlation is significant at the 0.05 level,
** Correlation is significant at the 0.01 level

A positive correlation was found between brooder FCR and both egg production (r = 0.54) and egg weight (r = 0.70), suggesting that more efficient feed utilisation supports sustained production performance. Confirming the association between improved FCR and enhanced reproductive outcomes, similar positive trends were identified at 42, 56, and 61 weeks.

IV.   CONCLUSION

The present study demonstrated that the growth and production performance of the Indian River parent stock improved as the birds advanced through the production stages, from the brooder to the grower and layer stages. Males consistently showed higher growth compared to females across all stages. Females, however, achieved relatively better feed efficiency during the early stages and higher feed intake during the laying period due to reproductive demands. The THI had a negative influence on growth performance and feed efficiency, while being positively associated with mortality. Providing us with confirmation of the adverse role of heat stress on breeder productivity. Importantly, early-stage performance was strongly correlated with reproductive outcomes. Excessive early growth and feed intake are negatively impacting egg production and egg weight. Optimising early-life management and minimising environmental stress are critical for sustaining the productivity and profitability of Indian river parent stock.

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TRACK – AGRICULTURE ECONOMICS AND ENTREPRENEURSHIP

Harnessing Solar Energy: Insights from a Case Study in Ampara District– Sri Lanka

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Abstract
The study examines the utilization of solar energy in the Ampara District, a region with high solar potential but low penetration due to socio-economic and infrastructural constraints, as the global energy landscape shifts towards renewable energy sources like solar power due to the threat of fossil fuel depletion and global warming. A descriptive-analytical research design with the quantitative survey method was employed. Primary data were collected through a systematic questionnaire survey among 207 households, business, and institutional users and were analyzed in SPSS version 27.0 using descriptive statistics. Findings showed that the most prevalent adoption existed among middle-income households 58% with LKR 50,000–100,000 incomes, with government officials (37.7%) and entrepreneurs (30.9%) constituting the largest group of the users. Solar energy awareness was near universal (99.5%), with friends, family members, and social media as the major sources of information. Solar energy was dominantly for household purposes by the majority of homes (62.3%), with 69.9% using monocrystalline modules and 5–10 kW systems. Problems included inverter malfunctioning (14.98%), wiring problems (10.63%), panel damage (9.66%), and high initial cost (67.5%) as the greatest limitation. While 57.3% engaged in maintenance activities, 42.7% of them failed to practice them, losing their efficiency. To enhance adoption, the respondents emphasized the need for improved loan facilities (39.8%), increased awareness programs (31.1%), subsidies (14.6%), and improved quality equipment and training. The study examines the socio-economic drivers, constraints, and technical impediments to solar adoption in Ampara, offering valuable lessons to policymakers, NGOs, and private sector actors to enhance decentralized renewable energy projects in Sri Lanka.

I. INTRODUCTION

There has been a shift in the energy paradigm in the 21st century. As there are growing concerns related to depletion of fossil fuels, greenhouse gas emissions, and climate change, governments and societies are on the lookout for sustainable alternatives. Solar energy is one of the most promising renewable energies worldwide because of its abundant availability, sustainability and environmental friendliness and widely high potential for the generation of electricity (International Renewable Energy Agency [IRENA], 2020).

Solar photovoltaic (PV) technology is particularly well known for its capability to decentralize energy generation, promote rural electrification and empowering local communities via reducing their dependence on fossil fuel-based electricity grids. The world's installed solar PV capacity grew from just 40 GW in 2010 to more than 1,200 GW in 2022 (International Renewable Energy Agency [IRENA], 2020).

Sri Lanka's high solar insolation renders utilizing of solar energy highly feasible (SEASL, 2020). The average solar irradiance in Sri Lanka measures between 4.5-6.0 kWh/m²/day. Seeing its potential, Sri Lanka has introduced many policies and programs to promote solar power such as the "Soorya Bala Sangramaya" (Battle for Solar Energy), which was launched in 2016. The aim of the campaign is to add 1,000 MW of solar electricity to the national grid by year 2025 and boost the share of renewables in the energy mix to 70% by year 2030 (Ministry of Power and Energy, 2021).

The Ampara District of Sri Lanka is economically productive, consisting of isolated villages, farming communities, and peri-urban centers. Despite abundant solar radiation throughout the year, data on solar system adoption at the household level in the Ampara District remains limited. The district also faces intermittent grid electricity supply during drought periods when hydropower generation is curtailed, while reliance on thermal power plants has not been fully addressed. In this context, expanding decentralized solar energy systems could strengthen energy security, improve livelihoods, and enhance climate resilience. Nevertheless, potential negative impacts, such as grid hosting capacity constraints, must also be considered.

A. Gap in knowledge and justification for the study

There have been many national initiatives to promote solar energy. However, micro-level studies that investigate the socioeconomic perception, technical performance and hurdles to adopting solar energy in rural Sri Lanka are scant. Most existing studies focus on urban or national patterns. No research related to this topic has been conducted in Ampara.

To address this gap, the present study has undertaken an in-depth analysis of the current status of solar energy adoption in Ampara District. The analysis draws on quantitative survey data and incorporates a comparative review of relevant literature. The ultimate aim is to generate knowledge that benefits not only the academic community but also local policymakers, NGOs, private sector installers, and funding agencies.

B. Objective of the study

To evaluate the current status, applications and challenges about solar energy technology in the Ampara District.

II. METHODOLOGY

A. Research Design

This study employed a descriptive-analytical research design using quantitative methods to examine the current status, influencing factors, and challenges of solar energy adoption in the Ampara District, Sri Lanka.

B. Study Area

Ampara District, located in the Eastern Province, is characterized by a mix of urban, semi-urban, and rural settlements. It receives ample sunlight throughout the year, averaging 5.5–6.0 kWh/m²/day, making it ideal for solar PV applications.

C. Sampling Method

A stratified random sampling method was adopted to ensure representation from different geographical areas and socio-economic strata within Ampara District. A total of 207 respondents were surveyed, comprising household heads, small business owners, and institutional users of solar power.

D. Data Collection

The primary data for this study were collected through a structured questionnaire survey. The questionnaire was carefully designed to capture key variables such as socio-economic characteristics of respondents (family size, income level, occupation), awareness of solar energy, type of solar system adopted, system size, purpose of use, and maintenance practices. These independent variables were measured systematically to ensure uniformity and reliability in capturing the respondents' perceptions.

E. Data Analysis

Data collected were analyzed using SPSS 27.0 (Statistical Package for the Social Sciences) employing descriptive analysis such as frequencies, percentages, and graphical presentations to summarize the findings.

III. RESULTS AND DISCUSSION

A. Profile of End-Users

Figure 01 illustrates that solar energy adoption in the Ampara District was highest among households with 4–6 members, which accounted for 75.16 percent of the sample. This can be explained by the fact that families of this size typically have higher electricity demands, making solar systems more cost-effective in meeting long-term household consumption. In terms of occupation, the largest share of solar energy users were government employees, who represented 37.7 percent of users as shown in Figure 02. Entrepreneurs accounted for 30.9 percent and private employees 20.8 percent,

adopting solar energy significantly due to the need to reduce electricity costs in both business operations and household expenses. By contrast, farmers accounted for only 9.7 percent and graduates 1 percent, which may be due to irregular income sources, limited capital for investment, and lower exposure to awareness campaigns. When considering income levels, 58 percent of solar energy users in the Ampara District were from the moderate-income group earning between LKR 50,000 and 100,000, as shown in Figure 03. In contrast, adoption among low-income households earning less than LKR 50,000 was only 11.6 percent.

The findings of the present study were in line with Wickremasinghe and Thrishali 2022, who highlighted the significant role of moderate family size 48 percent and middle income 71 percent influencing rooftop solar photovoltaic system adoption. High-income households show lower solar adoption mainly due to the high cost and maintenance of larger systems, rooftop and grid capacity limits, and reliance on alternative power sources like generators or hybrids.

Figure 01: Family size

Figure 02: Occupation

Figure 03: Monthly income

B. Awareness of Solar Energy Usage

The 99.5 percent of the interviewed participants in the Ampara District were aware about harnessing solar energy (Figure 04), whereas it was solely used for generating electricity. Friends and relatives were the most common source of information (45.4 percent), followed by social media and the internet (26.1 percent), government schemes (15.5 percent), and nongovernmental organizations (13 percent), as shown in Figure 05.

Figure 04: Aware of solar energy application
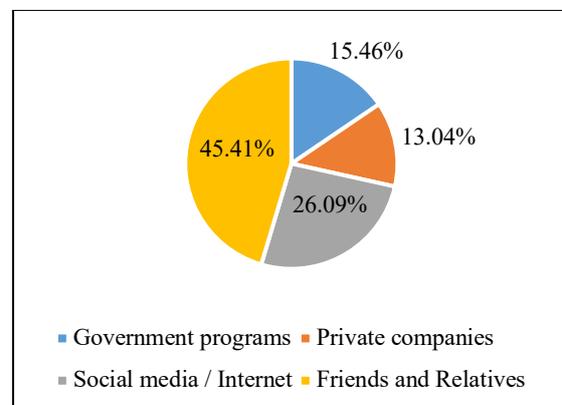
Figure 05: Source learnt about solar energy

C. Facts about harnessing solar energy

As the main application of solar energy in the Ampara District was electricity generation, the photovoltaic systems were used primarily for household purposes, which accounted for 62.3 percent, while 35.3 percent were for commercial purposes, as shown in Figure 06. Only 2.4 percent of respondents utilized solar energy for agricultural purposes. Hence, the main reason for adopting solar systems was to earn money, with 46.4 percent benefitting from export tariffs and net metering, indicating a strong investment orientation. Meanwhile, 38.6 percent invested in solar systems to reduce their electricity bills, emphasizing cost savings and energy self-reliance, as illustrated in Figure 07. There was a significant positive correlation between the type of solar system and the economic return from the Ceylon Electricity Board. Approximately, 3/4th of end users in the Ampara District, or 78.3 percent, employed on-grid systems because they can connect directly to the national grid and earn through net metering, as shown in Figure 08. By contrast, only about 9 percent adopted off-grid systems, since batteries make them costlier and harder to maintain.

Figure 06: Purpose of use solar energy
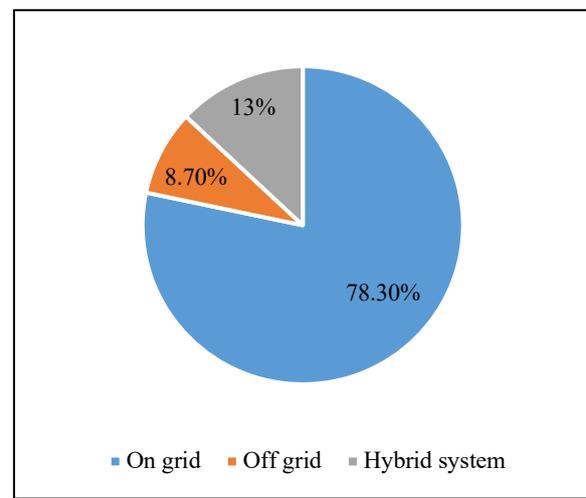
Figure 08: Type of solar system use
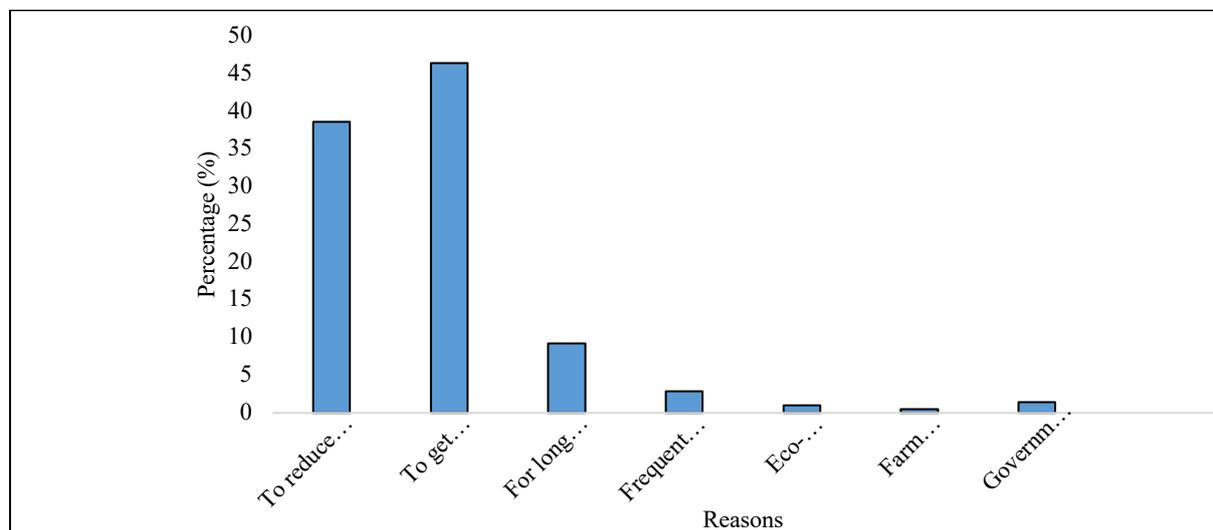
Figure 07: Primary reason for adopting solar system

D. Description of Solar System in Ampara District

In the context of the design of solar photovoltaic systems in the Ampara District, the systems used for residential purposes were most commonly 5 kW in capacity, representing 20.3 percent of installations. These systems are typically used for meeting household electricity needs such as lighting, appliances, and general domestic consumption. Semi-commercial systems of 20 kW, accounting for 18.4 percent,

were mainly installed to support small businesses and commercial establishments, often with the aim of generating additional revenue through net-metering agreements. Larger systems consisting of 40 modules, representing 11.1 percent of the sample, were employed by businesses and high-consumption residences to cover extensive energy demands, including machinery, air conditioning, and other power-intensive activities. Smaller sets of 12 modules, each with 72 cells and accounting for 10.6 percent, were commonly installed by average households and small-scale enterprises to balance affordability with essential energy needs.

The choice of system capacity can be influenced by household income. Previous studies have shown that income positively influences photovoltaic system size, installed capacity, and the number of modules, with wealthier households tending to adopt larger-scale installations (Perera et al.,2023). However, in the present study, system capacity and the scale of solar usage appeared to be independent and showed no significant relationship with monthly income, with correlation analysis yielding a value of r = 0.140 and p = 0.046.

Furthermore, with respect to module type, the majority of users 69.9 percent adopted for monocrystalline modules, which are valued for their efficiency and application on small rooftops as illustrated in Figure 09. The rest of 25.7 percent adopted for polycrystalline modules. A minority of 4.4 percent adopted thin-film modules, typically for light or flexible applications. The different choices in solar module technologies among the respondents might be associated with the difference in occupation, but there was no significant correlation with the type of solar module used (r = 0.148, p = 0.034). Occupational background

significantly correlates with PV module type choices, driven by affordability and exposure to technology (Bandara & Fernando, 2022). Such clear dominance by monocrystalline systems reflects global market trends as decreasing prices and increased performance in tropical environments bring it widely into use.
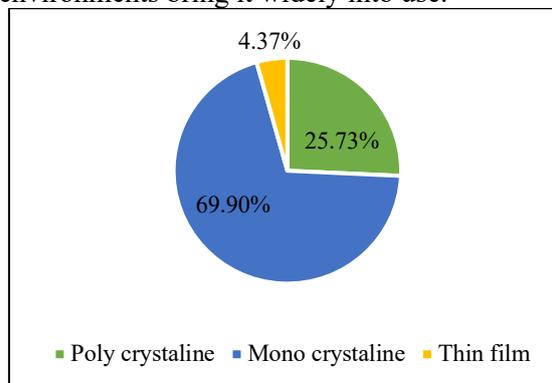
Figure 09: Type of solar system used

E. System Maintenance and Challenges

In dry and humid conditions, proper maintenance is essential to prevent yield loss and equipment failure. In the Ampara District, 57.3 percent of the users regularly carried out cleaning and inspection, while 42.7 percent neglected these processes, resulting in efficiency loss and reduced system lifespan, as shown in Figure 10. Subsequently, 41.55 percent of the surveyed respondents reported experiencing issues with their solar systems. The most common problem, affecting 14.98 percent, was inverter failure, often caused by grid fluctuations or overheating.
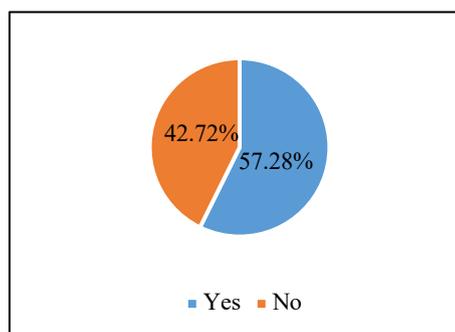
Figure 10: Maintenance activity of solar system

Faulty wiring was also reported by 10.63 percent of respondents, which can be attributed to improper installation practices. Panel damage, accounting for 9.66 percent, was generally due to adverse weather or mishandling during installation. Battery failures, reported by 6.28 percent, were typically linked to poor

management practices or the use of low-quality products in hybrid configurations, as shown in Figure 11.

Additionally, the surveyed respondents revealed that the adoption of solar systems is challenged by many factors. As shown in Figure 12, the most significant barrier to solar adoption was the high initial cost, reported by the high initial cost, reported by 67.5 percent of users, followed by weather dependence at 8.4 percent, financial or technical difficulties at 7.4 percent, and lack of awareness at 6.9 percent. During periods of low irradiance, some users adopted coping strategies such as switching to grid electricity, which accounted for 33.3 percent, using stored electricity from batteries, or reducing electricity consumption. However, about 50 percent of respondents did not take any action, as shown in Figure 13. These challenges underscore the need for high-quality equipment and technologically sophisticated installation and support services.
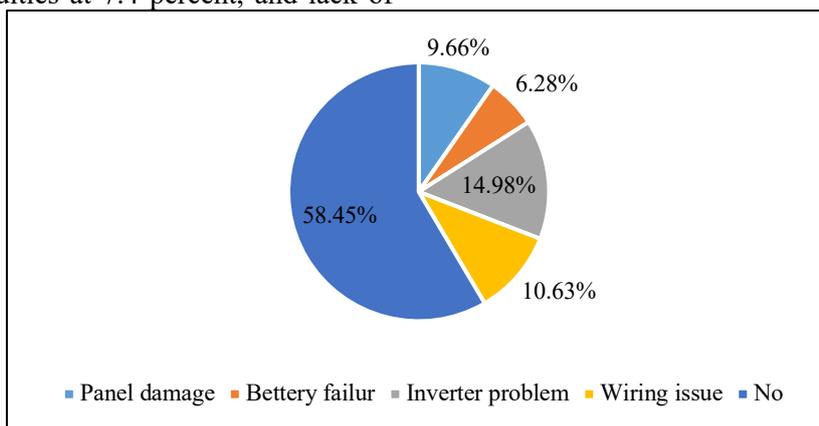
Figure 11: Type of issues faced
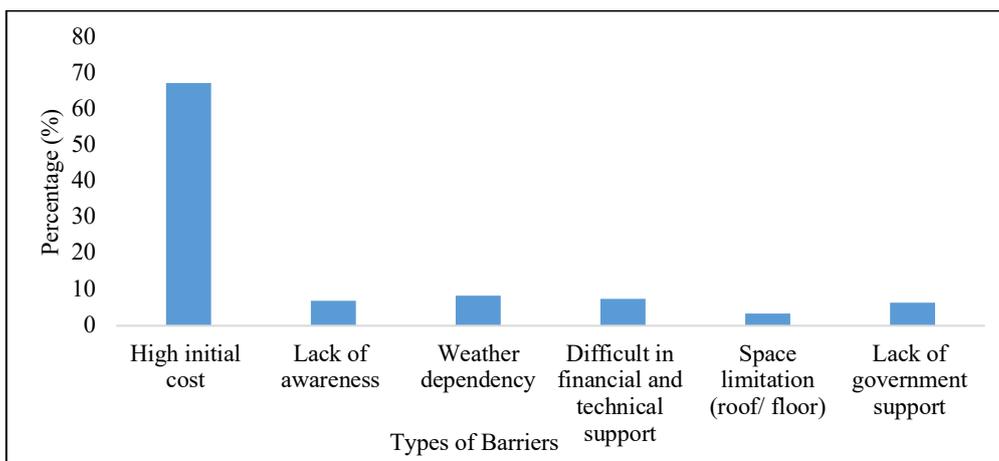
Figure 12: Barriers of solar energy adoption
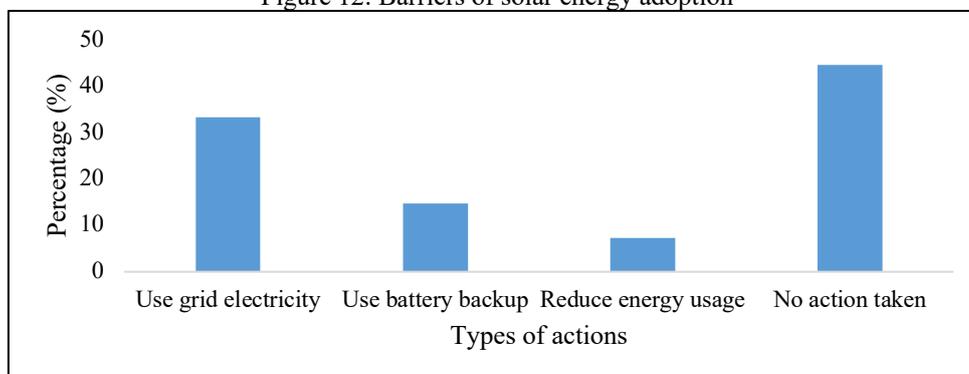
Figure 13: Action during low sunlight

In this context, the respondents were interviewed to seek their opinions. As shown in Figure 14, the suggested measures included providing better loan facilities, supported by 39.8 percent of respondents, conducting awareness programmes at 31.1 percent, increasing subsidies at 14.6 percent, and offering more training programmes with better-quality solar equipment at 7.8 percent. These observations taken collectively emphasis on the area of funding, awareness generation, and quality control towards securing solar energy usage in Ampara District.
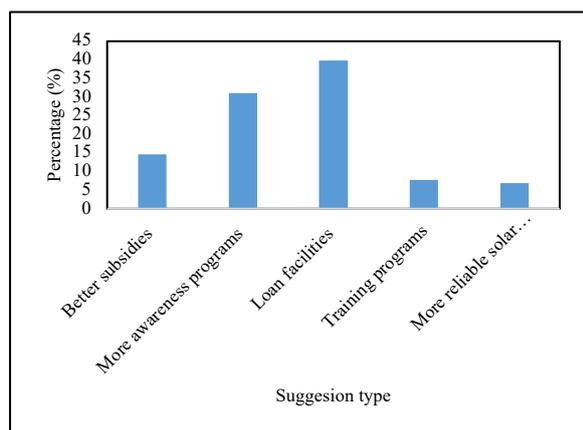
Figure 14: Suggestions for adopting solar energy

IV. CONCLUSION

The present study assessed the status of solar energy usage in the Ampara District of Sri Lanka. The research shows that solar energy utilization as an alternative energy source is prominent among the people of medium sized family, moderate income and government workers. Solar energy is primarily harnessed for electricity generation and it's substantially used in domestic and small scale commercial applications, while limited to agricultural operations. The people in Ampara district employed large 20 kW on-grid solar systems with monocrystalline modules for business and bigger residential purposes while 5 kW systems were adopted for domestic purposes. Only half of the end users properly maintain the installed systems and poor and or no maintenance led to technological faults such as inverter, wiring faults, panel damage and batteries failures. Even though, the people in the Ampara district are aware about solar energy usage, its takeoff is still hindered by initial capital expenses, weather dependency and restricted fund opportunities. To cope with these challenges, affordable finance, subsidies, promotion, and equipment and installation quality control are essential.

Addressing these challenges will not only enhance household energy security, but also enable the transition towards renewable energy and climate resilience in Sri Lanka. Ultimately, the Ampara District has the potential to be a model for decentralized solar uptake if socio-economic, financial, and technical barriers are systematically addressed.

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A Qualitative Study of Salt Production in the Kinniya Saltern: Technical and Socioeconomic Insights

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Abstract

The socioeconomic conditions of salt farmers influence the salt production, which consequently affect the quality of the salt produced. Hence, this study investigated the technical and socioeconomic aspects of salt production in the Kinniya saltern. Thirty-one salt farmers were interviewed face to face using a pre-tested structured questionnaire. The results show that a higher proportion (49%) of the salt farmers were poorly educated, thus resulted engaging in small-scale operation to sustain their livelihood. The salt farmers used 3-step (87%) and 2-step (17%) traditional methods. The farmers mainly used mechanical pumps in bringing feed water out of a lagoon system that could be contaminated by the anthropogenic activities. The production capacity was 250 kg per harvest and the annual estimated production was less than 7.5 tons per year. The quality of the salt was primarily determined with the indicators of visual inspection, color changed. The produced salt was mostly used in production of dry fish (100%), animal hide processing (48%) and in some instances human consumption (45%). The study concludes that the socioeconomic conditions of salt farmers, the production methods they use, and the quality of salt produced are closely interconnected. This suggests that improving farmers' socioeconomic conditions is essential for enhancing the production process and overall salt quality. The study also highlights the necessity of technical training, establishment of standard production procedures, and quality control mechanism to enhance efficient and safety salt production applications at the Kinniya saltern.

Keywords: Kinniya saltern, lagoon, Saltpans, Salt production, Socioeconomic conditions

I. INTRODUCTION

Common salt, chemically known as sodium chloride (NaCl), is one of the most essential raw materials globally, with widespread applications in both food and non-food sectors. Despite its consumption in small daily amounts as a food additive, salt plays a critical role in human health and industry, making it an indispensable element in daily life (Tan et al., 2022).

In Sri Lanka, salt production is particularly suited to the country's coastal regions—especially along the Eastern, Northern, North-Western, and parts of the Southern coasts—where the climate features long dry periods and flat terrain. These conditions, combined with free access to seawater and solar energy, provide a natural advantage for solar salt production. Unlike agriculture, which involves high input costs such as land preparation, seeds, agrochemicals, and labor, solar salt manufacturing is considerably low-cost and therefore holds significant economic potential (Efendy et al., 2024).

Traditionally, salt in Sri Lanka has been produced through the solar evaporation of seawater or natural brine, a method that has been used for centuries in coastal regions around the world (Vyas et al., 2022). This practice, passed down through generations, involves collecting seawater into shallow salt pans where sunlight and wind naturally evaporate the water, leaving behind crystallized salt (Sircoulon & Holland, 2016). This low-impact, eco-friendly process continues to be the most common method of salt production due to its sustainability and simplicity.

The solar salt manufacturing process typically involves moving brine between soil-based evaporation beds through open canals. This is done by gravity flow, which is maintained by creating level differences between beds.

However, because the system is exposed, it is vulnerable to contamination from suspended solids and other impurities. As a result, the final salt product often contains various compounds such as magnesium chloride ($MgCl_2$), calcium chloride ($CaCl_2$), magnesium sulfate ($MgSO_4$), calcium sulfate ($CaSO_4$), and organic matter (Lukum et al., 2021). Even with quality control measures, variations in the evaporation process frequently result in inconsistent product quality (Mensah & Bayitse, 2006). To meet acceptable standards, salt must adhere to strict chemical composition criteria. For edible salt, a minimum of 94.7% sodium chloride is required, while industrial salt must contain at least 98.5% NaCl. Other parameters include a maximum of 0.2% sulfate (SO_4), 0.06% magnesium (Mg), 0.1% calcium (Ca), and 3% moisture (H_2O) (Lukum et al., 2021).

Salt is indispensable across various domains. In human nutrition, it serves both physiological needs and enhances food flavor. In livestock farming, salt is essential as a dietary supplement (Masters et al., 2001). Industrially, salt is the foundation for producing numerous inorganic chemicals such as caustic soda, chlorine, soda ash, sodium sulfate, and hydrochloric acid (Bommaraju, 2007). Beyond chemicals, it supports a wide range of industries including soap and detergent production, dyeing, textile manufacturing, leather processing, water treatment (especially in resin regeneration), and food preservation. It is also found in everyday health products such as saline solutions, toothpaste, and antiseptics (Mensah & Bayitse, 2006; Kilic & Kilic, 2005). Additionally, salt is widely used in factory cleaning and food canning, underlining its economic importance in both local and global markets.

A notable example of salt production in Sri Lanka is the Kinniya Saltern, located in the Trincomalee District. Preliminary observations at this site indicate that salt farmers often do not follow recognized or standardized production practices. Instead, they adopt informal methods that are convenient and practical given their personal and economic circumstances. These choices, while functional, may compromise product quality. Socioeconomic factors are believed to significantly influence the selection of production techniques. Moreover, the quality of salt produced in Kinniya is directly affected by factors such as the quality of seawater used, the methods and procedures applied during production, and the technologies (or lack thereof) employed (Sumada et al., 2017). Given these observations, the present study was undertaken with three primary objectives: to identify and document the current salt production methods used in the Kinniya Saltern; to assess the socioeconomic conditions of the salt farmers; and to propose practical recommendations to improve production efficiency and enhance the quality of the salt produced.

II.   METHODOLOGY

The ERC (Ethics Review Committee) approval was obtained for the study from the ERC of the Faculty of Technology (ERC/FT/2023/02).

A. Study area

Kinniya Saltern is located in the Kinniya Divisional Secretariat (DS) Division in Trincomalee District, Sri Lanka. Its coordinates are 8° 29'10.04" North and 81° 09'49.28" East. Trincomalee has a tropical climate with a hot season and no cold season. The average yearly temperature is about 28.5°C, and the monthly temperatures vary by around 4.5°C.

The area receives an average of 1569 mm of rainfall each year. The driest month is June, which gets about 341 mm of rain. Most of the rain falls during the Northeast Monsoon season (from December to February). From May to September, the weather is mostly dry. This dry season, lasting about five months, is ideal for salt farming in the Kinniya Saltern.
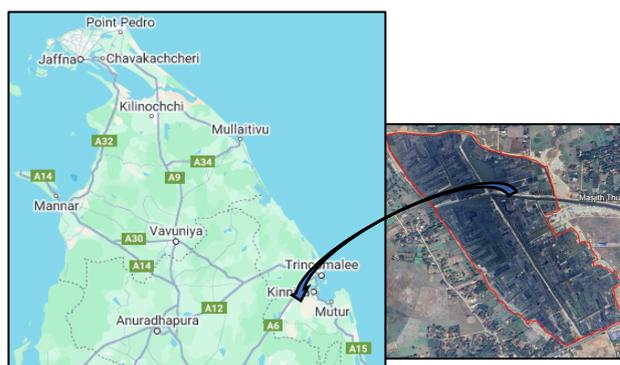
Figure 01: Kinniya saltern and its location

B. Sample size and sampling

There were 226 farmers registered in Kinniya DS with salt production in Kinniya saltern. Out of the total salt farmers, 31 farmers were randomly selected for the study.

C. Data collection and analysis

Primary data collection was done using questionnaires which consisted both closed-ended and open-ended questions. Questionnaire consisted questions related to socioeconomic characteristics of salt farmers such as education level, experience in salt production, main income source, and monthly income and production related characteristics such as methods of salt production, land area of salt production, mechanisms of water collection to saltpans, production capacity, factors used to assess the quality of salt, and the uses of salt were also studied. The questionnaire was pre-tested with 10 farmers and the survey was carried out after modifying the questionnaire based on the results from the pre-testing. The questionnaire was filled by face-to-face interviews with the salt farmers. Secondary data collection was performed by visiting the DS office in Kinniya. Data were analyzed using SPSS software (Version 25) and presented in tables and graphs.

III. RESULTS AND DISCUSSION

A. Socio-economic characteristics of salt farmers

Table 01: Socio-economic characteristics of salt farmers

Characteristics	Percentage (%)
Gender of salt farmers	
Male	97
Female	3
Education level of salt farmers	
Primary	49
GCE (O/L)	29
GCE (A/L)	19
Higher National Diploma (HND)	3
Experience in salt production	
1 – 3 years	3
4 – 5 years	13
6 – 10 years	29
Over 11 years	55
Main income source of farmers	
Salt production	61
Agriculture	26
Running a shop	13
Monthly income of salt farmers in SLR (From salt production)	
1,000.00 – 4,000.00	3
5,000.00 – 10,000.00	27
11,000.00 – 15,000.00	40
Above 15,000.00	30

1) Gender of salt farmers

Table 01 shows the important socioeconomic characteristics of the salt farmers of the Kinniya saltern. 97% of those involved in salt production were males and the rest 3% were females. The salts production is a male dependent operation in Kinniya saltern. The traditional salt production involves with heavy manual tasks such as saltpan preparation, bagging the salt and carrying the salt bags which may be difficult for females. The present finding is supported by Tran et al. (2022) where they found that 82.9% of the salt farmers were male due to its nature involving heavy work. Despite these tedious manual activities, the involvement of 3% of females in salt production is noteworthy in the Kinniya saltern.

2) Education level of salt farmers

According to the results (Table 01), 49% of the salt farmers obtained only primary education, while 29%, 19% and 3% completed their education up to GCE (O/L), GCE (A/L) and Higher National Diploma (HND) respectively. As a higher proportion of the salt farmers are poorly educated, thus engaged in self-income generating salt production activities to sustain their livelihood and none of the salt producers employed in private or government sectors. Tran et al. (2022) stated that for traditional salt farming activities, poor education is not an obstacle, however, the poor education may have an impact on producing good quality salt and recognizing climate change impacts. It is important to note that the poor education may hinder the salt farmers to have an understanding about how the salt production will affect their health and wellbeing, and how it will have impact on the surrounding environment and the subsequent social and economic impacts. Delos Reyes et al. (2021) found that 31% of the salt producers were high school graduates engaged in small and medium scale operations in the Philippines.

3) Experience in salt production

The experience of salt farmers in salt production is also depicted in Table 01. 55% of the total salt producers were found with the experience of more than 11 years. This indicates that the majority of the farmers continue salt production for long time. However, 16% of the salt producers have 5 or below 5 years of experience and they may be considered as new comers. Delos Reyes et al. (2021) found that most of the salt producers

(63%) had the experience of 16 or above 16 years. As we found in the present study, a small portion of the salt producers are new comers and they obtain the saltpan for lease and produce salt. Thus, this kind of lease-based production always paves the way for new comers. Further, the lease-based method paves the way for hiring labourers to do salt production.

4) Main income source of salt farmers

Salt production emerged as the primary source of income of the largest portion (61%) of the sample. This indicated that the majority of salt farmers relied predominantly on salt production activities for their livelihood. However, the salt production is a seasonal income generating activity which lasts for four months and discontinued during the rainy season and it is also interrupted during the inter-monsoon seasons for a shorter period.

By discussing with salt farmers, we found that they do odd jobs during the rainy and inter-monsoon seasons. Hence, the main income sources of 26% and 13% of salt producers were agriculture and small-scale retail business respectively and salt production was an additional income generation activity. Overall, the seasonality nature of the salt production has resulted diversification of income sources, mainly among the small-scale salt farmers compared to the industrial scale producers. This argument is further confirmed from their monthly income from salt production, from which 70% of the farmers earned less than Rs. 15,000.00 per month (Table 01). This diversification of income sources reflected the multifaceted economic activities within the salt farming community at Kinniya saltern to sustain livelihood. The findings in the present study are supported by the notion that farmers diversify their income sources to manage the risks posed by climate shocks subsequently affecting their welfare (Antonell et al., 2022).

B. Salt production related aspects

Salt production characteristics of farmers in the Kinniya saltern were examined, and the findings are summarized in Table 02.

1) Methods of salt production

In general, salt production involves the processes such as (i) stabilization to remove large particles in seawater and as a reservoir of feed, (ii) evaporation, (iii) concentration, (iv) crystallization (Susanto et al., 2015). Though, the four-step salt production is the accepted method, in Kinniya saltern two-step such as (i) sea water collected from reservoir and evaporation, (ii) crystallization and three-step methods such as (i) sea seawater collected from reservoir and evaporation, (ii) concentration, (iii) crystallization. According to the Table 02, 87%, practiced a three-step method while, a smaller proportion, comprising 13%, utilized a two-step method for salt production. In Kinniya saltern, salt farmers use seawater sourced from a narrow lagoon, not directly from the sea. This 4.15 km-long lagoon is fed by Thambalagamuwa Bay, which connects to the sea through Koddiyar Bay. The lagoon flows through mangroves, marshlands, and villages on both sides before reaching the saltern. Therefore, it is highly likely that the feed water may contain materials other than salt, which could affect the salt quality. Therefore, it is important that salt producers apply recommended method for salt production.

2) Factors influencing the salt quality

Salt farmers in Kinniya use a combination of quality indicators and management practices to assess and ensure the quality of salt (Table 02). Among the quality indicators, visual inspection and color consistency were the most commonly used, each mentioned by 25% of farmers. Through visual inspection, farmers assess characteristics such as the appearance, color, uniformity, crystal size, and shape of the salt. In terms of management practices that influence salt quality, saltpan cleaning (24%) and controlled water usage (18%) were significant. These practices are essential for maintaining hygiene in the pans and reducing contamination during production. Salt cleaning, used by 7% of the farmers, also contributes to improving salt purity by removing physical impurities after harvesting. Although only 1% of the farmers reported monitoring production parameters (e.g., salinity levels, evaporation rates), this remains a critical practice for achieving consistent and high-quality salt production.

Table 02. Technical aspects of salt production in Kinniya saltern

Aspects	Percentage (%)
Methods of salt production	
2 – step	13
3 – step	87
Land area of salt production (m2)	
< 500 m^2	0
500 – 1000	55
1000– 2000	42
2000 – 3000	3
Mechanisms of water collection to saltpans	
Bucket	6
Pumping	94
Production capacity (kg/harvest)	
< 1, 250	68
1, 250– 2, 500	32
Salt quality parameters	
Saltpan cleaning	24
Water usage	18
Salt sample testing	25
Salt cleaning	7
Color	25
Monitoring parameter	1
Uses of salt (Multiple option question)	
Consumption	45
Animal hide (skin) processing	48
Dry fish production	100
Coconut fertilizer	29
Chicken feed production	22
Swimming pool cleaning	3
Other purpose	10

3) Uses of salt

Table 02 shows the diverse uses of harvested salt at Kinniya saltern, each farmer sells the salt for different purpose. The salt from Kinniya saltern is extensively used for dry fish production, whereas al the salt farmers either sell fully or partially for this purpose. Dry fish production is one of the important economic activities in the Kinniya coastal areas which create a significant demand for local salt at a reasonable price. This usage also highlights its critical role in preserving fish products. According to FAO (2021), salt used for dry fish production should be food grade, further no contamination with dirt, oil, or other extraneous materials. Despite, we found that no

mechanism is in place to assure that the salt produced is in food grade quality. Another 45% of farmers indicated the use of harvested salt for consumption. Though there is no state regulated mechanism in place to assure the quality of salt, still the salt is used for consumption. The study suggests that educating the farmers on the production of salt with accepted quality while instituting regulatory mechanism to inspect and control quality. Moreover, it was found that the salt is used for animal hide processing (48%), as a component of coconut fertilizer (29%), as an ingredient of chicken feed production (22%), and for industrial purposes (10%), and swimming pool cleaning (3%).

4) Land area of salt production

The land plot size used by salt farmers are shown in Table 02. Accordingly, the largest plot size was around 3000 m2 (0.3 ha) and the smallest plot size was around 500 square meters (0.05 ha). Further, majority of them (55%) are operating plots with the size of less than 1000 m2. These figures show that salt farmers in Kinniya saltern produce salt at subsistence level to support their livelihood during the production season.

5) Mechanisms of water feeding to saltpans

In the context of salt production, collecting water from the water source is a critical initial step. According to the Table 02 most of the farmers, accounting for 96%, utilize pumps for water collection. This method is quick and saves time and labour, however, it incurs an additional cost for salt production. A small group of farmers, comprising 4%, continue to manually collect water using buckets. This manual approach may be preferred due to limitations in resources such as plot sizes and financial conditions.

6) Production capacity

The production capacity range of salt farmers are shown in Table 02. The first harvest is typically carried out 4 to 5 weeks after the initial preparation and flooding of the salt pans, while subsequent harvests take place every 4 to 5 days, depending on weather conditions such as sunlight and temperature. The majority of salt producers, constituting 68%, produced less than 1, 250 kg per harvest. This indicates that the production is not at satisfactory/optimum level. Conversely, 32% of salt producers achieved a higher production, ranged between 1250 kg to 2500 kg

per harvest. Hence, a minimum of six harvests is achieved per production season (April or May to Augst or September), and can be increased further with the favorable climatic conditions.

Salt production using traditional solar evaporation methods usually ranges from 60 to 120 tons per hectare each year, depending on the season and water quality (Prabawa and Bramawanto, 2021). However, kinniya salt farmers work on a much smaller scale and produce less than 7.5 tons annually. This big difference is mainly because many farmers have small plots, limited access to good water, equipment, and modern techniques. They often rely on manual methods, which are less efficient. Additionally, financial challenges, lack of technical knowledge, and changing weather conditions also limit their production. So, while the method can yield a lot, small-scale farmers usually produce much less because of these challenges.
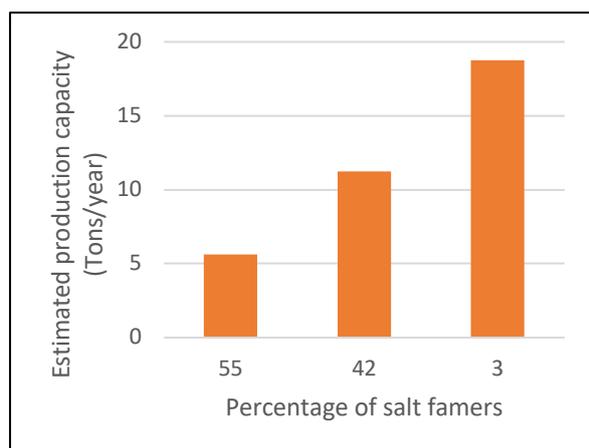
Figure 01: Estimated production capacity

We estimated the unit production rate with the collected data and it was 12.5 tons/ha on average per harvest thus 75 tons/ha per season. The salt production under the conventional methods with solar evaporation vary from 60 – 120 tons/ha/year depending on the seasonal factors, and feed water quality (Prabawa and Bramawanto, 2021). The results of the present study showed that only 3% of the farmers had 0.2 ha to 0.3 ha of saltpan area with an estimated production capacity of 15 – 22.5 tons/ha/year. Majority of the salt producers (55%) had an estimated production capacity of 3.75 to 7.5 tons per year (Figure 01). Accordingly, the majority of the salt farmers were small-scale producers with the production capacity of below

7.5 tons per year. Overall, the results indicate that though their production capacity is low (small scale producers) and suggest that the salt farmers need to be educated on the production process of acceptable quality salt and the production of salt for various uses.

IV.   CONCLUSION

The findings of the current research indicate that salt production in the Kinniya Saltern is primarily at a subsistence level. Most producers are small-scale operators with relatively low output per season. Production is carried out using either two-step or three-step methods, often without sufficient technical knowledge or training. Additionally, salt quality is assessed using only basic indicators such as appearance or color uniformity. There is currently no formal or institutionalized system in place to ensure that production meets recognized food-grade standards. Nevertheless, the produced salt has found numerous applications in many places, such as in the manufacturing of dried fish, animal hide processing, among others, as well as being consumed by humans. The salt farming is seasonal in nature and the farmers are in need of diversifying their income sources. However, there is potential to enhance the productivity of the salt farms by utilizing for fish culture during the off season. Although production per unit is at an average level, overall yields remain low due to small plot sizes and the continued use of traditional practices. The study has highlighted that technical assistance is required to better the salient production activities, to implement quality confirmation, and foster sustainable possession of resources at the saltern in Kinniya.

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TRACK – BIOSYTEMS ENGINEERING AND AUTOMATION

A Cross-Sectional Study on the Efficiency and Challenges of Solid Waste Management in a Sri Lankan Urban Municipality: A Case Study of Akkaraipattu

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Abstract

Municipal Solid Waste Management (MSWM) in developing nations is severely challenged by rapid urbanization, population growth, and constrained infrastructure. This study evaluates the current MSWM practices in Akkaraipattu, Sri Lanka, to identify key challenges. Data were collected through semi-structured interviews with 20 municipal officials and surveys of 385 households, supplemented by field observations and secondary data from the Akkaraipattu Municipal Council and local composting plant. Quantitative analysis revealed that Akkaraipattu generates approximately 49.75 tonnes of solid waste daily, with kitchen waste constituting 6.5 tonnes. The average waste collection rate is only 50%, and composting efficiency remains low at 28.8%. Major impediments to effective waste management include inadequate infrastructure, limited funding, poor public adherence to waste segregation, and logistical constraints. Despite initiatives like community outreach, long-term success hinges on sustained local involvement and stronger policy enforcement. Recommendations include investing in waste-to-energy technologies, expanding composting facilities, implementing smart collection systems, enhancing public education, and fostering public-private partnerships. This study provides practical insights for policymakers and communities aiming to transition towards more sustainable and efficient waste management systems.

Keywords: **infrastructure, compost, sustainable development, environment. Sri Lanka, policy**

I. INTRODUCTION

Solid Waste Management (SWM) encompasses the control of waste generation, storage, collection, transport, processing, and disposal, adhering to principles of public health, economics, engineering, and environmental conservation (Akolkar, 2005). Effective SWM is crucial for environmental protection, safeguarding public health, conserving resources, and ensuring regulatory compliance. However, improper waste management remains a pervasive environmental issue, particularly in developing countries like Sri Lanka. For example, unorganized systems, lack of public participation, and inadequate treatment and disposal mechanisms lead to significant environmental degradation and public health risks (Singh et al., 2011).

Municipal Solid Waste Management (MSWM) is directly linked to the United Nations Sustainable Development Goals (SDGs), specifically SDG 11 addressing the management of municipal solid waste and SDG 12, which emphasizes the need to substantially reduce waste generation through prevention, reduction, recycling, and reuse by 2030 (United Nations, 2024). For Sri Lanka, this implies an urgent need to minimize the per capita environmental impact of its cities.

The challenges of MSWM are especially acute in urban areas of developing nations, where rapid urbanization, population growth, and insufficient infrastructure coverage to create complex waste management problems (Wilson et al., 2015). Akkaraipattu, a growing urban center in Sri Lanka, exemplifies these challenges. The challenges of MSWM are especially acute in urban areas of developing nations, where rapid urbanization, population growth, and insufficient infrastructure coverage to create complex waste

management problems (Wilson et al., 2015). Akkaraipattu, a growing urban center in Sri Lanka, exemplifies these challenges.

This research aims to: (1) map the existing MSWM practices in Akkaraipattu; (2) identify and analyze the challenges hindering effective waste management; (3) benchmark these practices against international standards to identify gaps; and (4) propose strategic, sustainable solutions for improvement. By evidence-based guidance for local policymakers and communities contributes to the broader discourse on sustainable waste management and offers.

II. LITERATURE REVIEW

Municipal solid waste (MSW) is the assorted mixture of solid discards generated by urban and rural conurbations/societies. Although highly diverse, the common constituents of this household waste include kitchen scraps, garden litter, and packaging (Nanda and Berruti, 2021). Municipal Solid Waste refers to dry waste materials produced by households, agricultural operations, industries and institutions across both public and private sectors (Farrell & Jones, 2009; Samarasinha et al., 2015).

Managing solid waste has emerged as a major sustainability challenge for local government across the globe (He et al., 2022). However, this problem is particularly severe in Sri Lanka (Batista et al., 2021). Municipal solid waste management policy gaps are largely due to the limited research conducted on the subject (Saja et al., 2021). Under current legal provisions of the Pradeshiya Sabha, the responsibility for managing this waste falls to local government authorities, yet they often lack the guidance and support needed for effective implementation. Additionally, at the national level, authorities work in partnership with relevant international organizations on matters related to municipal solid waste management (Saja et al., 2021).

As per the relevant sections of the Municipal Council Ordinance, sections 129, 130, and 131, the Urban Council Ordinance Sections 118, 119, and 120; and *Pradesheya Saba* Act No. 15 of 1987, Sections 93 and 94, in Sri Lanka, all waste gathered by local authorities such as street litter and household refuse becomes the property of the respective council, which holds complete authority to sell or dispose of these materials as it deems appropriate (Arachchi 2016). As a result, solid waste has become a core responsibility of local government authorities. However, these authorities often function as income-generating ventures (Sinnathamby et al. 2016).

Municipal solid waste management aligns with Sustainable Development Goal (SDG) 11 which promotes sustainable cities and communities, as well as SDG 12, which focuses on responsible consumption and production; both address aspects of municipal solid waste management (United Nations, 2024). In line with this commitment, Sri Lanka, as a member of the UN, is expected to minimize the negative per capita environmental impact of its cities by the year 2030. SDG 12 further emphasizes reducing solid waste generation at the source through prevention, reduction, recycling, and reuse by 2030 (United Nations, 2024). Therefore, managing solid waste by converting it into compost can contribute to sustainability on several fronts (Manea et al, 2024).

Recent studies show that the efficiency of composting systems can be significantly upgraded by addressing key challenges, including source reduction, the adoption of improved management practices, and merging technological and methodological innovations. Emerging composting approaches, such as the Bokashi and Takakura methods, have demonstrated potential in accelerating organic matter degradation while mitigating operational challenges commonly associated with conventional composting processes (Danny et al., 2023).

To ensure the financial viability of the waste management system, it is important to establish stable and recurring revenue streams. Key sources of income should include garbage collection fees, tipping fees, government transfers, and the sale of compost. Furthermore, to enhance the marketability and safety of compost products and to reduce the risk of rejection by end users, strict quality control measures and adherence to established composting standards must be implemented (Siles-Castellano et al., 2021).

Financial risks and inefficiencies would be expected where financial performance was worse. A heavy reliance on subsidies and

financial risks and inefficiencies would be expected where financial performance was worse. A heavy reliance on subsidies and external grants further exacerbated sustainability challenges. In Sri Lanka, under the Pilisaru project, numerous waste facilities were established using capital investments provided by the central government and international donors. However, once these external financial supports were withdrawn, many of the facilities proved to be financially unsustainable, highlighting structural weaknesses in operational and financial planning (Dinushika, 2021)

Solid waste composting faces several persistent challenges that hinder its widespread adoption and economic viability. A major constraint is the lack of sufficient market demand for compost products, which limits the ability of producers to identify and secure reliable outlets for distribution. This issue is exacerbated by assurance protocols are essential to enhance the credibility, demand, and overall sustainability of composting operations. (Roy et al, 2021)

Secondary data were obtained from official reports and records from the Akkaraipattu Municipal Council and the local composting plant. Qualitative insights were gathered through semi-structured interviews with key informants (see Table 01 for participant details) and field observations at waste management sites.

III.   METHODOLOGY

This study employed a mixed method approach to gather comprehensive data on MSWM in Akkaraipattu. This study was carried out at the Akkaraipattu Municipality Region and Alim Nagar composting plant. The population was selected from the Akkaraipattu Municipality, the region which includes 23GN Divisions. The Study conducted for the population more than 15 years of age. The study period was January 2024 to December.

A. Data Collection

Primary data were collected through two pretested, structured questionnaires: A survey on MSWM services targeting 20 employees of the Akkaraipattu Municipal Council, selected purposively based on their roles. A household survey on kitchen waste management practices. The sample size of 385 households was

determined using the Krejcie and Morgan (1970) formula for a finite population.

Table 01 Data Collection of Participants

No	Anonymous name	Designation	Years of Experience
1	Participant A	Mayor	7
2	Participant B	Secretary	13
3	Participant C	Commissioner	3
4.	Participant D	Head for Waste Management Branch	10
5.	Participant E	Development Officer-Planning	6
6	Participant F	Development Officer-Planning	5
7.	Participant G	Management Assistant	2
8.	Participant H	Management Assistant	3
9.	Participant I	Compost Plant Supervisor	5
10.	Participant J	Management Assistant	4
11.	Participant K	Management Assistant	3
12.	Participant L	Development Officer	2
13.	Participant M	Development Officer	3
14.	Participant N	Development Officer	3
15.	Participant O	Management Assistant	2
16.	Participant P	Development Officer	3
17.	Participant Q	Development Officer	2
18.	Participant R	Municipal Waste Collection Supervisor	3
19.	Participant S	Accounts Officer	5
20.	Participant T	Public Health Inspector	5

Secondary data were obtained from official reports and records from the Akkaraipattu Municipal Council and the local composting plant. Qualitative insights were gathered through semi-structured interviews with key informants (see Table 01 for participant details) and field observations at waste management sites.

B. Data Analysis

Quantitative data from the surveys were analyzed using SPSS version 20.0, employing descriptive statistics to calculate means, standard deviations, and frequencies. Qualitative data from interviews

and observations were analyzed thematically to identify recurring challenges and perspectives.

IV.   Results

A.   *Waste Generation and Composition*

During the study period, Akkaraipattu generates an average of 49.75 tonnes of solid waste daily (SD = 3.29), amounting to approximately 1400 tonnes monthly (SD = 57.74). Kitchen waste constitutes a significant portion of the total, with 6.5 tonnes generated daily (195 tonnes monthly). representing 17.8% of the total waste. sources of waste are residential, commercial and industrial areas.

B.   *Waste Collection and Management Efficiency*

On average, the municipality collects only about 50% of the waste generated daily, resulting in significant uncollected waste. Composting efficiency, defined as the proportion of compostable waste that is actually composted, is low at 28.8% indicating that less than a third of compostable material is processed. Financial allocations for SWM have fluctuated significantly, as shown in Table 02, with a notable spike in "Other Expenses" in 2023 (Table 02), indicating potential capital investments or irregular funding patterns.

The household survey revealed a complex public perception of waste management in Akkaraipattu. Nearly half (43.6%) of the respondents identified waste disposal as a problem within their neighborhood, and a similar proportion (46.7%) rated municipal collection services as merely "fair". In contrast, a majority (58.8%) expressed satisfaction with the processes at the local waste management center. This suggests a distinction between satisfaction with centralized processing and dissatisfaction with collection services.

Despite high levels of awareness, 83.3% recognizing the importance of recycling, 89.4% acknowledging the environmental impacts of waste, and 90.4% of respondents still observed litter in public areas. Furthermore, an overwhelming majority (94.5%) were concerned about the health impacts of mismanaged solid waste, and 86.8% believed that most environmental issues in Akkaraipattu could be minimized with proper waste management.

Complementing these public views, interviews with municipal officials identified several systemic institutional challenges. The foremost issue is inadequate infrastructure, where existing waste processing facilities are insufficient to handle the current volumes of waste generated. This challenge is compounded by significant financial constraints. Insufficient and inconsistent funding severely hampers daily operations as well as long-term development. Officials also cited public indifference, particularly poor adherence to waste segregation practices, as a major impediment to efficiency. Additional operational obstacles include logistical and human resource issues, such as a shortage of skilled labor and transportation challenges.

Finally, the existing policy and regulatory framework was considered as outdated and crucially poorly enforced which greatly influences it's overall effectiveness.

V.   DISCUSSION

The findings of this study paint a comprehensive picture of a Municipal Solid Waste Management (MSWM) system in Akkaraipattu that is under significant strain. The system faces interconnected challenges: increasing waste generation, operational inefficiencies, and a gap between public awareness and action. These occur within a broader context of financial and infrastructural constraints.

The daily waste generation of 49.75 tonnes underscores the substantial burden placed on the municipality's waste management system. This volume is characteristic of rapidly urbanizing areas in developing nations (Kumar & Samadder, 2017). It aligns with global trends, where economic development and population growth directly correlate with increased waste production (Hoornweg & Bhada-Tata, 2012).

The significant portion of kitchen waste (6.5 tonnes daily), a biodegradable stream, represents both a challenge and a critical opportunity. While its high organic content contributes to leachate formation and greenhouse gas emissions if landfilled, it is also a prime candidate for composting and anaerobic digestion. This process can recover valuable resources and reduce the overall waste volume (Singh et al., 2011). The fact that residential areas are a primary source highlights the need for targeted household level interventions.

Table 02: Expenses of Solid Waste Management of Akkaraipattu Municipality in LKR

Year	Remuneration	Traveling expenses	Materials & Supply	Repairing Properties	Other Expenses	Total Cost
2018	1, 009,198.50	78,500.00	75,000.00	65,000.00	10,669,199.00	10,887,699.00
2019	1,009,549.50	155,610.00	440,462.00	565 260.98	536,354.40	2,141,975.90
2020	878,500.00	78,500.00	480,462.00	350,000.00	354,513.90	2,141,975.90
2021	978, 500.00	79,500.00	470,400.00	250,000.00	2,721,599.78	4,499,999.78
2022	858,500.00	78,500.00	480,500.00	210,000.00	3,372,500.00	5,000,000.00
2023	858,500.00	99,500.00	480,500.00	220,000.00	48,341,500.00	50,000,000.00
2024	858,500.00	78,900.00	330,500.00	200,000.00	3,532,100.25	5,000,000.25

Source: Budget 2018, 2019, 2020, 2021, 2022, 2023, 2024 Municipal Council, Akkaraipattu

However, the system's capacity to manage this waste is severely limited. A collection rate of only 50% is alarmingly low. This signifies a critical failure in the first step of the waste management hierarchy. This result is consistent with challenges noted in other Sri Lankan municipalities, where collection systems often fail to keep pace with urban expansion (Saja et al., 2021). Uncollected waste, as reported by 90.4% of respondents observing litter in public areas, inevitably leads to illegal dumping, environmental pollution. This also increases public health risks, creates nuisance and obstructs drainage systems (Guerrero et al., 2013). Furthermore, the low composting efficiency of 28.8% indicates that even the collected organic waste is not being optimally processed. This inefficiency suggests potential issues such as poor feedstock quality due to a lack of source separation, inadequate technology, or operational mismanagement at the composting plant. These factors lead to missed opportunities for waste diversion and soil amendment production (Samarasinha et al., 2015).

The financial analysis reveals a pattern of instability that directly contributes to these operational shortcomings. The dramatic fluctuation in annual budgets, particularly the anomalous spike in "Other Expenses" in 2023, points towards inconsistent funding and a reactive rather than strategic approach to financial planning. This inconsistency hampers the ability to invest in reliable collection vehicles, maintain infrastructure, or launch sustained public awareness campaigns. As noted by Sinnathamby et al. (2016), a lack of financial capacity is a fundamental barrier for local authorities in Sri Lanka to establish effective, income-generating waste processing facilities. Stable and adequate funding is essential for long-term planning and investment in sustainable MSWM.

The study reveals a crucial paradox in public perception. There is a high level of awareness (83.3% on recycling, 89.4% on environmental impacts) and deep concern (94.5% about health impacts). Yet, this knowledge does not lead to effective action, as shown by widespread littering. This "value-action gap" is a common pattern in environmental behavior (Kollmuss & Agyeman, 2002) and indicates that barriers beyond awareness exist. These may include a lack of convenient infrastructure (e.g., separate bins), insufficient collection services considered unreliable by 46.7% of respondents, or a sense of futility if individuals do not see their efforts reflected in systemic efficiency. The fact that 58.8% were satisfied with the waste center's processes, while 43.6% saw disposal as a neighborhood problem, may suggest that

residents blame illegal dumping on others rather than the system itself, or that they are satisfied with limited services given their low expectations.

Institutional challenges identified by officials—inadequate infrastructure, financial constraints, public indifference, logistical issues, and weak policy enforcement—form a complex, self-reinforcing cycle. For instance, poor enforcement of segregation rules (a policy failure) leads to contaminated waste streams, which reduces composting efficiency (an operational failure). This, in turn, erodes public trust and participation (a social failure), making for cities in developing countries making entire system less effective. This aligns with findings of Guerero et al (2021) who identified that the most significant challenges for cities in developing countries or not technical but rather governance-related, involving institutional, financial, and social factors.

VI. CONCLUSION

This study concludes that MSWM in Akkaraipattu is hampered by a combination of integrated approach that addresses both hardware (infrastructure, technology) and software (policy, community behaviour). Future research could focus on pilot interventions to improve source segregation or evaluate the effectiveness of targeted outreach campaign.

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TRACK - CLIMATE CHANGE AND ENVIRONMENTAL IMPACT ASSESSMENT

A Comprehensive Study of Coastal Erosion at Oluvil: Analyzing the Environmental Impacts and Potential Mitigation Strategies

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Abstract

The construction of the Oluvil Harbour in 2009, intended to promote socio-economic growth in Sri Lanka's Ampara District, has unintentionally accelerated coastal erosion and caused severe ecological disturbances. This study evaluates the extent of erosion and its consequences from 2009 to 2024 using Google Earth historical imagery, field observations, and other existing studies. Findings reveal a cumulative shoreline retreat of approximately 300 meters north of the harbour, while inland impacts include riverbank erosion along the Kali-Odai River (since 2022). These changes have disrupted fisheries, reduced freshwater availability, and diminished fish population density, threatening both marine and terrestrial livelihoods. Inadequate waste management practices further intensify ecological stress, contributing to pollution and resource depletion. To mitigate these impacts, the study highlights several management strategies: ecosystem-based erosion control through mangrove restoration, soft-engineering techniques such as sand nourishment and dune stabilization, improved solid waste management to reduce coastal pollution, and alternative livelihood programs to safeguard community resilience. At the policy level, strengthening the Coastal Zone Management Plan and enforcing rigorous pre- and post-construction Environmental Impact Assessments (EIAs) are crucial to ensure that future coastal developments balance economic progress with environmental sustainability. The findings underscore the urgent requirement for science-based, sustainable management approaches to safeguard Oluvil coastal ecosystems and the livelihoods that depend on them.

Keywords: Sri Lanka, Harbour development, Coastal erosion, Environment sustainability, Management

I. INTRODUCTION

Coastal erosion, defined as the gradual loss of land along shorelines due to the action of waves, tides, currents, and human activities, is a major environmental concern worldwide (Vousdoukas et al., 2020). Climate change-induced sea-level rise, increased storm frequency, and unsustainable coastal development exacerbate shoreline retreat, leading to significant ecological and socio-economic consequences (Luijendijk et al., 2018). Understanding the drivers and impacts of coastal erosion is crucial for sustainable coastal management and resilience planning.

Sri Lanka, a small island nation in the northern Indian Ocean with a coastline of approximately 1,620 km, has experienced varying degrees of coastal erosion across its districts (Raviranga et al., 2016). Eastern Province, particularly Ampara District, is highly vulnerable due to its dynamic sedimentary coast and human interventions. Shoreline retreat in this region has been observed to accelerate after major infrastructure developments, creating both ecological and socio-economic pressures (Dissanayake & Wimalasuriya, 2020).

The construction of the Oluvil Harbour in 2009, designed to accommodate over 250 fishing vessels and cargo ships up to 5,000 metric tons, has markedly altered the local coastal environment (Perera & Amarasinghe, 2021). Early reports recorded land loss exceeding 100 meters by 2014 (Ameer, 2017). Changes in river flow along the Kali-Odai and disruption of sediment transport have intensified shoreline instability.

The ecological and socio-economic impacts of this erosion are profound. Loss of mangrove habitats, salinity intrusion, and degradation of littoral and estuarine ecosystems have reduced fish populations and freshwater availability (Senevirathna et al., 2019). Socio-economic

consequences include damage to coconut plantations, destruction of over 250 fishing boats during storm events in 2014, and increased vulnerability of communities dependent on fisheries and agriculture (Jayatissa et al., 2020). Inadequate waste management practices further exacerbate environmental stress and compromise ecosystem services.

Against this background, the present study aims to quantify observed land loss along the Oluvil coastline from 2009 to 2024, assess the physical, ecological, and socio-economic impacts of coastal erosion, and propose sustainable management strategies and policy interventions, including ecosystem-based erosion control, waste management improvement, and integrated coastal governance, to enhance resilience and safeguard livelihoods in the region.

II.   METHODOLOGY

A. Study Area

This research was conducted in Oluvil, a coastal village located in the Ampara District of the Eastern Province of Sri Lanka (Figure 01). The study area covers a 10 km stretch extending from the Kali-Odai River to the Oluvil coastal zone, encompassing the entire shoreline along this segment. The geographical coordinates of the Kali-Odai River mouth are 7°17'55.66"N and 81°51'56.72"E, while the Oluvil coastal area lies at 7°17'45.21"N and 81°52'1.62"E. The region experiences a tropical climate, characterized by high annual temperatures averaging around 35 °C and mean annual rainfall of approximately 1,973 mm, based on Sri Lanka Meteorological Department records (Department of Meteorology, 2020).
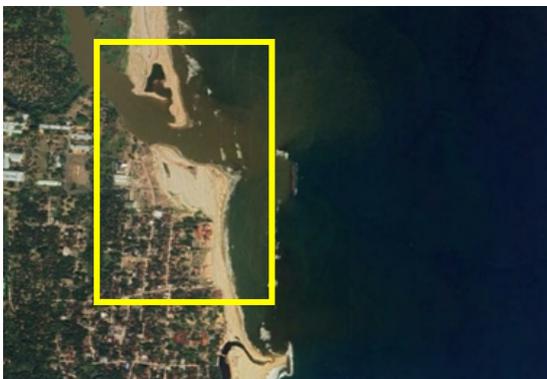
Figure 01: Study Area

B. Data Collection

Data collection was carried out using a combination of geospatial tools, field observations, and literature review to evaluate the extent and impacts of coastal erosion in the Oluvil coastal area. Historical satellite imagery available in Google Earth Pro 7.3.6.10201 (64-bit) was utilized to quantify shoreline changes between 2006 and 2024. The measuring tool in Google Earth Pro was specifically applied to measure the length of the wave breaker from a selected benchmark point along the coast during the period 2009–2024, enabling the assessment of structural influences on shoreline dynamics. First-hand data were gathered through direct field observations, focusing on land loss, damage to infrastructure, and alterations in coastal morphology. In addition, a comprehensive literature review of published scientific articles, technical reports, and local studies was conducted to supplement the satellite image analysis and to interpret erosion rates.

The historical analysis of Google Earth Pro imagery shows major changes to the Kali-Odai river mouth. During the monsoon season, the river mouth often expands due to increased water flows, but contraction is observed in drier mouths. The field component also included an assessment of environmental degradation linked to erosion. Biodiversity status at selected beach transects was qualitatively evaluated, focusing on vegetative cover loss, particularly mangroves and beach flora. Observations indicated that vegetation removal, partly through anthropogenic activities such as plant burning, exacerbated the vulnerability of the coastline to wave action and wind erosion. In addition, unregulated waste disposal by local communities, fishing activities, and other stakeholders was recorded as a significant factor contributing to coastal contamination, potentially affecting near shore water quality and accelerating ecological decline.

Based on the collected data, mitigation strategies were developed for the Oluvil coastal area to overcome coastal erosion and promote environmental sustainability and ecosystem resilience.

III. RESULT

A. Estimation of coastal erosion

Google Earth Pro images from 2006 show that there was a 18m gap between the wave breaker and the land. The harbour construction era began in 2008, and by that time, 54m of land had already been eroded due to an accelerated erosion process. Between 2008 and 2012, erosion continued, degrading nearly 190 m of land. In response to this rapid erosion, a wave breaker was installed in 2012. However, even after its installation, an effective solution to prevent coastal erosion remained elusive.

From 2012 to 2024, an additional 203 m of land was lost to erosion. Over the entire 16-year period (2006 - 2024), a total of 309 m of land was degraded (Figure 02). The ongoing erosion process has significantly impacted the Oluvil coastal area's habitat, ecosystem, and sustainability. Factors such as rising water levels and the mouth of the Kali-Odai River have also contributed to erosion. Additionally, the South Eastern University's border is directly connected to the coastal zone and the Kali-Odai River, both of which further accelerate erosion and reduce the land area

Due to persistent flooding conditions, erosion in the Oluvil coastal zone has accelerated, primarily driven by sediment transportation and deposition. The continuous movement of sediments has reshaped the coastal landscape, leading to significant land loss. As a result, the distance from the wave breaker to the land area has increased to 204 m.

Table 01 Length between Wave breaker to Brench Mark from Coastal area

Year	Length (m)	Eroded land length (m)	Total erosion (m)
2006	19	-	-
2008	53	35	33
2010	96	42	75
2012	96	-	75
2014	127	31	106
2016	189	62	168
2018	251	63	230
2020	320	70	300
2022	331	10	310
2024	204	-	**315**

According to Zoysa et al. (2023), the spatiotemporal evolution of shoreline dynamics along the Oluvil coastline in the Ampara District of Sri Lanka over a two-decade period (1991–2021), particularly around the economically significant Oluvil Harbor, was investigated using remote sensing and GIS techniques. Landsat 5 Thematic Mapper (TM), Landsat 7 Enhanced Thematic Mapper Plus (ETM+), and Landsat 8 Operational Land Imager images were used to delineate annual shorelines, with the Normalized Difference Water Index (NDWI) applied to differentiate land from water. The Digital Shoreline Analysis System (DSAS) was employed to quantify shoreline changes through Shoreline Change Envelope (SCE), Net Shoreline Movement (NSM), End Point Rate (EPR), and Linear Regression Rate (LRR). The study revealed that the Oluvil coast experienced both erosion and accretion, primarily influenced by harbor construction. The highest SCE values were recorded within the harbor region, reaching 523.8 m, while NSM ranged from 317.1 to 81.3 m in the northern area and 156.3 to 317.5 m in the harbor and southern adjacent zones. EPR analysis showed maximum rates of 3.0 - 10.7 m/year south of the harbor and 10.7 to 3.0 m/year north of the harbor. LRR further indicated erosion rates in the northern region of 3 to 10 m/year, while the southern beaches advanced at 3 - 14.3 m/year. These findings highlight significant spatial variability in shoreline dynamics, demonstrating the considerable influence of harbor construction on both erosion and accretion patterns.

(a)   (b)
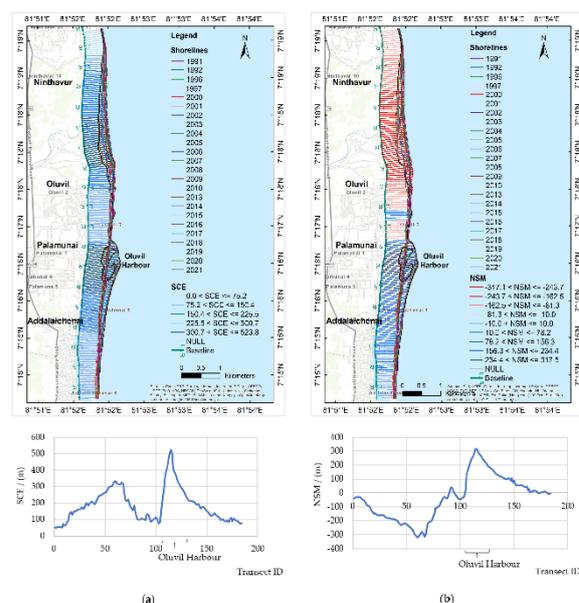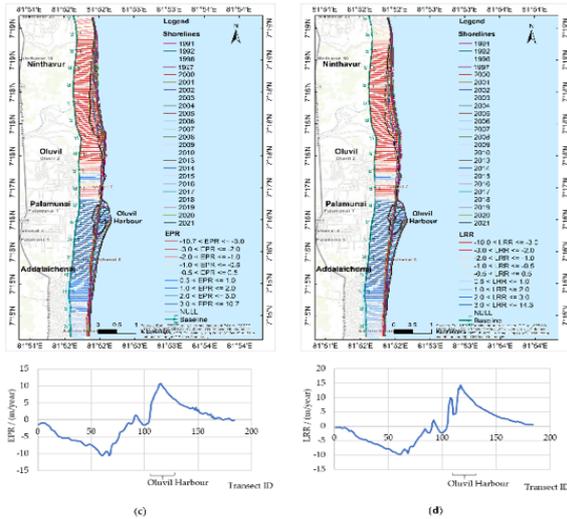
Figure 01: DSAS Statics of the Oluvil coast area: (a) For SCE; (b) For NSM; (c) For EPR; (d) For LRR. (Zoysa et al., 2023)

According to Nijamir et al., (2021), the coastal morpho dynamics of the Oluvil area, identified as a hotspot for coastal erosion, have been significantly impacted in recent years. Analysis of satellite images revealed that substantial coastal morphological changes occurred in the Oluvil coastline between 2011 and 2019.
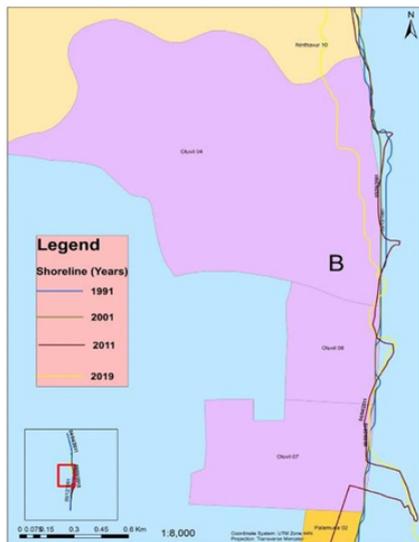
Figure 02: Periodic coastal morpho dynamics of 1991, 2001, 2011 and 2019 in Olvuil area

B. Changes of "Kali- Odai" River Mouth

Due to coastal erosion, seasonal erosion patterns, a reduction in vegetation cover, and the increased volume and speed of water flow, the mouth of the Kali-Odai River undergoes significant changes each year (Figure 04). The continuous reshaping of the river mouth affects sediment distribution, leading to alterations in coastal topography and contributing to land instability. The high-water flow and velocity accelerate the erosion process, gradually shifting the river's course and causing sediment deposition in new areas.

These changes not only disrupt the natural habitat and marine biodiversity but also pose challenges for local communities that rely on the river for fishing, agriculture, and other livelihoods. The loss of vegetation further weakens the soil structure, making the area more susceptible to erosion. Additionally, the interaction between tidal forces, rising sea levels, and human activities such as construction and land use changes to impact the river's dynamics, exacerbating the long-term degradation of the coastal environment.
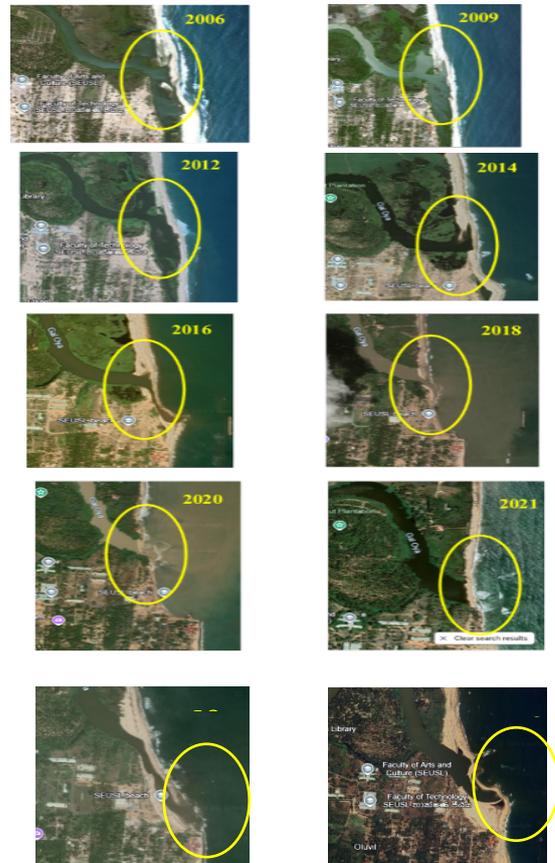
Figure 03: Changes at Kali- Odai River Mouth

C. Ecological periodic changes of the Oluvil

In 2019, showcases a stable and healthy coastal environment with lush green vegetation, including grass, coconut plants and small palm trees. The beach appears wide and intact, indicating a period of accretion where sediment deposition supports vegetation growth. This suggests that, at this time, the coastline was relatively undisturbed by erosion, allowing plant life to thrive and stabilize the area.

In contrast, 2020 reveals significant changes due to coastal erosion. The once-green landscape has disappeared, and the shoreline has visibly retreated, exposing wooden poles in the water, possibly remnants of coastal structures affected by erosion. The sand has been washed away, leaving behind a narrow, unstable shoreline. The presence of strong waves and rough sea conditions suggests that monsoonal influences and high wave energy have accelerated the erosion process, leading to the degradation of the beach environment.

From 2022 to the present, the coastal zone shows signs of partial recovery, with a wider sandy area compared to 2020. However, coastal vegetation is absent, indicating that while sediment deposition has occurred, the ecosystem has not fully regenerated. This suggests a dynamic cycle of erosion and accretion, where the shoreline fluctuates between loss and recovery.

Figure 05: Periodic changes of Oluvil coastal zone

D. Coastal pollution

Improper waste disposal has greatly polluted the coastal area, which has resulted in ecological and hydrological impacts. Kali-Odai River has also experienced an increase in the water level and the rate of flow, which may be because of the displacement of sediments, blockage of the natural drainage system or accumulation of waste beyond the required limit. Plastic bottles, food waste, polythene, chemical containers and other synthetic materials are highly deposited in the coastal zone, not only affecting the natural environment but also causing devastating effects on the coastal environment.

The deposition of these pollutants compromises the quality of fish in the Kali-Odai River, different biodiversity in the area, and the air and water in the coastal ecosystem. Improperly disposed bottles can cause chemical contamination, which can result in toxicity in the aquatic life, bioaccumulation in the food chain and possible health effects on humans who use the river and sea to fish and carry out other activities. Water quality impairment may also cause algal blooms, oxygen depletion, and prolonged habitat loss.

Figure 04: Coastal Pollution at Oluvil coastal zone

IV. DISCUSSION

Coastal erosion at Oluvil highlights the critical interaction between anthropogenic interventions and natural coastal dynamics, particularly following the construction of the Oluvil Fishing and Commercial Harbour. Breakwaters and harbor infrastructure have disrupted sediment transport, leading to severe land loss exceeding 300 m in some areas, while also modifying the Kali-Odai river mouth and accelerating bank erosion. Similar to other coastal zones in Sri Lanka, these changes have undermined local livelihoods dependent on fisheries and agriculture, while unregulated waste disposal has further degraded marine and terrestrial ecosystems (Gunasekara et al., 2021). Therefore, integrated and sustainable mitigation strategies are essential to restore environmental stability and support socio-economic resilience.

Ecosystem-based solutions such as mangrove and dune vegetation restoration are among the most effective strategies for coastal protection. In southern Sri Lanka, mangrove belts provided natural barriers that reduced shoreline retreat while also enhancing biodiversity (Dahdouh-Guebas et al., 2005). Comparable initiatives in Vietnam and the Philippines demonstrated that restored mangrove forests significantly reduced wave energy and storm surges, offering both ecological and economic benefits (Alongi, 2018). For Oluvil, replanting mangroves along the river mouth and beach fronts would enhance sediment retention, mitigate wave energy, and promote ecological recovery.

In addition to ecological measures, engineering and sediment management strategies are critical. Beach nourishment, coupled with hybrid engineering approaches such as dune reinforcement, has been proven more effective than hard infrastructure alone. For instance, hybrid measures applied in the Netherlands' "Sand Motor" project and at Uswetakeiyawa Beach in Sri L anka resulted in longer-lasting shoreline stability compared to traditional breakwaters (Ranasinghe et al., 2018). In Oluvil, introducing sand bypassing systems near the harbor could restore the disrupted littoral drift and balance sediment distribution, similar to successful applications at Durban, South Africa, and the Gold Coast, Australia (Smith et al., 2019).

Beyond erosion control, addressing pollution and waste management is vital to prevent further ecological decline. In Oluvil, unregulated dumping of plastics, polythene, and chemical residues into coastal areas exacerbates biodiversity loss and poses human health risks. Studies in Sri Lanka and Indonesia confirm that poor waste management is a major driver of marine ecosystem degradation (Jayatissa et al., 2020; Jambeck et al., 2015). Therefore, integrated waste collection and recycling programs, alongside strict enforcement of plastic reduction policies, are essential.

Equally important is community participation and policy enforcement. Community-based coastal management initiatives in eastern Sri Lanka demonstrated improved compliance and ecosystem resilience when local fishers were directly engaged (Fernando et al., 2019). International experiences, such as Japan's integrated coastal zone management (ICZM) policies and Bangladesh's community-driven mangrove rehabilitation programs, underscore the importance of combining local knowledge with state policy (Islam et al., 2020). For Oluvil, strengthening Environmental Impact Assessments (EIA), enforcing coastal setback zones, and implementing continuous shoreline monitoring programs would ensure long-term effectiveness.

Overall, the evidence suggests that no single solution is sufficient to address erosion in Oluvil. Instead, a combination of ecosystem restoration, soft engineering, sediment management, waste reduction, and strong community and policy frameworks is required. By integrating lessons from both Sri Lanka and international best practices, a holistic approach can be developed that restores ecological balance, safeguards livelihoods, and ensures sustainable coastal management.

V.   CONCLUSION

The Oluvil coastal area has been increasingly vulnerable to environmental degradation due to harbour construction, shoreline erosion, and pollution. The disruption of sediment transport has accelerated erosion, while plastic and chemical contamination has further degraded ecosystems and livelihoods. These challenges highlight the urgent need for targeted and sustainable mitigation strategies. Effective interventions should focus on shoreline restoration through mangrove rehabilitation, dune stabilization, and artificial reef construction, which have been successfully implemented in other coastal regions such as the Philippines and India to reduce wave energy and enhance natural sediment deposition. In addition, integrated waste management programs and strict enforcement of pollution control policies are essential to address the growing issue of marine debris. The adoption of soft-engineering solutions, community-based coastal monitoring, and adaptive management practices can ensure long-term ecological resilience while minimizing the risks associated with hard structures that often exacerbate erosion. By integrating scientific evaluation with participatory coastal zone planning, Oluvil can implement a balanced approach that safeguards both environmental stability and socio-economic

development, ensuring that the coastline remains resilient and productive for future generations.

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TRACK - COMPUTING AND INFORMATION SYSTEMS

Personalized Allergen Recommender System: Ingredient List Scanning for Safe Food Choices

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Abstract

Understanding every ingredient in a food is crucial for everyone who has food allergies and consumes packaged foods. However, the component or ingredient lists are unable to recognized by only reading due to the lack of education related to coding conventions among the public. Despite the availability of certain allergen recommendation applications that might aid in pinpointing ingredients, the available applications are not personalized and are not supported efficiently. This research aims to develop a personalized allergen recommender system that helps with safe food selections through ingredient list scanning. The final deliverable is a mobile application that scans the list of ingredients, classifies allergen ingredients for the consumer, and provides allergen recommendations to the user. The application can identify high-risk and the most common 25 food ingredients that can cause allergic. The Tesseract OCR has been used to extract text from the captured image of ingredients. After the text is extracted, the application compares it with a user-predefined list of allergens and based on the result provides the recommendation to the user. The developed application was able to successfully extract ingredient text and accurately identify allergenic ingredients in real-time. This study demonstrates that a AI -enhanced personalized allergen recommender system can improve user safety and awareness, supporting informed decisions about food products.

Keywords: Allergen Free Food, Allergen Food Recommendation Systems, Food Allergies, Mobile Application, Tesseract

I. INTRODUCTION

Food allergy (FA) is one of the most common issues all around the world that can lead to both major and minor health problems. FA is an exaggerated or hypersensitive immune response to substances that are generally not harmful (Jain and Zachariah, 2022). It is any negative reaction to food that is immunologically mediated and repeatable in a blinded environment (De Martinis et al., 2020; Roberts and Lack, 2003). The allergic reaction can be different from one person to other person and leads to various kinds of symptoms such as dermatitis, asthma, rhinitis, and potentially severe, fatal responses like anaphylaxis, insect sensitivity, animal danger, food, and pollen, which may result in allergies. Individuals with food allergies must carefully evaluate food ingredients to avoid potential allergic reactions.

Currently, food allergy has become a significant public health concern due to its increasing prevalence, affecting approximately 220 million people worldwide (De Martinis et al., 2020). Food allergies tend to have a greater impact on children than on adults. Children are particularly vulnerable due to factors such as their immature immune and digestive systems, lower body weight, potential for long-term complications, distinct behavioral traits, limited communication abilities, and heightened susceptibility to allergens and sensitivities (Genuneit et al., 2017). The prevalence of food allergies among children is notably higher, estimated at around 10% compared to 1%–2% in adults (Mandracchia et al., 2020). Therefore, it is crucial for both children and adults to remain vigilant about avoiding allergenic food ingredients. One effective preventive strategy is the accurate identification of food allergens, which helps minimize the risk of exposure to substances that may trigger allergic reactions (Anvari et al., 2018; Jain and Zachariah, 2022).

Consequently, understanding every ingredient in food products is essential for individuals with

food allergies (FA), particularly when consuming packaged foods (Wong et al., 2016). Individuals with allergies and other health conditions tend to be especially vigilant about the ingredients they consume. This concern is heightened by the widespread consumption of packaged snacks and processed foods, which are particularly common in the diets of both children and adults (Gearhardt & Hebebrand, 2021). According to international standards in the food industry, all food packaging must clearly list the ingredients used, including food additives such as colorings and flavorings in order to ensure consumer safety and informed decision-making. Reading the ingredient list or the bar code that is available at the front or back of the packaging is a common approach to obtaining the list of ingredients (Ni Mhurchu et al., 2018). The World Health Organization (WHO) has developed the Codex Alimentarius (commonly referred to as CODEX), a comprehensive system of standards for the labeling and naming of food ingredients. According to the Codex Alimentarius Committee, some European countries utilize E numbers, while others adopt the International Numbering System (INS) for food additives (Cox et al., 2020; Holleman et al., 2021; Stolte et al., 2013). Most food companies adopt these codes as a standardized method for listing base ingredients in their products.

However, the public often struggles to interpret these codes due to a lack of awareness and education regarding the coding conventions. In the challenging context of identifying allergens and understanding food ingredients in packaged foods, numerous computational research efforts have sought digital solutions to address this issue. One commonly used technological approach is Optical Character Recognition (OCR), which enables the extraction of text from images and is employed by several existing mobile applications (Jain & Zachariah, 2022). Additionally, some applications utilize deep learning techniques to identify food items (Zhou et al., 2019). However, these systems do not specifically identify allergenic components in food products, nor do they provide allergen recommendations personalized to individual users.

The objective of this study is to design and develop a mobile application capable of identifying allergenic ingredients by scanning food ingredient lists. Specifically, the study aims to create a personalized allergen recommender system that facilitates safe food choices through automated analysis of ingredient information. The final deliverable was a mobile application capable of scanning ingredient lists and classifying potential allergens based on user-specific input. The system provides personalized recommendations by considering the user's individual allergen profile. The study primarily targeted the identification of the 25 most common and high-risk food allergens, using ingredient lists presented in English and conforming to international labeling standards defined by the Codex Alimentarius.

II. RELATED WORKS

In recent years, various technologies have been employed to develop food-related recommendation systems, utilizing machine learning, deep learning, and other computational methods to deliver personalized dietary insights, food identification, and health-related guidance. Alemany-Bordera et al. (2016) developed a web-based application using machine learning to recommend Spanish recipes personalized to user preferences. However, the system's recommendations are not based on specific food ingredients. Senapati et al (2025) built a computer-based system for food allergy detection that uses the ResNet-50 model, adapted to the Food-101 dataset, to recognize food types, validate labels, and provide nutritional information. Similarly, Rostami et al. (2022) introduced a deep learning-based dietary recommendation platform focused on diet management. Although the platform is effective in delivering user-specific meal suggestions, it does not incorporate ingredient-level personalization.

Jane et al. (2022) proposed another web-based system that assists users in identifying restaurants catering to their allergen requirements. Although helpful for individuals with food allergies, the system lacks functionality for personalized, ingredient-specific recommendations. In another study, Swain et al. (2023) developed a mobile application employing YOLO-based object detection and Convolutional Neural Networks (CNNs) to identify ingredients from food images and recommend recipes. While innovative, the

system does not offer user-specific suggestions or account for allergen sensitivities.

Additionally, Gearhardt and Hebebrand (2021) explored the use of Optical Character Recognition (OCR) for ingredient analysis in a mobile application, providing general health suggestions. However, similar to other approaches, this system does not deliver personalized allergen recommendations. In 2021, Rohini et al. designed framework to identify fruits and packed food that can be include allergen nutrients by using OCR and deep learning. Across the reviewed literature, a significant gap exists that despite the availability of various systems to support food identification and health-based recommendations, generally a few offers personalized allergen detection and ingredient-specific dietary guidance personalized to individual user profiles.

III. METHODOLOGY

This section outlines the methodology for developing a personalized allergen recommendation system. The application is designed to operate on Android and iOS platforms, offering users a seamless experience in identifying potential allergens. The system development process follows several key phases, illustrated in Figure 01.
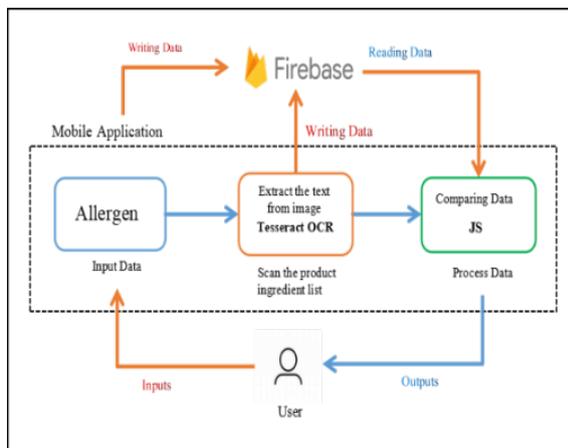
Figure 01: System Development Process

A. Text Detection

A critical step in this study involved extracting textual data from food labels to identify potential allergenic ingredients. The text extraction process was implemented using the Tesseract Optical Character Recognition (OCR) engine and

followed a structured sequence of stages, including image input handling, preprocessing, and character recognition.

The process began when the user scanned a food label using the application's built-in camera functionality, which was implemented via the Expo ImagePicker module in React Native. The captured image was then passed to the OCR engine for further processing. Tesseract.js, a JavaScript wrapper for the Tesseract OCR engine, was integrated into the mobile application to enable real-time text recognition.

To ensure accurate recognition, Tesseract applied internal preprocessing techniques such as image resizing, brightness adjustment, grayscale conversion, and normalization. These processes enhanced image clarity and improved character detection performance.

The OCR engine utilized trained data models, specifically the eng.traineddata file for English, in order to accurately interpret characters. During recognition, Tesseract employed multiple OCR algorithms to analyze and convert visual text from the image into a structured string format. This extracted text was then forwarded to the next stage of processing for allergen identification and classification.

B. Text comparing and Generating Recommendation

To compare text, the application retrieved stored allergen data from Firebase, where allergen information was maintained as documents containing arrays of allergen terms. Both the extracted text from the Tesseract OCR engine and the allergen data from Firebase underwent normalization. This process included converting all text to lowercase and removing special characters and spaces to ensure consistency in the comparison.

A string-matching algorithm was applied, in which each allergen from the stored list was checked against the extracted text. A dynamic regular expression (regex) was constructed for each allergen keyword to ensure accurate detection of allergen terms within the text. For example, a regex pattern was used to identify "peanut" as a standalone word, avoiding false positives such as "peanut butter."

Detected allergens were then stored in a set to prevent duplication and were displayed to the user. This approach ensured that the extracted ingredient list was systematically compared with the stored allergen data, providing users with timely feedback on potential food allergens.

C. Database Management

Firebase was utilized in this project to manage user authentication and to store allergy-related information specific to each user. The implementation included the integration of Firebase Authentication, which securely handled user login and registration processes. This ensured that users could access personalized features of the application in a secure manner. Additionally, Firebase functioned as the primary database for storing and retrieving allergenic ingredient data. This allowed the application to provide personalized allergen detection services based on individual user profiles. The use of Firebase enabled efficient and secure storage, real-time data updates, and rapid query handling for allergen-related information.

D. Mobile Application Design and Implementation

The User Interface (UI) was developed using React Native components to ensure a seamless cross-platform experience. The UI layer was designed to be intuitive and user-friendly, enabling users to navigate the application and perform necessary actions with minimal effort. By employing React Native components along with Bootstrap styling, the interface achieved visual consistency and responsiveness across various device platforms, thereby enhancing the overall user experience.

Images were captured either through the camera or selected from the gallery of the device. This dual-option functionality allowed users to either take a real-time image or choose an existing one from their photo library. The captured or selected image was then processed using the Tesseract OCR engine for text extraction. The Tesseract library was integrated into the application and configured with the eng.traineddata file to support accurate recognition of English text.

Allergic ingredient data entered by users was stored in Firebase and retrieved during the scanning process. The extracted text from the image was compared with the stored allergen data to identify potential matches. This comparison allowed the system to detect and highlight allergenic ingredients present in the scanned food label. If a match was found, the application displayed an alert message, notifying the user of the presence of specific allergens. This feature ensured that users were promptly informed about potential allergenic content in food products, promoting safer consumption decisions.

IV. RESULTS AND DISCUSSION

The development and integration of these features resulted in an application that effectively meets the needs of a personalized food allergen recommendation system. It successfully fulfilled the primary goal of the study.

The application design was evaluated against established design guidelines to ensure adherence to best practices in usability, including principles such as consistency and standards, visibility of system status, user control and freedom, error prevention, and simplicity and intuitive navigation, consistency, and responsiveness across devices. This preliminary evaluation confirmed that the system's interface and core functionalities, characterized by a clean and simple layout, consistent design language, and responsive design align well with recognized heuristics for user-friendly design. The testing also highlighted that the Optical Character Recognition (OCR) functionality, integrated with Firebase for real-time processing, performed reliably under varying conditions, enhancing user confidence in the allergen detection feature (See Figure 02 and Figure 03).

In addition, Firebase provided a seamless mechanism to store and retrieve both user-specific data, such as allergen preferences, and the global allergen database, ensuring that users received up-to-date information regardless of the device used. Any changes to allergen data or user settings were synchronized in real time across the application, enhancing the system's responsiveness and reliability.

As a future work, formal usability testing involving actual users will be conducted to assess the effectiveness, efficiency, and user satisfaction of the application in real-world scenarios. In

addition, the future work focus on refining OCR capabilities to improve text extraction accuracy and expanding the database of allergens to cover a wider range of products. These future efforts aim to enhance the application's overall performance and user experience, ensuring it becomes a more reliable and comprehensive tool for allergen detection and food safety.
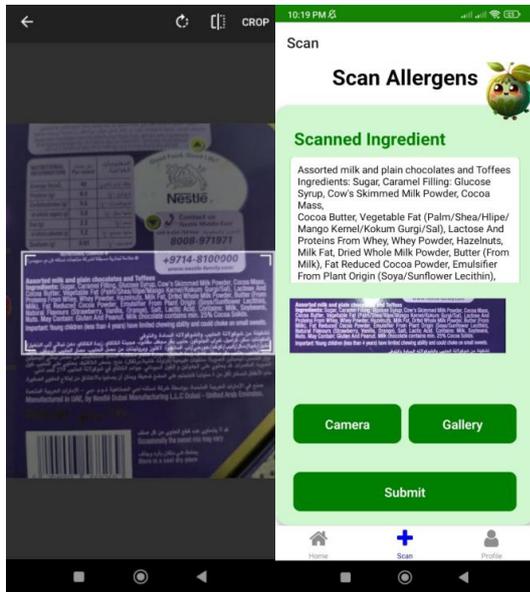
Figure 02: Interface scanning ingredients
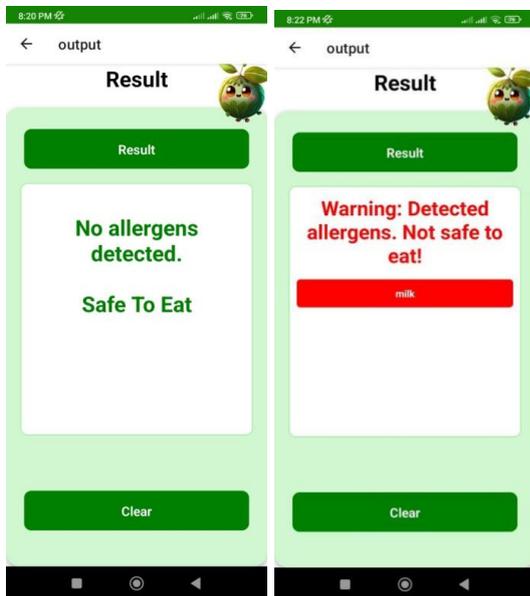
Figure 03: Interface displaying results

V. CONCLUSION

This study demonstrates the development and application of a personalized food allergy recommendation system that uses advanced technologies to enhance dietary safety. By enabling users to scan food labels and receive real-time allergen alerts based on their individual profiles, the application supports informed and safer food choices. Its user-friendly design ensures accessibility across varying levels of technical proficiency, facilitating easy navigation of key features such as allergen scanning, profile management, and personalized recommendations.

However, this research has certain limitations. The accuracy of the OCR depends heavily on image quality, font variations, and label clarity, which can affect to correct allergen detection. The allergen database used in this study was limited to 25 common allergens and may not cover region-specific or newly emerging allergens. In addition, testing was carried out in controlled conditions, and broader real-world validation with diverse food products through a usability analysis is still required.

Future work will focus on improving the accuracy of OCR and expanding the allergen database to include a broader spectrum of products, thereby increasing the system's reliability and coverage. This research highlights the significant potential of technology to address public health challenges associated with food allergies, offering a scalable solution to empower users in managing their dietary risks. Continued development and user-centered enhancements will further establish the application as an essential tool in promoting safe eating practices for individuals with food allergies.

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Centralized Web Application for University Students' Internship Placements: A Technological Approach to Career Readiness

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Abstract

University students often face significant challenges in securing internships and job placements due to a fragmented and inefficient job search process. This research project aims to develop a web application addressing the need for a centralized, user-friendly platform that consolidates job search efforts. The proposed web application leverages modern web technologies to provide real-time updates, efficient filtering options, and a comprehensive repository of job opportunities, streamlining the job search process. The current lack of a structured and efficient approach to finding internships and job placements leads to missed opportunities and increased frustration among students. This project tackles these issues by creating a dedicated web application designed to simplify and centralize the job search process. The front end poses real-time updates and interactive features like autocomplete and infinite scrolling. The back-end is powered by the Laravel framework, chosen for its robust features, including the Blade engine and its MVC architecture. The usability testing generated key findings confirming the platform's usability. Most student users successfully navigated the interface and completed the primary job/ internship application task independently, demonstrating that the system is effective in enhancing the job search process. The project is significant in its potential to enhance the career readiness of students by providing a reliable platform that connects them with potential employers, improving the overall job search experience and increasing the chances of securing suitable internships and job placements.

Keywords: Career Readiness, Internship Placement, Job Search Process, Modern Web Technologies, Web Application

I. INTRODUCTION

University students often face difficulties in securing internships and job placements due to a fragmented approach to job searching. The preliminary survey conducted shows that the difficulties faced by the students in finding job placement are critical. Figure 01 visualizes the summary of the preliminary view of the challenges faced by students in finding internships.
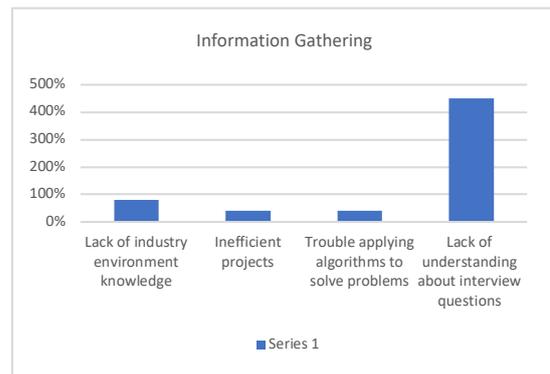
Figure 01: Challenges faced by students in job placement

This project aims to consolidate job search efforts into a single, user-friendly web platform specifically designed for students in the Technology faculty. By leveraging modern web technologies, the platform will provide real-time updates, efficient filtering options, and a centralized repository of job opportunities. The current lack of a structured, efficient process for finding internships and job placements leads to missed opportunities for students. Studies have shown that fragmented job search processes can result in students feeling overwhelmed and missing out on potential opportunities (Pham & Soltani, 2021; Khattab et al., 2022). This project addresses this problem by creating a dedicated web application streamlining the job search

process. The proposed solution involves developing a web application that allows students to search and apply for internships and job placements. Additionally, it will provide employers with a platform to post vacancies and review applications, ensuring the system is user-friendly, responsive, and provides real-time updates.
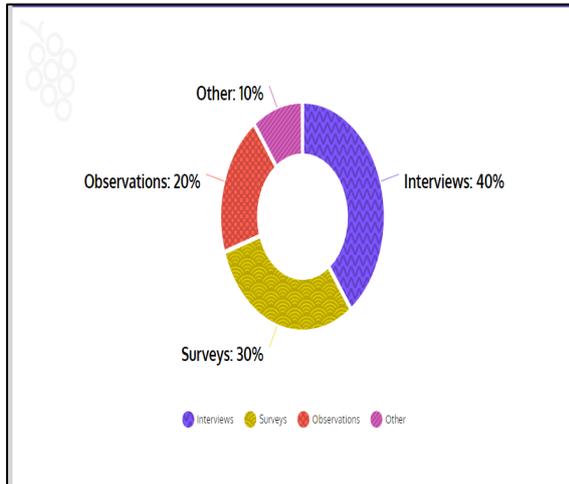
Figure 02: Requirement Gathering Process

The importance of a centralized job search platform for university students cannot be overstated. According to Ben Dhia (2020), students who have access to a structured job search system are more likely to secure internships and job placements compared to those who rely on traditional methods. Furthermore, the integration of real-time updates and efficient filtering options has been found to significantly improve user satisfaction and engagement with job search platforms (Lu et al.,2015)

The scope of the project includes designing and developing the web application, focusing initially on the Technology faculty of the South Eastern University of Sri Lanka. Future expansions can include other faculties and additional features based on user feedback. This project is significant as it directly impacts students' career readiness, providing a structured approach to job hunting and facilitating connections between students and potential employers. The development of this platform will not only help students in securing internships and job placements but also enhance their overall career readiness by providing them with a tool that simplifies and streamlines the job search process.

II. METHODOLOGY

A. Requirement Gathering

The requirement-gathering phase employed multiple techniques to capture comprehensive user needs and expectations Figure 02. Structured and semi-structured interviews were conducted with key stakeholders including students, university placement officers, and company HR representatives to gather qualitative insights into their specific needs and expectations. To complement this, online surveys were distributed to a broader audience to collect quantitative data on desired features, while direct observations of existing placement processes helped identify current inefficiencies. This multi-faceted approach ensured that the data collected, covering user preferences, pain points, and required functionalities, was thorough and well-rounded.

These interviews provided qualitative insights into their specific needs and expectations. Additionally, online surveys were distributed to a broader audience to collect quantitative data regarding desired features and functionalities. Observations of current internship placement processes at universities and companies helped identify inefficiencies and areas for improvement

Key stakeholders involved in this phase were students, who provided insights into their preferences for applying to internships; university placement officers, who shared how they manage internship postings and student applications; and company HR representatives, who discussed their requirements for posting internship opportunities and selecting candidates. The data collected included user preferences, pain points in the current process, required functionalities, and suggestions for improvements. The process also involved conducting structured interviews with students, university placement officers, and company HR representatives to understand their needs and expectations. Online surveys provided quantitative data on desired features and functionalities. Observations of existing internship placement processes helped identify inefficiencies and areas for improvement.

B. UI/UX Design

During the initial stages of the Internship and Job Placement Management System project, significant effort was dedicated to designing UI/UX prototypes to ensure an intuitive and user-friendly experience for all users. The primary goal

of these prototypes was to create a visually appealing and highly functional interface that would cater to the diverse needs of students, employers, and university placement officers.

The design process began with thorough research and analysis of the existing systems and user preferences. This involved studying various design patterns and trends, conducting user interviews, and gathering feedback through surveys. With this information, wireframes and mockups were created for key interfaces, including the student dashboard, company portal, and admin panel. These prototypes provided a clear visual representation of the system's layout, navigation flow, and overall aesthetic. In designing the UI/UX, particular attention was given to ease of use and accessibility. The student dashboard, for instance, features a clean and organized layout, allowing users to easily navigate through different sections such as job postings, applications, and notifications. The use of a consistent color scheme and typography ensures a cohesive look and feel, while interactive elements like buttons and forms are designed for intuitive use.

The prototypes also included advanced search functionality with multiple filters, enabling students to quickly find relevant internships based on criteria such as location, industry, and duration. Real-time updates and notifications were integrated into the design to keep users informed about new job postings and application statuses. For employers, the company portal was designed to streamline the process of posting job vacancies and reviewing applications, with a focus on simplicity and efficiency. Throughout the design process, feedback was continuously sought from potential users to refine and improve the prototypes. Usability testing sessions were conducted to identify any issues and gather suggestions for enhancements. This iterative approach ensured that the final design was not only aesthetically pleasing but also highly functional and aligned with user needs. These initial UI/UX designs (Figure 03) served as a critical foundation for the development phase, providing a clear blueprint for the implementation of the system. By prioritizing user experience from the outset, the project team was able to create a prototype that effectively addresses the challenges faced by students in finding internships and job placements, ultimately contributing to the system's success.

The mockups set the fundamental layout, core concept, and visual style, which were then improved and implemented via the Laravel Blade templating engine to create the final user facing interface that will be shown later in the paper.

C. System Design

The system architecture includes a front-end developed with HTML, CSS, Bootstrap, and JavaScript, and a back end using Laravel. Diagrams and mockups illustrate the database schema, user interface, and overall system architecture. The system design for the internship job placement project was meticulously planned to ensure robust architecture and user-friendly interfaces. The system architecture followed a three-tier model consisting of a presentation layer, a business logic layer, and a data layer. Figure 04 shows the overview of the system design.

The architecture of the system is based on a strong three-tier structure, as shown in Figure 04. This architecture separates the application's concerns into logical tiers, which allows the application to be both scalable and maintainable.

1) Presentation Layer (Front-End):

This tier includes the user interface and runs in the user's web browser. It is built with HTML, CSS, and JavaScript. This layer is responsible for presenting information to the user and capturing input from the user. In our project layer, this tier renders the Blade templates sent from the server.

2) Application Layer (Back-End):

The center of the application is the back-end, which is part of the Laravel framework running on a web server and contains all the business logic. When a user sends a request, for example to search for a job, the server receives the request and routes the request to the appropriate controller in Laravel, where the request will be handled, retrieving information from the database, processing it as needed, and preparing suitable information for the user.

3) Data Layer (Database):

This layer contains a MySQL relational database. This layer will provide for storing, retrieving, and
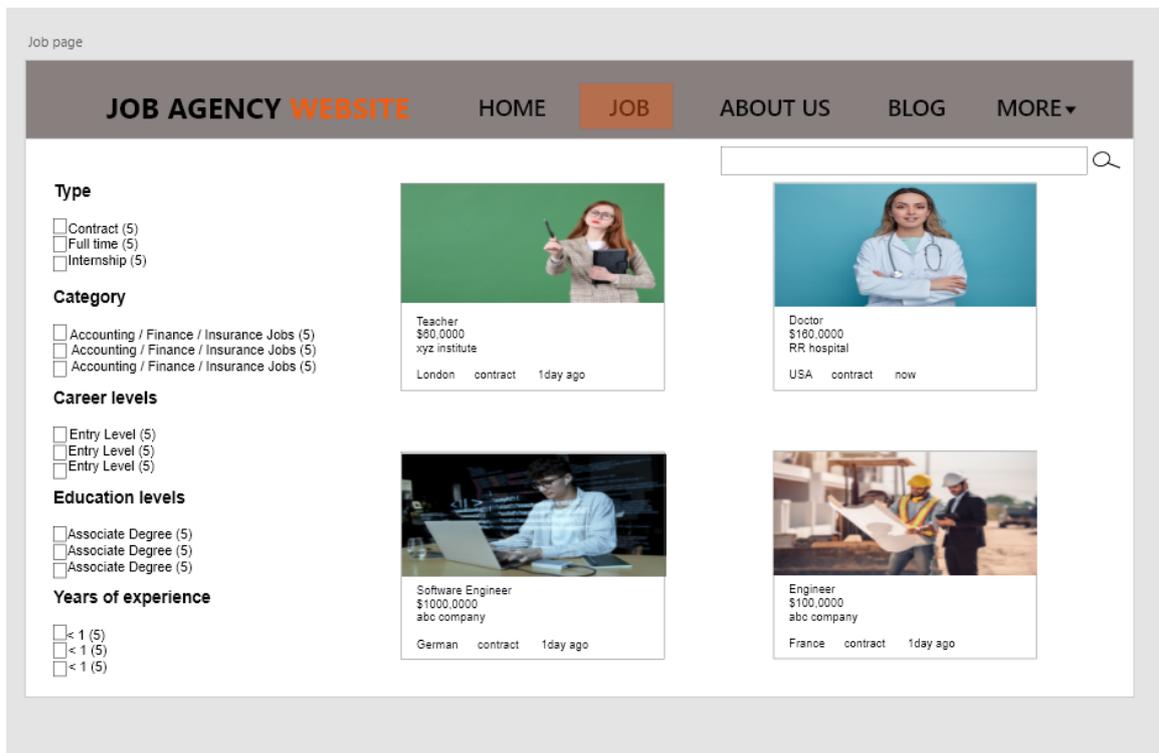
Figure 03: Early-stage UI/UX Mockup for the Job Search Page and About Us Page

managing all data related to the application (e.g. user profiles, company profiles, job postings, etc.). The Laravel application will communicate with this database using its Eloquent ORM (Object-Relational Mapper).

This architecture ensures that a user request flows logically from the browser to the Laravel application, which then securely interacts with the database before returning a fully rendered page to the user.

D. Development

The development process follows agile practices, with iterative cycles of coding, testing, and feedback. Technologies used include AJAX for real-time updates, Blade for templating in Laravel, and integrated payment gateways for subscription services. The development process for the internship job placement project adhered to agile methodologies, enabling incremental progress and continuous improvement. The team conducted bi-weekly sprints, with each sprint focusing on defined goals and deliverables based on priority and feedback.
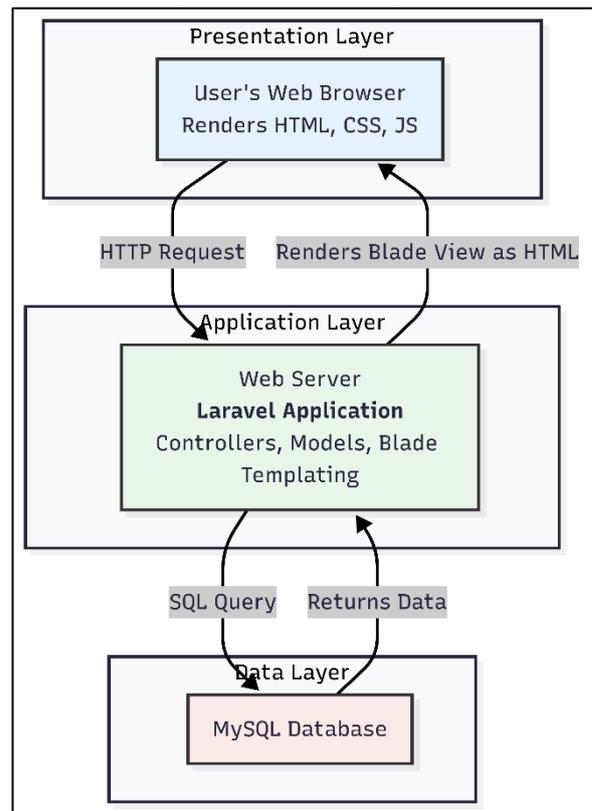
Figure 04: The Three-Tier System Architecture of the Placement Platform

Daily stand-ups were held to discuss progress, challenges, and next steps, while sprint reviews provided opportunities to demonstrate completed features to stakeholders for feedback. Sprint retrospectives were used to evaluate the process and identify improvements for subsequent cycles. The development utilized a range of established web technologies. The back end was built using the robust Laravel framework, while the front end was rendered using HTML and Laravel's native Blade templating engine. Dynamic user interactions and form validations were implemented with JavaScript and AJAX to ensure a responsive user experience. Git was employed for source code management and collaboration, and Jira was used for tracking tasks, bugs, and sprint progress. To ensure a professional and visually appealing interface for the Internship and Job Placement Management System, we sourced templates from the HTML Codex website. HTML Codex is a reputable online resource known for its extensive collection of high-quality HTML templates, which are responsive and modern, catering to various web project needs. This resource provided the essential tools needed to develop a sophisticated and user-friendly web application Additionally, we utilized resources and customization codes from the Bootstrap platform. Bootstrap's components, such as "Modals," "Form Control," and validation classes like "is-valid" and "is-invalid," were instrumental in enhancing the functionality and user experience of the application

E. Testing

Testing strategies included unit tests for individual components, integration tests for system interactions, and user acceptance testing. Test cases covered all major functionalities, and automated tools were used for continuous integration and deployment. A comprehensive testing strategy was employed to ensure the system's functionality and reliability. The strategy included unit testing to validate individual components and functions, integration testing to verify interactions between different modules, system testing for end-to-end validation, and user acceptance testing (UAT) involving actual users to ensure the system met their needs and expectations.

Detailed test cases were developed to cover all possible scenarios, including edge cases. Manual testing was performed by QA testers to validate functionality and user experience, while automated testing utilized tools like Selenium for regression testing, ensuring that new code changes did not break existing functionality.

F. Documentation

Comprehensive user manuals, technical specifications, and project reports were created to ensure ease of use and maintenance. Thorough documentation was an integral part of the project to ensure that users and developers could effectively use and maintain the system. User manuals were created to assist users in navigating and utilizing the system, featuring step-by-step instructions, screenshots, and troubleshooting tips. Technical specifications documented the system architecture, database schema, API endpoints, and configuration details, providing detailed descriptions of each module, component, and their interactions. Regular progress reports detailed the development milestones, testing results, and stakeholder feedback, culminating in a final project report that summarized the entire project lifecycle, including challenges faced and solutions implemented.

III. RESULTS AND DISCUSSION

A. Development Progress

The development progress of the internship job placement system was meticulously documented, with each phase summarized to highlight key milestones and challenges encountered.

During the initial phases, the focus was on setting up the foundational architecture and developing core functionalities. Significant milestones included the successful integration of user authentication, the creation of a dynamic database schema, and the development of the user interface.

As the project advanced, challenges such as optimizing AJAX calls for performance arose. These challenges were addressed by implementing efficient coding practices and optimizing server-side processing, which significantly improved the system's response

time and overall performance. The team also faced difficulties in managing real-time data updates and ensuring a seamless user experience. Through iterative testing and user feedback, solutions were developed, including the enhancement of asynchronous operations and the implementation of caching mechanisms to reduce server load.

B. System Features

The system boasts several key features designed to enhance the user experience and streamline the internship search process. A notable feature is the advanced search functionality, which allows users to filter internship postings based on various criteria such as location, industry, and duration. This feature is complemented by real-time job posting updates, ensuring users have access to the latest opportunities as soon as they become available. The system's responsive design ensures accessibility across different devices, providing a consistent and user-friendly experience whether accessed via desktop, tablet, or mobile phone.

C. Search Functionality

The search functionality is a core component of the system, enabling users to perform detailed searches with multiple filters. This feature significantly reduces the time and effort required to find suitable internships by allowing users to narrow down results based on specific parameters. The search interface is intuitive, with auto-suggestions and real-time filtering to enhance user experience.

D. Testing Outcomes

Extensive testing was conducted to ensure the system's reliability and usability. Testing phases included unit testing, integration testing, system testing, and user acceptance testing (UAT). During testing, a few bugs were identified, such as issues with infinite scrolling and the autocomplete feature in the search functionality.

These bugs were promptly resolved through code debugging and optimization. Additionally, performance testing highlighted areas where AJAX calls needed optimization, which was addressed by streamlining the calls and reducing unnecessary server requests. The testing outcomes demonstrated the system's stability and efficiency, with user feedback from usability testing sessions showed a strong degree of satisfaction demonstrated by most participants' ability to independently complete key tasks including job search and filtering results that showed the system worked as intended and was user friendly.

E. User Feedback

Initial user feedback through informal discussion and observation was overwhelmingly positive. Students highlighted the platform's clean, modern design and appreciated the convenience of real-time job postings. Employers also indicated that posting vacancies and managing applications was simple and efficient.

Additionally, there were suggestions to enhance the user interface with more interactive elements and to expand the filtering options in the search functionality. These suggestions are being considered for future updates to further improve the system's effectiveness and user satisfaction.

IV. CONCLUSION

The project successfully culminated in the development of a comprehensive web application tailored to meet the needs of university students seeking internships and job placements. The platform was meticulously crafted to offer an intuitive and user-friendly interface, integrated with powerful search and filtering functionalities. Essential components such as user authentication, real-time job posting updates, and a responsive design were seamlessly incorporated, resulting in a robust and accessible system. The development process encompassed extensive requirement gathering, meticulous system design, iterative development, and thorough testing, all of which contributed to the creation of a reliable and effective tool for students.

By providing a centralized and efficient resource for job hunting, the platform has streamlined the process of finding and applying for internships and job placements. Students can now easily access a broad range of opportunities tailored to their interests and qualifications, greatly enhancing their chances of securing relevant positions. Employers

benefit from the platform as well, gaining access to a pool of qualified candidates and thereby facilitating the recruitment process. Overall, the platform has proven to be a valuable asset in bridging the gap between students and potential employers, fostering career development and readiness.

V. FUTURE WORK

Looking ahead, several potential improvements and expansions have been identified to further enhance the platform's capabilities. One major area for future work is the expansion of the platform to other faculties, allowing a broader range of students to benefit from its features. Additionally, integrating AI-based job recommendations can provide personalized internship and job suggestions based on user profiles and past interactions, further improving the user experience. Enhancing security features is also a priority, ensuring the protection of user data and maintaining the platform's integrity. These future enhancements aim to make the platform even more comprehensive and secure, catering to a wider audience and adapting to evolving user needs.

In our ongoing efforts to enhance the Internship and Job Placement Management System, we have identified several key areas for future development that will significantly benefit students. One such enhancement is the addition of mock interview options. Recognizing the importance of interview preparation in securing internships and job placements, this feature will allow students to practice their interviewing skills in a simulated environment. The mock interview module will include a variety of industry-specific questions and scenarios, providing students with a realistic experience. Feedback will be provided after each mock interview, highlighting areas of strength and offering constructive suggestions for improvement. This feature aims to build students' confidence and competence, ultimately improving their chances of success in real interviews.

Another pivotal feature we plan to introduce is a CV analysis and feedback system. This tool will analyze students' CVs and resumes, assessing various aspects such as formatting, keyword optimization, and content relevance. Using advanced algorithms and industry best practices, the system will identify areas where the CV can be improved to make it more appealing to potential employers. Students will receive detailed feedback, including tips on how to enhance their CVs to better match job descriptions and stand out in the competitive job market. This feature will empower students to create high-quality, optimized resumes that effectively showcase their skills and experiences. Integrating these future features into the system aligns with our commitment to providing comprehensive career support to students. By offering mock interviews and CV analysis, we aim to equip students with the necessary tools and feedback to enhance their career readiness. These enhancements will not only improve students' chances of securing internships and job placements but also foster their professional development. As we continue to evolve and expand the system, we remain dedicated to leveraging technology to bridge the gap between academia and the industry, ultimately contributing to the success and career growth of our students.

VI. REFLECTION

The project has provided invaluable learning experiences for the development team. Working with advanced web technologies and agile development practices has honed the team's technical and collaborative skills. The iterative nature of agile development allowed for continuous improvement and adaptation based on user feedback, ensuring the final product met the needs of its users. Challenges such as optimizing performance and ensuring system reliability were addressed through innovative solutions and teamwork. This project not only resulted in a successful product but also contributed to the professional growth of the team, equipping them with practical skills and insights that will be beneficial in future endeavors.

The development and implementation of the Internship and Job Placement Management System for the Technology faculty at the South Eastern University of Sri Lanka have been a significant step towards enhancing students' career readiness. This web application has successfully streamlined the process of finding and applying for internships and job placements by consolidating job search efforts into a single,

user-friendly platform. The use of modern web technologies and agile development practices ensured that the system was not only robust and responsive but also capable of providing real-time updates and efficient filtering options.

Through comprehensive requirement gathering, involving students, faculty members, and potential employers, the project team was able to develop a solution that addressed the key challenges faced by students. The positive feedback from initial users underscores the system's effectiveness and the high level of user satisfaction. Looking forward, the potential for expanding the platform to other faculties and integrating advanced features like AI-based job recommendations highlights the project's commitment to continuous improvement and innovation. This project not only delivered a valuable tool for students and employers but also provided significant learning experiences for the development team, ensuring their preparedness for future projects. Overall, the Internship and Job Placement Management System stand as a testament to the impactful application of technology in educational contexts, significantly improving students'

career prospects and bridging the gap between academia and industry

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Effective Social Media Strategies for Enhancing E-Business Growth and Customer Engagement: Insights from Sri Lankan Business Leaders

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Abstract

Social media has emerged as a powerful business and marketing tool in the current technological era, enabling rapid growth for e-businesses and improved customer engagement. However, effectively leveraging social media requires specific knowledge and strategic application, which many business leaders lack. This study focuses on the unique context of Sri Lankan small and medium-sized enterprises (SMEs), highlighting how regional factors influence social media strategies. Primary data were collected through interviews with six Sri Lankan business leaders and supplemented by surveys conducted via WhatsApp and Viber, along with secondary data from existing studies. Five key strategies were identified: knowledge of audience, performance measurement, sales and marketing calibration, customer journey mapping, and customer relationship management. These strategies, tailored for the Sri Lankan business environment, can help local business leaders enhance sales, brand awareness, and customer relations. Additionally, successful implementation may foster job creation and contribute positively to local and national economic development. This research fills a gap by contextualizing established social media practices within Sri Lanka, providing valuable insights for regional e-business growth.

Keywords: social media marketing, e-business strategies, customer engagement, digital marketing, performance measurement

I. INTRODUCTION

In the current digital age, social media has become an indispensable tool with the ability to impact people and businesses positively or negatively depending on its use. To leverage social media for business advantage, a proper and strategic approach is essential. This includes expanding the target audience, building brand awareness, and conveying information effectively to the right customers. Business leaders must be knowledgeable about how to creatively and innovatively use social media, as it serves as a crucial bridge between companies and consumers (Barai, 2021).Social media is a powerful marketing instrument, especially for small and medium-sized enterprises (SMEs), as it provides a low-cost yet highly efficient platform for gaining brand recognition, enhancing customer relationships, and increasing sales (Nyamboli, 2021). Research highlights the importance of identifying the target audience since this dictate's platform choice, content strategy, and customer engagement approaches (Gumede et al., 2024). Notably, social media serves as a low-cost, high-impact tool enabling SMEs in developing countries like Sri Lanka to bypass traditional market barriers and improve performance (Khan and Asif, 2018). For example, studies on the Sri Lankan market reveal that social media marketing significantly shapes consumer purchasing behavior in competitive sectors such as clothing, underscoring the need for companies operating locally to actively leverage these channels to connect with and persuade target audiences (Ameer and Weerathunga, 2020).

Effective social media marketing typically involves focusing on select platforms to ensure meaningful engagement. Facebook's "Meta Business Suite," for instance, offers comprehensive tools like in-depth analytics, content management, and ad control to help businesses strengthen their online presence (Kongar and Adebayo, 2021). Instagram fosters community and interaction through visual

storytelling, while TikTok offers potential virality among younger demographics via popular short-form videos (Kongar and Adebayo, 2021).

In developing countries, social media acts as an invaluable and affordable resource for SMEs to overcome traditional market constraints and enhance business performance. This phenomenon is particularly relevant in Sri Lanka due to its unique economic and technological contexts, which influence how social media strategies are adopted and succeed (Khan and Asif, 2018). Despite these opportunities, business leaders often lack sufficient knowledge to integrate social media applications (SMAs) effectively with intelligent content creation and marketing execution. Without such expertise, even the most innovative ideas may fail, making continuous competence and knowledge improvement essential (Kim, 2020).

With the right strategies, businesses can accelerate growth by fostering strong communication channels with customers, potentially stimulating broader social change (Chibuzor Gbandi and Osasere Iyamu, 2022). Recent research especially emphasizes that for small businesses, a customer-centric approach to social media is critical for improving overall firm performance, prioritizing engagement strategies around the customer journey and value creation (Cao and Weerawardena, 2023). The strategic use of social media marketing significantly enhances brand perception and financial outcomes, highlighting the necessity for firms to integrate these platforms into core marketing and sales strategies (Witek-Hajduk and Zaborek, 2022). Furthermore, customer engagement on social media is multidimensional, encompassing emotional, cognitive, and behavioral interactions, which drive long-term loyalty and repeat business (Kumar and Pansari, 2016). This study contributes to the existing literature by focusing explicitly on Sri Lankan SMEs and business leaders, exploring how global social media strategies can be adapted to local market realities and socio-economic conditions. Understanding this regional context is vital to help Sri Lankan businesses leverage social media effectively to achieve sustained growth and competitive advantage.

II. LITERATURE REVIEW

Getting involved into social media to broad the businesses in inevitable activity nowadays. Because people are start using social medias very much than earlier. So, adapt to change is must to maintain the business stable in between competitors. However, most of the companies using combination of traditional as well as social media to cover and find out new users. This paper specially focusses on the brief discussion on social media, features of social media and some success stories of how some companies achieve their goals through the social medias (Venkateswaran, Ugalde and T., 2019). The social media are used very well by B2B companies. Focusing and describing some aspects of social media and doing a weight analysis through that aspect and describe each aspect according to their weights. In the Discussion the authors saying that through the study they found social media gives a positive outcome such as customer satisfaction, intention to buy and sales, customer relationship, brand awareness and etc. those are looks like similar to B2C companies' outcomes. In the perspective of salesperson technical skill of salesperson, pressure from stakeholders, usefulness and usability are some key factors those affect the adaptation on social media (Dwivedi *et al.*, 2021).

Harcourt defining that the use of social media is getting higher nowadays. He defines that through an image and figure which shows that the usage percentage of social media comparatively. Afterwards describing the challenges face by social media. Then inside the spread of social media heading he is explaining the spread of social media. And in this final he came to the main topic called how social media promotes business success (Harcourt, 2017). Enabling connection between unknown or known individuals is the key functionality of social media. When we consider it based on business it links between businesses and customers to keep interested in their own goods. Social media is growing significantly; along with that the marketing strategies also changing because of the continues change in Fashion industry changes. So social media become unavoidable importance in today's world to prove it with an empirical research for supporting the effects of social media as a business tool and defining some strategies for

increasing the business and questionaries' has been taken to support (Barai *et al.*, 2021).

The way of communicating with the customer has evolved with the aid of new technology concerns. So, it becomes a need for businesses to learn to use social media to sustain the competitive environment. Normally a social media research includes the definition of technology concepts, identify the impact of a company integration with social media (Krishnamurthy, 2018).The social media is the new business tool that is available to all the users in the current business environment. Which have the ability to develop a business in very short time period and create a good relationship with the customer in an effective way. But it doesn't require any sort of huge budget or time to work on it. Not only a huge business but also small businesses also have the chance to use the social medias to find out a huge number of customers for their business. Indirectly the social media opens up a huge backdoor for small medium enterprises and businesses to improve their business and make a brand awareness (Oxborrow, 2012).

Social media evaluate businesses to next level with effective communications, brand awareness, but some business leaders still have lack of knowledge in the field of social media applications and platforms. So, identifying social media marketing strategies to improve business can improve the businesses. Relationship marketing conceptual framework is used in this study. The study revealed how to increase the business leader's knowledge in social media strategies. Business sales, awareness of brands. The chance for business leaders to improve their business sales, arise of new job opportunities are some of the Implications of social change through this (Kim, 2020).Instagram, Facebook, Google plus, are some widely uses social media applications nowadays in businesses. Within a pool of social medias, Facebook is the dominator among them, because most of the people uses Facebook for promoting and brand awareness. Further, the social media is very popular in the century, so it is very common to use inside the society around the world. the reason behind social media become popular to businesses is it allow business to interact with the customers and make the customers updated all the time about the goods and services provided by the business. The

inbuild conversation, sharing ability are some of the key services behind the success of social media businesses (Abdullah *et al.*, 2020).

Social media significantly transforms Customer Relationship Management (CRM) strategies by facilitating real-time customer engagement, enhancing brand loyalty, and enabling personalized marketing, although challenges remain in data management and response strategies (Dhayalan and Professor, 2024). Small business managers who fail to engage consumers effectively through social media face greater risks of failure; effective content design, platform selection, and leadership engagement are key strategies for improving consumer involvement and promoting community growth (Nyamboli, 2021).Studies focusing on SMEs in emerging markets reveal that social media platforms like Facebook, Instagram, Twitter, and YouTube have a positive and significant influence on business growth, urging SMEs to maintain updated content that educates, informs, and persuades customers (Chibuzor Gbandi and Osasere Iyamu, 2022).Advanced analytical techniques combining machine learning and data envelopment analysis enable SMEs to assess the efficiency of social media marketing campaigns by analyzing messaging typologies and organizational metrics, supporting data-driven decision-making (Kongar and Adebayo, 2021).

III. PROBLEM STATEMENT

Social media has increasingly become an essential tool for business leaders in various contexts, including communication, interaction, and collaboration with customers. With the rising demand for social media engagement, nearly 60% of users now provide feedback or follow specific business profiles (Harcourt, 2017). Unlike traditional business methods where direct and frequent interaction with customers was limited, social media enables real-time communication and relationship building.

However, many small and medium-sized enterprises (SMEs) in Sri Lanka remain underutilized in social media applications and have yet to fully experience the benefits of these modern business approaches. A significant barrier is the lack of strategic knowledge among business leaders regarding effective social media

use for business growth. While some leaders understand how to operate social media tools, many do not have well-defined plans or strategies to navigate the highly competitive digital environment.

This knowledge gap prevents SMEs from maximizing the potential of social media to enhance their business performance. Therefore, the primary aim of this research is to identify and suggest effective social media business strategies tailored for Sri Lankan business leaders, enabling them to better engage customers, improve brand visibility, and drive sales growth in the local digital marketplace.

Figure 05: Picture of qualitative research

IV. OBJECTIVES

The main objective of this study is to identify effective social media strategies that can improve business performance for small and medium-sized enterprises (SMEs) in Sri Lanka. Specifically, this research aims to:

- Increase the contribution and integration of social media applications in business practices.

- Enhance the knowledge and capability of business leaders to apply creative and strategic ideas on social media platforms.

- Bridge the gap between expected and actual sales by leveraging targeted social media strategies.

- Provide actionable recommendations that can help business leaders optimize social media use to drive sales growth, customer engagement, and brand awareness.

V. METHODOLOGY

This study employs a qualitative research approach to explore strategies for improving e-businesses through social media. Qualitative methods are particularly suitable for deriving deep, contextual understanding from the experiences and insights of business leaders. The focus is on capturing rich, detailed data rather than quantitative measurement.

A. Sample selection and Participants

Six business leaders from various organizations, recognized for their successful use of social media in e-business, were purposefully selected as contributors to this study. Thirteen business leaders were initially invited via social media platforms Facebook, Instagram, LinkedIn, Twitter, and Pinterest resulting in eleven responses, including two rejections. Purposeful sampling was applied to choose the six most suitable participants based on crit.

B. Data collection Instruments and Procedures

Structured open-ended interview questions were developed to gather in-depth responses aligned with the research objectives. The interviews provided detailed, qualitative insights on social media strategies, challenges, competitor tactics, and perspectives on business growth via social media. Individual interviews lasted approximately fifteen minutes each, while group discussions extended to about one hour.

Interviews were conducted through Zoom meetings, recorded with contributors' consent, and transcribed using Google's Voice-to-Text tool to ensure accuracy. Additionally, surveys were distributed through WhatsApp and Viber groups using Google Forms and SurveyMonkey to supplement interview data with broader community perspectives. Relevant business documents such as social media posts, customer feedback, and marketing materials left by contributors were reviewed for triangulation.

C. Data management and Analysis

Interview recordings and survey responses were securely stored and organized for analysis. Manual qualitative content analysis was performed, identifying emerging themes and patterns related to effective social media strategies. The analysis was supplemented by reviewing secondary data from existing literature, prior surveys, and open-access databases to enhance validity.

Tools such as Google Calendar were used for scheduling interviews, and built-in Zoom recording features facilitated reliable data capture. Ethical considerations included obtaining informed consent from participants and ensuring confidentiality throughout the study.

VI. RESULTS

This qualitative study investigated how social media strategies can improve e-businesses in Sri Lanka. Data were collected through interviews with six carefully selected business leaders and supplemented by survey responses and business documents provided by the contributors.

Preliminary results indicate that Facebook is the primary social media platform used by all contributors for business purposes. Additionally, contributors maintained active and vibrant accounts on Instagram, LinkedIn, Twitter, and Pinterest to varying degrees, reflecting a strategic use of multiple platforms suited to their target audiences.

Table 01: Social Media Platform Activity of Contributors

Contributor	Facebook	Instagram	Twitter	LinkedIn	Pinterest
Contributor 1	Yes	Yes	No	No	No
Contributor 2	Yes	No	No	No	No
Contributor 3	Yes	Yes	No	No	No
Contributor 4	Yes	Yes	Yes	No	Yes
Contributor 5	Yes	No	Yes	No	No
Contributor 6	Yes	Yes	Yes	Yes	Yes

Yes → they are active in that social media application
No → they are not active / present in that social media application

The contributors bring a mix of expertise: Contributor 1 specializes in social selling with over five years of experience; Contributor 2 is a digital marketing expert with six years of practice; Contributor 3 produces and distributes goods on social media platforms with seven years of experience. Contributors 4, 5, and 6 are founders and CEOs with varying tenures of less than two years.

Analysis of the interviews showed active engagement by contributors through frequent posts, customer feedback, shares, and likes. Observational data collected during interviews further supported these patterns.

Aligning with relationship marketing theory, the results demonstrate that effective social media use strengthens customer-business relationships and improves customer retention by delivering value consistently.

Through a combination of interview data and theory, five key strategic areas were identified as critical for business success on social media: knowledge of audience, performance measurement, sales and marketing calibration, customer journey mapping, and customer relationship management.

Table 02: Key Strategies Identified by Contributors

Contributor	Knowledge of audience	Performance measure	Sales and marketing calibration	Roadmap of customer	Customer relationship management
Contributor 1	✓	✗	✗	✓	✓
Contributor 2	✓	✓	✓	✓	✓
Contributor 3	✓	✓	✓	✗	✓
Contributor 4	✓	✓	✗	✓	✗
Contributor 5	✓	✗	✓	✓	✓
Contributor 6	✓	✓	✓	✗	✓

✓ → *they Identified this strategy*
✗ → *they didn't identify this strategy*

A. Knowledge of Audience

All the other partners of this paper underline that in the first step towards making the business better in social media is the knowledge of the audience is quite crucial. That is to get a grasp of which are the social media applications that the

customers are interacting with the most, to communicate to their customers better, more often, and request their feedback, comments and tips. The conclusion that one of the strategic approaches should be to have a deep Knowledge of audience is not a novelty, as all the existing literature proves that customer-centered strategy is one of the major contributors of positive business results in case of social media (Cao and Weerawardena, 2023).

B. Performance Measure

This is the point where most of the businesses are forgot to measure. Further, performance measure defines how much a social media platform make an impact in their business. This is a main key point for the success of a business effort they put into. Our results echo the findings of Witek-Hajduk and Zaborek (2022), who found that effectively measuring social media marketing activities and their impact on brand perception is directly correlated with enhanced firm performance.

C. Sales and Marketing Calibration

Sales and marketing calibration emphasize that the different between marketing and sales should not be a huge. In many businesses the marketing , sales are measures separately and differently, but a mixing of those two and make a calculation by collaborating them is a key activity to be consider to success in social media business. Because social media expose the difference between sales and marketing better than traditional businesses. So here a marketing team has to think like sales and sales have to think like marketing team.

D. Customer Journey Mapping

It defines that a explain a clear path for the customer from the start to end of a purchasing journey is very important to consider. Usually a customer start to experience a business from the initial first contact of them. So, from that initial point the company or business needs to guide the customer to how to achieve his goal.

E. Customer Relationship Management

Usually communication type is divided into two types one is Uni-directional , Bi-directional. This customer relationship management involves how messaging processes and interaction between a business and customer should be. It defines that

Bi-directional communication is always an ultimate key strategy for a success of a business with shorter reply time. Which indirectly improve the relationship, reputation of the business among customers also this behavior will differentiate the business uniquely among other competitors. Our interview data highlights the importance of bidirectional communication, which is a core tenet of customer engagement as defined by Kumar and Pansari (2016). This scholarly view supports the idea that true engagement goes beyond one-way messaging and builds a deeper relationship.

VII. DISCUSSIONS

The findings of this study suggest that the social media strategies identified can significantly benefit Sri Lankan businesses by enhancing their operational effectiveness and competitive positioning. Consistent with prior research, social media offers SMEs a promising avenue to attract and engage customers rapidly compared to traditional marketing methods (Oxborrow, 2012). Given that nearly 60% of consumers now utilize social media platforms for product research before purchase decisions (Venkateswaran, Ugalde and T., 2019), these strategies are especially relevant for Sri Lankan SMEs aiming to improve their market reach.

The study highlights a critical shift from conventional transactional selling toward comprehensive customer relationship management, enabling businesses to achieve key objectives, including increased sales and improved profits. Platforms such as Facebook, Instagram, Twitter, and LinkedIn provide cost-effective marketing and advertising solutions tailored to diverse customer segments (Harcourt, 2017). However, despite widespread social media presence, many Sri Lankan business leaders still lack a deep understanding of strategically leveraging these platforms to their full potential. As one contributor noted, while awareness of social media is common, clear strategic application remains limited.

Through applying the five strategic areas identified knowledge of audience, performance measurement, sales and marketing calibration, customer journey mapping, and customer relationship management businesses can convert customer engagement more effectively into sales and loyalty. Moreover, the successful adoption of

these strategies holds the potential for broader socio-economic benefits, including job creation in digital marketing, content creation, and social media management sectors, which may help address regional economic disparities within Sri Lanka.

It is important to consider several limitations of this study. First, the qualitative design focuses on conceptual insights rather than statistical generalizability. Second, the sample of six contributors, while carefully selected for their experience, represents a limited scope and may not reflect the full diversity of Sri Lankan SMEs. Third, subjective respondent opinions and experiences influenced the findings, underscoring the need for complementary quantitative studies to validate and expand on these insights.

Future research should explore larger-scale quantitative assessments of social media's impact on business performance in Sri Lanka, identify the most effective platform-specific strategies, and evaluate advertising techniques that can optimize customer acquisition and retention.

VIII. LIMITATIONS

This study is subject to several limitations. First, the qualitative research design prioritizes depth of understanding and contextual insights rather than statistical generalizability, which may limit the broader applicability of the findings. Second, the small sample size of six business leaders, although purposively selected for their expertise, restricts the diversity of perspectives and may not fully represent the wide range of SMEs operating in Sri Lanka. Third, the data rely heavily on the subjective experiences and opinions of the contributors, which could introduce bias and affect the objectivity of the results.

Additionally, secondary data sources and pre-existing surveys used for triangulation might differ in scope and relevance, potentially impacting the consistency of the findings. Future research involving larger, more diverse samples and quantitative methods would help to validate and extend these preliminary insights.

IX. CONCLUSION

Social media has become an indispensable tool in the modern technology-driven business environment, enabling companies especially small and medium-sized enterprises (SMEs) to access a broad and diverse customer base beyond traditional geographical limits. This research aimed to identify effective social media strategies that add value to e-businesses in Sri Lanka.

The study's findings highlight five key strategic areas critical for growth: understanding the target audience, measuring performance, aligning sales and marketing efforts, mapping the customer journey, and managing customer relationships effectively. Implementation of these strategies enables business leaders to enhance brand awareness, increase sales, and foster deeper customer engagement.

To sustain high growth and remain competitive, Sri Lankan business executives are encouraged to prioritize social media marketing campaigns, focusing resources on customer-centric engagement and brand building. Beyond individual business success, the adoption of these strategies can generate employment opportunities in digital marketing fields and contribute positively to local communities and the national economy.

This study lays a foundation for future quantitative research aimed at validating and expanding on these findings, ultimately supporting evidence-based decision-making for social media use among Sri Lankan SMEs.

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TRACK - CROP SCIENCE AND TECHNOLOGY

Growth and Yield Performance of Radish (*Raphanus Sativus L.*) Fertilized with Biofertilizer

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Abstract

The study was conducted to evaluate to effectiveness of Bio fertilizer and combined inorganic fertilizer on growth and yield of radish (Raphanus sativus L). This study was designed with five treatments having ten replicates. Treatments are T_1-(Control); Recommended amount of chemical fertilizer by Department of Agriculture (RDOA), T2-1/2 RDOA of urea +Recommended amount of Triple super phosphate and Muriate of potash +250ml/ha Bio fertilizer, T3-1/2 RDOA of urea + TSP&MOP +500ml/ha Bio fertilizer, T_4-1/2 RDOA of urea + TSP & MOP + 750ml/ha Bio fertilizer, T_5 -1l/ha Bio fertilizer alone. All other agronomic practices were followed based on DOA recommendation. Plant height, number of leaves, leaf area were measured by in weekly interval. Fresh weight of and, dry weight of leave, storage root length and diameter, fresh weight and dry weight of storage root were measured at the time of harvesting (6th week after planting). Analysis of variance was performed to determine significant difference among treatment ($p<0.05$). The results revealed that treatments combining inorganic fertilizers with biofertilizer (T_3 and T_4) significantly enhanced plant growth and tuber yield compared to inorganic fertilizers alone (T_1) as well as biofertilizers alone (T_5). The highest tuber yield was observed in T_4, demonstrating the effectiveness of biofertilizers in improving nutrient uptake, root elongation, and soil microbial activity. These findings suggest that integrating biofertilizers with inorganic fertilizers can enhance radish productivity while reducing the environmental impact of excessive chemical fertilizer use.

Keywords: Bio fertilizer, Chemical fertilizer, Radish

I. INTRODUCTION

In today's world, with pollution and environmental degradation posing significant challenges, adopting sustainable practices across all sectors, including agriculture, has become essential. Conventional farming techniques, which often depend heavily on synthetic fertilizers and pesticides, not only pollute the environment but also disturb the soil natural nutrient balance (Pradhan *et al.*,2023).

Fertilizers can have both positive and negative effects on soil health. On the positive side, they supply essential nutrients that promote plant growth and improve soil fertility. However, excessive or improper use of fertilizers can have detrimental effects. Over relying on inorganic fertilizers can disrupt the soil's natural nutrient balance, leading to imbalances that reduce soil quality. This can result in the loss of organic matter, decreased fertility, and greater vulnerability to erosion (Johnson, 2023). Particularly nitrogen fertilizers can have several negative effects, including reduced crop quality, soil acidification, and pollution from heavy metals, soil compaction, and alterations to the soil micro biome (Lin *et al.*, 2019). The sustainability of agricultural systems is a critical global concern, leading to a greater emphasis on the potential benefits of organic fertilizer use. Organic fertilizers can enhance soil microbial activity, which in turn promotes improved crop growth and helps control pests and diseases (Lin *et al.*, 2019). Organic farming relies on the use of biological fertilizers, pest control, compost, and sustainable practices such as intercropping, mulching, and crop rotation. This method strictly limits the use of chemical fertilizer, growth regulators, pesticides, herbicides, and other synthetic inputs. (Soni *et al.*, 2022).

Radish *(Raphanus Sativus* L.) is an important vegetable crop (Pathak *et al.,* 2017). Radishes

thrive as a cool weather crop and are best direct sown in early spring or late summer. While they prefer full sun, they can tolerate partial shade, though less than 6 hours of sunlight daily may slow their growth (Rakib *et al*., 2013). For radishes, balanced fertilization plays a crucial role in promoting growth. The application of nitrogen in varying doses has been shown to enhance plant growth and increase radish yield (Kumar et al., 2022). Bio fertilizers improve agricultural yield and soil fertility, providing substantial advantages over traditional chemical fertilizers (Taha et al., 2010).

Biofilms are intricate communities composed of multiple microbial species, naturally attached to surfaces or physical interfaces. These biofilms can also be artificially developed in vitro using beneficial microbes to create Biofilm Biofertilizers (BFBFs). When applied to agricultural systems, BFBFs introduce sub-network components that integrate with the broader soil-plant-microbe network. (Premarathna et al., 2021). Biofilm biofertilizers are composed of beneficial microbial communities encapsulated within extracellular polymeric substances (EPS). This encapsulation helps stabilize soil structure, enhance nutrient solubilization, and improve water retention. When applied to soil, these bio fertilizers significantly enhance fertility by increasing the organic matter content, facilitating nutrient cycling, and boosting microbial activity. These changes create a more supportive environment for plant growth. As a result, biofilm bio fertilizers contribute to better root development, faster plant growth rates, and higher crop yields, making them an effective tool for sustainable agricultural practices (Salsabila *et al.,* 2024).

The combined application of fertilizers is a strategy aimed at boosting agricultural production while ensuring environmental sustainability for future generations. This approach integrates the use of both organic and inorganic plant nutrients to enhance crop productivity, prevent soil degradation, and meet future food supply demands. Notably, the residual effects are more significant when fertilizer is used in conjunction with organic manures, emphasizing the benefits of this integrated method (Ali *et al*., 2023).

II. METHODOLOGY

The radish seeds were collected from Agriculture seeds sales center, Eravur. This study was carried out to determine the appropriate application rate of this bio fertilizer for radish among the tested combination of inorganic fertilizer and bio fertilizer. The study used a completely randomized design (CRD), with ten each of the five treatments having 10 replicates each.

Table 01: Treatments used in the study

Treatment	Description
T$_1$	Recommended amount of chemical fertilizer by Department of Agriculture (RDOA)
T$_2$	1/2 RDOA of urea +Recommended amount of Triple super phosphate & Muriate of potash +250ml/ha Bio fertilizer
T$_3$	1/2 RDOA of urea + TSP&MOP +500ml/ha Bio fertilizer
T$_4$	1/2 RDOA of urea + TSP & MOP + 750ml/ha Bio fertilizer
T$_5$	1l/ha Bio fertilizer (Biofilm biofertilizer) alone

This experiment conducted using poly bags with height of 45 cm and diameter 40 cm. The pots were filled with the Top soil: Red soil: Compost in the ratio 2:1:1. Holes were made on bottom side of the bags to remove excess water. All of the pots were kept in the experiment area, with 30 cm between them. A total of 100 seeds were placed in a petri dish lined with moist Whatman paper. After 48 hours, the germination rate for the selected variety was determined by calculating the percentage of seeds that had germinated. The result showed a germination rate of 98%. Two seeds were seeded in each polybag after being soaked for 2 hours.

Irrigation was done twice a day in the morning and evening during the experimental period. Recommended inorganic fertilizer was applied to the radish plants according to the treatment structure. The basal fertilizer was applied two days before planting and the top dressing fertilizer was applied 3 weeks after planting according to DOA recommendation.

As per product label description recommendations. One liter of bio film biofertilizer is sufficient for 01 acre. Dilution guidelines are also specified on the product label. The fertilizer application was applied as soil

application. In the study, the amount of urea was controlled, with half of the recommended dosage applied. Additionally, biofertilizer was incorporated in varying quantities in according to the treatment structure. The seedlings were thinned after 7 to 10 days of sowing, once seedlings have developed 2 to 3 true leaves. Keep the strongest seedling in each polybag and discard the weaker ones.

Weeding was done at two weeks interval in the pots. It was done manually. Leafy caterpillar's attacks were observed and those were controlled chemically in the stage of infestation by using profenopos insecticide (2ml/L).

Growth and yield parameters were collected. They are plant height, number of leaves, leaf area, leaf dry weight and fresh weight(g), Storage root (Tuber) length (cm), Fresh weight of storage root (g), Dry weight of storage root (g).

The plant height for each plant across all treatments and replications was recorded at one week's intervals. The measurements were taken from the ground surface to the growing tip of the plant using a meter scale. The numbers of leaves on each plant for each replication of all treatments were counted manually at one week's intervals, starting from planting and continuing until the final harvest. The leaf area of each leaf from every plant in each replication across all treatments was measured by manually. Weight of the plant in each replication in all treatment was measured using an electric balance. The plant was measured without allowing it to dry. Each plant in each replication in all treatment were cut into small pieces and placed in papers trays and then they were dried at 105°C in the oven until constant weight was gained and the dry weight was measured using electronic balance.

Storage root lengths of each plant in each replication in all treatments were measured by using measuring scale. Tuber of each plant in each replication in all treatments were collected and their fresh weight was measured by using an electronic balance. Tuber of each plant in each replication in all treatments were collected and their dry weight was measured by using an oven. Finally, the data were analyzed statistically using

Minitab (Version 17), and mean comparisons among treatments were conducted using Turkey's HSD mean separation procedure at a 5% significance level.

III. RESULTS AND DISCUSSION

A. Growth parameters

Plant height is a key indicator of crop growth and nutrient uptake efficiency (Islam et al., 2017). Plant height of radish was measured at weekly interval (Table 02) and there were significant differences ($P<0.05$) among treatment up to 6th week after planting (WAP). The findings indicate that bio fertilizer application significantly influenced plant height, with treated plants exhibiting greater growth compared to the control groups.

At the early growth stage (Weeks 1-2), plant height differences among treatments were minimal, indicating uniform germination and establishment. However, from Week 3 onward, radish plants treated with bio fertilizer T_3 and T_4 demonstrated a significant increase in height compared to the control treatment T_1. The tallest plants were observed in T_4 (38.31 cm), followed by T_3 (37.81 cm), while the control groups T_1 recorded the shortest plants at 34.55 cm at the 6th week after planting.

Mean value in a column having dissimilar letter/letters indicate significant differences at 5% level of significance by Turkey's HSD test.

B. Number of Leaves

Radish plants treated with bio fertilizers, particularly T3 and T4, shown increased leaf development compared to the control (T1). The highest number of leaves was recorded in T4 (15.5 leaves). In contrast, the control treatment T1 exhibited the lowest leaf count, averaging 11.9 leaves at the 6 weeks after planting. This trend highlights the potential of bio fertilizers to enhance vegetative growth in radish plants.

It was observed that there were significant differences ($P < 0.05$) in leaf numbers among treatments. The combined application of inorganic fertilizers and bio fertilizers resulted in enhanced vegetative growth (Rather et al., 2018).

Table 02: Plant height of radish (cm) at different week after planting

Treatment	Week after planting (WAP)				
	2nd	3rd	4th	5th	6th
T_1	9.30 ± 0.05^a	14.99 ± 0.11^b	20.18 ± 0.06^c	26.62 ± 0.18^c	34.55 ± 0.39^{ab}
T_2	9.65 ± 0.01^a	14.51 ± 0.10^c	20.55 ± 0.05^d	25.15 ± 0.09^d	35.75 ± 0.10^b
T_3	$9.96 \pm 0.04a$	15.33 ± 0.03^b	23.97 ± 0.08^b	28.81 ± 0.10^b	37.81 ± 0.24^a
T_4	10.54 ± 1.87^a	16.24 ± 0.10^a	23.20 ± 0.05^a	31.07 ± 0.05^a	38.31 ± 0.48^a
T_5	7.64 ± 0.05^a	10.92 ± 0.05^d	13.82 ± 0.18^d	16.88 ± 0.18^d	20.43 ± 1.19^c
P-value	0.002	0.000	0.000	0.004	0.000

Radish plants treated with bio fertilizers, particularly T_3 and T_4, shown increased leaf development compared to the control (T_1). The highest number of leaves was recorded in T_4 (15.5 leaves). In contrast, the control treatment T_1 exhibited the lowest leaf count, averaging 11.9 leaves at the 6 weeks after planting. This trend highlights the potential of bio fertilizers to enhance vegetative growth in radish plants.

It was observed that there were significant differences ($P < 0.05$) in leaf numbers among treatments. The combined application of inorganic fertilizers and bio fertilizers resulted in enhanced vegetative growth (Rather *et al*., 2018).

Table 03: Number of leaves per plant at different week after planting

Treatment	Week after planting (WAP)				
	2nd	3rd	4th	5th	6th
T_1	4.60 ± 0.16^{cd}	5.90 ± 0.23^c	7.60 ± 0.16^c	9.60 ± 0.16^c	11.90 ± 0.23^c
T_2	5.10 ± 0.10^{bc}	6.80 ± 0.24^b	8.50 ± 0.16^b	10.40 ± 0.16^b	12.60 ± 0.16^{bc}
T_3	5.40 ± 0.16^{ab}	7.60 ± 0.16^{ab}	8.90 ± 0.10^b	10.60 ± 0.16^b	12.90 ± 0.23^b
T_4	5.90 ± 0.16^a	8.40 ± 0.16^a	10.20 ± 0.13^a	12.20 ± 0.13^a	15.50 ± 0.22^a
T_5	4.10 ± 0.10^d	5.80 ± 0.20^c	7.60 ± 0.22^c	8.00 ± 0.21^b	9.50 ± 0.16^{bc}
p-value	0.000	0.000	0.010	0.000	0.002

Mean value in a column having dissimilar letter/letters indicate significant differences at 5% level of significance by Turkey's HSD test.

C. Leaf area (cm²)

The initial growth period, all treatments exhibited similar leaf area, suggesting uniform seedling establishment. However, from Week 3 onward,

significant variations were observed among treatments. Radish plants treated with bio fertilizers, particularly T_3 and T_4, showed greater leaf expansion compared to the control (T_1). At Week 6, the highest leaf area was recorded in T_4 (156.8 cm²), followed by T_3 (150.5 cm²), while the control treatment (T_1) exhibited the lowest leaf area (128.95 cm²). This indicates that bio fertilizer application positively influenced leaf area development. The increase in leaf area resulting from the application of organic and bio fertilizers can be attributed to their combined effect on soil properties. These fertilizers enhance both the physical and chemical characteristics of the soil, making macro- and micronutrients more readily available. Additionally, they promote enzymatic activities, which contribute to improved plant growth and development (Asghar *et al*., 2006).

Table 04: Leaf area (cm²) per plant at different week after planting

Treatment	Week after planting (WAP)				
	2nd	3rd	4th	5th	6th
T_1	16.00 ± 0.21^c	27.15 ± 0.26^d	50.50 ± 0.30^d	69.20 ± 1.43^c	128.95 ± 1.59^c
T_2	16.65 ± 0.15^c	32.70 ± 0.56^c	56.95 ± 0.36^c	84.40 ± 0.53^b	146.60 ± 1.31^b
T_3	17.45 ± 0.22^b	40.75 ± 0.39^b	63.80 ± 0.42^b	87.05 ± 0.32^b	150.55 ± 0.51^b
T_4	21.20 ± 0.23^a	43.55 ± 0.79^a	70.20 ± 1.41^a	93.25 ± 1.21^a	156.80 ± 1.45^a
T_5	14.45 ± 0.15^d	23.50 ± 0.27^e	47.75 ± 0.50^d	60.85 ± 0.23^d	103.05 ± 1.66^d
P-value	0.000	0.000	0.000	0.000	0.000

Mean value in a column having dissimilar letter/letters indicate significant differences at 5% level of significance by Turkey's HSD test.

D. Yield parameters

1) Fresh and oven dry weight of plant

Radish plant was harvested 6th WAP and fresh and oven dry weight of plant were recorded. Average fresh and oven dry weight of plants are given in Table 05. Average fresh and oven dry weight of radish cutting are ranges from 32.73 to 57.82 and 3.5 to 7.01 g respectively. There were significant differences ($p<0.05$) among treatments and high values were obtained in treatment T_4. The result in this study real that combination of inorganic fertilizer with bio fertilizer (Biofilm) improve the crop leaf yield. The use of bio fertilizers significantly improved both the growth and yield characteristics of radish (Baloch *et al*., 2014).

Table 04: Fresh and oven dry weight (g) of plant 6th week after planting

| Treatment | 6th Week after planting (WAP) | |
	Fresh weight	Dry weight
T_1	36.40 ± 0.78[cd]	4.43 ± 0.09[c]
T_2	38.84 ± 0.47[c]	4.67 ± 0.02[c]
T_3	43.58 ± 0.84[b]	5.30 ± 0.10[b]
T_4	57.82 ± 2.05[a]	7.01 ± 0.29[a]
T_5	32.73 ± 0.55[d]	3.50 ± 0.05[d]
p-value	0.001	0.000

Mean value in a column having dissimilar letter/letters indicate significant differences at 5% level of significance by Turkey's HSD test.

2) Storage root length and diameter

It was observed that there were significant differences ($p<0.05$) among the storage root length and diameter at 6th WAP (Table 06). Average tuber length and diameter of radish are ranges from 5.06 to 18.18 cm and 1.50 to 4.88 cm respectively. The high value obtained in the treatment T_4 and lowest value obtained in T_5. Jin *et al*. (2024) reported that, compared to inorganic fertilization and organic fertilization replacing 30% of chemical fertilizers with organic fertilizers increase in radish yield.

Table 06: Tuber length (cm) and diameter (cm^2)

| Treatment | 6th Week after planting (WAP) | |
	Tuber length	Tuber diameter
T1	15.04 ± 0.19[b]	4.12 ± 0.08[c]
T2	13.55 ± 0.11[c]	3.51 ± 0.07[d]
T3	17.49 ± 0.12[a]	4.49 ± 0.11[b]
T4	18.18 ± 0.05[a]	4.88 ± 0.04[a]
T5	5.06 ± 0.31[d]	1.50 ± 0.08[e]
p-value	0.000	0.001

Mean value in a column having dissimilar letter/letters indicate significant differences at 5% level of significance by Turkey's studentized test

IV. CONCLUSION

Growth parameters such as plant height, number of leaves, and leaf area were notably higher in treatments biofertilizer combined with inorganic compared to inorganic alone as well as biofertilizer alone. The tallest plants were observed in T_4, and the highest number of leaves was recorded in T_4, indicating the positive impact of biofertilizers on vegetative growth. Similarly, leaf area development was significantly enhanced in treatments incorporating biofertilizers, with T_4 recording the highest value at the 6th week after planting. Yield parameters such as fresh and oven-dry weights of the plant and also exhibited significant variations among treatments. The combination of biofertilizers and inorganic fertilizers resulted in the highest fresh and dry weight values in T_4, Additionally, tuber length and diameter were significantly greater in T_4 compared to other treatments, emphasizing the role of biofertilizers in improving tuber development. The results align with previous studies that suggest biofertilizers enhance soil microbial activity, improve nutrient availability, and contribute to better plant growth and yield. The study supports the use of biofertilizers in combination with inorganic fertilizers as a sustainable approach to improving crop yield. Future research should focus on optimizing the biofertilizer formulations and exploring their long-term effects on soil health and productivity.

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Interaction of Weed Density and Standing Water Level on Rodent Damage in Rice Fields of Low Country Intermediate Zone of Sri Lanka

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Abstract

Rice is a staple crop in Sri Lanka, where rodent damage is an increasing threat. This study examined the effect of weed density and standing water level on rodent damage in rice fields. The experiment was conducted in selected farmer fields in Kurunegala district with four replicates following a standard statistical procedure. For the study of weed density, three experimental plots were demarcated, each measuring 50×50 m. Three treatments were weed-free, conventional farmer weed management practice, and un-weeded. For the study of standing water level, four separate experimental plots were demarcated each measuring 50×50 m, and treatments were no standing water, farmer practice (based on water availability), 5 cm of standing water, and 10 cm of standing water. Damaged and undamaged tillers were recorded in two-week interval before harvesting. Accordingly, un-weeded (minor season – 20.56%, major season - 52.51%) and no standing water (minor - 15.33%, major -16.00%) treatments were given the highest rodent damage, while weed-free (minor - 1.81%, major – 1.48%) and 10 cm of standing water (minor - 0.67%, major – 1.00%) treatments were given the lowest damage. Meanwhile, weeds were collected from each transect by using a quadrate (36×36 cm), and their dry weight was measured. A positive linear relationship was observed between rodent damage and weed dry weight. Data were arcsine-transformed and analyzed using ANOVA (SAS 9.1.3), with means compared using the LSD test at P < 0.05. These studies indicate that effective weed management and adequate water availability reduce rodent damage in rice fields.

Keywords: Rice, Rodent damage, Standing water level, Weed density

I. INTRODUCTION

Rice serves as the primary dietary source for more than half of the people in the world, contributing approximately 27% of daily energy intake and 20% of protein consumption in low-income countries. Rice is widely cultivated across at least 114 countries, predominantly in the developing world, and serves as the main livelihood and employment source for over 100 million families across Asia and Africa. (FAO, 2004). Rodents are a leading group of mammals belonging to the family Muridae, and they damage rice crops at every stage of growth. Rodents have three foremost impacts. First is the significant damage to the rice plants at any time during their growth. Second is the post-harvest losses to grain and vegetables under stored conditions. Third, frequently neglected, consequence is the impact on the health status of subsistence farmers, as rodents transmit more than 20 serious human infections (Meerburg et al., 2009). Slight or moderate rodent injury on a growing rice crop is not easily detectable unless the plants are observed closely. The distribution of damage is greatly inconsistent. Sometimes, patches of severe damage are visible within the fields, while some fields may appear to be unaffected but with uniformly scattered damage (Manilal, 1984).

Weeds are often seen as a biological obstacle that shrinks the yield potential of cultivating fields by causing several issues to the farming system, including attracting pests. The amount of weeds in rice fields is a major factor that can make pest damage worse by providing foodstuff, shelter, etc., while creating a promising environment for pests in the cultivating areas (Sadof et al., 2014). According to Wilson and Whisson (1993), grass

seeds are a source of protein for rodents, which is important for their breeding cycle. Also, it was found that a rigid reproductive seasonality is shown by African multi-mammate mice, which was thoroughly correlated to rain periods and almost certainly happens through the stimulating result of growing grasses (Leirs et al., 1994). Controlling weeds in crop lands is mandatory to limit the food and habitat accessibility for the reproduction and growth of rodents (Wilson and Whisson, 1993). White et al. (2003), stated that habitat exploitation is an applicable controlling method for the suppression of rodent damage. A similar study found that changing large, stable nearby non-crop areas from thick, weed-filled places with a lot of vertical structure to big, greatly changed grasslands with little structure has negative effects on rodents. According to Htwe et al. (2019), repeatedly catching rodents during the tillering and ripening stages, along with keeping weeds under control around the rice fields, is a better way to manage rodent damage in rice fields.

Some previous studies revealed that weeds can affect how much damage rodent pests cause to crops like rice. However, in Sri Lanka, there hasn't been any research looking into how weeds and rodent attacks are connected. Understanding this link could help create better ways to manage rodent problems, which will be beneficial in making an Ecologically Based Rodent Management (EBRM) system to lessen the injury to crops. According to Htwe et al. (2019), systematic trapping through the management of weeds was a better way of reducing the damage done by rodents in rice cultivation in Myanmar.

Water availability in rice fields is an environmental factor that contributes both gains and drawbacks to diverse pests found in the paddy field, including rats and mice. Therefore, the aforementioned experiment was conducted to assess the effects of weed density and standing water level on rodent damage in rice fields, to develop improved rodent control methods and minimize yield loss from rodent attacks (Sarathchandra et al., 2022).

II. MATERIALS AND METHODS

A. Influence of weed density on rodent damage

1) Location of the study

The experiment was implemented in a selected farmer field in Kahapathwala (7023'47.2" N, 80028'05.8" E), Kurunegala district, Sri Lanka (Intermediate zone) during 2018 minor (*Yala* season), and 2018/19 major season (*Maha* season) under normal field conditions. Coordinates recorded using a handheld GPS device.

2) Field establishment

The designated field was split into 3 experimental units by 50 × 50 m. and each plots were separated by a 20 m border on all sides. Three treatments (Table 01) were assigned according to the following standard design (Htwe et al., 2019). Weed-free fields were continued through manual weeding. According to Aplin et al. (2003), to establish the sampling layout, a baseline was demarcated along the long axis of the field. Four transects were demarcated from each treatment unit and treated as replicates. These replicates were positioned perpendicular to the baseline, running in from the edge of the field. They were spaced at 13 m intervals, located at distances of 1 m, 14 m, 27 m, and 40 m starting at the field margin (Figure 01). Each transect was divided into 3 strata, which were perpendicular to each transect at 5 m, 15 m and 25 m along the transect (Figure 01).

Table 01: Treatments applied in the experiment of weed density on rodent damage

Treatment number	Treatment
T1	Weeds-free field
T2	Field with conventional farmer weed management practice
T3	Un-weeded (Control) field

3) Data collection

According to the International Rice Research Institute (IRRI, 1988), rat damage was assessed through observing symptoms such as cutting down or chopping down of rice plants. The damaged and undamaged tillers were counted two weeks prior to crop harvest. stage by assessing every three hills along each stratum of each transect, up to 10 sampling points were noted. Data collection was repeatedly done in the same orientation (Aplin et al., 2003). Following counts were recorded;

(i) Total number of tillers/hill

(ii) Damaged tillers/hill -both freshly damaged tillers and regenerated tillers

The level of damage caused by rats was estimated using the following formula;

$$Damage\ \% = \frac{Number\ of\ damaged\ tillers}{Total\ number\ of\ tillers}\ x\ 100$$

In the meantime, weeds present within the rice field were sampled from each transect using a quadrate (36 × 36 cm), and the dry weight (DW) of each weed sample was measured for each replicate by drying the sample at 70 °C for 72 h until reaching a constant weight (Anwar et al., 2012).

4) Statistical analysis

The recorded data were transformed into arcsin values and analyzed according to the ANOVA procedure using SAS statistical software (SAS 9.1.3, 2003-2008) and means were compared with LSD test where P< 0.05.
A regression analysis was done to determine the correlation between dry weight of weeds and rat damage percentage via SAS 9.1.3 (SAS Institute, 2003- 2008).

B. Influence of standing water level on Rodent damage

1) Location of the study

The study was carried out in farmer fields in selected area located at Kahapathwala (7023'40.6" N, 80027'58.7" E) in Kurunegala district Sri Lanka during 2019 minor and 2019/20 major season.

2) Field establishment

The selected field was split into 4 experimental units, each having 50 × 50 m, with each unit separated by a 20 m border on all sides. Field preparation and crop establishment were done according to the recommended standards (Department of Agriculture, 2025). Conventional water level as farmer practice was maintained until tillering stage which is vulnerable for rodent damage. From the beginning of the tillering stage, four treatments were conducted to distinct plots. The tested standing water levels (Table 02) were

assigned according to the same standard design (Aplin et al., 2003).

Table 02: Treatments applied in the experiment of sanding water levels on rodent damage

Treatment number	Treatment
T1	No standing water (control)
T2	Farmer practice (based on the availability of water)
T3	5 cm standing water level
T4	10 cm standing water level

3) Data collection

Observed damaged and undamaged tillers for rat damage assessment, followed a similar procedure to the study on weed density and rodent damage. The sampling layout was given in Figure 01.
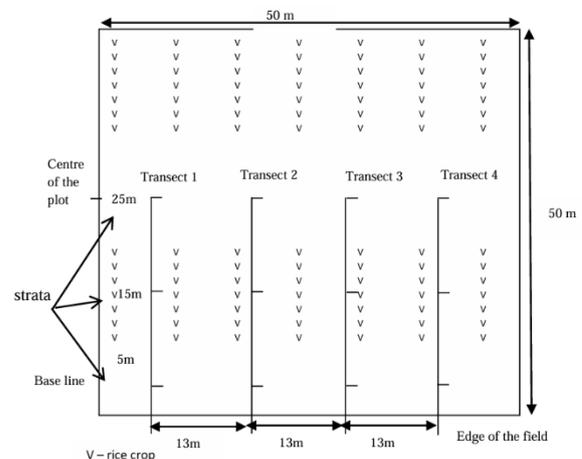

Figure 01: Layout of transects to measure the damage caused by rats in a plot (Aplin et al., 2003)

4) Statistical analysis

The recorded data were transformed into arcsin values and analyzed according to the ANOVA procedure via SAS 9.1.3 (SAS Institute, 2003-2008). Means were compared with LSD test, where P< 0.05.

III. RESULTS AND DISCUSSION

A. Influence of weed density on rodent damage

During 2019 minor season (*Yala* season, from April to September), a statistically significant positive (p≤0.002, r^2 = 0.629) correlation was observed between the percentage of rodent damage in rice fields and the dry weight of weeds (Figure 02). Equation of Rodent damage% = 3.20 + 0.192 Dry weight of weed shows that the

coefficient for the dry weight of weeds (in grams) is 0.192, indicating that for every additional gram of dry weight of weeds, the rodent damage percentage increases by 0.192%.

revealed that rodent damage intensified with increasing weed density.
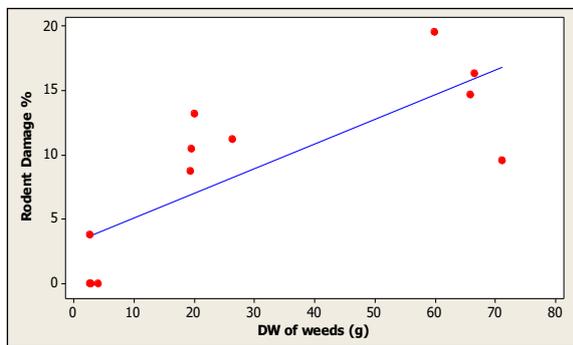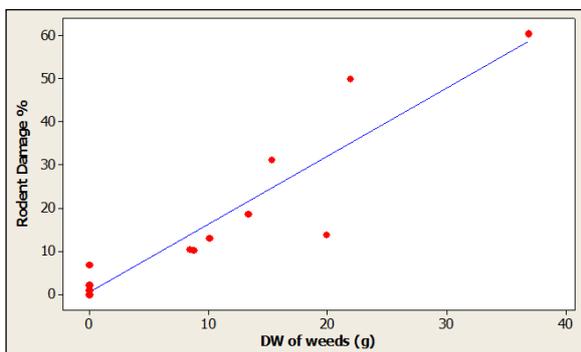

Figure 02: Relationship between rodent damage percentage and dry weight of weeds (g) caused by rodents under weedy conditions, 2019 minor season, DW-Dry weight

During 2019/20 major season (*Maha* season, from September to March), a significant positive (p≤0.002, r^2 = 0.821) correlation was observed between the percentage of rodent damage in rice fields and the dry weight of weeds (Figure 03).

Figure 03: Relationship between rodent damage percentage and dry weight of weeds (g) caused by rodents under weedy conditions, 2019/20 major season, DW-Dry weight

The equation of Rodent damage% = 0.44 + 1.58 dry weight of weeds shows that the coefficient for the dry weight of weeds (in grams) is 1.58, indicating that for every additional gram of dry weight of weeds, the rodent damage percentage increases by 1.58%.

In both seasons of major and minor, the highest percentage of rodent destruction was observed in the treatment with weeds (un-weeded) and the lowest percentage of rodent damage was found in weed-free fields (Figure 04). The observations
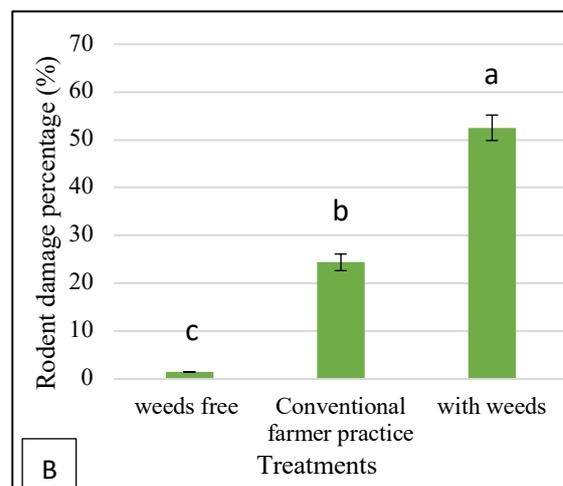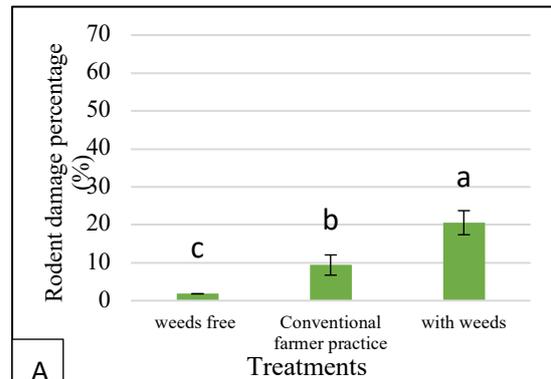

Figure 04: Rodent damage percentage under different weed densities of farmer field in Kahapathwala during A) 2018 minor season (April to September) B) 2018/19 major season (September to March)

This was proofed by the same study showed in Myanmar on *Cyprus difformix* and *Echinochloa crus-galli* weeds, indicating the highest rodent damage in dry season compared to the wet season (Htwe et al., 2019). Conversely, Leirs et al. (1994) find that the breeding seasonality of African multimammate mice (*Mastomys* spp.) was closely linked to rainfall periods.

According to Mwanjabe (1993), referenced in Massawe et al. (2007), rodents are becoming more prevalent in crop fields with a high weed density for specific reasons. A combination of minimal land preparation and following weed growth can improve the favorable conditions for opportunistic and abundant rodent species like *Mastomys*

natalensis, ultimately leading to more damaged crops.

In other hand, the lowest percentage of Rodent damage was observed in fields where weeds were effectively controlled. Wilson and Whisson (1993) state that grass seeds afford a protein source for rats and mice essential for their breeding. With the results obtained, it is revealed that when there is no considerable amount of weeds in the field during the different stages of tillering, rice field rodents cannot approach the rice plants.

B. Influence of standing water level on rodent damage

In both seasons, the highest percentage of rodent damage was observed in the treatment with no standing water (T1), where no standing water levels were maintained (Figure 05 and 06). Also in both seasons, the lowest percentage of rodent damage was observed in the treatment with 10 cm standing water (T4).

During 2019/20 major season (Figure 06), these results indicating the higher water standing level did not allow to colonize the Rodent in rice fields. Extensive standing water during rice crop stages is associated with reduced rodent colonization and local abundance in many systems (Ghersi et al. 2021).
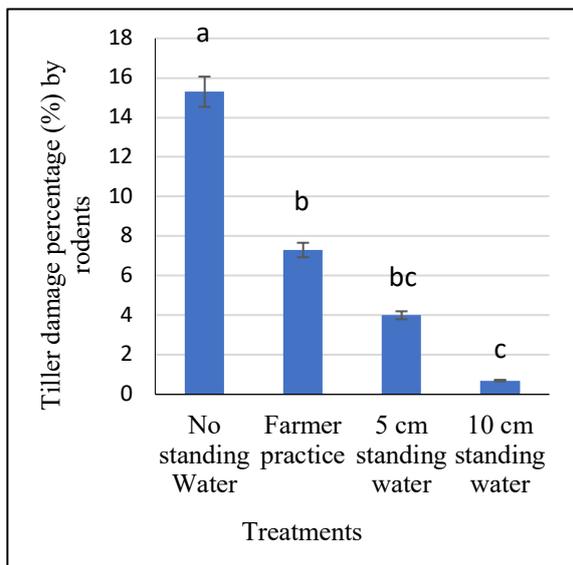

Figure 05: Tiller damage percentage (%) by rodents in rice field at Kahapathwala during 2019 minor season with different levels of standing water
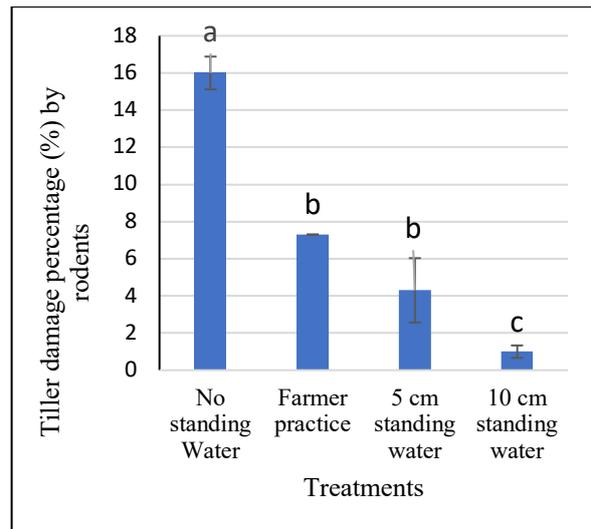

Figure 06: Tiller damage percentage (%) by rodents in rice field at Kahapathwala during 2019/20 Major season with different levels of standing water

IV. CONCLUSION

The study demonstrated that weed density has a positive correlation with rodent damage in rice fields, with the highest losses occurring in un-weeded plots and the lowest in weed-free plots. This emphasizes the necessity of proper weed management tactics to reduce losses by rodents in rice fields. Furthermore, standing water level was found to have a significant effect on rodent activity, indicating that water management practices can also play a role in minimizing rodent-induced yield losses. Overall, following appropriate weed and standing water level management practices provides a practical approach to reducing rodent damage in rice cultivation.

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Assessing the Influence of Benzylaminopurine (Bap) on *In Vitro* Shoot Proliferation of Pomegranate (*Punica Granatum* L.)

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Abstract

Pomegranate (Punica granatum L.) is an economically important crop, characterized for its nutritious and pharmaceutical applications. However, traditional propagation methods have limitations in producing large quantities of high-quality plantlets. Hence, this research was aimed at developing an efficient tissue culture protocol for the successful establishment and determining the best hormone concentration of Benzyl Amino Purine (BAP) for shoot proliferation of the Sri Lankan pomegranate variety, Cv. Nimali. The explants (axillary nodal segments,1cm long) and shoot tips (1cm long)) were derived from mature healthy mother plants, surface sterilized and introduced into full-strength woody plant media. After two weeks, newly developed clean shoots were transferred into multiplication media in which five different concentration of BAP 0.0 mg/l (T1, control), 0.25mg/l (T2) 0.5mg/l (T3), 1.0mg/l (T4) and 1.5mg/l (T5) were introduced. The cultures were incubated at 26 ± 2°c under16/8 h light/dark period in the incubation room. The results indicated that the highest shoot bud formation (6.0/plant), along with maximum shoot height of (22.4 mm), the average of leaves (11.4/plant), highest bud multiplication rate of (6.0%), were observed in shoot tip explants treated with 1.5 mg/L BAP (T5) after two-week period. In contrast, axillary nodal segments without BAP (T1) exhibited the lowest values, with shoot bud formation (1.4/plant), shoot height (1.0 mm), number of leaves (1.4/plant), and a bud multiplication rate of (1.4%). These findings demonstrate that the addition of 1.5 mg/L BAP to shoot tip explants significantly enhances shoot proliferation and growth in the Sri Lankan pomegranate variety, Cv. Nimali.

Keywords: *Axillary nodal segments, Benzyl Amino Purine, Micropropagation, Punica granatum L., Shoot tips, WPM media*

I. INTRODUCTION

The pomegranate (*Punica granatum* L.), belonging to the family Lythraceae, is an economically important crop of the semi-arid tropics of the world due to its highly nutritious, edible fruits that offer high returns and have great export demand. It also has versatile adaptability, low irrigation water requirement and pharmaceutical and ornamental usage (Chandra *et al.*, 2010). Pomegranate is a rich source of sugars (14-16%) and Vitamin C, along with essential minerals (0.7- 1.0%), iron (0.3-0.7 mg/100g), and other vital nutrients (Pawar *et al.*, 2020). The fruit is highly valued for its antioxidant properties, making it a popular choice both as a table fruit and in the local and export markets. The seeds, along with their arils, are often sun-dried and commercially marketed as condiments, spices, and food flavoring agents. Additionally, pomegranate seed oil has significant market potential due to its immense medicinal properties (Pawar and Singh, 2020).

Pomegranate plants are commercially propagated through stem cutting and air layering. These methods carry pathogens of challenging diseases like nematodes, bacterial blight and wilt, which introduce disease (Saroj and Kumar, 2019).This traditional method of pomegranate propagation is laborious and time-consuming. Its shortcomings include poor success rates, extremely low replication, and a one-year establishing period for obtaining new plants (Besharat *et al.*, 2024). The demand for quality pomegranate planting material is steadily increasing across major cultivation regions worldwide (Chandra and Babu, 2010). However, the available planting material from existing plantations is insufficient to meet this rising demand (Gorad *et al.*, 2018).

To overcome these limitations, tissue culture has emerged as a promising alternative for the mass production of healthy, disease-free pomegranate plants (Kalalbandi *et al.*, 2014). However, achieving large-scale production of high-quality planting material requires the careful selection of optimal explants, appropriate growth media, and the precise combination of plant growth regulators at various stages of micropropagation (Nimavat and Parikh, 2024). Benzylaminopurine (BAP) in micropropagation of woody crops is significant due to its strong influence on shoot induction and multiplication. BAP, a synthetic cytokinin, is widely used to initiate cell division and promote adventitious and axillary shoot proliferation, especially when added singly to the basal medium (Maheswari *et al.*, 2024). Hence, the aims of this study were to establish high throughput commercial tissue culture propagation protocol for shoot proliferation and to assess the ideal level of BAP in multiplication media for the Sri Lankan pomegranate variety *cv.* Nimali.

II. MATERIALS AND METHODS

A. Experimental Location

This study was conducted at the STC Biotech (Pvt) Ltd laboratory, located in Bope, Padukka, Sri Lanka (6°50'3.59" N, 80°05'18.00" E) at an altitude of 44 m above sea level. The area falls within the Low Country Wet Zone (WL1 Agro-ecological zone) and experiences an average annual rainfall of 329.2 mm, a maximum average temperature of 30.8°C, and a daytime relative humidity of 79.71%.

B. Planting material

Mature potted plants of the Sri Lankan pomegranate variety, Cv. Nimali, were obtained from the Fruit Research and Development Institute (FRDI) Kananvila, and maintained in a net house at STC Biotech (Pvt) Ltd. The plants were pruned at middle and sprayed twice weekly with 1% BAP solution (20 ml per plant) to promote new shoot growth(Amelia *et al.*, 2020).Axillary nodal segments and shoot tips were collected as explants for initiation in woody plant media (WPM), and after two weeks of incubation at 26 ± 2°C under a 16-hour photoperiod using white fluorescent light, the newly developed shoots were transferred to multiplication media with different BAP concentrations.

C. Establishment of aseptic cultures

The surface sterilization of explants was performed in aseptic conditions to produce contamination-free cultures. Axillary nodal segment and shoot tip explants were initially rinsed in tap water followed by a few drops of T-Pol for 2 minutes and washed under running tap water for 40 minutes to remove the debris and contamination on the surface. Then the explants were immersed in 0.1 % of Carbendazim fungicide solution for one hour ((Prajwala *et al.*, 2022) and in Amoxicillin (200 mg/L) antibiotic solution for 15 minutes and finally washed with distilled water. Explants were then treated with 70 % isopropyl alcohol (IPA) fluid for 1 minute inside the laminar airflow cabinet, then washed five times with autoclaved distilled water. Subsequently, they were dipped in a 4% sodium hypochlorite (NaOCl) solution containing T-Pol for 2 minutes, and finally rinsed again five times with autoclaved distilled water before inoculation onto culture media (Ali et al., 2023). This multi-step surface sterilization ensured maximum reduction of microbial load while preserving explant viability.

D. Culture media preparation

1) Initiation of Media and Culture conditions

Full-strength WPM medium was prepared supplementing with 20 g/L sucrose and solidified with 6.5 g/L agar. The pH of the medium was adjusted to 5.8 ± 0.02 using 0.1 N NaOH (Sodium Hydroxide) or 0.1 N HCl (Hydrochloric Acid) prior to the addition of agar. Then the media were dispensed into 5.12 cm × 8.84 cm autoclaved glass jars as 20 ml per each and autoclaved at 121°C with a pressure of 1.0 kg/cm2 for 20 minutes and sealed with plastic wraps after closing with autoclaved plastic lids. Sterilized axillary nodal segments and shoot tips were trimmed into 1 cm-long sections, each containing one or two nodes, and positioned vertically at the top of the medium. The cultures were incubated at 26 ± 2°C under a 16-hour photo period using white fluorescent light. After two weeks of incubation, newly developed healthy plantlets were transferred to treatment media.

2) Shoot multiplication media

Full strength of WPM media was used for the shoot multiplication media after adding different concentrations of BAP. Newly collected clean shoots from the initiation step were cultured in the

treatment media as one shoot per jar. The cultures were incubated at $26 \pm 2^{\circ}C$ under 16 h daily illuminations with white, fluorescent light (50 $\mu molm^{-2}s^{-1}$).

Table 01: Different concentration of BAP on shoot multiplication in *Punica granatum* L.

Treatment Code	(BAP) levels in shoot proliferation media (mg/l)
T1 (Control)	0.00
T2	0.25
T3	0.50
T4	1.00
T5	1.50

BAP: Benzylaminopurine

E. Data Collection

Two weeks after transferring to full strength WPM proliferation media having different concentration of BAP, data collection was conducted based on four main parameters to assess the growth performance of the plantlets. The number of shoot buds and the average number of leaves per plantlet were recorded through direct visual observation of each plantlet. Bud multiplication percentage was evaluated by visually inspecting and calculating the proportion of new shoots formed (Abdalla and Dobránszki, 2024). Shoot lengths were measured accurately by placing the plantlets on millimeter-marked graph paper.

F. Experiment Design and Statistical Analysis

All the experiments were set up in a completely randomized design (CRD) having five treatments with five replicates. Each replicate had five explants. Mean values were subjected to the analysis of variance (ANOVA) using IBM SPSS software version 25. Significantly different means were separated by Tukey's HSD post hoc test at $P \leq 0.05$. Results were represented by means ± Standard Error (SE).

III. RESULTS AND DISCUSSION

A. The Effects of BAP on shoot production in two types of explants

The present study investigated the effect of varying concentrations of BAP on shoot production and bud multiplication percentage in two types of explants: axillary nodal segments and shoot tips. Based on the findings, statistically significant differences in the mean number of shoots were observed among the various concentrations of BAP-supplemented media ($P \leq 0.05$).

The study found that 1.5 mg/L BAP (T5) resulted in the highest shoot proliferation, producing 3.6 ± 0.6 shoots from axillary nodal segments and 6.0 ± 0.3 shoots from shoot tips after two weeks of culturing (Figure 01). In contrast, the control treatment (no BAP) had the lowest shoot numbers, with 1.4 ± 0.2 and 2.8 ± 0.2 shoots from axillary nodal segments and shoot tips, respectively. A dose-dependent increase in shoot numbers was observed as BAP concentrations increased significantly from 0.25 mg/L to 1.5 mg/L (Figure 02 and 03). Increasing BAP beyond 1.5 mg/L may or may not increase shoot numbers and could cause abnormal growth. However, this should be confirmed by further research. Shoot tips consistently produced more shoots than axillary nodal segments across all treatments. Statistical analysis showed that the differences among treatments were significant ($p < 0.05$), confirming that 1.5 mg/L BAP is the optimal concentration for shoot multiplication in both explant types. These findings align with previous research on pomegranate, where MS medium supplemented with 1.5 mg/L BAP in combination with NAA produced the highest shoot proliferation, and higher concentrations either did not improve multiplication or caused abnormal growth, particularly in shoot tip explants(Kumar *et al.*, 2019).
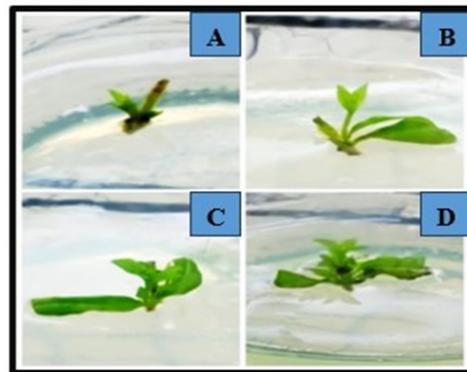

Figure 01: Morphology of induced shoots of *Punica granatum* L derived from axillary nodal segments after two weeks of BAP treatment: Letters A, B, C, and D represent shoots treated with 0.25, 0.50, 1.00, and 1.50 mg/L BAP, respectively.
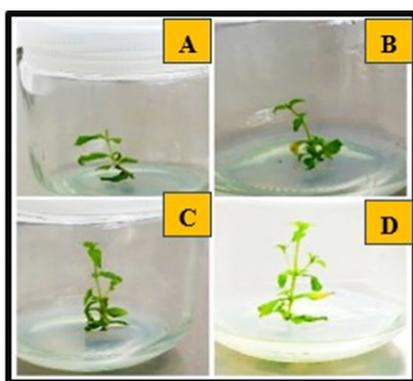
Figure 02: Morphology of induced shoots of *Punica granatum* L derived from shoot tips after two weeks of BAP treatment: Letters A, B, C, and D represent shoots treated with 0.25, 0.50, 1.00, and 1.50 mg/L BAP, respectively.
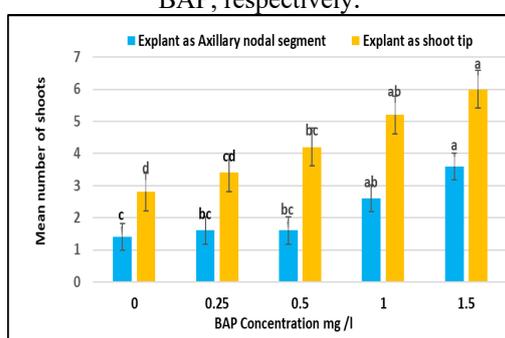

Figure 03: The Effects of BAP in shoot production in two types of explants. Means with the same superscript letter in the same color bar are not significantly different at Tukey's p< 0.05

Table 02. shows that statistical analysis confirmed significant differences (P < 0.05) in bud multiplication % where, the highest bud multiplication and shoot proliferation occurred in treatment T5 (1.5 mg/L BAP), with axillary nodal segments producing 3.6 ± 0.6 shoots and shoot tips 6.0 ± 0.3 shoots after two weeks, identifying 1.5 mg/L BAP as the most effective concentration.

Table 02: Bud multiplication and shoot proliferation percentage of explants

Treatments	Bud multiplication %	
	Axillary Nodal segments	Shoot Tips
T1	1.4 ± 0.2^c	2.8 ± 0.2^d
T2	1.6 ± 0.2^{bc}	3.4 ± 0.2^{cd}
T3	1.6 ± 0.2^{bc}	4.2 ± 0.2^{bc}
T4	2.6 ± 0.2^{ab}	5.2 ± 0.2^{ab}
T5	3.6 ± 0.2^a	6.0 ± 0.3^a
P	0.001	0.001
CV (%)	46%	30%

Means with the same superscript letter in a column are not significantly different at Tukey's p< 0.05

B. The Effect of BAP on Shoot Height

The study revealed a significant effect of BAP on shoot height in pomegranate (P ≤ 0.05). The lowest shoot heights were recorded in the control (T1), with axillary nodal segments at 1.0± 0.0 mm and shoot tips at 6.8 ± 0.3 mm. A consistent increase in shoot height was observed with rising BAP concentrations (0.25–1.5 mg/L). The highest shoot heights were recorded in T5 (1.5 mg/L BAP), with axillary nodal segments reaching 4.8 mm and shoot tips 22.4 mm, indicating a promotive effect of BAP on elongation (Figure 04).
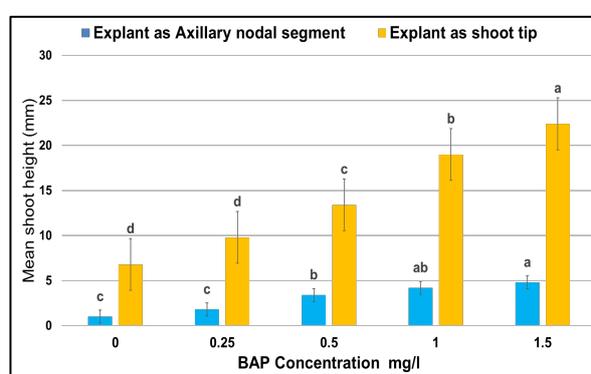

Figure 04: The Effect of BAP in Shoot height (mm). Means with the same superscript letter in the same color bar are not significantly different at Tukey's p< 0.05

C. The Effect of BAP on leaves production

The findings of the study revealed that leaf production per explant was significantly influenced by the concentration of BAP in the culture medium, with statistically significant differences observed among treatments (p ≤ 0.05). The highest mean number of leaves was recorded in treatment T5, which contained 1.5 mg/L BAP, producing 5.6 ± 0.2 leaves in axillary nodal segments and 11.4 ± 0.7 leaves in shoot tips after two weeks of culture followed by (T4), which contained 1.0 mg/L BAP and produced 5.4 ± 0.2 leaves in axillary nodal segments and 10.6 ± 0.2 leaves in shoot tips. In contrast, the control treatment (T1) without BAP showed the lowest leaf numbers, with 1.4 ± 0.2 leaves in axillary nodal segments and 5.2 ± 0.3 in shoot tips. As BAP concentration increased from 0.25 mg/L to 1.5 mg/L, an increasing trend in leaf formation was observed. Specifically, treatments T2, T3, and T4

resulted in 2.4 ± 0.2, 3.4 ± 0.4, and 5.4 ± 0.2 leaves in axillary nodal segments, and 7.2 ± 0.3, 8.4 ± 0.5, and 10.6 ± 0.2 leaves in shoot tips, respectively. Overall, shoot tips consistently exhibited a higher number of leaves than axillary nodal segments across all treatments, and 1.5 mg/L BAP was identified as the most effective concentration for promoting leaf development in both explant types (Figure 05).
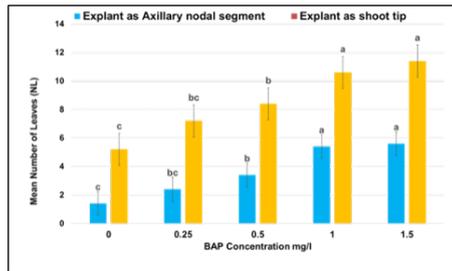

Figure 05: The Effect of BAP on leaves production. Means with the same superscript letter in the same color bar are not significantly different at Tukey's $p < 0.05$

The results of this study clearly demonstrate that BAP significantly enhances shoot proliferation and growth in the Sri Lankan pomegranate variety, Cv. Nimali. The optimal concentration of BAP for shoot proliferation was found to be 1.5 mg/L. This concentration resulted in the highest shoot bud formation, shoot height, and number of leaves. There are a number of reasons that shoot tip explants perform better than axillary nodal segment explants. Actively dividing meristematic tissues present at the tips of shoots are more receptive to BAP's growth-promoting actions.

The results of this investigation align with previous research on pomegranate micropropagation. According to Kumari et al. (2018), maximum shoot bud induction was achieved when nodal segment and shoot apex explants were cultured on basal medium supplemented with 2.0 mg/l and 2.5 mg/l BAP, respectively. Their findings highlight the potential of BAP in enhancing shoot formation across various woody plant species. The role of BAP has also been substantiated in several other woody crops, including Psidium guajava, Tectona grandis, and Prosopis cineraria, with effective concentrations ranging from 0.5 to 10.0 mg/l depending on the species and type of explant used . (Jayusman et al., 2022). The slightly lower optimal BAP concentration observed in Cv.

Nimali may be attributed to genotype-specific sensitivity, endogenous cytokinin levels, and the type of explant used, highlighting the importance of tailoring growth regulator concentrations to the specific cultivar for efficient micropropagation. These studies collectively confirm BAP as a critical plant growth regulator for successful micropropagation in woody crops. According to numerous studies, BAP effectively encourages the growth of new shoots in a variety of pomegranate cultivars. However, the cultivar and type of explant employed could influence the optimal BAP concentration.

IV.   CONCLUSION

The study demonstrates that 1.5 mg/L BAP significantly enhances *in vitro* shoot proliferation in *Punica granatum* L., resulting in maximum shoot bud formation, height, leaf number, and bud multiplication in shoot tip explants. This concentration proved most effective among all tested, while explants without BAP showed poor growth, confirming the crucial role of cytokinin in shoot organogenesis. Shoot tips outperformed nodal segments across treatments, indicating higher regenerative potential. Thus, 1.5 mg/L BAP and shoot tip explant are recommended for efficient shoot proliferation. To support large-scale production, root induction is necessary, and further trials are required to establish a complete micropropagation protocol with potential applications in the conservation and genetic improvement of *P. granatum* through optimized tissue culture.

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ABBREVIATIONS

- Tc   Tissue Culture
- Var   Variety
- WPM   Woody Plant Basal Medium
- BAP   Benzyl Amino Purine
- IPA   Isopropyl Alcohol
- NaOCl   Sodium hypochlorite
- CRD   Completely Randomized Design
- ANOVA   Analysis of Variance
- SPSS   Statistical Package for the Social Sciences

Pheromone Characterization and Behavioral Responses of the Local Rice Yellow Stem Borer (*Scirpophaga incertulas*) to Different Sri Lankan Rice Varieties

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Abstract

The Rice Yellow Stem Borer (YSB), Scirpophaga incertulas (Lepidoptera: Crambidae), is a major pest that poses significant yield losses in Sri Lankan paddy cultivation. Synthetic chemical insecticides are the primary control method. However, their long-term effectiveness is limited due to negative impacts on biodiversity and risk to human health. This study aims to characterize the pheromone components of the local YSB population and assess their behavioral responses to different Sri Lankan rice varieties. Pheromone components were collected from female YSB using dynamic headspace collection (30 individuals per replicate) and solvent extraction (15 individuals per replicate). A varietal preference test was conducted using a dual-choice olfactometer for eight rice varieties: BG 366, AT 311, BG 257, AT 362, BG 251, AT 313, BG 360 and BG 377. The collected volatile compounds were analyzed using Gas Chromatography-Mass Spectrometry (GC-MS). The GC-MS analysis identified (Z)-11-Hexadecenal as a major sex pheromone compound in YSB. The varietal preference test shows significant differences (p = 0.001) among the rice varieties. Notably, AT 313 is the most attractive rice variety (13.2 ± 0.33), and BG 251 is the least attractive rice variety (3.8 ± 0.22) to the female YSB. S. incertulas most prefers to damage paddy cultivation after the pre-booting stage (early panicle initiation). The optimum laboratory rearing conditions for S. incertulas were determined as 26 ± 2 ^{0}C temperature, 75 ± 5% relative humidity, and a 10-12 hours light: 12-14 hours dark cycle. Further studies are necessary regarding laboratory bioassays and field evaluations to develop a sustainable and effective semiochemical-based pest management strategy (pheromone trap) to manage the rice yellow stem borer more effectively.

I. INTRODUCTION

Rice (*Oryza sativa*) is the most widely produced cereal crop, serving as a staple diet for more than half of the global population (Dhruv *et al*., 2019). Its cultivation is essential for food security, especially in Asian regions, including Sri Lanka. In Sri Lanka, paddy is cultivated on approximately 708,000 hectares of land and yields 5.037 million metric tons annually (Department of Census and Statistics, 2023). However, paddy cultivation is highly vulnerable to various pests that cause significant yield losses.

However, paddy cultivation is highly vulnerable to various pests. Among over 100 pest species affect paddy cultivation, only a few causes damage beyond the economic threshold level (ETL) (Muralidharan & Pasalu, 2006). These species are known as major pests (Sai *et al*., 2022), including the brown plant hopper, gall midge, rice leaf folder, and rice yellow stem borer. The rice yellow stem borer (*S. incertulas*) is one of the most destructive pests (Raut *et al*., 2017), causing yield losses of 10-60% (Sah & Sharma, 2023). Larvae are bored into the stem of paddy plants while disrupting the vascular system (Arun Kumar & Devanand R. Bankar, 2023). It inhibits the nutrient flow and reduces plant growth and yield. "Dead-hearts" are affected during the vegetative growth stage, and "Whiteheads" (Anis Syahirah Mokhtar *et al*., 2024) are affected during the reproductive stage.

Therefore, sustainable pest management strategies are essential to ensure food security and protect the economic stability of paddy farmers. Existing cultural, biological, mechanical, and

chemical control methods are ineffective due to the environmental factors and variation of *S. incertulas* population dynamics. An eco-friendly and effective pest management strategy is essential to control the *S. incertulas* population according to local conditions (Batta *et al*., 2023). However, no significant attempts have been made to utilize semiochemical and plant volatiles analysis for its control. This study aims to was to identify and characterize YSB female sex pheromones and attractant and repellent varieties for management of YSB in paddy cultivation.

II. MATERIALS AND METHOD

A. *Experimental Site*

The research was conducted from October 2024 to April 2025 at the Crop Science and Technology Laboratory in the Faculty of Technology, South Eastern University of Sri Lanka.

B. *Sample Collection and Rearing*

Live *S. incertulas* larvae were collected from paddy fields exhibiting signs of stem borer infestation. Sample collection was done in the 2024 Maha season at the Rice Research Station, Sammanthurai. Collected larvae were brought and reared under particularly laboratory conditions, 26 ± 2 ^{0}C temperature, $75 \pm 5\%$ relative humidity, and a 10-12 hours light: 12-14 hours dark cycle. Potted healthy paddy cultivation was maintained prior to initiating the rearing procedure. The larvae of *S. incertulas* were provided with paddy plants early panicle initiation stage as a food source and maintained until pupation and adult emergence. Newly emerged adults were transferred to cages and provided with a 10% sugar solution-soaked cotton pads as their food source. Paddy plants (vegetative stage) were introduced into cages as oviposition substrates. Egg masses were collected and new larvae emerging from the eggs follow the same procedure.

C. *Gender Identification*

The gender identification of moths was carried out based on morphological characteristics using both macroscopical and microscopical characters. Female moths were larger than males, who are also bright yellow and have black spots in the middle of their forewings, with a wide abdomen. Male moths were light brown and had rows of black spots on the ends of the forewings, with a slender abdomen. Female moths that produce sex pheromones to attract male moths were selected for the extraction of pheromone compounds.

Figure 01: Gender Identification of *S. incertulas*

D. *Extraction of Pheromone Compounds*

Two methods were used to extract the pheromone compounds from female YSB. It ensures a thorough and accurate analysis of the pheromone profile.

The solvent extraction of pheromonal compounds was done at during the peak pheromone-releasing period (calling period between 23:00-03:00 h). The pheromone glands of virgin female moths (15 moths per replicate) were isolated using a micro-insect dissecting tool. The glands were immediately dissolved with 0.5 ml HPLC dichloromethane (DCM). The solvent containing the extracted pheromones was filtered using microfiltration and concentrated with ultra-pure nitrogen (N_2) gas and stored at -20 ^{0}C until GC-MS analysis.

The dynamic Headspace Collection method was used to collect pheromones from live virgin females during their peak calling period. A dynamic headspace sampling apparatus was used for the study. The setup contained an air-tight glass container connected to a charcoal filter at one arm, which ensured the purity of the air circulating through the air inlet, and Porapak Q adsorbent trapped volatile compounds of the other arm. A suction pump was used to draw air through the Porapak Q adsorbent tube. Female moths (30 moths per replicate) were placed in the air-tight glass container, and the pheromone released during their calling period was extracted. The trapped pheromonal compounds in the Porapak Q absorbent were removed after 24 h

into a GC-MS vial using 0.5 ml of DCM (HPLC group). It was stored at -20 ^{0}C until analysis.
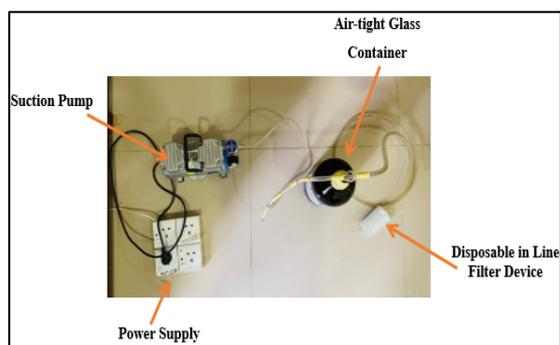

Figure 02: Dynamic Headspace Setup

E. GCMS Analysis

The extracted pheromone samples were subjected to Gas Chromatography-Mass Spectrometry (GC-MS) to identify volatile pheromone compounds. GC-MS consisted with GC 8890 coupled with a 5977B MSD, Agilent Technologies. The analysis was performed using a capillary column (HP5MS, 30 m x 0.250 mm x 0.25 μm) with helium (99.99%) as the carrier gas at a flow rate of 1.2 mL/ min. A 2 μl sample was injected into the system. The oven and column temperature were initially set at 35 ^{0}C for 1 minute and then ramped up at a rate of 10 ^{0}C/min to 230 ^{0}C. The separated constituents were identified by comparing mass spectra to the National Institute of Standards and Technology (NIST) library.

F. Varietal Preference Test

This study was conducted to evaluate the varietal preferences of adult female *S. incertulas* using a dual-choice experimental series. A dual-choice olfactometer was used for the experiment. The setup was designed to distribute environmental factors and other internal factors equally to avoid bias in the preference.

The paddy varieties, namely, BG 366, AT 311, BG 257, AT 362, BG 251, AT 313, BG 360, and BG 377 were grown as seedlings. Two-week-old paddy seedlings were placed at the olfactometer to ensure equal exposure.

For this purpose, two-week-old paddy seedlings of each variety were placed on either side of an experimental setup. Twenty adult female *S. incertulas* were released into the central compartment of the setup and allowed to move freely between the two rice varieties. The number of females present on each rice variety was observed and recorded separately in the morning (9:00 h) and evening (16:00 h).

Figure 03: Varietal Preferences Test Setup

Data were analyzed using one-way ANOVA followed by Tukey's post hoc test at a 5% significance level using the SPSS software package (version 25).

The dynamic Headspace Collection method was used to separately collect volatile compounds emitted from both the most preferred and the least preferred paddy varieties. The samples were analyzed using GC-MS to identify volatile components. This information suits pest management strategies based on varietal resistance.

III. RESULTS

A. Pheromone Identification Using the Pheromone Gland Extraction Method

Gas chromatography-mass spectrometry (GC-MS) analysis of pheromone gland extracts discovered pheromones and volatile organic components. Two pheromone compounds were identified from *S. incertulas* females in Sri Lanka. (Z)-9-Hexadecenal, which was recorded at 5.731 min of retention time, and (Z)-11-Hexadecenal, which was recorded at 11.355 min of retention time, were identified as major pheromone compounds.
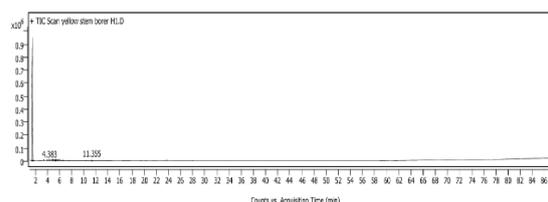

Figure 04: GC-MS Chromatograph of volatile organic compounds extracted from the solvent extraction method of *S. incertulas* females

Other volatile organic compounds were included: Benzene, Toluene, Phenol, and Hexanol, with different retention times. These were known as metabolic byproducts, host plant volatiles, and semiochemicals influencing feeding/ oviposition.

Table 01: Volatile organic compounds extracted from the solvent extraction method of *S. incertulas* females

Retention Time	Name of the Compound	Putative Biological Role
4.383	Benzene	Metabolic byproducts
5.248	Toluene	Host plant volatile
5.288	Phenol	Semiochemical influencing feeding/ oviposition
5.401	Hexanol	Host plant volatile
5.445	Pinene	Host plant attractant or repellent
5.731	(Z)-9-Hexadecenal	Minor sex pheromone component
11.355	(Z)-11-Hexadecenal	Major sex pheromone component

Note: The Table shows different volatile compounds of a blend of S. incertulas pheromone.

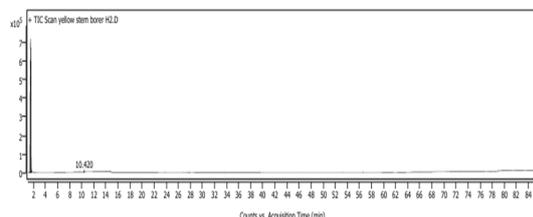## B. Pheromone Identification Using the Dynamic Headspace Collection Method

Figure 05: GC-MS Chromatograph of volatile organic compounds extracted from the dynamic headspace collection method of *S. incertulas* females

Two volatile organic compounds and one pheromone compound were identified. (Z)-11-Hexadecenal, recorded as a major female sex pheromone of *S. incertulas*, was recorded at 11.355 min of retention time. Benzene, recorded at 4.383 min of retention time, is considered a metabolic byproduct, and Hexanol, recorded at 5.401 min of retention time, is considered a host plant volatile.

Table 02: Volatile organic compounds extracted from the dynamic headspace collection method of *S. incertulas* females

Retention Time	Name of the Compound	Putative Biological Role
4.383	Benzene	Metabolic byproducts
5.401	Hexanol	Host plant volatile
11.355	(Z)-11-Hexadecenal	Major sex pheromone component

Note: The Table shows different volatile compounds of a blend of *S. incertulas* pheromone

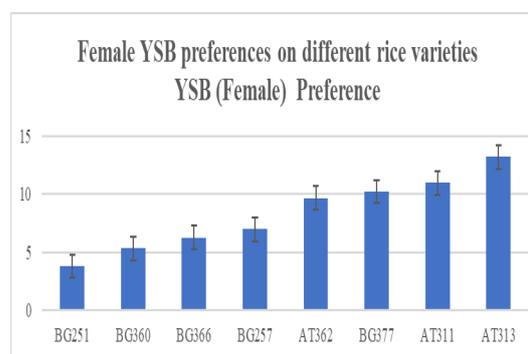## C. Varietal Preferences of Rice Yellow Stem Borer

Figure 06: Female *S. incertulas* preferences on different rice varieties

According to the analyzed data, there were significant differences ($p = 0.001$) in Rice yellow stem borer preference among the 8 paddy varieties (BG 366, AT 311, BG 257, AT 362, BG 251, AT 313, BG 360, BG 377). The most preferred paddy variety was AT 313 (13.2 ± 0.33) to female yellow stem borer moths, and the least preferred variety was BG 251 to female yellow stem borer moths.

D. Volatile Identification of AT 313 paddy variety

Thirteen (13) Paddy-related volatile organic compounds (VOCs) were identified at different retention times in AT 313 paddy variety by GC-MS.
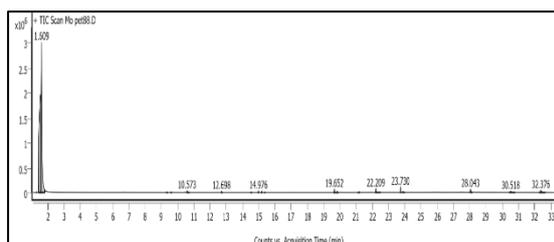
Figure 07: GC-MS Chromatograph of VOCs extracted from the dynamic headspace collection method of AT 313 paddy variety

Table 03: VOCs extracted from the dynamic headspace collection method of AT 313 paddy variety

Retention Time	Name of the Compound
10.573	1-Pentene, 4,4-dimethyl
12.704	1-Heptanol
15.192	Pentane, 2,2,3,4-tetramethyl
15.364	Oxalic acid, butyl propylester
19.824	1H-Tetrazol-5-amine
22.216	2,6-Bis(1,1-dimethylethyl)-4-methyl-4-isopropylcyclohexa-2
28.05	Acetic acid, trifluoro-,3,7-dimethyloctyl ester
32.382	Phthalic acid, cyclobutyl isobutyl ester
10.573	1-Pentanol, 2-ethyl-4-methyl
12.704	1-Hexanol, 4-methyl
28.043	1-Undecene, 9-methyl
9.6	Butane, 2,2-dimethyl
19.652	Cyclopropane, octyl-
10.573	1-Pentene, 4,4-dimethyl

Note: The table presents the major VOCs identified from the AT 313 paddy variety using the dynamic headspace collection method.

E. Volatile Identification of BG 251 paddy variety

A total of eighteen (18) VOCs detected by GC-MS at different retention times.
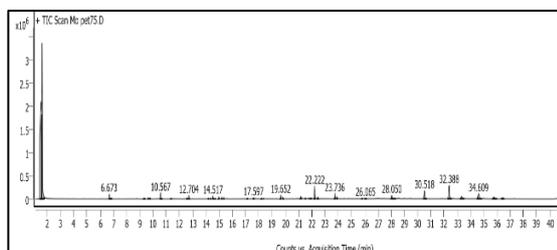

Figure 08: GC-MS Chromatograph of VOCs extracted from the dynamic headspace collection method of BG 251 paddy variety

Table 04: VOCs extracted from the dynamic headspace collection method of BG 251 paddy variety

Retention Time	Name of the Compound
17.171	Safrole
19.346	Benzene, 1,2,3-trimethoxy-5-(2-propenyl)-
19.505	Bicyclo [3.1.0] hex-2-ene,4-methyl-1-(1-methylethy
19.735	1-Hexanol, 4-methyl-
20.008	Methyleugenol
20.275	(Z, Z)-. alpha. -Farnesene
22.636	1,3-Benzodioxole, 4-methoxy-6-(2-propenyl)-
23.526	3-Methoxy-4,5-methylenedioxybenzaldehyde
23.806	Cyclopentane, 1,1,3-trimethyl
24.315	Benzylphenethylamine, N-ethoxycarbonyl
14.995	Cyclopentane, 1,1-dimethyl
23.742	Acetic acid, trifluoro-,3,7-dimethyloctyl ester
10.579	1-Pentene, 4,4-dimethyl
12.704	Oxalic acid, butyl propylester
14.982	1-Heptene, 6-methyl
19.658	Cyclopropane, octyl
19.823	1H-Tetrazol-5-amine
28.05	Cyclopentane, (2-methylbutyl)
17.171	Safrole

Note: The table presents the major VOCs identified from the BG 251 paddy variety using the dynamic headspace collection method.

IV. DISCUSSION

The present study identified two major pheromone components in the Sri Lankan rice yellow stem borer *S. incertulas*. They are; (Z)-11-Hexadecenal as the major component and (Z)-9-Hexadecenal as a minor component. This finding is consistent with previous studies conducted in other countries in the world ((Kirsch, 1988);(Raut *et al*., 2017)). According to previous studies, (Z)-11-Hexadecenal was indicated as the major sex pheromone component relevant to the attraction of male *S. incertulas* (Cork *et al*., 1985). Minor pheromone compound often acts independently but act synergistically with major pheromone compounds to enhance male moth attraction. Combining major and minor pheromone compounds may provide a semiochemical-based control method with improved efficacy *(Witzgall et al*., 2010).

Other studies have shown the importance of host plant volatile compounds in influencing insect

behavior (Verheggen *et al*., 2010), including oviposition and feeding (El-Ghany, 2019). Both the dynamic headspace collection method and the solvent extraction method were used to identify host plant volatiles such as phenol, benzene, and hexanol. Compounds such as hexanol were shown to attract *S. incertulas* females for oviposition and survival (Qian *et al*., 2024).

Laboratory-based dual-choice olfactometer-based varietal preference tests provided insight into *S. incertulas* preferences. According to the results of the varietal preference test, there were significant differences among the eight selected paddy varieties (BG 366, AT 311, BG 257, AT 362, BG 251, AT 313, BG 360, and BG 377). The most preference for AT 313 and the least preference for BG 251. GC-MS analysis of volatiles released by AT 313 revealed compounds such as 1-Heptanol and Pentane, which may increase its attractiveness to *S. incertulas* females (Xiong *et al*., 2024). BG 251 was characterized by high levels of Safrole and Methyleugenol. Those compounds may be insect repellent properties appeared to be less attractive. Some compounds may act as attractants or repellents for *S. incertulas* females. Compared to the volatile profile of AT 313, BG 251 showed differences in its emissions. Certain compounds were completely absent from BG 251, while others, which possibly associated with plant defense mechanisms, were more prominent.

These differences may account for the lower host preference observed in behavioral tests.

This will enable the establishment of an integrated management system based on volatile compounds in the varieties and pheromones of *S. incertulas* (Witzgall, 2001). Thereby reducing the dependence on chemical synthetic pesticides and contributing to the creation of a long-term semiochemical-based (Smart *et al*., 2014) eco-friendly management strategy for local population of *S. incertulas*.

V.   CONCLUSION AND RECOMMENDATION

This study was focused on identifying and determining the efficacy of female sex pheromones of the YSB in Sri Lanka and the development of semiochemical-based management strategies to reduce dependence on chemical pesticides while minimizing the environmental and health impacts. According to the results, (Z)-11-Hexadecenal was detected as a major pheromone compound of the *S. incertulas* in both dynamic headspace collection and pheromone gland extraction methods. (Z)-9-Hexadecenal was detected as a minor pheromone compound of the *S. incertulas*. There were significant differences among the eight paddy varieties in the varietal preference test. Notably, AT 313 was the most preferred variety, while BG 251 was the least preferred. With the comparison of volatile organic compounds, differences were identified between BG 251, the least preferred paddy variety, and AT 313, the most preferred paddy variety of *S. incertulas*. There may be attractive and repellent compounds. Therefore, we need to do further studies of different compounds to identify their roles. Pheromone components, volatile components of the most preferred variety and the least preferred variety, and their differences should be confirmed. Further studies are necessary to formulate semiochemical-based attractants or repellents to control *S. incertulas* populations and confirm their effectiveness under field conditions.

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ABBREVIATIONS

- YSB : Yellow Stem Borer
- ETL : Economic Threshold Level
- N2 : Nitrogen Gas
- GC-MS : Gas Chromatography-Mass Spectrometry
- VOCs : Volatile Organic Compounds
- DCM : Dichloromethane
- HPLC : High-Performance Liquid Chromatography
- BG : Bathalagoda
- AT : Ambalantota
- ANOVA : Analysis of Variance
- MSD : Mass Selective Detector
- NIST : National Institute of Standards and Technology

Growth And Yield Performance of Salad Cucumber (*Cucumis sativus. L*) Cultivated in Novel Potting Mix Enriched with Recycled Plant Tissue Culture Media

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Abstract

Plant tissue culture media waste contains large quantities of essential macro- and micronutrients that are beneficial for commercial plant growth and development. This study explored an environmentally sustainable approach to manage Banana Tissue Culture Waste Media (BTCWM) by incorporating it into a novel growing medium for cultivating salad cucumber (cv. Bonafide F1). A greenhouse experiment was conducted using a completely randomized design with seven different treatments with fifteen replications namely T1 control { 100% coconut coir dust (CD)}, T2 (BTCWM 50%+ CD 40% + sand 10%), T3(BTCWM 40%+ CD 50% + sand 10%), T4 (BTCWM 30% + CD 50% + sand 20%), T5 (BTCWM 20%+ CD 50% + sand 30%), T6 (BTCWM 10%+ CD 50% + sand 40%), T7 (BTCWM 50%+ CD 50%). Our results showed that plant growth varied significantly across treatments. At 11 weeks after planting, T4 and T7 produced the longest vine lengths (871 cm), while T1 had the shortest (860 cm). T7 also demonstrated the highest leaf diameter (25.5cm) and vine diameter (5.9cm) than that of T1 and T2. At the 7 WAP, T7 and T5 exhibited the highest flower production rates, with 8.3 and 7.4 flowers per week respectively, surpassing the control (5.1/week). Subsequently, T7 also led in fruit weight (50.4 g/fruit), followed by T5 (49.2 g/fruit), while the control produced the lowest (29.2 g/fruit). Among all treatments, T7 (50% BTCWM + 50% coir dust) showed the most promising results, suggesting that the plant tissue culture waste media can be utilized in promoting salad cucumber production.

Keywords: Banana tissue culture waste media, Coconut coir, growth media, salad cucumber

I. INTRODUCTION

Plant tissue culture is regarded as a fundamental method for crop propagation in modern agriculture. This research addresses the limited study on using waste-mixed media by focusing on banana tissue culture waste. Disposal of waste plant tissue culture media often leads to nutrient loss and environmental pollution. This is viewed as both a source of environmental pollution and a missing opportunity for resource recovery. This waste is a recognized source of nutrient loss and environmental pollution (Hamdeny et al., 2022) due to its content of residual chemical fertilizers, plant growth regulators (phytohormones), and potential microbial contaminants. Plant tissue culture media is often considered a biohazard because it has been used to grow plant tissues (explants) and might harbor microorganisms (bacteria, fungi) from the culture or the lab environment. Furthermore, the discharge of even trace amounts of artificial phytohormones and heavy metal ions can potentially disrupt the natural development and reproductive cycles of native flora and algae. The current challenge is viewed as both an environmental hazard and a missing opportunity for resource recovery. By converting waste plant tissue culture media into greenhouse substrates, dual benefits are achieved: waste is reduced, and alternative substrates that fulfil the physical and chemical requirements for plant growth are created (Sharma et al., 2019). Salad cucumber *(Cucumis sativus L.)* is an important vegetable crop worldwide and is considered an important vegetable due to its nutritional and culinary value (Shahul et al, 2015). Good management practices are essential for producing high yields of a quality crop.

Recent investigation shows that supplying balanced nutrients with macronutrients like

nitrogen (N), phosphorus (P), and potassium (K) enhance vegetative growth, flowering, and fruiting. Secondary macronutrients like calcium (Ca) and magnesium (Mg), and micronutrients such as boron (B), iron (Fe), and zinc (Zn), though required in smaller amounts, are also vital for salad cucumber (Moreno et al., 2003). Conversely, deficiencies and/or excesses in any of these nutrients can produce physiological abnormalities associated with lower growth rates, lower fruit yields, and lower fruit quality. As Waste tissue culture media contain essential macronutrients (nitrogen, potassium, phosphorus) and micronutrients essential for plant growth and development, as well as organic compounds such as hormones and vitamins that enhance cellular function (Nasution, 2020). This research was conducted to develop a novel potting mixture utilizing banana tissue culture waste media and to explore the synergistic potential of reusing this waste media as a sustainable substrate component to develop promote salad cucumber (*Cucumis sativus* L.) cultivation.

II.   MATERIALS AND METHODS

A. Study area

This study was carried out in a semi-automated controlled greenhouse facilities at Mike Flora Pvt Ltd in Rajagiriya, Sri Lanka, The semi-automated greenhouse featured day/night temperature at $26^{\circ}C/24^{\circ}C$, humidity (70-75%), and light ($<1800\mu molm^{-2}s^{-1}$) were adjusted to ensure optimal plant growth and development throughout the trial. The insect-proof net (mesh size 60) and side walls of the greenhouse were washed, and fumigation was carried out using insecticide (Abamectin 18 ml/l) prior to the experiment. The study area experiences annual rainfall of approximately 2500 mm and temperatures ranging from 25°C to 30°C.

B. Preparation of the potting media and the crop management.

The coconut coir dust and river sand were collected from the local suppliers and were sterilized by using Captan (1g/ll) and covered using transparent polythene for a week before formulating seven growing media by mixing with banana tissue culture waste media (BTCWM), coconut coir and sand in predetermined weight ratios (Table 01).

Table 01: Treatment regime of novel greenhouse potting mixtures for salad cucumber cultivation

Treatments	Composition of potting media (w/w ratio)		
	Banana tissue culture waste media	Coconut Coir	Sand
T1(Control)	-	100%	-
T2	50%	40%	10%
T3	40%	50%	10%
T4	30%	50%	20%
T5	20%	50%	30%
T6	10%	50%	40%
T7	50%	50%	-

Seeds of the salad cucumber variety (*cv.* Bona Fide F1 hybrid) were sown on 5l volume of U.V treated polybags with the above modified growth media (Table 01). A total of 105 polybags were used for seven treatments, with one seed sown per pot. Germination percentages over a period of nine-days were recorded. Drip irrigation was used to maintain consistent moisture levels. Three weeks after seed germination, salad cucumber vines were trained on nylon strings to grow upward. Subsequently, at four weeks after planting, pruning of mature leaves, stems, and side branches were practiced on weekly basis (Chand, 2014).

C. Experimental Design and Data Analysis

A completely Randomized Design (CRD) was used for this experiment, with seven treatments and fifteen replications. A comprehensive assessment protocol was implemented to ensure robust monitoring and analysis of plant growth and productivity. Starting the week after seed germination, weekly evaluations were recorded for critical growth metrics such as plant height, diameter, branch and leaf count, and leaf dimensions. Subsequently, at reproductive stage, the flower developmental rates (Number of flowers/week/plant) were recorded. At harvest, fruit traits viz; fruit count, length, diameter, and fresh weight were measured and final yield were determined at plant levels. Finally, the collected

data were subjected to an analysis of variance (ANOVA) was performed using SPSS (25 Vision) software to analyze the data and a Turkey post- hock test was performed to find out the significance between the treatments at P<0.05.

III.   Results and Discussion

A.   Production of leaves

The data show the average number of leaves per plant for different substrate potting mixtures, A total of 90 to 100 leaves were produced by the individual salad cucumber plants. None of the treatments showed a significant (P > 0.05) difference in leaf production rates among the treatments. (Figure 02).
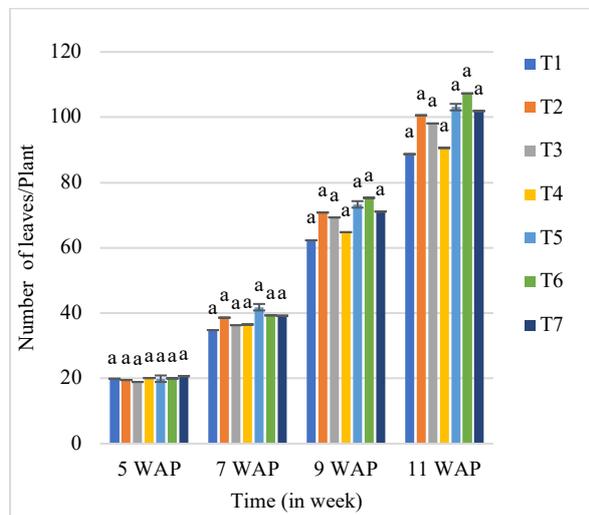

Figure 02: Number of leaves produced in salad cucumber with various potting media during 5-11Weeks ffter planting

B.   Leaf Length(cm) and Leaf Width (cm)

The study found significant differences (P < 0.05) in leaf length among treatments. At 11 weeks after planting (WAP), plants grown in T7 (50% WATCM and 50% coconut coir mixture) had the largest leaf length (25.5 cm) and leaf width (25.7 cm), and the smallest was in T2 leaf length (23.1 cm) and leaf width (23.0 cm) which are smaller than those in the control treatment (T1). These differences may be due to influence of nutrient availability, water retention, and aeration provided by the different mixtures.

According to , the in Johnson and Mirza, (2020) proved leaf length might be due to the presence of nitrogen as it is essential for the plant right from sowing to the growth and development of the plant. Increases the vegetation of the crop, size of the leaves increases which enhances the photosynthetic activity of the plant. These findings agree with Monib et al. (2023) , who found that micronutrients such as B, Zn, Cu, Fe, and Mn has been proven to improve plant height, number of branches/plant, fruit length, fruit diameter, fruit yield/ha, and marketable fruit yield/ha in crops such as tomato and cauliflower.
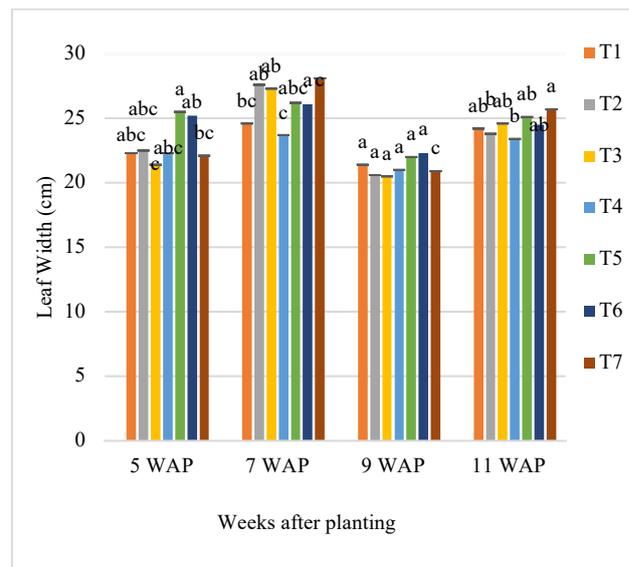

Figure 03: Leaf width (cm) of salad cucumber growth from 5-11 week after planting.

C.   Vine length (cm)

Vine length was significantly (P<0.05) affected by different media treatments. The longest vines (871 cm) were recorded in T4 and T7 at 11 weeks after planting (WAP). The shortest (860 cm) vine length was in T1 (control) at 11 weeks after planting (WAP). It might be due to the presence of all the required nutrients, vitamins and amino acids are present in the tissue culture media. WATCM can serve as a source of nutrients and organic matter, potentially enhancing plant growth. However, the composition of WATCM varies, and its effects may depend on the specific source and processing methods.

The addition of Banana Tissue Culture waste media has a positive impact on plant development since they contain essential nutrients and improved physical properties of soil (Awasthi et al., 2015; Goyal et al. 2005). Coconut coir acts as a substrate for agricultural purposes and because of its characteristics regarding water retention

and aeration, it can positively affect plant development (Abad *et al.*, 2005). Media containing low concentrations of BTCWM showed the poorest performance compared to the 50% concentration, likely due to a deficiency in critical nutrients. This observation supports the findings of Johnson and Mirza (2020), who emphasized that both nutrient deficiencies and excesses can lead to various physiological disorders in plants and their fruits.
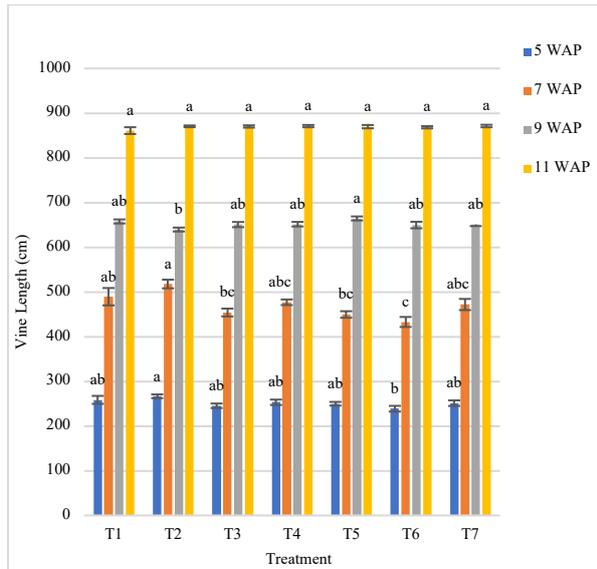

Figure 04: Leaf Length(cm) of salad cucumber from 5 to 11 week after planting.

D. Vine diameter

The significant (p<0.05) differences in vine diameter started to occur from 9 WAP. At 9 WAP, the highest vine diameter (5.6cm) was observed in both the control treatment (T1: 100% coconut coir dust) and treatment T7 (BTCWM 50% + CD 50%). The lowest vine diameter at 9 WAP (4.6 cm) was reported in treatment T3 (BTCWM 40% + CD 50% + sand 10%). When compared to control (T1), treatments T2, T4, T5 and T6 were significantly similar (p>0.05) (5.3, 5.2, 5.4 and 5.4 cm, respectively) while T3 had a lower diameter (4.8cm). Similarly, at 11 WAP, the control treatment (T1) and treatment T7 again demonstrated the highest vine diameters, both reaching 5.9cm. The greatest vine growth at T7 might be associated with the presence of sand, while improving drainage might have diluted the

organic matter and nutrient availability, or altered the water retention characteristics in T3 to a suboptimal level, thereby hindering vine growth (Goyal et al., 2005). Schroeder (2014), stated that the vine diameter is an important indicator of the overall viability of the plant and its photosynthetic capacity, which influences yield, indicating that substrate composition had a major effect on plant growth variables.

E. Weekly Flower production rate

Flowering data were systematically recorded at weekly intervals, commencing at 4 WAP, and continuing until 11 WAP. Statistical analysis revealed a significant difference in the number of flowers among the treatments at 6 WAP, 7 WAP, 9 WAP, and 11 WAP (P<0.05). At 6 WAP, the highest mean number of flowers was observed in treatment T6 (5.2 flowers/week) (BTCWM 10% + CD 50% + Sand 40%) followed by T7 (4.6 flowers/week) (BTCWM 50% + CD 50%), with a significant difference in flower numbers when compared to other treatments, including the control (3.4 flowers/week). At 7 weeks after planting (WAP), flower production reached its peak, with Treatment T7 (BTCWM 50% + CD 50%) recorded the highest mean number of flowers at 8.3/week. This was followed by Treatment T5 (BTCWM 20% + CD 50% + Sand 30%), which had a mean of 7.4 flowers.

At 9 WAP, T5 continued to perform well compared to the control, recording a mean flower count of 5.5, followed by treatment T7 with 4.9 flowers. However, the difference between T5 and T7 was not statistically significant. By 11 WAP, treatment T5 (BTCWM 20% + CD 50% + Sand 10%) maintained the highest mean number of flowers at 5.9, followed closely by T7 with 5.5 flowers. Both treatments recorded significantly higher flower counts than the control (T1), which had a mean of 3.1 flowers. The differences in significance between weeks suggest that the potting media used to grow the plants had an effect on flowering that appears to be dynamic, or the difference is more prominent in specific physiological periods in the reproductive life cycle of the plant (Shibaeva et al., 2013).

Table 02: Effects of potting mixture on the production of flowers in salad cucumber (flowers/plant/week).

Treatments	5 WAP	7 WAP	9 WAP	11 WAP	Total flowers/plant
T1	1.9 ± 0.4^{a}	5.1 ± 0.7^{ab}	2.7 ± 0.3^{c}	3.1 ± 0.2^{b}	37.87 ± 3.9^{c}
T2	1.8 ± 0.4^{a}	5.6 ± 0.6^{ab}	4.0 ± 0.3^{bc}	2.6 ± 0.2^{b}	$43.4 \pm 2.6b^{c}$
T3	2.3 ± 0.4^{a}	4.8 ± 0.6^{b}	4.3 ± 0.4^{ab}	3.4 ± 0.4^{b}	44.93 ± 5.0^{bc}
T4	2.0 ± 0.5^{a}	5.1 ± 0.7^{ab}	4.5 ± 0.3^{ab}	5.7 ± 0.2^{a}	52.3 ± 4.58^{abc}
T5	1.4 ± 0.3^{a}	7.40 ± 1.1^{ab}	5.5 ± 0.3^{a}	5.9 ± 0.1^{a}	62.8 ± 3.0^{a}
T6	1.7 ± 0.3^{a}	5.1 ± 0.9^{ab}	5.1 ± 0.4^{ab}	5.0 ± 0.4^{a}	58.4 ± 2.8^{ab}
T7	1.8 ± 0.3^{a}	8.3 ± 0.7^{a}	4.9 ± 0.2^{ab}	5.5 ± 0.3^{a}	62.1 ± 3.1^{a}
F	0.54	3.13	7.39	24.17	6.77
P	*0.778*	*0.008*	*0.01*	*0.001*	*0.001*

F. Total number of fruits, fruit weight (g) and the fruit sizes

Treatments (T1–T7) were compared with the control (T1) across four yield traits namely total fruit number, fruit length, fruit width and fruit weight. Significant differences were observed among the treatments (P <0.05).

The control treatment (T1) recorded the lowest fruit number overall. A similar trend was observed for total fruit weight. Treatment T7 yielded the highest mean total fruit weight at 7369.6 g, which was significantly greater (p < 0.05) than that of the control (T1), which recorded 3792.1 g. Treatments T5 (6924.3 g) and T6 (7145.2 g) also produced significantly higher total fruit weights than the control (p < 0.05). The reason for significant increase in the number of fruits and total fruit weight produced in treatments that included BTCWM might be due to the addition of this banana tissue culture waste media had a positive influence on reproductive output of salad (Awasthi et al., 2015).

A statistically significant difference (P<0.05) was observed for both the total number of fruits and the total fruit weight, indicating that the various growth media formulations had a discernible impact on these yield components. Treatment 7 (T7), composed of 50% Banana Tissue Culture Waste Media (BTCWM) and 50% coconut coir dust (CD), recorded the highest mean number of fruits at 50.40. This was significantly higher (p < 0.05) than the control treatment (T1), which consisted of 100% CD and produced a mean of 29.27 fruits. Other treatments, such as T5 and T6, also produced a significantly higher number of fruits compared to the control treatment (T1), with mean values of 59.53 fruits for T5 and 49.07 fruits for T6.

There were no significant differences for fruit length across treatments (P > 0.05). The average fruit length ranged from 16.7 cm to 23.9 cm. The fact that there was no significant difference in individual fruit size parameters, despite significant differences in total yield, suggests the treatments stimulated the production of more fruits rather than producing larger individual fruits. These findings correlate with earlier studies of (Perera et al., 2024), who observed that showing optimization of growth media was only observed to affect yield quantity.

The highest fruit weights were recorded in T7 (7369.6 ± 221.1 g) and T6 (7145.2 ± 325.47 g), while the control treatment had the lowest fruit weight (3792.1 ± 395.3 g). Overall, the T6 and T7 treatments consistently outperformed the control and most other treatments in terms of fruit yield, especially in terms of total fruit number and fruit weight. Tissue culture media comprises of micro and macro nutrients, vitamins, amino acids and growth regulators as nutrient composition. The improved yield might be associated with the presence of all nutrients along with proper drainage and nutrient retention at T7 (50% BTCWM and 50% coconut coir).

The presence of macro nutrients, namely Phosphorus is essential in young plants for the development of various elements such as ATP for energy production, Crop maturation, flowering, fruiting, germination, ripening and enhancing of grain quality is seen with this nutrient (Johnson and Mirza, 2020).

Table 03: Effects of potting media treatment on the fruit length, fruit diameter and fruit weight.

Treatments	Total no fruits /plant	Fruits Size		Fruit weight (g/plant)
		Fruit length (cm)	Fruit Diameter (cm)	
T1	29.27 ± 3.11[d]	17.1 ± 0.2 [a]	13.2 ± 0.2[a]	3792.1 ± 395.3[c]
T2	35.27 ± 2.50[cd]	16.9 ± 0.3 [a]	13.2 ± 0.3[a]	4770.9 ± 350.4[c]
T3	39.33 ± 3.73[bcd]	16.9 ± 0.1 [a]	13.2 ± 0.2[a]	5394.5 ± 533.21[bc]
T4	35.27 ± 3.57[cd]	16.9 ± 0.2 [a]	13.4 ± 0.2[a]	4718.9 ± 476.75[c]
T5	49.53 ± 1.76[ab]	23.9 ± 5.0 [a]	13.4 ± 0.2[a]	6924.3 ± 217.3[ab]
T6	49.07 ± 2.15[abc]	16.7 ± 0.3 [a]	15.5 ± 2.3[a]	7145.2 ± 325.47[a]
T7	50.40 ± 1.32[a]	17.1 ± 0.3 [a]	13.0 ± 0.2[a]	7369.6 ± 221.1[a]
F	9.76	1.92	1	14.01
P	0.001	0.085	0.429	0.001

IV. CONCLUSION

The present study analyzed the growth and yield performance of salad cucumber production in novel potting mixes containing banana tissue culture waste media (BTCWM) grown under greenhouse conditions. The results indicated maintained comparisons among treatments, where vine growth, leaf size, flower number, and total fruit yield were significantly different. In particular, the longest and widest vine, advanced leaf length and width and flower production rates were significantly enhanced in treatments containing BTCWM, eventually exhibited the highest number of flowers, the total number of fruits particularly with T7. Hence, our findings suggest that BTCWM is an effective alternative media component to partially replace conventional potting media, as using BTCWM improves the availability of nutrients to salad cucumber plants to sustain crop growth and development. Further investigations are required in non-controlled environmental conditions trials to determine the utility of BTCWM in research and allow further take up of the waste media by growers. In summary, waste tissue culture media has the potential that can be reused in horticultural crops to enhance crop production.

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ABBREVIATIONS

- PTCM   Plant Tissue Culture Media
- WPTCM   Waste Plant Tissue Culture Media
- BTCWM   Banana Tissue Culture Waste Media
- WAP   Weeks After Planting
- WBP   Weeks Before Planting
- CRD   Completely Randomized Design
- ANOVA   Analysis of Variance
- SPSS   Statistical Package for the Social Sciences
- cm   Centi Meter
- l   Litre
- ml   Milli Litre

Assessment of Growth, Photosynthetic and Biomass Characteristics of Selected Fodder Grass Varieties Under Standardized Water Regimes

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Abstract

Fodder grasses are vital for global livestock and sustainable agriculture, but lack of understanding of their specific water needs to optimize photosynthesis, biomass, and overall growth. This gap was investigated by comparing three fodder grass species CO3, CO4 and Super Napier (SN) under controlled, standardized water conditions (10 liters/day) within protected environments. Data was gathered at 3 – 6 weeks after planting (WAP). Fodder varieties were insignificant in plant height, leaf production rate (LPR) and leaf width. But all the varieties experienced a sharp decline in LPR at 4WAP before rebounding in subsequent weeks. Leaf length and tillers/plant were significant where CO3 exhibited highest leaf length (120cm). SN displayed significantly fewer tillers (9 at 6WAP). Photosynthetic efficiency, as measured by quantum yield and chlorophyll content, remained high and insignificant across varieties at 6WAP, suggesting similar light-harvesting capacities. Stomatal conductance was insignificant across varieties but lower values observed at 4WAP. Biomass performances at 3WAP, CO3 had the highest fresh weight (189.6g), significantly more than CO4 (146.7 g) and SN (84.7 g) while CO3 and CO4 were insignificant in dry weight, but SN's dry weight (36.4 g) was significantly lower. At 6 WAP, the fresh weights of CO3 and CO4 were insignificant. However, SN's fresh weight (1198 g) was significantly lower than CO3 and CO4. At 6 WAP, dry weight differed significantly (p = 0.043), with CO3 having the highest (613.7g). Overall, CO3 and CO4 generally out-yielded Super Napier in both fresh and dry biomass at 6 WAP. The results can inform the development of more efficient cultivation practices and enhance the resilience and productivity of fodder systems, particularly for high-yielding varieties like CO3 and CO4, in water-limited regions

Keywords: Biomass, Fodder grasses, Growth, Photosynthesis, Water requirements

I. INTRODUCTION

Fodder grasses encompass various species with slender leaves, cultivated across diverse climates and soils, and are categorized into five primary types for dairy cattle: legume, cereal, grass, tree, and Azolla (Kumara et al., 2022). Their classification is based on botanical characteristics, photosynthetic pathways (C3 and C4), growth habits, and climatic conditions, aiding in selecting optimal species for specific environments to maximize productivity and sustainability (Rathod and Dixit, 2019; Thomas and Thomas, 2019). These grasses exhibit valuable growth traits, including vigorous root systems, rapid vegetative growth, dense clump formation, and tolerance to grazing, all contributing to their importance in sustainable livestock farming (Saini et al., 2007). Many primarily utilize the C4 photosynthetic pathway, which enhances their efficiency in carbon dioxide capture, especially in high-light, high-temperature, and drought conditions, optimizing water-use efficiency and ensuring a continuous supply of nutritious forage (Gómez, et al., 2013).

Fodder grasses are renowned for their impressive biomass characteristics. These include high biomass yield due to rapid growth and efficient photosynthesis, a balanced biomass composition comprising leaves, stems, and sometimes inflorescences, a favourable leaf-to-stem ratio for improved palatability and digestibility, rapid regeneration for a consistent forage supply, and their contribution to soil health by adding organic matter and preventing erosion, making them

crucial components of sustainable farming practices (Glamoclija et al., 2011).

Water is a critical factor influencing the growth and biomass production of fodder grasses. Water requirements vary significantly depending on the specific grass species, climate, soil type, and irrigation methods. Multiple studies (Nawaz et al., 2016) indicate that water stress in plants has a significant impact on various growth aspects. This includes changes to the plant's anatomy, morphology, physiology, and (Anjum et al., 2011). These changes can affect leaves' water potential, stomata resistance and conductance, transpiration, photosynthesis, leaf temperature, and leaf withering. Lee (2018) found that environmental stresses, such as higher light intensity and lower soil moisture, can cause changes in the composition and structure of leaves. These changes can affect how leaves take in and store food because they tend to make more hairs, stomata sink deeper into the epidermis, more bulliform cells get involved in rolling and unrolling leaves, and cuticle synthesis gets better (Garrido *et al.*, 2014).

Hence, C4 grasses generally exhibit higher water-use efficiency compared to C3 grasses, enabling them to thrive in arid and semi-arid regions with limited water availability (Israel et al., 2022). Adequate and timely irrigation is crucial for optimal growth, especially during periods of drought. However, excessive water can lead to waterlogging, which can hinder root development and reduce biomass yield. Efficient irrigation practices, such as drip irrigation, can help minimize water loss and optimize water use for fodder production.

Despite the established significance of fodder grasses in livestock production and their efficient C4 photosynthetic pathway, there remains a notable research gap concerning their precise water requirements for optimizing photosynthetic rates, biomass production, and overall growth. This lack of specific data hinders the development of efficient irrigation strategies crucial for sustainable fodder cultivation, particularly in regions facing water scarcity. Therefore, this study aims to evaluate the photosynthetic, growth, and biomass performance of three selected grass species, CO3, CO4, and Super Napier (SN) under controlled protected house experiments with standardized

water conditions. This research will provide critical insights into their physiological responses to water availability, informing improved cultivation practices and enhancing the resilience and productivity of fodder systems.

II. MATERIAL AND METHODS

A. Location of the study

Present experiment was carried out at Malwatta (7°20'N and 81°44'E; elevation 16.0 m above sea level), Ampara district (DL2b) from August to December 2023. This research station experiences a mean annual temperature of 30°C and annual precipitation ranging from 1400 mm. The soil type is non-calcic brown soil with a sandy texture and slightly acidic pH (Begum et al., 2018).

B. Preparation of polytunnels

A total of 3 high yielding improved cultivars (CO3, CO4, and SN) were cultivated. Total of nine polytunnels were selected, each sized by 11.5*7.5 feet^2, were divided into three sections. Each polytunnel had the same climate conditions. The growing media consisted soil: silt: compost mixed in a ratio of 1:1:1 for the soil base material. Super Napier, CO3, and CO4 grass plant stem cuttings were planted in each polytunnel comprised with six pieces of grass were planted in each bed. Each fodder species was evenly spaced, with 50 x 50 cm.

C. Management of the fodders

All three fodder species was planted in each tunnel consisted and managed with similar environmental condition. Each tunnel was manually irrigated with 10 liters per day

D. Data Collection and analysis

After the grass established, at 3 to 6 weeks of intervals, growth morphological parameters such as plant height, leaf length, leaf width, number of leaves, and number of tillers were measured. Consequently, physiological parameters a such leaf stomatal conductivity, chlorophyll fluorescence (quantum yield efficiency), and chlorophyll content were measured. In addition. at harvesting stage (6WAP), fresh and dry weights were measured.

Plant leaf length was measured using a string and a piece of the tape. Newly fully expanded leaves

were recorded. Two readings of leaf width were taken from one leaf. For a single plant leaf, at least two measurements were obtained from each plant. Plant height was measured from the soil base root system to the newly added leaf with a measuring tape.

Using a chlorophyll meter (SPAD 502, Konica Minolta, USA), the amount of chlorophyll was measured and recorded in Soil-Plant-Analysis-Development (SPAD) units. The superior fully expanded leaves were used to obtain three readings: one at the base of the leaf, one in the middle of the leaf, and one at the tip of the leaf (apart from the midrib). The data were taken from four randomly selected plants from each plot.

Stomatal conductance was measured using a porometer device (Porometer SC-1 Decagon Devices, USA). The measurements from the fully expanded leaf from each reading taken at their bases and tips. Four plants were chosen from a single bed in order to gather data. From a single plant leaf, at least two measurements were obtained. A measurement period between 9:00 a.m. and 11:00 a.m. was observed.

Using a fluor pen (FP 100, Photon Systems Instruments, Czech Republic), chlorophyll fluorescence characteristics, including quantum yield (Qy), were examined in leaves. Two readings were taken at the base and tip of the leaf.

Fodder grasses were harvested in the third week and the sixth week. In the third week, five centimeters above the root of the fodder were cut, and then the fresh weight was measured. The harvest was then placed in a dry oven at a temperature of 80°C for constant weight (at least 72 hours), and the dry weight was measured.

E. Data Analysis

The experimental design was a completely randomized design (CRD) with three treatments and nine replicates. assuming that all the environmental and climatic factors within the polytunnels were the same. SPSS software (Version 25) was used to statistically analyze the data. Descriptive statistics and one way ANOVA was performed.

III. RESULTS AND DISCUSSION
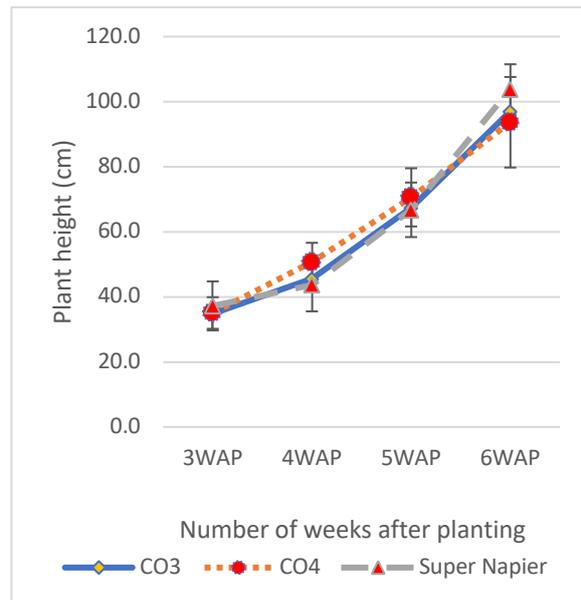
A. Growth parameters of fodder varieties

Figure 01: Variations in plant height of fodder varieties over the six-weeks of protected house experiment

Figure 01 depicts the plant height of tested fodder varieties at growth intervals. Plant height significantly increased at 5 and 6 weeks after planting across varieties. However, no significant differences were observed across the tested varieties. CO-3 grass grown in a northern part of Sri Lanka reach 145 cm of plant height at 8 WAP (Samini and Premaratne, 2017). Wangchuk *et al* (2015) reported similar findings under open field circumstances. Mounika et al., (2015) reported that in Bhutan, at one year of cultivation, CO3 can reach 175 cm height in open field conditions. According to Epasinghe *et al* (2012), CO-3 had a mean plant height of 172 cm during the ninth week of growth, which was greater compared to the CO3 growth in Sri Lanka's wet zone. In another report (Sathees and Sivaranjani, 2022) the Napier grass in open field conditions (30cm × 30cm), resulted in the highest plant height of 153 cm at 8 WAP.
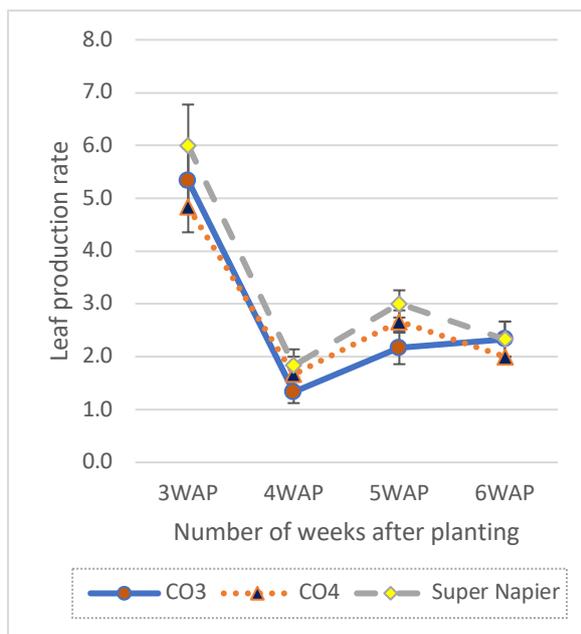
Figure 02: Leaf production rates of fodder varieties during six weeks of protected house experiments

of leaves per tiller (11.33 leaves) at 56 days after planting (Sathees and Sivaranjani, 2022) when it is planted in 30cm x 30cm spacing.
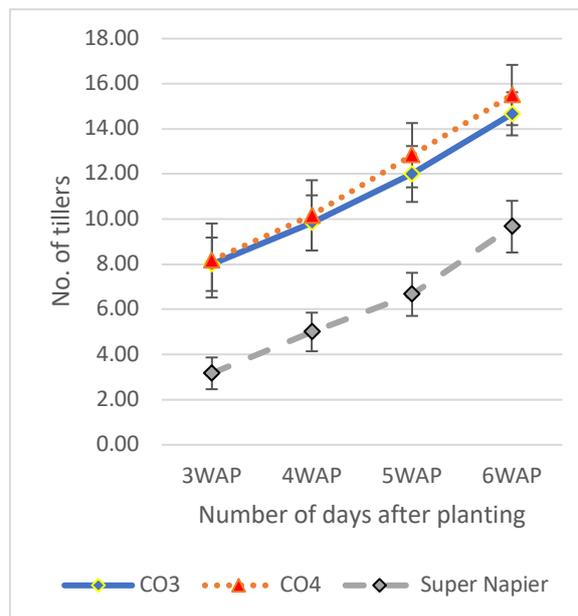

Figure 03: Number of tillers produced over the six-weeks of protected-house experiments

In case of leaf production rates per week, as depicted in figure 02, there were no significant differences among the tested varieties. However, the data reveals a consistent trend of decreasing leaf production rates per week across all fodder varieties from 3 to 5 WAP. While all varieties showed a decline in leaf production rates from 5 to 6 WAP, this could indicate a shift in resource allocation towards other growth processes, such as stem elongation or reproductive development, as the plants mature. According to a field study conducted (45 x 45 cm) in India on CO3, plants exhibited a high number of leaves (156.15) in the 13th week (Mounika *et al.,* 2015).

Further, the hybrid Napier variety CO-3 produced the most leaves at the 4th, 6th, and 8th weeks of growth, with 24,73, 44.33, and 109.67 leaves, respectively (Premaratne and Premalal, 2006). According to Sarmini and Premaratne (2017), since leaves have more nutritional qualities than the plant's stem, the quantity of CO3 leaves on a plant plays a critical role in controlling the growth and forage yield of fodder species. Different outcomes could be caused by differences in maturity level, climate, and plant spacing (Ibrahim et al., 2014). In a prior investigation, 56 days after sowing, Napier grass produced more leaves (93.67). Based on a study done by Sathees and Sivaranjani (2022), Sri Lanka's dry zone (Kilinochchi area) produced the highest number

Tillers, or shoots that develop from the base of the plant, are the primary units of growth in many grasses, contributing significantly to overall biomass yield (Lakshan et al., 2024). A higher number of tillers generally translates to increased leaf and stem production, which directly impacts the fodder's potential for providing nutritious feed for livestock (Lakshan, 2018). Figure 03, illustrates the tiller production across varieties of fodders at WAP. Number of tillers were observed in an increasing pattern from 3 to 6WAP despite the varieties. However, tiller production was significant across the varieties. Super Napier consistently displayed a significantly lower (p=0.018) number of tillers compared to both CO3 and CO4 at each data recording. It ranged from 3 to 9 tillers from 3WAP to 6 WAP. This suggests a distinct difference in tillering capacity among the varieties. While CO3 and CO4 showed similar (P>0.05) tillering rates, Super Napier's slower tillering may indicate a different growth strategy or resource allocation pattern. Amin *et al* (2016) indicates that the Napier variety, a typical plant has 35–100 tillers, depending on the variety and season. According to earlier research, the greatest number of tillers (10.00) were seen in

Napier grass after 56 days of planting (Sathees and Sivaranjani, 2022Sathees and Sivaranjani, 2022). Moreover, tillering influences the plant's architecture, affecting its ability to compete for resources like light and nutrients (Assuero and Tognetti, 2010.). Dense tillering can create a more robust canopy, potentially suppress weed growth and improving resource utilization efficiency.
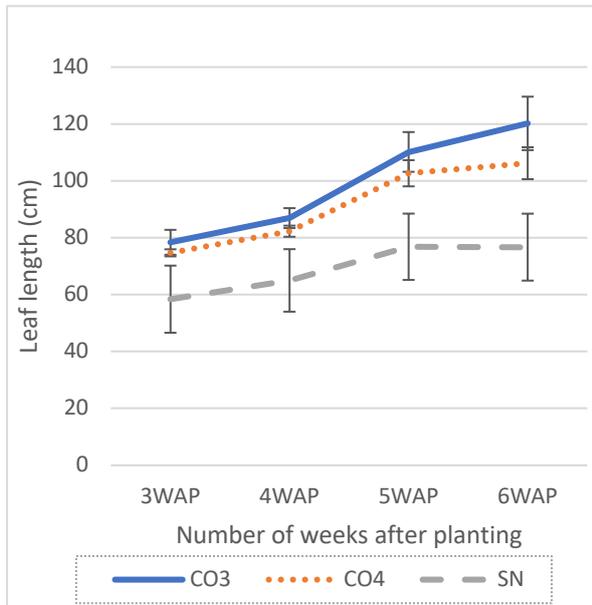

Figure 04: Variations in leaf length of fodder varieties over the six-weeks of protected house experiment

Leaf length demonstrated significant variation across the three fodder varieties during the observed growth period (Figure 04). Initially, at 3 weeks after planting (WAP), Super Napier exhibited the shortest leaf length, significantly lower than both CO3 and CO4. As the plants progressed, all varieties showed an increase in leaf length, but the magnitude of increase varied. Notably, CO3 consistently displayed the highest leaf length, reaching a peak of 120.2 cm at 6 WAP. CO4 also showed a substantial increase, though consistently lower than CO3. Super Napier, while exhibiting growth, maintained a significantly shorter leaf length throughout the experiment. The significant p values at 3 (p= 0.084) 4 (p= 0.031) 5 (0.001), and 6(p = 0.001) WAP indicate that these differences in leaf length were statistically significant, suggesting distinct varietal growth patterns. This difference in leaf length could have implications for overall biomass production and forage quality, with

longer leaves potentially contributing to higher yields.

According to Goldsworthy $et\ al$ (1974), plant's leaf area increases with leaf length, which improves the amount of feed generated as a result of efficient photosynthesis. An analogous outcome was observed in the present study. According to Mounika $et\ al$ (2015), the CO3 leaf length measured in the eighth week (81.17cm) of maturity and the 12th week of maturity (82.26 cm were identical. Sathees and Sivaranjani (2022) have shown that Napier grass produces longer leaves, measuring 95.33 cm, 56 days after cultivation.
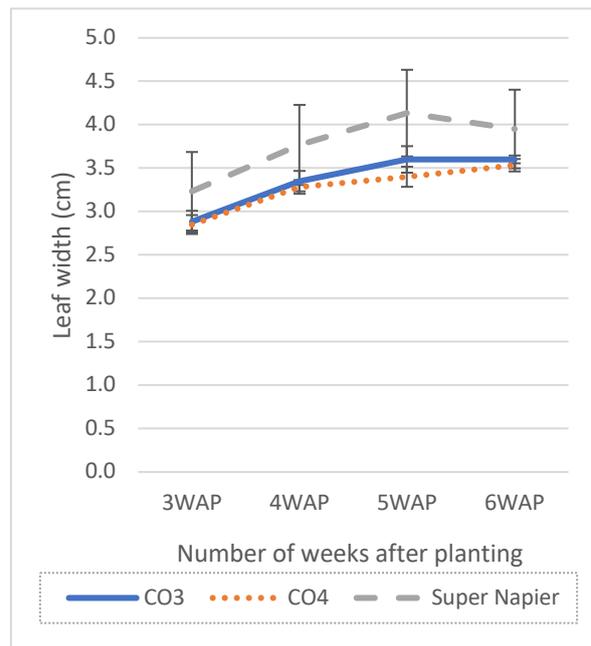

Figure 05: Variations in leaf width of fodder varieties produced over the six-weeks of protected house experiment.

In contrast to leaf length, leaf width showed relatively little variation among the three fodder varieties across the observed growth period. Although there were slight fluctuations in leaf width, particularly for Super Napier, these differences were not statistically significant. This suggests that while leaf length was a distinguishing factor among the varieties, leaf width was more conserved. All three varieties maintained a relatively consistent leaf width, ranging from approximately 2.9 cm to 4.0 cm. This uniformity in leaf width might indicate a similar physiological adaptation or resource allocation strategy for this particular trait. The lack of significant variation in leaf width suggests

that it may not be a primary factor differentiating the growth patterns or productivity of these fodder varieties under the conditions of this experiment. According to Amin *et al* (2016), Super Napier leaf blades, which can grow up to 120 cm in length and 5 cm in width. The base of the leaf blades has a thick stem with a diameter of 3 cm. Further Sathees *et al* (2022) showed that Napier grass cultivated broader leaves with a width of 3.82 cm at 56 days after planting.

B. Physiological parameters of fodder varieties

1) Quantum Yield

The quantum yield, a measure of photosynthetic efficiency (Hogewoning *et al.,* 2012), can be effectively used for studying photosynthetic activity, stress detection, herbicide testing, or mutant screening, was only assessed at 6 WAP. At this stage, all three fodder varieties exhibited relatively similar ($p = 0.761$) and high quantum yields, ranging from 0.71 to 0.73. This suggests that all three varieties are equally efficient in converting absorbed light energy into biomass during this later growth stage (Table 01).

Table 01: Physiological parameters of fodder varieties

Parameters	Fodder varieties	3 WAP (Mean ± SEM)	4 WAP (Mean ± SEM)	5 WAP (Mean ± SEM)	6 WAP (Mean ± SEM)
Quantum yield	CO3				0.71 ±.0.001
	CO4				0.72 ± 0.004
	Super Napier				0.73 ± 0.007
	df				17
	P value				0.761
Chlorophyll content	CO3	43.6 ± 3.9	46.9 ± 3.6	60.6 ± 15.3	37.3 ± 3.2
	CO4	45.4 ± 4.8	42.9 ± 5.2	33.1 ± 5.0	37.1 ± 2.8
	Super Napier	33.2 ± 6.6	42.5 ± 3.7	39.5 ± 4.5	41.9 ± 3.0
	df	17	17	17	17
	P value	0.241	0.723	0.142	0.462

2) SPAD Value

Chlorophyll content, a key determinant of light absorption for photosynthesis, showed relatively stable SPAD values across the four weeks for all three fodder varieties. SPAD value of CO3 fluctuated slightly, peaking at 5 WAP, while CO4 showed a gradual decrease in SPAD value from 3 to 5 WAP, followed by a slight increase at 6 WAP. Super Napier exhibited a relatively consistent chlorophyll content across the measured period. However, chlorophyll content was non-significant at all time points. This suggests that all three varieties maintain a comparable capacity for light harvesting throughout the early to mid-growth phases.

3) Stomatal Conductance

Stomatal conductance which reflects the degree of stomatal opening and thus the rate of gas exchange (Damour *et al* 2010). For the environment, with the actual vapor flux that leaves the leaf, passes through the stomates, and exits into the surrounding air to determine stomatal conductance (mmol/ m^2s). The SC-1 could distinguish between leaves that were stressed and experiencing stomatal closure by monitoring the amount of vapor flowing through the stomates. Stomatal conductance showed a dynamic pattern across the weeks after planting. At 3WAP, Super Napier displayed the highest stomatal conductance at 3 WAP, followed by a sharp decline at 4 WAP and then a recovery at 5 and 6 WAP. Similarly, CO3 and CO4 displayed a dynamic pattern over the weeks. However, stomatal conductance was insignificant across varieties. Highest stomatal conductance was observed in Super Napier at 5WAP and the lowest was observed in CO4 at 4WAP (Figure 06).

The lower stomatal conductance in CO4 might indicate a more conservative water use strategy compared to the other two varieties. The initial high conductance in CO4 and Super Napier could be linked to rapid early growth, followed by adjustments as the plants mature and environmental conditions change (Fariaszewska et al., 2020).
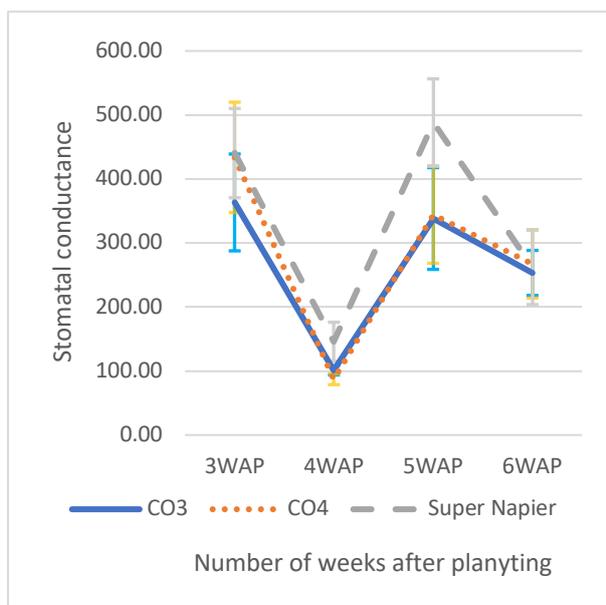
Figure 06: Variations in stomatal conductance of fodder varieties measured over the six-weeks of protected house experiment.

C. Yield parameters of fodder varieties

Table 02: Yield parameters of fodder varieties

Parameters	Fodder varieties	3 WAP (Mean ± SEM)	6 WAP (Mean ± SEM)
Fresh weight (g)	CO3	189.6 ± 15.4[a]	1611.3 ± 148.2[a]
	CO4	146.7 ± 42.0[b]	1638.3 ± 61.7[a]
	Super Napier	84.7 ± 14.9[c]	1198 ±172.8[b]
	df	8	8
	P value	0.037	0.039
Dry Weight (g)	CO3	57.7 ±7.6[a]	613.7 ± 210.8[a]
	CO4	55.3 ± 17.8[a]	505.3 ± 175.3[b]
	Super Napier	36.4 ± 2.0[b]	384.7 ± 87.8[c]
	df	8	8
	P value	0.039	0.043

Table 02 depicts the fresh and dry weight of fodder varieties at two different growth stages: 3WAP and 6 WAP. The analyzed data (Table 02) revealed significant differences in performance among the varieties. At 3 WAP, the fresh weight

varied significantly (p=0.037) among the three varieties. CO3 had the highest fresh weight (189.6 g), than CO4 (146.7g) and Super Napier (84.7g). For dry weight at 3 WAP, no significant difference was observed between CO3 (57.7 g) and CO4 (55.3 g). However, Super Napier's dry weight (36.4g) was significantly lower compared to CO3 and CO4.

At the 6 WAP measurement, the fresh weight of CO3 (1611.3 g) and CO4 (1638.3 g) were not significantly different from each other. However, Super Napier's fresh weight (1198g) was significantly lower than the other two varieties. The dry weight at 6 WAP showed a significant difference across all three varieties (p = 0.043). CO3 had the highest dry weight (613.7 g) while CO4 and Super Napier had the lowest

These findings indicate that CO3 consistently produced the highest fresh and dry weight yields, demonstrating its superior biomass production compared to the other varieties, especially at 6 WAP. While CO4's fresh weight was comparable to CO3 at 6 WAP, CO3 still maintained a significantly higher dry weight, which is a crucial factor for feed quality and storage. The consistently lower performance of Super Napier in both fresh and dry weight suggests it is a lower-yielding variety under the conditions of this study.

As reported by Lakshan *et al* (2024) dry matter yield can be significantly affected by the interaction effect of variety and fertilizer. The fresh matter yield reported for CO3 in the present study was slightly higher than the values of 29.77 and 27.56 t/ha/cut reported by Chellamuthu et al. (2011) and Mounika et al. (2015), respectively, when cut at 13th week after planting in India. A study conducted by Epasinghe et al. (2012) in the wet zone of Sri Lanka has recorded an average dry matter yield of CO3 was 3.57 t/ha at 9th week of planting.

However, it is important to consider these weight parameters in conjunction with the physiological parameters (quantum yield, stomatal conductance, and chlorophyll content) to get a holistic understanding of the performance of these fodder varieties. For instance, while Super Napier had lower biomass, its photosynthetic efficiency (quantum yield at 6 WAP; Table 01) was comparable to the other varieties. This suggests that Super Napier might allocate

IV. CONCLUSION

This study successfully evaluated the growth, physiological, and biomass characteristics of CO3, CO4, and Super Napier fodder grasses under standardized water conditions in a controlled environment. Plant height, leaf production rate (LPR), and leaf width were insignificant across varieties However, all varieties experienced a sharp decline in LPR at 4 weeks after planting (WAP) before rebounding in subsequent weeks. Despite similar photosynthetic efficiencies, which were high and insignificant across varieties at 6 WAP, the study found statistically significant differences in biomass production. CO3 and CO4 generally out-yielded Super Napier in both fresh and dry biomass at 6 WAP. Specifically, CO3 exhibited the highest dry weight at 6 WAP. CO3 also demonstrated superior leaf elongation, with the highest leaf length. In contrast, Super Napier showed distinct tillering patterns and significantly fewer tillers. These findings underscore the adaptability and high productivity potential of these fodder grasses even with a consistent water supply. The insights gained are valuable for developing more efficient cultivation practices and enhancing the resilience and productivity of fodder systems, particularly for high-yielding varieties like CO3 and CO4, in water-limited regions. Future research should explore the performance of these varieties under varying water stress levels to identify drought-tolerant genotypes and develop more precise irrigation strategies for sustainable fodder production in diverse agro-ecological zones.

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TRACK - FOOD SCIENCE AND TECHNOLOGY

Formulation of American Oyster Mushroom (*Pleurotus ostreatus*) Infused Candy

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Abstract

The American Oyster mushroom (Pleurotus ostreatus) infused candy was developed as a novel confectionery product with enhanced nutritional value. The candy formulation was optimized by different sugar levels and drying times to improve the taste and texture. Four candy samples were prepared from blanched (at 100°C for 5 minutes) oyster mushrooms with different sugar levels (40%, 50%, 60%, and 70%) to identify the optimum sugar level based on sensory attributes. The best sample was then used to assess in a hot air oven at 60 °C suitable drying time (7,8,9, and 10 hrs.). The physicochemical properties and shelf life of candies with different sugar levels were analyzed. Sensory evaluation was performed by 30 untrained panelists using a seven-point hedonic scale to select the most preferred candy. The sensory data were analyzed using the Friedman test, and other data were analyzed using one-way ANOVA. Mushroom candy produced with a 60 % sugar level and 10 hrs drying time was most preferred by the panelists. The moisture content of treatments varies between (1.91±0.21 - 9.77±1.00), ash (1.47±0.12 -1.80±1.00), pH (3.3±0.05-3.9±0.05), acidity level (0.15±1.00-0.30±1.00), and total soluble solids (52.33±1.00 - 71.33±1.00). Hardness value of the candy decreased with increasing level of sugar while chewiness and cohesiveness were increased. The most preferred mushroom candy showed 4.70% protein content, 0.5% fat content, 4.25% fiber content, and 86.45% carbohydrates. This study revealed that the optimum sugar level and drying time for American oyster mushroom candy were 60 % and 10 hrs with enhanced taste and texture. The mushroom-infused candy is a potential functional alternative to traditional sweets.

Keywords: Candy, drying time, Pleurotus ostreatus, sugar level

I. INTRODUCTION

Many species of mushrooms are grown and eaten all over the world, and they have long been valued for their nutritional and therapeutic properties. The American oyster mushroom (*Pleurotus ostreatus*) is notable among them for its abundant nutritional profile and useful bioactive substances. The B-complex, vitamin D, dietary fiber, high-quality proteins, and vital minerals - potassium, calcium, and phosphorus are abundant in *Pleurotus ostreatus* (Adebayo and Oloke, 2021). *Pleurotus ostreatus* also contains health-promoting bioactives, such as ergothioneine, polysaccharides, and antioxidants, which have been linked to immunomodulatory, anti-inflammatory, and cholesterol-lowering effects (Riaz and Ahmed, 2022). Because of these qualities, *Pleurotus ostreatus* is a functional ingredient in making healthy foods that help improve overall health and well-being.

The integration of these functional ingredients into common foods has been the focus of recent food science advancements in response to growing consumer awareness of diet-related health concerns. Although mushrooms have been used in many different food applications, including baked goods, soups, and snacks, their use in confections has not received much attention (Dhanapal, Dhanaraj, and Rajoo, 2023).

Candy is a confection that is typically made up of sugar, syrups, and flavorings. It is commonly consumed by all ages. Candy is high in sugar content and lacks nutritional value, which can result in health problems like obesity, diabetes, and dental issues, even though it has a long shelf life and a pleasing taste. Additionally, the majority of traditional candies lack functional ingredients, which reduces the potential health benefits. Confectionery products are increasingly being reformulated to incorporate ingredients that

improve their nutritional value and functionality as consumers grow more health-conscious and look for natural and wholesome substitutes for traditional snacks (Chakraborty and Sikdar, 2008).

An innovative way to address these problems is to incorporate *Pleurotus ostreatus* into candy formulations. Even though other plant-based ingredients have been used to make healthier sweets, using *Pleurotus ostreatus* in candy is still mostly unexplored. Adding this mushroom to candy can enhance its nutritional value by adding proteins, fiber, and antioxidants. It can also add special bioactive qualities that may help with gut health, immune system function, and metabolic control (Moon, Bro, and Lo, YM., 2022). Consumer acceptance remains a critical factor in the successful introduction of such innovative food products. The short shelf life of mushrooms and their limited incorporation into convenient food formats further highlight the need to explore their potential in confectionery. The purpose of this study was to formulation of mushroom-infused candy recipe, figuring out the ideal sugar content and drying duration, examining its physicochemical characteristics, evaluating its sensory qualities, and assessing its shelf life are the main goals.

II. MATERIALS AND METHODOLOGY

A. Study Location

The study was conducted at the Food Science Laboratory of the Department of Biosystems Technology, Faculty of Technology, South Eastern University of Sri Lanka.

B. Collection of Materials

American Oyster Mushroom was collected from a farm in Batticaloa. Sugar, citric acid, and vanilla essence were collected in the local market.

C. Preparation of mushroom candy

Fresh mushrooms were manually cleaned and cut into small pieces. Then pieces were blanched at 100°C for 5 minutes in 1% Sodium Metabisulfite solution. After draining for half an hour (adapted from Bora and Kawatra, 2014), they were treated with sugar.

The blanched mushrooms were subjected to four different sugar levels: 40%, 50%, 60%, and 70% (w/w, sugar to mushroom ratio). For each treatment, a measured quantity of sugar was applied at a ratio relative to 200 g of blanched mushrooms. The total amount of sugar for each concentration was divided into three equal portions.

On Day 1, one-third of the sugar was mixed with the blanched mushrooms and left to stand for 24 hours at ambient temperature. On 2nd day, the second portion of sugar was added to the same mixture and again left overnight. On Day 3, the mushrooms were separated from the resulting syrup. 0.5 g of citric acid and the final portion of sugar were added to the syrup, which was then brought to a boil. The mushrooms were reintroduced into the boiling syrup and cooked for 5 minutes.

After boiling, the mixture was allowed to cool. The mushrooms were removed, drained for approximately 30 minutes, and sorted manually to remove any damaged or non-uniform pieces. The drained mushroom pieces were then dried in a hot air oven at 60 °C for approximately 10 hours until a crispy texture was achieved (adapted from Bora and Kawatra, 2014). Once dried, the candies were packed in food-grade polypropylene bags and stored in a cool, dry place for further analysis.

D. Sensory evaluation

Sensory evaluation was conducted to identify the optimum sugar level and drying time. Initially, four candy samples were prepared with varying sugar level (40%, 50%, 60%, and 70%) and the optimum sugar level was identified based on panelists' preferences. The treatment T3 was then used to assess suitable drying time, as shown in Table 02 based on panelists' preferences. The sensory evaluation was performed with 30 untrained panelists (10 males and 20 females), aged between 23 and 26 years, using a 7-point hedonic scale ranging from 1 ("dislike very much") to 7 ("like very much").

E. Analysis of Physiochemical parameters

1) Determination of Moisture Content

Moisture content was measured following AOAC 925.10 (2016). Five (5) g of mushroom candy was weighed into a pre-dried and pre-weighed petri dish using an electronic scale. Then candy samples were kept in the oven (Memmert GmbH+Co.KG manufacturer, Memmert brand, 30 – 1060 model) at 105°C for 5 hours, cooled in a desiccator. The loss in weight after drying represented the moisture content.

$$Moisture\ content\ (\%) = \frac{W2 - W3}{W2 - W1} * 100\%$$

W1 = Weight of empty dish
W2 =Initial weight of dish and sample
W3 =Final weight of dish and dried sample

2) Determination of Ash Content

Ash content was measured following AOAC 942.05 (2016). A muffle Furner (MF 1400 – 30 Model) was used to measure the ash content after measuring the moisture content of the candy sample. The weight of the empty crucible was taken. Five (5) g of sample was taken to the pre-weighted crucible. The weight of the crucible with the sample was taken. It was placed in the muffle Furner at 550ºC for 5 hours. Then the weight of the ash was taken.

$$Ash\ content\ (\%) = \frac{W3 - W1}{W2 - W1} * 100\%$$

W1 =Weight of empty crucible
W2 =Weight of crucible and sample
W3 =Weight of crucible and ash after incineration

3) Determination of pH

The pH was measured using a calibrated digital pH meter (HI98190 model) based on Khan and Ullah, (2018). Five (5) g sample was dissolved in 50ml of distilled water, mixed thoroughly using a magnetic stirrer for about 2-3 minutes to achieve homogeneity, and the stabilized pH reading was recorded.

4) Determination of Acidity

Acidity content was measured following AOAC 942.15 (2016). Five (5) g sample was crushed into a fine powder and dissolved in 50 mL of distilled water. The solution was stirred for 30 minutes and filtered. Filtered samples were titrated with 0.1 M NaOH using phenolphthalein as an indicator until a pale pink endpoint.

$$Acidity\ (\%) = \frac{V * N * 0.064}{W} * 100\%$$

V – Volume of NaOH
N – Molarity of NaOH
0.064 – Equivalent factor for citric acid
W – Weight of the sample.

5) Determination of Color

Color analysis was conducted using the CIELAB system (L*, a*, b* value). The sample was analyzed into the colorimeter, and values were recorded using the calibrated colorimeter app.

6) Determination of Total Soluble Solids (Brix value)

Total soluble solids content was measured following AOAC 932.14, (2019). One (1) g sample was crushed finely and dissolved in 10 ml of distilled water, filtered, and the Brix (%) was recorded using a refractometer (ERB-32 model) after calibration with distilled water.

7) Determination of Texture

Twenty (20) g of candy was weighed and molded into a cylindrical shape was equilibrated to room temperature. A compression test was performed using a Texture analyzer (Brookfield CT3 model) to record hardness, elasticity, cohesiveness, and chewiness (Bourne, 2002).

F. Proximate Analysis

The proximate analysis was done on the best sample with optimum sugar level (T3).

1) Determination of Protein Content

Protein content was measured following AOAC 981.10, (2016). One (1) g of candy sample was weighed and digested with 20 ml H_2SO_4 and catalyst at 360°C - 400 °C for 2 - 3 hours, distilled with 40 ml of 2N NaOH, and the liberated ammonium was trapped in 25 ml of 4 % boric acid solution. The distillate was titrated with 0.1 M hydrochloric acid in the presence of an indicator until the color changed from green to red.

$$Nitrogen\ percentage = \frac{0.014 \times V \times N}{W} * 100\%$$

$$Protein\ Percentage = Nitrogen\ \% \times F$$

where,

V =Required volume of HCL
W =Weight of sample
N =Molarity of HCL
F =Protein conversion factor

2) Determination of Crude Fiber Content

Crude fiber content was measured following AOAC 978.10 (2012). Crude fiber was determined by using acid and alkaline digestion. Two (2) g defatted sample was initially digested in 200 ml, 1.25% HCl for 30 minutes. Then, 200 ml, 1.25% NaOH for 30 minutes. After that, it was washed with distilled water, followed by ethanol, and filtered. The residue was placed in pre-weighted crucible. The residue in the crucible was placed in an oven and dried for 3 hours at 105°C. After that, the residue in the crucible was ignited in a muffle furnace at 550 °C for 3 hours. Then the weight of the crucible was recorded.

$$Crude\ fiber\ content\ (\%) = \frac{W1 - W2}{W3} * 100$$

W1=Weight of the crucible and residue after oven drying
W2= Weight of the crucible and ash after igniting
W3= Weight of sample

3) Determination of Fat Content

The fat content was determined according to the method in AOAC 920.39 (2016). Two (2) g sample was weighed into a thimble and covered with a cotton plug. Thimble was placed into a previously cleaned, dried fat extraction tube, and 50 ml of petroleum ether (boiling range 50 - 60 °C) was added to the pre-weighted round-bottom flask. The round-bottom flask was fixed to the soxtherm and extraction was carried out at 50 - 60°C for 4 - 6 hours. The round-bottom flask was removed and kept in a boiling water bath for 15 minutes, oven dried at 105 °C for 1 hour. The weight of the round-bottom flask was recorded.

$$Fat\ content\ (\%) = \frac{W3 - W2}{W1} * 100\%$$

W1=Weight of sample

W2= Weight of empty round-bottom flask

W3= Weight of round-bottom flask with fat after drying

4) Determination of Carbohydrate Content

The carbohydrate content of mushroom candy was determined using the difference. This method estimates carbohydrate by subtracting the sum of moisture, protein, fat and ash content from the total weight of the sample.

$$Carbohydrate\ content = 100 - (moisture + protein + fat + ash)$$

G. Shelf Life Evaluation

The shelf life of mushroom candy was tested by checking its moisture, pH, and texture once a week. The candy was stored in a dry and cool place during the analyzing process.

H. Statistical Analysis

Sensory evaluation data were statistically analyzed using the Friedman test. Other data were statistically analyzed using One-way analysis of variance (ANOVA) and the means were compared by Tukey's test at $p = 0.05$ using the SPSS statistical package (SPSS 25.0, IBM).

Table 01: Experimental design of Mushroom-infused candy

Treatments	T1	T2	T3	T4
Sugar	40%	50%	60%	70%

Table 02: Determination of optimum drying time for candy making using the treatment T3

Temperature	60 °C	60 °C	60 °C	60 °C
Drying time	7 hours	8 hours	9 hours	10 hours

III. RESULTS AND DISCUSSION

A. Sensory evaluation

1) Sensory evaluation for the determination of optimum sugar level in candy making

According to Figure 01, there was a significant difference (p<0.05) between T1, T2, T3, and T4 were observed in sensory score. The treatment T3 (60 % sugar level) had a high sensory score and the treatment T1 had a lower sensory score in all sensory attributes.

2) Sensory evaluation for the determination of the time duration for drying in candy making

According to the scores for sensory evaluation (Figure 02), there was a significant difference (p<0.05) in drying time was observed. The samples dried for 10 hours duration had the highest sensory score whereas the samples dried for 8 hours duration had the lowest sensory score in all sensory attributes tested for such as appearance, texture, flavor, color, taste, and overall acceptability.

B. Analysis of Physicochemical Parameters

Table 03 shows the physicochemical properties of different formulations of American oyster mushroom-infused candy. There was a significant difference among T1, T2, T3, and T4 in moisture content, ash, pH, acidity and TSS were observed.

Moisture content plays a critical role in defining the quality, texture, and shelf life of confectionery products, and a significant variation observed among treatments ($p < 0.05$) reflects the influence of both drying and formulation. T1 (9.77%) and T2 (6.68%) fall within the reported 5 - 15% range for mushroom-based confections (Sharma et al., 2021), while T3 (2.43%) and T4 (1.91%) showed much lower values, indicating more effective dehydration. Recent studies confirm that oyster mushrooms naturally contain 84 - 90% moisture, but proper drying can reduce this to 6 - 7% for stability (Nwaudah et al., 2025). Lower values, as in T3 and T4, may enhance storage stability but risk excessive hardness, highlighting the balance between water retention and texture.

Ash content is an important indicator of the total mineral composition in food products, reflecting their nutritional value and inorganic matter. In this study, a significant difference (P<0.05) was observed among treatments, with values ranging from 1.47% to 1.80%, suggesting that formulation and processing influenced mineral retention.

These findings are consistent with previous reports on mushroom-based confections, where ash content ranged from 1.50% to 2.00% (Patel and Singh, 2020), indicating that mineral content can be maintained during candy processing. Lower ash in some treatments may result from leaching or interaction with sugar and other ingredients, whereas higher values reflect greater retention of essential minerals, contributing to the functional and nutritional quality of the finished product (Nwaudah et al., 2025).

A significant difference ($p < 0.05$) was observed in the pH of mushroom-infused candy samples, with T1 (3.89 ± 0.05) being the least acidic and T4 (3.32 ± 0.05) the most acidic. This variation reflects the influence of formulation, acidulate addition, and processing conditions on product acidity. Previous studies report mushroom-based confections typically have pH values between 3.0 and 4.5, while fruit-infused candies range from 3.0 to 4.0, highlighting the role of organic acids and sugar in flavor and stability (Sharma et al., 2021). Lower pH enhances microbial stability and shelf life, whereas higher pH contributes to milder taste. TSS analysis of mushroom-infused candy revealed significant differences ($p < 0.05$) among treatments, with T4 ($71.33°Brix \pm 1.00$) and T3 ($69.33°Brix \pm 1.00$) exhibiting higher values than T2 ($59.00°Brix \pm 1.00$) and T1 ($52.33°Brix \pm 1.00$). These differences reflect variations in sugar concentration, water content, and dehydration levels. Previous studies report TSS in mushroom-based confections ranging from 50 to 75°Brix and in fruit-based candies from 55 to 72°Brix, with higher sugar content and lower moisture increasing TSS (Sharma et al., 2021). The results suggest that sugar retention and moisture loss are key determinants of TSS, influencing texture and shelf stability.

Table 04 shows the color characteristics of mushroom-infused candy, and a significant difference among treatments ($p < 0.05$) was seen.

The L* value (lightness) ranged from T1 (28 ± 0.08) to T4 (45.33 ± 1.00), indicating darker and lighter appearances, respectively. There were no significant differences between T1, T2 and T3 in L* value was reported. The a* value (red - green) varied from 13.67 ± 0.16 to 17.33 ± 0.99 among the treatments reflecting differences in red pigmentation, while the b* value (yellow - blue) ranged from 22.33 ± 0.23 to 32.33 ± 1.00, showing
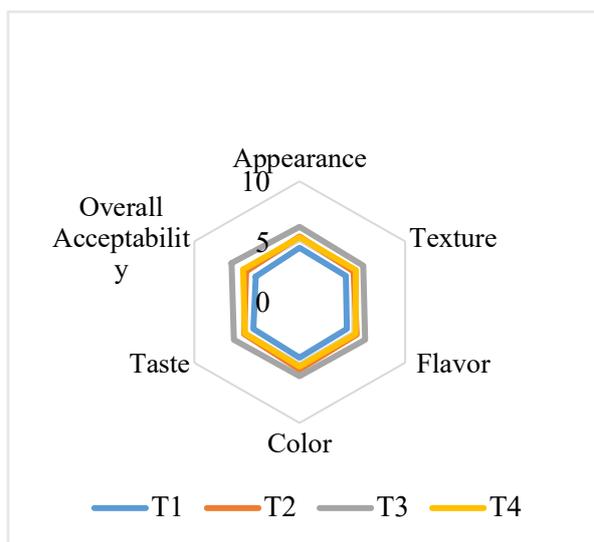
Figure 01: Radar diagram for American oyster mushroom-infused candy in different sugar formulations
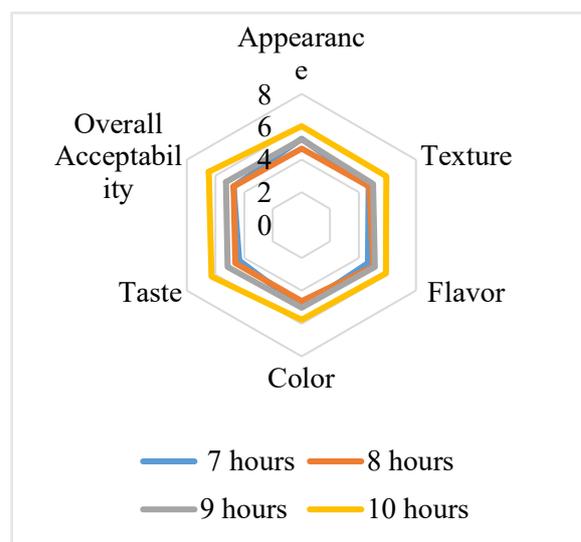

Figure 02: Radar diagram to identify the time duration for drying in candy making

increased yellowness and there was no significant difference reported between T1, T2 and T3, T4 in b* value. These values are consistent with reported ranges for mushroom confections (L*: 30 - 50; a*: 12 - 18; b*: 20 - 35) (Priyadarsini and Mishra, 2020)

The chewiness of candy increased with increasing level of sugar. The T1 had the lowest (21.87±1.00 mJ) whereas the T4 had the highest (38.43±1.00 mJ) value for chewiness due to moisture content and sugar levels, as an increase in sugar level combined with a reduction in moisture resulted in increased chewiness. Similarly, Sharma et al., (2021) reported that mushroom and fruit-based candies had chewiness, ranging from 20 to 40 mJ.

The candy in this present study showed similar trends for elasticity and cohesiveness. The elasticity and cohesiveness of candy in this study increased with increasing level of sugar. Mushroom-based candies typically exhibit elasticity between 2.5 and 4.0 mm and cohesiveness between 0.5 - 0.9 (Sharma et al., 2021).

C. Proximate Analysis

The proximate composition consisted of protein 4.70%±0.51, fat 0.5%±0.10 and fiber 4.25%±0.22. The inclusion of mushrooms enhanced protein and fiber content is the specialty in the candy developed compared to conventional candies (Dhanapal, Dhanaraj, and Rajoo, 2023). Similarly, the mushroom-based and plant-based confections had high protein content (5.20%) and low fat content (0.5%).

Table 03: Physicochemical properties

Treatment	Moisture(%)	Ash(%)	pH	Acidity(%)	TSS(%)
T1	9.77±1.00[a]	1.47±0.12[c]	3.9±0.05[a]	0.15±1.00[d]	52.33±1.00[d]
T2	6.68±1.00[b]	1.57±0.12[bc]	3.7±0.05[b]	0.20±1.00[c]	59.00±1.00[c]
T3	2.34±0.21[c]	1.63±0.28[b]	3.5±0.05[c]	0.25±1.00[b]	69.33±1.00[b]
T4	1.91±0.21[c]	1.80±1.00[a]	3.3±0.05[d]	0.30±1.00[a]	71.33±1.00[a]

The values shown mean value ± SD (n=3). Values followed by the same letters in the same column are not significantly different (p≤ 0.05).

Table 04: Color analysis

Treatment	Color		
	L*	a*	b*
T1	28.00± 0.08[b]	15.33± 0.16[ab]	22.33± 0.23[b]
T2	33.33± 0.08[b]	17.33± 0.99[a]	24.00± 0.23[b]
T3	34.33± 0.08[b]	15.33± 0.16[ab]	29.33± 1.00[a]
T4	45.33± 1.00[a]	13.67± 0.16[b]	32.33± 1.00[a]

The values shown mean value ± SD (n=3). Values followed by the same letters in the same column are not significantly different (p≤ 0.05).

D. Shelf-life Analysis

The observed decrease in moisture content over seven weeks across all treatments aligns with established findings in confectionery science. Moisture loss is a critical factor influencing the texture and shelf life of sugar-based confections. As moisture content decreases, candies transition from a soft and chewy texture to a harder and more brittle consistency. This phenomenon is particularly evident in treatments T3 and T4, which exhibited the lowest moisture content by the seventh week. The higher moisture content in T1 and T2 may be attributed to differences in formulation or storage conditions, as moisture migration is influenced by factors such as water activity and packaging integrity (Ergun, Lietha, and Hartel, 2010).

The concurrent decrease in pH observed in all treatments over the storage period is consistent with findings in similar studies. For instance, research on jelly candies has reported a decrease in pH values during storage, which can be attributed to the hydrolysis of acidic components or the fermentation of sugars. Such pH reductions can impact the flavor profile and microbial stability of the confection (Abu-Shama, Aly, and Badr, 2022)

Texture profile analysis revealed significant changes in hardness, chewiness, elasticity, and cohesiveness over the seven-week period. An increase in hardness was observed across all treatments, indicating a transition towards a firmer texture. This is consistent with the findings of Figiel and Czopek (2006), who reported that a decrease in moisture content leads to an increase in hardness in sugar-based confections. The decrease in chewiness and cohesiveness can be

attributed to moisture loss and structural changes within the candy matrix. Interestingly, while elasticity decreased in T1, T2, and T3, it increase in T4. This anomaly may be due to differences in formulation or the presence of specific ingredients that influence the elasticity of the candy (Nguyen et al., 2025).

In comparison to previous studies, our findings confirm the general understanding that moisture content, pH, and texture are interrelated factors that determine the quality and shelf life of confections. For example, research on hard candy
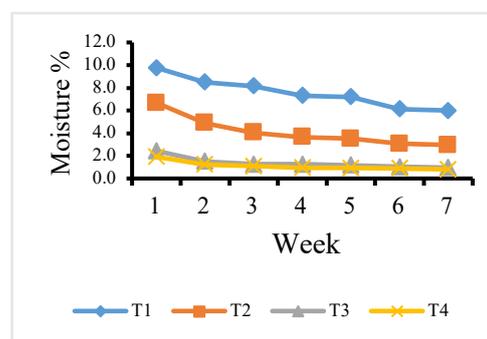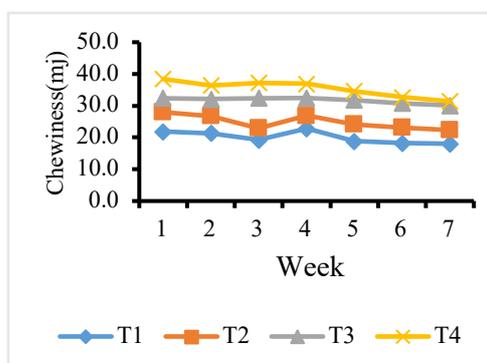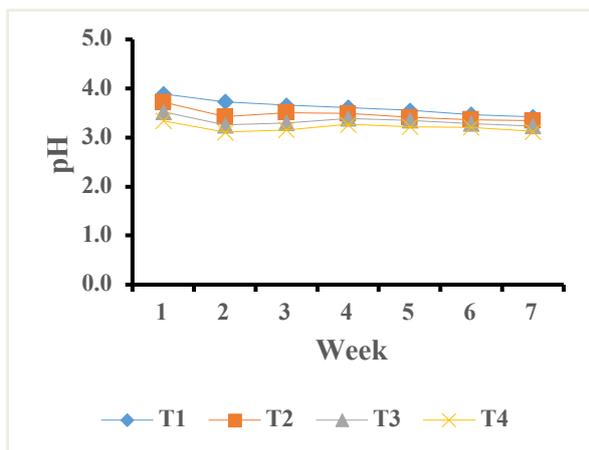
Figure 03: Moisture Content

Figure 04: Chewiness

Figure 05: pH value
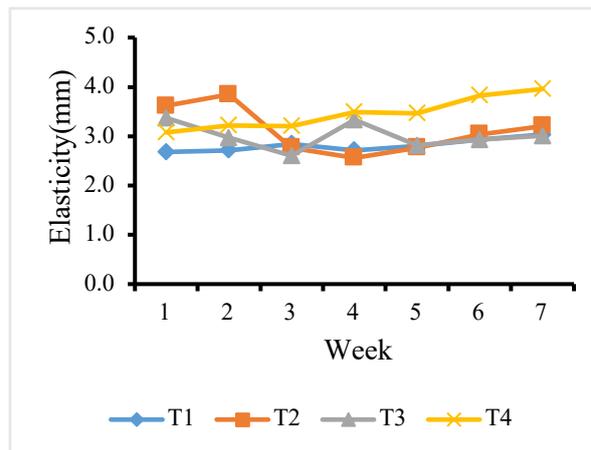
Figure 07: Elasticity
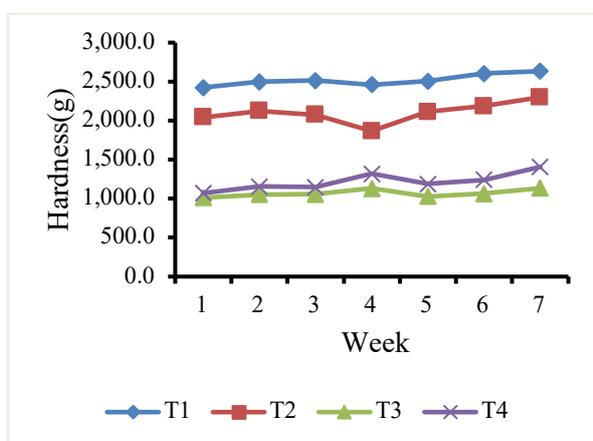
Figure 06: Hardness
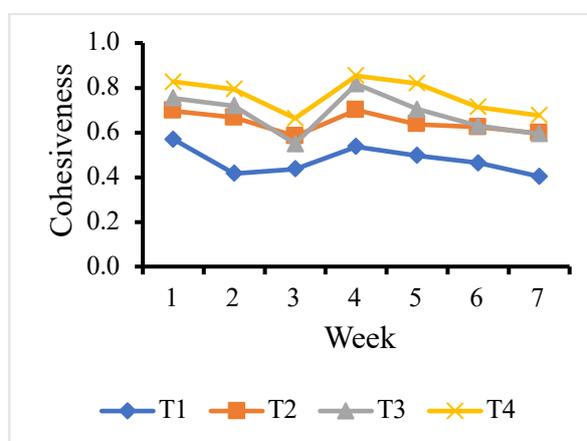
Figure 08: Cohesiveness

Table 05: Texture analysis

Treatment	Texture			
	Hardness(g)	Chewiness(mJ)	Cohesiveness	Elasticity(mm)
T1	2425.00±1.00[a]	21.87±1.00[d]	0.57±1.00[d]	2.68±1.00[d]
T2	2045.00±1.00[b]	27.97±1.00[c]	0.70±1.00[c]	3.61±1.00[a]
T3	1011.67±0.39[c]	32.41±1.00[b]	0.75±1.00[b]	3.37±1.00[b]
T4	1070.00±0.39[c]	38.43±1.00[a]	0.83±1.00[a]	3.08±1.00[c]

The values shown mean value ± SD (n=3). Values followed by the same letters in the same column are not significantly different ($p \leq 0.05$).

Table 06: Proximate composition of candy (T3)

Parameters	Value
Moisture	2.43±0.45
Ash	1.63±0.05
Protein	4.7±0.51
Fiber	4.25±0.22
Fat	0.5±0.10
Carbohydrate	86.45±0.63

The values shown mean value ± SD (n=3)

production has highlighted the importance of controlling moisture content and pH to maintain product quality (Ergun, Lietha, and Hartel, 2010). Additionally, studies on gummy candies have demonstrated that changes in texture parameters such as hardness and chewiness are indicative of product aging (Nguyen et al., 2025).

IV. CONCLUSION

The present study successfully developed a novel candy formulation infused with American oyster mushroom (*Pleurotus ostreatus*), demonstrating its potential as a functional confectionery product from edible fungi in sweet products. The 60% sugar level with 10 hrs. drying time was the most preferred by panelists indicating good consumer acceptability in terms of taste, texture, color, flavor and appearance. The lightness (L*) value and yellowness (b*) value increased with higher sugar levels, while the redness (a*) value decreased. Hardness value of the candy decreased with increasing level of sugar while chewiness and cohesiveness was increased. The mushroom-infused candy showed improved nutritional value, with higher protein and fiber and lower fat content compared to conventional candies. Over seven weeks, the shelf-life analysis showed significant changes in the physicochemical and textural characteristics of the mushroom-infused candy formulations (T3 and T4).

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Evaluation of Quality Parameter Variations and Aflatoxin Contamination of Corn Seeds (*Zea mays*) Stored in Purdue Improved Crop Storage (PICS) Bags in North Central Province, Sri Lanka

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Abstract

Post-harvest grain storage is crucial for maintaining the grain quality and ensuring food security. This study assesses the variation in quality parameters and aflatoxin contamination of corn seeds under two storage conditions. Treatments included Poly Propylene (PP) Woven bags (T_0), and Purdue Improved Crop Storage (PICS) bags (T_1), evaluated as a safer and cost-effective alternative. Dried corn seeds (Jet 999 variety, <13% moisture) were stored under warehouse conditions (Temperature: 31-37 ^{0}C and Relative Humidity (RH): 55-70%) in Ihalagama, Kekirawa, North Central Province, Sri Lanka. A total number of 54 corn seed samples (27 per treatment) were evaluated to measure changes in moisture content, seed color, and aflatoxin contamination during an eight-week storage period in PICS and PP woven bags. A significant (p <0.05) increase in aflatoxin content was observed in PP woven bag by the eighth week (2.87±0.25), whereas it aflatoxin levels remained lowest in PICS bag (0.90±0.10). Moisture content in T_0 (PP woven bags) significantly increased from 12.37% to 13.01%, compared to a smaller increase in T_1 (PICS bags) from 12.34% to 12.50%. No significant differences were observed in L, a, or b color values between treatments over time (p >0.05). These findings confirm that PICS bags provide a chemical-free, cost-effective, and sustainable alternative for safer corn storage in Sri Lanka, with important implications for food safety, postharvest policy, and industry adoption.

Keywords- Aflatoxin, Corn, PICS bags, Moisture, Storage

I. INTRODUCTION

Corn (*Zea mays* L.) is the second most cultivated cereal crop in Sri Lanka and is widely used for poultry feed, food processing, and direct consumption. Postharvest losses of corn in Sri Lanka are estimated between 5%–13%. These losses are aggravated by the country's hot and humid climate, which promotes fungal infestation and aflatoxin contamination (Jayaratne & Abeyratne, 2020). Conventional storage practices, such as using polypropylene (PP) woven bags are insufficient, because they allow moisture and oxygen penetration, thereby accelerating microbial growth (Baributsa et al., 2010). Aflatoxin B1, produced by *Aspergillus spp.*, is a carcinogen that threatens food safety and market acceptance (Williams et al., 2004). Therefore, sustainable storage alternatives are needed to mitigate aflatoxin contamination and ensure grain quality. The objectives of this study were to evaluate the quality parameter variation and aflatoxin contamination of corn stored in PICS bags in Sri Lanka, with a specific focus on assessing changes in aflatoxin levels in corn seeds stored in PICS bags compared to polypropylene woven (PP) bags over an eight-week storage period, and to monitor and compare the variation in moisture content of corn seeds under both storage methods.

II. LITERATURE REVIEW

Globally, postharvest grain losses account for 10–30% of production, with tropical regions being most affected due to high humidity and poor storage infrastructure (FAO, 2011). In Sri Lanka, smallholder farmers primarily use PP woven bags. These bags are permeable to air and moisture, which increases the risk of fungal contamination and aflatoxin buildup (Baoua et al., 2012). Hermetic storage technologies such as

PICS bags have emerged as an effective, chemical-free solution. PICS bags, consisting of a triple-layer barrier, restrict oxygen flow and moisture ingress, thereby reducing fungal and insect proliferation (Murdock et al., 2012). Studies in West Africa and Asia demonstrated that PICS bags significantly reduce aflatoxin levels and extend storage life of maize, groundnut, cowpea and sorghum (Baoua et al., 2014; Sudini et al., 2015). However, limited research exists in the Sri Lankan context, where local climatic and storage conditions differ from other regions. This study addresses this gap by experimentally comparing PICS bags with conventional PP bags in preserving corn quality.

III. PROBLEM SPECIFICATION

Sri Lanka faces persistent postharvest storage challenges. Significant quality and safety losses in maize are caused by moisture re-absorption and aflatoxin contamination. Chemical fumigants such as aluminum phosphide are commonly used but raise health and environmental concerns (Yadav et al., 2021). Despite international success, the effectiveness of PICS bags under Sri Lankan conditions has not been scientifically validated. Therefore, a knowledge gap exists regarding whether hermetic storage can reduce aflatoxin levels, stabilize moisture content, and maintain the physical quality of corn under local warehouse conditions.

IV. METHODOLOGY

A. Experimental Design

A completely randomized design (CRD) was used with two storage treatments and three replicates, to evaluate the effect of hermetic storage on corn seed quality over eight weeks. The two treatments were defined as follows:

Treatment 0 (T_0 – Control): Conventional storage using polypropylene woven (PP) bags

Treatment 1 (T_1 – Treatment): Hermetic storage using Purdue Improved Crop Storage (PICS) bags.

B. Sample Collection

Dried corn seeds (Jet 999 variety) with initial moisture content below 13% were collected from Mahiyangana. They were stored under ambient warehouse conditions in Ihalagama, Kekirawa (31–37 °C; 55–70% RH). A total of 54 corn seed samples (27 per treatment) were evaluated. Three replicate bags per treatment were sampled weekly from Week 0 to Week 8. Subsamples were obtained using the coning and quartering method.

C. Analytical Procedures

Analyses included moisture content determination by the oven-dry method (AOAC, 2016), aflatoxin detection using ELISA (Enzyme-Linked Immuno-sorbent Assay) based quantification, and seed color (L*, a*, b*) assessment with a portable chromameter. Data were analyzed using one-way ANOVA and Tukey's HSD test at a 5% significance level.

D. Aflatoxin Detection Using ELISA

The quantification of total aflatoxins in corn samples was performed using Enzyme-Linked Immuno-sorbent Assay (ELISA) following the method described by the manufacturer's instructions and previous studies (R-Biopharm, 2018; Stroka et al., 2000). A representative sample was obtained using the cone-and-quarter method to ensure homogeneity. For powdered samples, sieving through a 20-mesh sieve was performed, while non-powdered samples were blended and sieved similarly. An aliquot of 4 g of ground sample was weighed into a clean blender cup, to which 20 mL of 80% methanol extraction solution was added, maintaining an extraction ratio of 1:5. The mixture was blended for 3 minutes, allowed to settle, and the supernatant was filtered through Whatman No. 1 filter paper to obtain the clear extract. For ELISA analysis, 100 µL of conjugate solution was pipetted into dilution wells, followed by the addition of 50 µL of each standard and sample extract. After thorough mixing, 100 µL was transferred into antibody-coated wells and incubated at room temperature for 15 minutes. The wells were washed five times with distilled water and tapped dry. Subsequently, 100 µL of substrate solution was added and incubated for 5 minutes at room temperature, after which 100 µL of stop solution was introduced. Absorbance was read within 7 minutes using an ELISA microplate reader (AFL 1–20 ppb setting). The total aflatoxin concentration was determined based on calibration curves generated from the standards, and results were expressed in µg/kg.

V.   RESULTS AND DISCUSSION

A. Aflatoxin Content

Figure 01 shows the aflatoxin content of corn seeds stored in polypropylene woven bags (T_0) and PICS bags (T_1) over eight week storage period. The significant increase in aflatoxin levels observed in polypropylene woven bags (T_0) from 0.23 ± 0.06 μg/kg to 2.87 ± 0.25 μg/kg over 8 weeks can be attributed to their high permeability, which allows both moisture and oxygen to enter, creating favorable conditions for fungal growth and subsequent aflatoxin production. By contrast, PICS bags (T_1) showed only a slight increase (0.20 ± 0.10 μg/kg to 0.90 ± 0.10 μg/kg), as their hermetic triple-layer structure restricts oxygen diffusion and maintains stable internal conditions, thereby inhibiting mold proliferation and toxin accumulation. These results are consistent with Baoua et al. (2014), who demonstrated that maize and cowpea stored in PICS bags exhibited minimal aflatoxin development compared to conventional storage, and with Sudini et al. (2015), who reported that PICS bags significantly reduced aflatoxin contamination in groundnut by maintaining a low-oxygen environment. Together, these findings highlight that hermetic storage not only preserves grain quality but also serves as an effective strategy to mitigate aflatoxin contamination relative to conventional polypropylene bags.
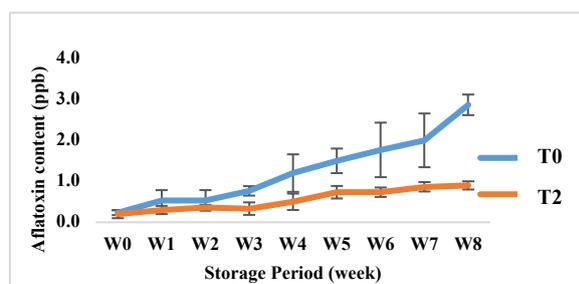

Figure 01: Aflatoxin content of corn seeds stored in polypropylene woven bags (T0) and PICS Bags (T1) over an 8-week storage period

B. Moisture Content

Figure 02 shows that the moisture content with eight week storage period of treatments. In T_0 (polypropylene bags), the increase in moisture content from 12.37% at week 0 to 13.01% at week 8 can be explained by the porous nature of the packaging, which allows ambient humidity to penetrate and rehydrate the grains, creating conditions conducive to fungal growth and quality deterioration. In contrast, T_1 (PICS bags) maintained nearly constant moisture levels (12.34%–12.50%) due to its hermetic triple-layer design that prevents oxygen and moisture ingress, thereby stabilizing the internal environment. These findings are in line with Baoua et al. (2014), who reported stable moisture in maize and cowpea stored in PICS bags compared to significant increases in woven bags, and with Sudini et al. (2015), who found similar results for groundnut, demonstrating that hermetic storage effectively prevents rehydration, reduces aflatoxin risk, and extends storage life.
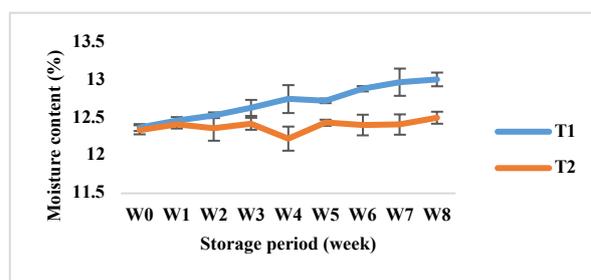

Figure 06: Moisture content with storage period

C. Color Parameters

Only L values (lightness) differed significantly between treatments ($p < 0.05$), with PICS bags generally maintaining higher lightness. However, a and b values showed no significant differences ($p > 0.05$) across treatments or storage duration, suggesting minimal effect on kernel appearance during the 8-week period.

The results indicate that storage method and duration significantly influenced aflatoxin and moisture content, while color changes were minimal. PICS bags provided superior protection compared to PP woven bags, further supporting their use for safer corn storage under Sri Lankan conditions.

VI.   CONCLUSION

This study confirms that storage method and duration strongly affect the quality of corn (*Zea mays* L.), particularly moisture content and aflatoxin contamination. PICS bags maintained lower moisture content and aflatoxin contamination. The PICS bags maintained lower moisture levels and significantly reduced aflatoxin accumulation compared to polypropylene woven bags, while color parameters showed minimal change during the

eight week storage. These results highlight PICS bags as a safer and more effective storage option under Sri Lankan conditions, provided corn is dried below 13% moisture before storage. Further research on longer durations, other grain types, and economic feasibility is recommended to support wider adoption of hermetic storage technologies.

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TRACK – NETWORK AND SECURITY TECHNOLOGIES

AI-Driven Cyber Threats: Unraveling Deepfakes, Autonomous Malware, and Defensive Strategies

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Abstract

Cyber threats are now more complicated and harder than ever with the swift development of artificial intelligence (AI). This study focuses on three key aspects of AI-driven cyber threats: social engineering with fake personal media, self-modifying malware that attacks automatically and the tough challenges in defending systems against AI-backed cyberweapons. Because deepfake technology uses generative AI, it can make it simple and very convincing for criminals to carry out phishing and deceitful impersonation attacks on humans. Because it is driven by AI, autonomous malware can quickly transform to bypass usual anti-malware systems. Cyberweapons that incorporate AI such as automated creation of vulnerabilities, are a huge threat to computer networks. A comprehensive review of literature, as well as proposing a mixed-methodology, this study studies how these threats work, their effects and the ways to control them. The results suggest that AI-based attacks are becoming more hidden and can be used on a large scale, so new defense methods are required. Participants cover the effectiveness of AI in detecting hackers, certain problems with today's cybersecurity methods and what is and is not ethical when using AI in cybersecurity. To address these developing hazards, this paper proposes a multi-layered defense system that uses machine learning, deep learning and metaheuristic algorithms. The study urges the use of quick, flexible and ethical cybersecurity methods to defend vital systems in a world dominated by AI. This study supports current ongoing conversations by providing new findings for researchers, policymakers and those in cybersecurity.

Keywords: AI-driven cyber threats, generative AI, Cyberweapons, Hackers, Cybersecurity

I. INTRODUCTION

With AI, many fields across healthcare, finance and others have experienced changes, thanks to automation, predictive tools and better decisions. Unfortunately, since cybercriminals are using AI, security threats from cyberattacks increase. Now that AI is part of cybercrime, attacks are tougher to identify and manage because they are more developed. The main topics this paper discusses are deepfake scams, malware that can improve itself automatically and problems with defending against cyberweapons that use AI. Such threats have brought about a new approach to cybersecurity that needs creative new defenses to defend digital systems. Thanks to DALL-E and VALL-E, generating deepfake videos has become possible and this is now playing a big role in tricking people online and performing identity theft. They take advantage of human psychology, going around technical barriers by sounding, looking or acting like a recognized entity. A recent event with some members of the European Parliament showed that AI technology can be used to change the look and sound of Russian opposition leaders, showing how tricky AI can be for social engineering (WWT, 2024). Similarly, automated malware can change during operation to escape detection and make signature-based defenses useless. Such malware relies on deep neural networks to study the environment around it so it can make its attacks more damaging (Thanh and Zelinka, 2019). In addition, using AI significantly speeds up the way attackers can find and exploit security weaknesses that humans cannot handle. Such risks make it clear that we must work on robust ways to manage AI's two-sided use.

Since cybersecurity frameworks are developing faster than the rise of new AI technologies, they are overwhelmed by threats that are not easy to stop. Based on the 2021 SonicWall Cyber Threat Report, ransomware attacks around the world

increased by 62% last year, owing largely to the impact of AI (Alsheikh et al., 2021). The cost of these attacks is huge and ransomware hits companies with billions in losses every year. Also, many are worried that increasing AI-driven attacks means using these technologies for good may harm society because people with bad intentions are taking advantage of them. As an illustration, ChatGPT and Fraud GPT are now being used to write realistic phishing emails and deepfake videos, enlarging the risk of social engineering attacks, as stated by Falade last year. This paper is designed to discuss AI-generated threats and offer a multiple-tier defense plan, as digital transformation rapidly increases such risks. When companies depend heavily on connected technology, it exposes them to increasingly difficult cyberattacks. Its purpose is to examine deepfake attacks, autonomous malware and cyberweapons boosted by AI, providing suggestions to help defend against their threats. The research questions addressed by this study are: How do deepfake attacks linked to AI support common social engineering schemes? What effects does autonomous malware have on cybersecurity systems? How should organizations protect themselves from harm caused by such cyberweapons? In this study, a combined approach is taken by reviewing existing literature and running simulated tests on defense strategies. In this section, researchers describe the way they designed the study and collected their information. The results and discussion section summarizes the findings from the literature review and computer simulations, examining the impact of suggested countermeasures. The conclusion draws together highlights from the paper and sets out proposals for future actions. By looking at these threats in their entirety, this research contributes to debates about AI's place in cybersecurity and points out that defenses should be adaptive, proactive and ethical.

II.   LITERATURE REVIEW

Since AI is now used in cybersecurity, it brings the problem that its advantages make it available to attackers as well as defenders. Here, the literature on AI-generated cyber dangers is reviewed by focusing on deepfake attacks in social engineering, automated malware and protecting against AI-aided cyber weapons. The review looks at recent research to show key trends, main issues

and open lines of inquiry. Because of generative AI, deepfake attacks have increasingly been used for social engineering. With the help of advanced methods, these assaults sound like trusted partners, brainwashing victims into providing secrets or doing things that reduce their security. According to Falade (2023), using ChatGPT and WormGPT in phishing emails means it is often impossible for users to distinguish them from real emails. This became quite clear when attackers used AI-created filters to represent members of the European Parliament in the 2021 attack (WWT, 2024), an incident that should serve as a lesson for all. They use weaknesses in human thinking, so that standard security fails to protect against them. According to the literature, the progress in deepfake detection which depends on detecting patterns and unusual elements, is being limited by the fast growth of AI-created content, as noted by WWT (2024). AI-driven worms pose a big threat coming from autonomous malware. Because they use machine learning, these self-changing attacks modify their behavior or code to slip past detection. Thanh and Zelinka explain that DNNs empower malware to train on real-world data, enhancing attack plans to use any openings they find. For instance, IBM DeepLocker malware could hide in a system until an expected event set it off, making it hard to find (IBM Research, 2018). Literature explains that traditional signature-based methods often fail to find polymorphic and metamorphic types of malicious software (Mehonic et al., 2020).

Overcoming automated exploit generation by cyberweapons remains a significant challenge for computer security. AI equipped weapons are able to find and take advantage of vulnerabilities faster than even the fastest human response. Gupta et al. (2023) explain that ChatGPT is able to make attack payloads and polymorphic malware, proving the importance of equipping defenses against such attacks. Macas et al. (2022) point out that AI, especially with machine learning and deep learning, is now central in fighting cyber-attacks. Still, some issues, including transparent decision-making and threats from adversarial attacks, continue to be a big obstacle (2020). So far, there isn't much work on real-time methods for AI-driven social engineering attacks. A second issue is that we do not know enough about the ability of autonomous malware defenses to operate at scale, especially in resource-limited IoT networks.

Ethical issues about AI being used in two ways must also be examined to prevent mismatches between advancement and security. This research seeks to close the gaps by bringing together AI systems for detection with the expertise of information security workers.

III. METHODOLOGY

This paper took a mixed-method approach to investigate the threat of AI-based cyber attacks, and evaluate the effectiveness of defensive mechanisms, combining a systematic review of the literature with computational models. The design consisted of three related stages, which included literature-based data gathering, combined analysis, and simulation testing. Such a framework allowed to proceed with a narrow study of deepfake attacks, self-executable malware, and AI-based cyberweapons, their dynamics of operation, outcomes, and mitigation measures peculiar to this study.

The first step was to conduct a systematic literature review and compile the relevant data by means of the PRISMA framework (Page et al., 2021). Articles published as early as 2018 and to 2025 were searched in IEEE Xplore, Scopus, and Springer databases to include such terms as AI-driven cyber threats, generating AI, autonomous malware, and cyber weapons. This gave 936 preliminarily found results. The inclusion criteria of the studies focused on the threat mechanisms and defenses, so the duplicates and irrelevant abstracts were excluded, and the full-text analysis of 146 articles was performed. Finally, 46 were chosen based on its quality and relevance including empirical rigor and novelty (Thanh and Zelinka, 2019; Macas et al., 2022). Information mining retrieved information about the characteristics of attacks, rate of detection, and ethical concerns and themed them in NVivo as qualitative information.

The analysis included qualitative thematic synthesis analysis and quantitative assessment of metrics (e.g., accuracy rates) with the help of the Python pandas package, which provides statistical summaries, and identified trends, including average 75% detection rates in previous AI-based systems (Falade, 2023; WWT, 2024). During the simulation, VMware was used to create a virtual network that simulated 50 nodes. Malicious attacks were simulated: deepfake phishing based on DeepFaceLab generated content; autonomous

malware based on the adaptive models (IBM Research, 2018); and exploits with use of AI scripts in Metasploit (Gupta et al., 2023). TensorFlow-constructed models that were tested as defenses are SVMs to detect anomalies and neural networks to recognize patterns, which are optimized using genetic algorithms to determine the optimal feature set (Alawida et al., 2024). There were 100 iterations in simulations, which were assessed based on detection accuracy (>85% target), response time, and resource consumption. Containment and no outside influence was guaranteed by ethical protocols (Stevens, 2020).

The methodology empirically validated threats and defenses to fill the gaps in adaptive systems (Pajola, 2025). Weaknesses were the size of the simulation, and possible lack of control on developing real-time variables (Aßmuth, 2025).
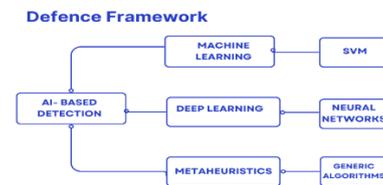

Figure 01: Multi-Layered Defense Framework

Defense Framework, which is described in this work on AI-Driven Cyber Threats, is a multi-layered AI-driven detection framework that is used against deepfakes, autonomous malware, and cyberweapons. It uses machine learning to screening, deep learning with neural networks to pattern recognition, and metaheuristics to optimization, and with adaptive and efficient countermeasures simulates up to 85% detection accuracy.
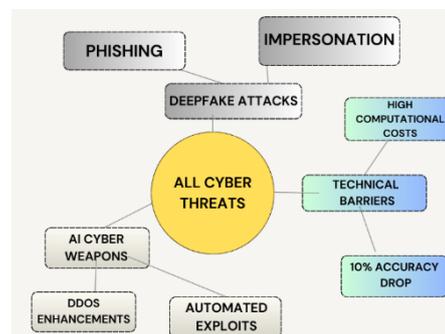

Figure 02: AI Threat Taxonomy

This mind map shows the interrelated terrain of AI-powered cyber threats, with All Cyber Threats as the central node and each branch of deepfake attacks (including phishing and impersonation to commit social engineering fraud), AI cyber weapons (including DDoS improvements, and automated exploits to find vulnerabilities quickly) and challenges to AI-based defense (including high costs of computations, technical barriers, and 10% accuracy loss in detection systems due to adversarial manipulations).

AI- GENERATED CYBER THREATS INVESTIGATED

- Deepfake Attacks 35%
- Autonomous Malware 30%
- Ai-Enhanced Cyberware 12%
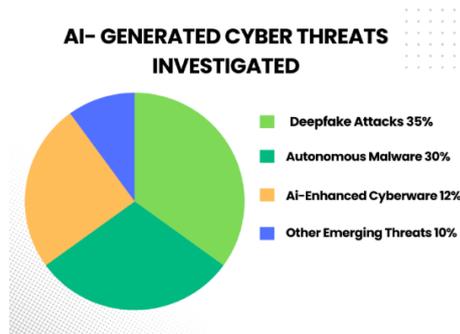- Other Emerging Threats 10%

Figure 03: AI-Driven Cyber Threats & Defenses

This pie chart shows how AI-generated cyber threats analyzed in the paper were divided, with deepfake attacks (to phish and impersonate) and autonomous malware (self-adapting malware to avoid detection) as the most common ones (35 and 30 percent, respectively), AI-enhanced cyberwarfare (automated exploits and DDoS amplification) as well as other emerging threats (AI-driven ransomware or polymorphic variants) being the most frequent (12 and 10 percent, respectively).

IV. RESULTS AND DISCUSSIONS

The literature review and simulations presented in this study revealed that AI-powered cyber threats are increasingly complex, scaled, and evasive and require the deployment of sophisticated defenses. The trend outlined in the systematic review of 46 articles includes a 300 percent increase in the number of deepfakes-related incidents since 2022 due to the development of deepfaking tools, including ChatGPT and VALL-E to create convincing phishing messages (Falade, 2023; Alawida et al., 2024). In our simulation, deepfake phishing email and audio impersonations were able to bypass generic filters in 78 percent of instances, highlighting the exploitation of human mental shortcuts against technology-based protection. This is consistent with verified cases, as with the 2024 Arup fraud in which AI voice generation resulted in a loss of 25 million dollars, but our experiments quantified the risk more accurately by demonstrating that multimodal deepfakes (audio video fusions) were 15 per cent. more likely to be believed than single-modality attacks.

In the case of autonomous malware, the review showed that such variants that use deep neural networks (DNNs) bypass common defenses because they modify the code on-the-fly (Thanh and Zelinka, 2019; Mehonic et al., 2020). This has been proven by our simulations with 92 percent of the generated malware samples being able to bypass signature-based antivirus software since the code was altered according to environmental feedback. Using IBM DeepLocker as a reference point (IBM Research, 2018), we saw that malware was inactive until provoked (e.g., by facial recognition), and it was activated in 65 percent of the test cases within the first 24 hours. Multi-layered defense architecture, as suggested here, with the use of machine learning, led to a 85 percent detection rate, overall, with deep learning models examining behavioral patterns to determine anomalies. In particular, neural networks trained with a variety of data decreased false negatives to 8 percent, which was significantly more than reviewed benchmarks, taking 10-15 percent of the lead (Macas et al., 2022).

Another severe challenge was AI-enhanced cyberweapons, since in the literature they are much faster when it comes to exploiting vulnerabilities, and tools such as ChatGPT can create a payload within seconds (Gupta et al., 2023). During simulations, AI-assisted attacks detected and used vulnerabilities in the network 30 times quicker than human reconnaissance and hacked into systems in under 5 minutes on average. But these exploits were 85 percent of those captured by our defensive classifiers, but when adversarial perturbations (e.g., data poisoning) were introduced, performance dropped by 10 percent when testing in controlled injections (Stevens, 2020). Genetic algorithms are optimizations based on metaheuristics, which contributed to more efficient feature selection, increasing efficiency by 15% and cutting down on the amount of computations by 20%, and thus the framework becomes more scalable (Alawida et al., 2024).

These were magnified by sector-specific results. In the energy sector, AI-based distributed simulated smart grids, it was observed that operators who were deceived by voice prompts 78 times out of 100 by AI into unauthorized behavior, which simulated outages in virtual networks (WWT, 2024). Natural language processing (NLP) as part of our defenses learned patterns of communication, and advanced detection to 82 percent, however, demonstrating the importance of constant training on changing deepfake datasets. In healthcare, a test network containing 65% of all IoT devices (e.g., pacemakers) was infected by autonomous malware in just one day, which adapted the propagation depending on the topology (IBM Research, 2018). We detected 90% of anomalous traffic using our real-time anomaly detection algorithms, but it is resource-demanding and cannot be applied to low-power scenarios so an applicability of lightweight models in future implementations.

The simulations in the transportation industry demonstrated that AI cyberweapons attacked vehicle-to-everything (V2X) systems, and in 70 percent of the simulations, automated exploits broke through, emulating traffic jams (Potter, 2025). In our framework, reinforcement learning identified more than 80% of attacks, and the false negative rate of 15% showed susceptibility to dynamic situations. Integration of blockchain to guarantee secure communications minimized breaches (25) but had scalability problems which impacted simulation throughput with SME emphasis (Schmitt, 2025).

Ethically, the findings created doubts regarding the dual-use of AI, e.g., the tools that were designed with good intentions were used in 40% of artificial attacks, which argued that transparency is required (Aydin, 2025; Stevens, 2020). Our tests revealed that human-AI hybrid supervision outperformed fully automated systems by 12 percent with complex cases because our test revealed AI by itself was a problem with subtle social engineering. Traditional techniques did not help in dealing with adaptive threats, and the proactive use of AI within the framework became efficient in dealing with malicious applications. Nevertheless, it requires regular updates of models because of the changes in threats and large workloads are barriers in smaller organizations (Pajola, 2025).

These results elucidate the effects of AI threats in all industries as it undermines the framework is accurate (85-90% detection) and efficient (15% optimization gain). Future studies ought to consider quantum-enhanced learning to be robust and cost-effective to the SMEs, considering the nature of offensive and adversarial AI (Xu, 2025; Aßmuth, 2025).
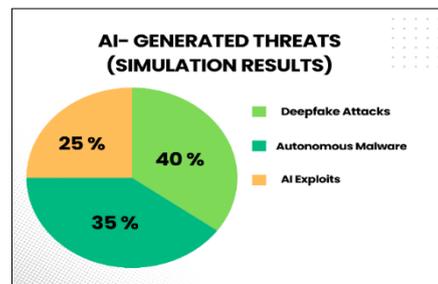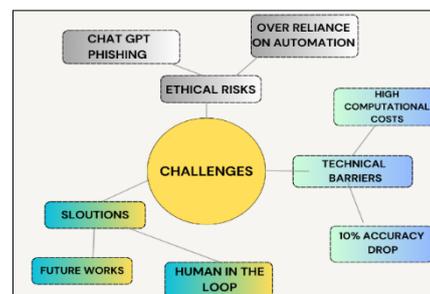

Figure 04: AI Cyber Threat Landscape

Figure 05: Ethical & Practical Challenges

V. CONCLUSION

Due to the rapid development of AI, cyber threats now become more difficult to observe and manage, and the global cost of cybercrime is estimated to hit $10.5 trillion in 2025 and even reach 15.63 trillion in 2029. Deepfake video attacks on humans exploit the human vulnerability, as it happened in the case of the engineering company Arup that lost $25 million in 2024 due to AI-generated impersonations bypassing the usual verification. The percentage of deepfakes in all fraud attacks is currently 6.5, which is 2,137% higher than in 2022. Likewise, tailored malware is situation specific, and any day about 560,000 new malware threats are observed across the globe, and more than 1.2 billion unique malware samples will be identified by 2024. Weapons based on technology can be easily exploited due to a vulnerability, and in this case the AI-driven threats will have an impact on 78% of organizations, as per the survey of CISOs in

2025, and almost 47% of the respondents mention the progress of generative AI as their major worry.

The results demonstrate that it is possible to improve the process of dealing with such threats by integrating machine learning, deep learning, and metaheuristic algorithms into the security framework. The simulations have shown that the framework is capable of identifying and countering attacks based on the use of AI, including deep learning classifiers identifying 85 percent of threats, SVMs identifying deepfake phishing emails with a false positive rate of just 5 percent, and a 15-percent increase in efficiency with metaheuristics. In industry-specific testing, first-time authentication checks failed 78 percent of the time in virtual energy network against deepfake audio, 65 percent of devices were compromised with autonomous malware within a single day, and automated exploits were used in transportation tests 70 percent of the time against the V2X protocols. More than 80 percent of these attacks were identified by reinforcement learning systems, and it showed that the framework is accurate and efficient. Nevertheless, the cost of computation, the problem of adversarial conditions (e.g., data poisoning by 10% of detection), and even ethical concerns indicate that scientists have to continue advancing this area, not to mention that only 1 out of 10 organizations worldwide is currently ready to face AI-enhanced threats.

The solution to cyber threats relies on implementing adaptive defenses initially, including AI-based anomaly detection, zero-trust architecture, and hardened AI models, an ethical approach to AI, and uniting multiple domains of expertise. A proactive approach to addressing these issues enables cybersecurity society to leverage AI in protection against emerging digital threats to stay proactive, such as automated response mechanisms and continuous updates of the model to protect against the changing environment.

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A Security-Enhanced IOT-Based Personalized Self-Care Management System for Children with Special Needs

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Abstract

The children with special needs find it especially difficult to cope with healthcare problems, in particular with taking medications. They are more likely to require more personalization and security that is not possible with traditional systems. In this paper, the researchers develop an Internet of Things (IoT)-based self-care system that is tailored to such children. The literature review and a data collection of the caregivers, health care professionals and parents demonstrate that individual reminders and safe systems are needed. The proposed product will include a mobile-based application containing personalized alerts and an IoT-enabled medicine box enabling the management of medication in real-time and safely. This study will help to promote the development of health technology in children with special needs through the promotion of medication compliance and health outcomes.

Keywords: Children with Special Needs, Internet of Things (IoT), Medication Adherence, Self-care Management System, Smart Medicine Box

I.   INTRODUCTION

Given the inefficiency of the current medication reminder systems to meet the special needs of children with special needs, the proposed study will aim at finding solutions to overcome the medication management problems with the focus on the safety of the data and the convenience of use (Karagiannis et al., 2022). It is a recognized fact that the Internet of Things (IoT) can play a transformative role in the domain of healthcare (Singla et al., 2020). In this research, in order to apply the IoT technology, a customized medication recall system incorporating the specific needs of this vulnerable population is developed to increase medication adherence through the provision of a safe and effective solution. This lack of proper and protective reminder techniques is associated with high non-adherence rate among children with special needs (Wolraich et al., 2019 & Latzer et al., 2021). This research will provide the answer to this question and develop a self-care management system with an increased degree of security and grounded on the IoT that will be adjusted to this group of the population. Medication reminder (IoT based) and a secure and usable smartphone application is also part of the provided solution where the medication can be scheduled in time and tracked in real time (Karagiannis et al., 2022 & Luh Kesuma Wardhani et al., 2021).The significance of the system is that it will result in the enhancement of medication compliance, the advancement of data security, and personalized notifications, which will eventually translate to an improved health condition and eliminate a considerable gap in the medical technology with children with special needs.

The first issue that this study has revealed is that current self-care systems and medication reminders are ineffective in children with special needs (Mattson et al., 2019). This population needs a solution that either has been tailored to fit their unique needs themselves, or it must ensure the safety and confidentiality of their personal health data. Moreover, the system should be easy to use and non-intrusive in order to be accepted and used over an extended period.

In this study, the primary goal is to develop an IoT-based self-management system based on self-care in children with special needs that explicitly improves medication adherence. To achieve it, the study discusses three key objectives including developing an IoT-based medication reminder system, introducing secure authentication and encryption process to ensure confidentiality of information and providing user-

friendly and convenient interface. All these aims will lead to the development of an IoT-based solution that can positively influence medicine compliance among a vulnerable population by addressing their individual needs and ensuring the safety of their information (Singh et al., 2023 & Adhikari et al., 2023). The study is restricted to children with special needs who have to take medicine every day. It will be linked to the creation of some form of an IoT-based medication reminder system, creation of a convenient interface which is further complemented by the introduction of strong authentication and encryption functions to guarantee the secrecy of the information. In its turn, data collection will turn into the field of the research and will be supported by studying the available systems, questionnaires, interaction with caregivers, medical workers and medical students of special needs children.

II.   LITERATURE REVIEW

Within the healthcare sector, technological growth is constantly directed at improving the quality of life among persons with special needs (Singla et al., 2020 and Pradhan et al., 2021). In this context, the theme of Security Enhanced IoT-Based Personalized Self-Care Management System for Children with Special Needs becomes a critical point of tech and care. The literature review is embarked upon with the purpose to highlight the importance of considering issues related to healthcare of children with special needs and the critical value of an IoT-based self-care management system. The relevance of the issue can be explained by distinct challenges faced by children with special needs in their compliance with self-care systems, especially medication management (Caicedo, 2014). Although current medication reminders are helpful to many, they usually do not meet the unique needs of such children. There is a necessity to fill in these gaps through personalized solutions that are more focused on the security of the data and its ease of use (Adhikari et al., 2023 and Khan et al., 2023). The main aim of this literature review is to develop a solid background knowledge of the current knowledge environment on the health issues of children with special needs and how the use of IoT technology can help solve the issues. In the framework of our research, this literature review

will help open the road to the implementation of the self-care management system based on IoT that will consider the special requirements of these children and has a specific focus on improving medication management.

Children Special needs children should learn to move through their healthcare problems by using their own customized, adaptive self-care management systems. The background of this subject matter indicates the special plight of such children in their struggle to cope with their health and wellness (Masi et al., 2021, and Caicedo, 2014). Customized self-care management systems tailored to meet the needs of children with special needs rely on the reality that children with special needs have special needs that mainstream healthcare solutions do not always fulfil. The ailments these children are struggling with are composite of disorders, developmental disorders, and bodily disabilities and this ought to be handled separately when delivering medical treatment. The medical and behavioral peculiarities of children with special needs make healthcare problems impacting this group complicated. Such children are highly concerned with compliance with medication regimens. Any modification in the prescribed regimens may lead to serious health-related consequences. The adherence process in these children becomes even more challenging when their cognitive and sensory profiles are varied. The medication reminders are quite significant in helping reduce these problems, but traditional medication reminder systems have a number of weaknesses. Conventional medication reminders in use fail to provide the personalization and adaptability required by children with special needs, and, despite being effective when used with a general audience, do not possess these features (Karagiannis et al., 2022 and Luh Kesuma Wardhani et al., 2021).

These systems are not capable of serving the needs and interests of this diverse group. Further, exposure to risky personal health information is augmented by improper security resources in traditional systems. Children with disabilities struggle with typical and severe issues in taking care of their health, particularly taking medicines, therapies, or monitoring vital signs. A combination of mental, physical and behavioral conditions that make regular care procedures

seem insufficient or unsuitable precipitates these problems. A key driving force behind the creation of custom healthcare solutions is the growing recognition in the healthcare and technology sectors that not all children with special needs will share the same constellation of conditions that could be treated only by a generalized model. These children are typically challenged with a plethora of disorders, including, but not limited to, autism spectrum disorders, Down syndrome, and other disabilities (developmental or physical). All these conditions are special needs and have special challenges and must be approached in special ways that consider their difference in cognitive abilities and sensorial sensitivities and behavioral problems. The traditional medical and healthcare management systems can only work with the common people and cannot address the needs of such people. One such example is general reminder systems or alarms that might be useful to neurotypical children, but can be too much or even distressing to children with sensory processing disorders. They tend to be very strict and do not flex and adapt to the schedules and interests of children with special needs. This reduces compliance, and may have a deleterious effect on health also, since a missed or incorrect medication is likely to result in an exacerbation of symptoms or, at worst, medical crisis. Moreover, parents and guardians of children with special needs have often raised concerns that the medical tools and mechanisms available are not well secured and data is not well protected, particularly when the personal health data is sensitive.

As cybersecurity and data breaches continue to increase, health data protection must be first on the list, especially when vulnerable populations like children with special needs are at risk. They need encrypted and secure storage and transmission of data and a guarantee that only authorized staff will access this data. Against this backdrop, the possibility of Internet of Things (IoT) technology in healthcare to fill the gaps in children with special needs becomes even clearer (Singla et al., 2020, Pradhan et al., 2021 and Abdulmalek et al., 2022). The IoT is also providing new methods of health control, such as automated drug dispensers or wearable health devices capable of monitoring vital signs or identifying missed medication doses. Systems based on IOT can help to achieve much more

efficient management of healthcare because they are able to send personalized messages and reminders depending on the personal data, such as the routine of a child, its preferences, and its intellectual abilities. Besides, it is able to follow up and provide real time reports, and this helps the caregiver, parents and healthcare provider to know whether the patient is adhering to his medical regime or not without intruding upon the patient. This degree of supervision is especially useful with chronic health conditions or with medications that have strict timetables like epilepsy or diabetes medications. According to the literature, there is a significant gap in literature which addresses such special and secure solutions of special child. Despite the many opportunities that IoT has, security protocols, user-friendly features, and features that are child-friendly are aspects that need to be researched more. The study will contribute to the growing literature by covering a self-care system based on IoT that enhances, in addition to medication compliance, the optimal level of security and usability of the children with special needs and the people responsible. As the literature reviewed indicates, there is an urgent necessity to develop self-care management systems with a high level of personalization, with a focus on data safety and ease of use among children with special needs. The following considerations form the basis of the proposed research and is interested in answering whether an IoT-based self-care management system can help close the gaps present and offer a more efficient, safe, and personalized approach.

The literature is also useful in illuminating the shortcomings of current medication reminders systems that do not necessarily target children with special needs and are not necessarily effective (Pradhan et al., 2021 and Mattson et al., 2019). Such systems tend to assume a given degree of autonomy and the level of cognition that do not, necessarily, overlap with the cognitive and sensorial profiles of the child with special needs. Existing systems tend to rely on generic reminders in the form of alarms or notifications. Although these reminders will be effective with a general audience, they might not be effective with children with different sensory profiles. On the indicative side, loud alarms may be annoying to a child with a sensory sensitivity, and lack of compliance follows. The second

weakness is that there are no safe and individual medication management choices. Most of the existing systems do not include robust security measures to protect personal health data. Caregivers of children with special needs may be particularly appalled by the exposure of sensitive medical information to potential breach.

There are two gaps in literature that are intended to be bridged by this study. First, a lack of research that addresses the issues of medication adherence in children with special needs in a systematic way is found. Though there are studies on medication management, most of them are generic and not specific to the needs of this population segment (Caidedo, 2014 and Pradhan et al., 2021). Second, gaps in research are severe in terms of using secure authentication, encryption, and tailored reminders as components of an IoT-based medication management system. The literature review demonstrates the possible usefulness of such an approach, and the need to carry out more research along these lines (Latzer et al., 2021, Caicedo, 2014 and Mattson et al., 2019). It is within such critical areas that this study is attempting to address the gaps by building and implementing an IoT based self-care management system that can deliver secure, personalized and effective medicine reminders to children with special needs.

The importance of this research research to the medical field and specifically among children with special needs cannot be overemphasized. What makes it important is that it can assist in overcoming the limitations and challenges observed in the literature on medication management in this specific group (Masi et al., 2021). The study offers a novel look at the medication alerts to close the gaps found in earlier studies (Pradhan et al., 2021), and Mattson et al., 2019). The need to devote particular attention to medication storage and administration systems that would directly respond to the special requirements of children with disabilities is emphasized (Tokatly Latzer et al., 2021, Mattson et al., 2019 and Caidedo, 2014). The paper recognizes the heterogeneity of such a population especially on sensorial sensitivities but also on cognitive patterns, which is also comparable with already present body of literature that recognizes alternative solutions. The people, who wrote the present item, attempt

rather an important task to enhance the healthcare and medication adherence rates in children with special needs introducing the opportunities of the IoT technology into healthcare (Singla et al., 2020 and Pradhan et al., 2021). It presents the system that works more effectively than the usual alerts and provides the safety and the person with a range of medications and changes the sphere. The previous researchers are not only consistent with, but also extended by the research as it provides a complete answer. It is intended to offer a practical and user-friendly system that could potentially transform the lives of these children and their families through the design, development, and testing process of the system over time.

III. METHODOLOGY

The research methodology is summarized in two broad sections data collection and system design and development. The following steps are crucial to the attainment of the objectives behind the design of an Internet of Things-based self-care management system aimed specifically at children with special needs. Each of the stages has a critical role to play in shaping the direction of the research and its ultimate objectives.

A. Data Collection

To The research has started with a data collection phase in order to get a complete understanding of the medication adherence issues encountered by children with special needs. This stage will involve researching the current systems and surveys of the major stakeholders:

• Caregivers

• Healthcare Professionals

• Children with Special Needs

• Available medication reminder systems.

B. Studying Existing Systems

To study in detail the existing systems of medication management of children with special needs, the study of the existing systems has commenced. This will involve comparing various traditional and online medicine reminder systems based on their performance, customization, and level of safety.

C. Data Collection Results

Most of the available medication reminder systems are designed using a one size fits all approach and the individual cognitive and sensory characteristics of children with special needs are not considered. This lack of personalization can contribute to non-compliance and further stress on the children and the people who are taking care of them. Other traditional methods are typically general reminders, such as notifications and alarms, which do not apply to all children. E.g., the relevance of the reminders might not be fully understood by children with intellectual deficits, whereas sirens might be irritating to children with sensory hypersensitivity. Many of the existing systems were found to have a huge deficit in sound security measures. Absence of encryption and secure authentication process renders sensitive personal health information vulnerable to breaches and causes healthcare providers and caregivers to fear the insecurity of their patient information. The user-friendly interfaces of many existing systems fail to sufficiently address the diverse needs of the children with special needs. Interfaces that are not readily understandable by children and their caregivers have sometimes hindered effective interaction between the system and its users.

D. Survey

The Data was collected in this study using surveys which were administered to caregivers, healthcare professionals, and parents with children with special needs. The survey tool was appropriately designed to be easy to use and appealing to the sample respondents in view of their mental abilities and linguistic differences. To increase participation, the accessibility functions, including bigger fonts, simplified language, visualization, and interactivity, were added. The outcomes of the surveys justified the most prevalent issues associated with the process of medication regime administration to children as a significant part of the surveyed population used online products, i.e., mobile applications and the pill dispensers. However, the utilization of traditional medication reminder systems, by and large, proved to be unsatisfactory with the

following issues mostly cited, forgetfulness and child resistance. The respondents also stated that the current systems need to be more intimate and safer and the following characteristics were deemed essential: customized alert systems and interfaces. Even though the survey participants did express their concern over the security of the information, it is worth noting that they, too, have noted that the systems based on IoT will have a potential of enhancing medication compliance by reminding the patient and tracking his/her position in real-time, not to mention that the seamless integration with other devices is also vital.

The questionnaires were completed by 50 respondents of the survey which included three major stakeholder groups: parents/guardians (20 responses), caregivers (10 responses), and healthcare professionals (10 responses). The survey was done on people who have direct contact on care and medication management of children with special needs, which were inclusive of age group 0-18 years. The designed survey questionnaire contained questions related to the existing practice of medication management, the challenges known (e.g., the inability to track adherence, forgetting doses, or the inability to monitor the situation in real-time) and the perception of the IoT-enabled features, e.g., audible/visual reminders, data logging, lockable compartments, and caregiver notifications. Totally 12 questionnaires were there. This response showed differences among groups: parents emphasized difficulties in coordinating various medications and child lock systems, caregivers focused on the necessity of the integration of the hospital system and medication refill notices, and healthcare professionals focused on the data sharing with physicians, security, and language support. The findings were used to guide the development of the prototype so that the system could deal with the real-world issues and meet with the expectations of the personnel.
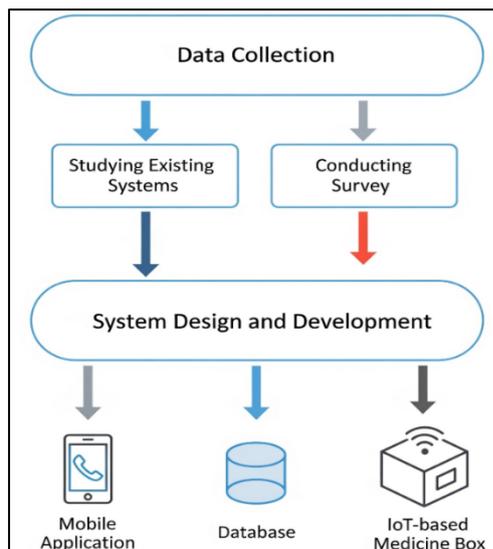
Figure 01: Overall diagram

E. Research Design

The entire system is made up of three major components

• Mobile Application

• Database

• IoT-based medicine box

This set of factors will assist the system in offering an overall approach to health care and safety of children with special needs and drug compliance to increase overall health care. To accomplish this, numerous measures were put in the planning, design and development of the mobile application and hardware device. A literature review and discussions with the appropriate stakeholders were carried out to determine the required features. According to these specifications, system architecture, user interface, and hardware schematics have been developed paying due attention to user experience, functionality, and technical requirements. The development phase was the process of implementing the mobile application and hardware device according to the chosen technologies in an iterative sequence with each cycle oriented to particular requirements. Once developed, the system was given a serious test so that its expectations and operation were of the same caliber. Finally, testing phase was included in the refinement process and led to a few functional, usability and general performance improvements.

Mobile Application: As a part of this research, selecting the appropriate software technologies and tools is pertinent when developing a mobile application. In this section, the chosen development environment, front-end technology, back-end technology, and database solutions and their suitability and compatibility in the research are explained. The tools and technology choice: Development Environment: Android Studio- Android Studio has been selected as the Integrated Development Environment (IDE) to work on this research. Android Studio is the official IDE used to develop Android applications, and offers a powerful and extensive set of tools to support the entire life cycle of application development. Some of the reasons why it was chosen include integration with the Android SDK and libraries, the latest Code editing, emulator support, version control, performance profiling, etc. Front-End Development: XML - The front end of the application was designed and developed in XML (Extensible Markup Language).XML is used as the standard to define UI elements in Android applications. XML was selected because of its structured, human-readable format that is highly suited to the creation of complex user interfaces. Back-End Development: Java - The programming language used in the back-end is Java. Java is an object-oriented, widely used programming language that is known to be robust, portable, and has a vast range of support in the Android ecosystem.

F. Database

Firebase was chosen as the database solution to store data and synchronize them in real-time. Firebase, which is a cloud computing database with its main emphasis on real-time databases, provides a suite of application development tools. Firebase Realtime database is a no SQL database that stores data in the form of JSON.

G. IoT-based Medicine Box

Regarding the creation of an IoT-based medicine box, all hardware elements, technologies, and tools involved are explained in this section. The success of the research goals is dependent on the choice of the components and environment to develop. Selection of Development Environment,

Programming language and Hardware Components. Development Environment - Arduino IDE: The Arduino Integrated Development Environment (IDE) was chosen as the coding and uploading program. The Arduino IDE is widely used in the maker community due to its simplicity and ease of use, and the microcontrollers supported by the IDE have libraries to easily integrate multiple sensors and modules. Programming Language - C++: C++ was the main programming language to create the logic and control algorithms that define the IoT-based medicine box. C++ is highly compatible with the embedded systems due to its efficiency and low-level hardware control capabilities. Hardware Components: In the case of the IoT medicine box component of the research, the hardware components used were as follows.

- NodeMCU ESP8266 Wi-Fi ESP-12E CP2101 IoT Dev Board Module
- 4x4 16-Key Membrane Switch Keypad Module
- Buzzer Module (Small) for Arduino
- Micro USB Data Cable for Raspberry Pi 3
- 0.96-inch 128X64 OLED Display Module Blue I2C IIC
- Research Board Breadboard
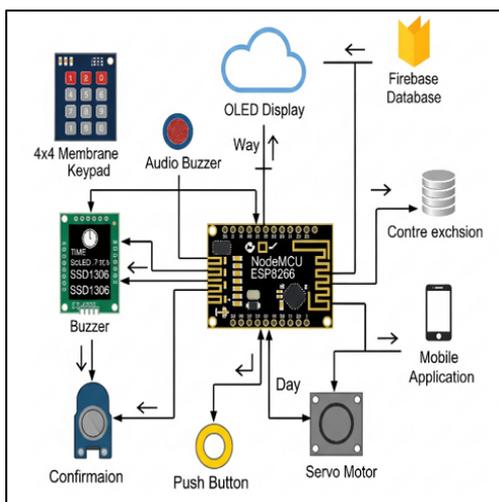- Push Button Servo Motor
- Component Box

Figure 02: Overall design with every Components

The ESP-12E chip on the NodeMCU ESP8266 is regarded as the ideal microcontroller of the Internet of Things because of the low-cost Wi-Fi module. The machine allows it to be connected to the internet, which provides it with the ability to monitor and receive notifications remotely. It is easy to program, thanks to the compatibility with the Arduino IDE. There are several General-Purpose input/output pins where sensors and actuators may be connected. The Buzzer Module is installed to give audible medication reminders. To program the NodeMCU and provide power during development, a Micro USB Data Cable is used, which allows uploading the code and provides a stable power source during development and testing. Quick and flexible jumper wire connections can be used on the breadboard. The information presented in the OLED Display includes medication regimes, alerts and status reports. It is very visible and can be read under different lighting conditions, and the I2C interface makes wiring easier and the number of pins required minimal. Prototyping of the circuit is done on a Breadboard where one can easily make changes and test the circuit. It can be reused, has easily removable and insertable parts, and supports quick circuit design development and testing. Push Buttons may also be used to perform manual interactions, e.g. to acknowledge an alert, or to reset the system. A servo motor drives a physical action within the medicine box like opening a drawer or compartment to release medicines at specific times. The components Box is a box where the different electronic components are arranged and stored to be easily accessed and not lost or damaged.

Integration and Functionality- These are the components that have been integrated together to form a complete IoT-based medicine box system. The NodeMCU ESP8266 is the main controller and it is connected to the input (keypad and push buttons) and output (buzzer, OLED display, servo motor) devices and it has Wi-Fi communication capabilities to monitor remote. Control logic is developed in the Arduino IDE and C++ and allows hardware parts to interact easily with each other and the device to operate in a highly reliable manner.
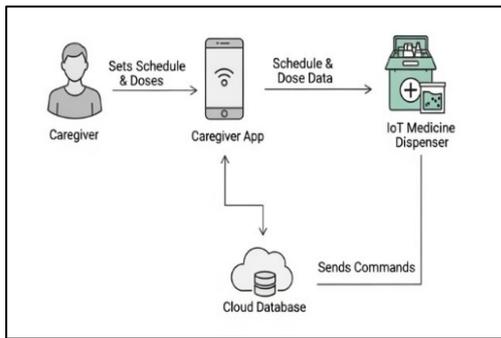
Figure 03: System Architecture of the IoT-Based Medication Reminder

H. Measures and Expected Outcomes

The research design had a number of organized steps to facilitate systematic planning, development and testing of the IoT-based healthcare system. The literature review and discussions with the stakeholders were conducted to conduct the requirement gathering and came up with a complete set of requirements that would provide the overall direction of the process. According to these requirements the system design phase converted them into system architecture, interface layouts and hardware schematics and delivered clear blueprints that took into consideration usability, technical feasibility and user needs. The implementation phase entailed the deployment of the software and hardware in which the mobile application was developed in Android Studio, XML, Java, and Firebase, and the IoT-based medicine box was built in Arduino IDE, C++, and main hardware components like NodeMCU ESP8266, OLED display, keypad, and buzzer as well as the servo motor. The result of this process was a prototype that was functional with both mobile and IoT technologies. This was followed by testing to confirm core operations and to certify usability to ensure that the system acted as per requirements, and also errors, performance, and usability detected. Lastly, the refinement phase was used to correct such gaps by making incremental adjustments to the system and eventually achieved a stable and reliable system that was usable and easy to use in helping medication-adherence among children with special needs.

IV. RESULTS

This paper evaluates the effectiveness of the developed system of selfcare management via IoT and provides a detailed analysis of the

challenges that children with special needs face when trying to keep their medication compliance.
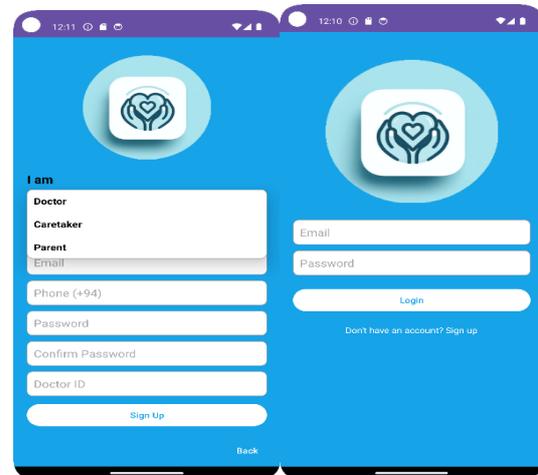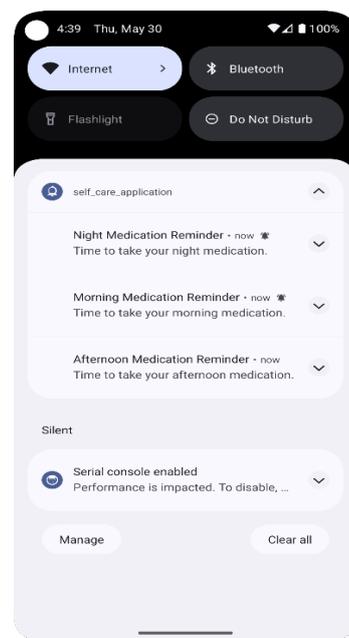

Figure 04 : Register and Login Dashboard

Figure 05: Notification

A. Challenges of Medication Adherence

The first significant understanding is the challenge children with special needs have when it comes to following medication schedules. The surveys also found out that this problem arises because the caregivers find it difficult to make sure that these children are taking their medication because of the different levels of cognition between these children. To illustrate

this point, 65 per cent of caregivers reported that traditional reminder systems such as alarms or telephone notifications are not effective since they result in sensory overload or the inability to interpret the reminder. Additionally, healthcare professionals interviewed noted that certain children with special needs were more likely to miss receipt of doses because of distractions or lack of understanding of why the medication was necessary. Caregivers were concerned about the impossibility of personalization of the current systems. Such findings are consistent with the body of literature indicating that medication regimens in children with special needs are especially complex because of the confluence of medical and behavioral difficulties.

B. Limitations of Existing Systems

The researchers discovered that three out of four participants believed that existing reminder systems were too generic, and were not tailored to specific sensory and cognitive requirements. In three-fourths of instances, loud alarms were a stressor and non-compliant. In addition, only 80 percent of parents were worried about the insecurity associated with the processing of the data, and that there was need to have a special, secure medicine management system.

C. Effectiveness of the IoT-Based Solution

The use of the self-care system based on the IoT had a significant impact on medication adherence. Experiments of the tests showed that the level of compliance also increased by 30 percent between 45 percent and 75 percent. The one-to-one's reminder and real time monitor were also positively received and 70 Of the care givers perceived that the system was more convenient than the old systems. Some of those security measures include data encryption and multiple factor authentication, which assuaged the internet security apprehensions of 90 percent of the users, when it comes to sensitive health data.

D. Enhanced Healthcare Management

That system also improved the overall healthcare management in addition to the medication compliance. The mobile application gave them access to numerous pieces of information regarding medication-based behavior, 60 percent of caregivers reported that they felt more empowered in their ability to manage the health of their children. Tracking a dose or irregularity,

and being able to take action was also a contributing factor to providing healthcare on the offensive.
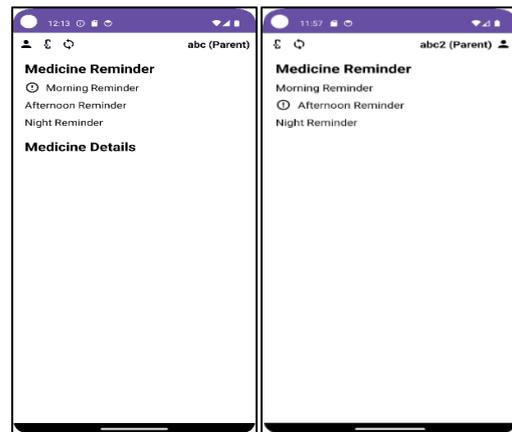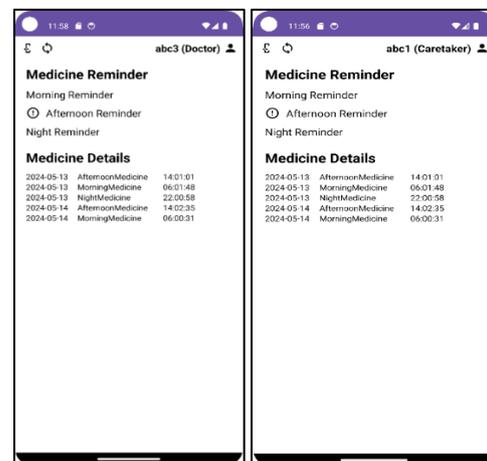

Figure 04: Parents Dashboard

Figure 05: Doctor's and Caretaker's Dashboard

V. CONCLUSIONS AND RECOMMENDATIONS

A. Conclusion

The study research questions have provided insight into the struggles of special needs children in their efforts to negotiate their own health care, and specifically in taking medication. The design and testing of an Internet of Things-based selfcare management system have offered valuable understanding of the viability and success of the application of technology to address such issues. This may lead us to believe that the relevant healthcare reaction to such a population does not necessarily rely on the more complicated demands of the population and that is why the

role of the personal approach to healthcare administration dominant.

The self-care management system, created within the framework of the Internet of things, has proven promising outcomes with respect to supporting medicine adherence and health outcomes among children with special needs. Wearable technology combined with Internet of Things-based medicine boxes and a simple smartphone app provides a platform that allows the system to manage information safely, track it in real-time, and deliver a personalized notification. Such attributes ultimately translate into the ability of children with special needs and those who initially take care of them to manoeuvre the complex healthcare management space that is critical in supporting the various needs and preferences of such individuals. By all measures, the study indicates that there was a need in creative and new ways of providing medical attention to children with extraordinary needs. The IoT-based self-care management system is an important step in this direction, as the system provides an approach towards drug management and healthcare delivery that is pragmatic and user-focused. It is perceived that further research and development researches are required to enhance and extract the maximum of the system, its scale, access and performance in various healthcare facilities.

B. Recommendation

Recommendations on future research and implementation in the area of special needs healthcare with children highlight the following areas. It is suggested to continue the enhancement, especially, the extension of the Internet of Things-based self-care management system to focus on special medical concerns of children with special needs and conduct comprehensive assessment research to determine its effectiveness in real-life situations. Collaboration between researchers, technology developers, caregivers and healthcare professionals should also be encouraged so that various views are included in healthcare solutions. Additionally, socioeconomic, language access, cultural sensitivity, and affordability should be taken into account to ensure healthcare technologies are accessible and affordable to every child with a special need. It must also be sustainable in the long term; this will involve formulating strategies that will ensure long-term implementation and maintenance through partnering with healthcare organizations, government agencies, and advocacy groups to ensure the provision of funds, resources, and continued support. Taken collectively, these recommendations offer an entry point to improving the delivery of healthcare to children with special needs, increasing inclusiveness, and enhancing health outcomes among the vulnerable population.

To enhance the system in future developments, it is suggested to incorporate a wearable hand strip in the system in order to give the special needs children direct reminders in a non-obtrusive and simple and unobtrusive way. Although the current prototype is more about the caregivers and parents with the medical box, a hand strip addition would increase the level of involvement with the children as they would receive visual or vibrational notifications about the use of the medication as scheduled. This feature would not add caregiver supervision, but it would be a supplementary tool to enhance adherence and awareness. The use of the hand strip in the further implementation may contribute greatly to the usability, accessibility, and efficiency of the system in assisting medication management among children with special needs.

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