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"Exploring Innovative Horizons through Modern Technologies for a Sustainable Future"

In Collaboration with

SLAAS (Eastern Chapter)

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

ICST 2024

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October 16th, 2024

"*EXPLORING INNOVATIVE HORIZONS THROUGH MODERN TECHNOLOGIES FOR A SUSTAINABLE FUTURE*"

.

Faculty of Technology
South Eastern University of Sri Lanka
Sri Lanka

ICST 2024

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MESSAGE FROM THE CHAIRMAN & VICE CHANCELLOR

As the Acting Vice Chancellor of the South Eastern University of Sri Lanka and the Dean of the Faculty of Technology, I am honoured and delighted to pen this message to the Fourth International Conference on Science & Technology (ICST 2024), themed "Exploring Innovative Horizons through Modern Technologies for a Sustainable Future." This theme is timely, addressing the pressing global challenges faced today since the era of technology and its structured evolution is crucial for achieving a sustainable future for the generations to come. The technological advancements are further required to address the pressing issues we face today. It is vital that innovations being developed worldwide today are disseminated and shared to ensure balanced application and effectively tackle these challenges.

The Faculty of Technology, the youngest at the South Eastern University of Sri Lanka, has shown remarkable growth and development in research and innovation, making significant contributions to both the local and global communities. This conference serves as a vital platform for researchers, academicians, research students, professionals and policymakers to exchange ideas, share information and discuss advancements that can lead to sustainable solutions. This year, our collaboration with the Sri Lanka Association for the Advancement of Science (SLAAS) has significantly enriched and empowered the research culture of the conference, extending beyond the borders.

We are proud to have received over fifty research papers from local and international scholars, highlighting our commitment to fostering a vibrant research culture. I extend my heartfelt gratitude to the keynote speakers, Prof. Dilanthi Amaratunga from the University of Huddersfield, United Kingdom, and Prof. Chaklam Silapasuwanchai from the Asian Institute of Technology, Thailand, sponsors, distinguished guests, scholars, presenters, the organizing committee, staff of the faculty, students and the administrative staff 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 a very success one.

I wish all presenters a great success in sharing their findings and contributing to our collective pursuit for a sustainable future.

Sincerely,
Dr. U. L. Abdul Majeed
Dean, Faculty of Technology
Vice Chancellor, South Eastern University of Sri Lanka
Sri Lanka.

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MESSAGE FROM THE COORDINATOR

As the coordinator of the International Conference on Science and Technology-2024 (ICST2024), I am excited to compose this message, a prominent event among the Technology Faculties in our country. The Faculty of Technology at the South Eastern University of Sri Lanka proudly orchestrated this distinguished gathering on 16th October 2024.

The theme of the ICST2024 is "Exploring Innovative Horizons through Modern Technologies for a Sustainable Future," which reverberates deep relevancy with the current state of affairs in the country. This event will be garnered by distinguished researchers, scientists, engineers, technocrats, technologists, and industrialists from around the globe. This annual event marks a significant stride among the technology faculties in the Country, showcasing our commitment to advancing knowledge and addressing pertinent issues. The wide spectrum of topics will be a good stimulus for new research ideas and new horizons.

As Sri Lanka gradually recuperates from the challenging aftermath of the COVID-19 Global Pandemic and the unprecedented economic downturn, initiatives like this conference are vital in propelling us forward towards a brighter future. At this crucial juncture, the use of Innovative Horizons and Modern Technologies for Sustainable Development Goals would uplift the nation. The emerging youth in the country is highly coupled with the technology that can be utilized to enhance research, innovations, and product development. Faculty of Technology always promotes research, innovation, and new product development, this is another platform for the scientific community to prosper further.

ICST2024 will have a significant prominence with two well-renowned keynote speakers: Prof. Dilanthi Amaratunga, an eminent personality on the global front and currently the Head of the Global Disaster Resilience Centre, United Kingdom. The other one is Prof. Chaklam Silpasuwanchai from the Asian Institute of Technology, Thailand.

We received 80 full paper submissions for double-blind peer review where 52 papers were accepted for oral presentations. The compiled abstract is available in the form of both hardcopy and electronic formats at the University e-repository and conference website. The selected best papers will be published either in the Sri Lankan Journal of Technology or the Journal of Information Communication Technology.

I highly appreciate the interest of all presenters who used this opportunity to gain their skills and knowledge from different perspectives. The remarkable support provided by the Steering Committee, Track Coordinators, Editor, Editorial Team, Editorial Assistants, Reviewers, Authors and other staff members was truly impressive, and their unwavering dedication did not go unnoticed, who were preparing this event for nearly a year. Moreover, I would like to extend gratitude to the Platinum sponsors for their generous financial support in making this event a grand success.

Dr. Muneeb M. Musthafa
Coordinator
4th International Conference on Science and Technology
Faculty of Technology
South Eastern University of Sri Lanka
Sri Lanka.

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MESSAGE FROM THE KEYNOTE SPEAKER

Many congratulations for the organising committee of the "2024 International Conference on Science & Technology ICST (ICST-2024)" at the Faculty of Technology, South Eastern University of Sri Lanka for initiating this very timely conference with the theme: "Exploring innovative horizons through modern technologies for a sustainable future".

The conference has many fields of interest including Network and Security Technologies, Agriculture Economics and Entrepreneurship, Food Science and Technology, which are closely aligned to achieving the Sustainable Development Goals (SDGs). Developed and deployed correctly, digital technologies are powerful tools that can have a transformational effect on SDGs. Technologies can help governments, businesses, and philanthropic organizations accelerate their efforts to achieve the 17 SDGs. Of the 169 SDG targets, 103 are directly influenced by the technologies, with established examples of deployment that provide insight into their potential to make an impact. A broad range of SDG targets, including 20 particular targets and 25 associated indicators, finds that further deployment of existing digital technologies will, on average, help accelerate progress toward the SDGs by 22% and mitigate downward trends by 23%. An estimated 70% of new value created in the economy over the next decade will be based on digitally enabled platforms – and leading innovators are re-imagining how we innovate, create, distribute and capture value in the new systems that are emerging

Technology is not a silver bullet, but it holds the potential to transform sectors rapidly and globally: to increase the productivity of systems while lowering emissions and waste, to enable us to monitor and manage the Earth's surface and resources at a speed and scale we couldn't have dreamed of before; to collect and harness vast amounts of data; and make breakthrough advances in areas like climate, healthcare, agriculture, energy, education and mobility.

Leveraging technology to achieve the SDG is evidenced in hazards early warning systems. With ever-increasing climate-related hazards, delivering climate justice to those on the frontlines of the climate crisis is everyone's responsibility. Early warning systems are helping decrease the number of deaths and to reduce losses and damages resulting from hazardous weather, water or climate events. Major gaps still exist, especially from the point of view of the effectiveness of the communication modes that are being used in this process. This is something I very much hope to reflect on during my keynote speech at the conference. This is just one aspect of this conference and indeed there are many more really interesting themes including Food Science and Technology.

I am waiting to hear deliberations and the post-conference summary arising from this very interesting and timely event.

Many congratulations!

Professor Dilanthi Amaratunga, BSc (Hons), PhD, FHEA, FRICS, FRGS, CMgr FCMI
Consultant, University of Huddersfield, UK
Joint Editor-in-chief: International Journal of Disaster Resilience in the Built Environment
Member, UNDRR Europe - Science and Technology Advisory Group
Expert member of the ICG/IOTWMS WG-1 on Tsunami Risk, Community Awareness & Preparedness
Expert of UN Women – Women's Resilience to Disasters Programme
Steering Committee Member, UK Alliance for Disasters Research
Member of the UNDRR MCR2030 Regional Coordination Committee for Europe.

MESSAGE FROM THE KEYNOTE SPEAKER

It is my great pleasure to pen this message for the fourth iteration of an esteemed conference organized by the Faculty of Technology, South Eastern University of Sri Lanka. I extend my heartfelt wishes for the success of this gathering, whose theme, "Exploring Innovative Horizons Through Modern Technologies for a Sustainable Future," could not be more timely or relevant.

We stand at a pivotal moment in human history. Our world grapples with rising mental health crises, persistent conflicts, and the unprecedented emergence of artificial intelligence. These challenges are not just headlines; they are urgent calls for our collective action and wisdom. As global citizens and technologists, we bear a profound responsibility. Our choices today will sculpt the contours of tomorrow's world, particularly in the realm of AI and its impact on society. Our civilization has been through a long technological journey - from stone tools to silicon chips, from the dawn of agriculture to the digital age, and now to the threshold of an AI-dominated era. We'll confront both the immense potential and the daunting risks that AI presents to our civilization.

At the heart of my presentation lies a crucial proposition: the need for a Human-First perspective in our approach to AI. We must grapple with fundamental questions: What defines our humanity? How do we ensure our coexistence with AI enhances rather than diminishes our essential nature? These are not abstract philosophical musings, but vital inquiries that will shape our future. As we venture into this new frontier, let wisdom be our compass, not fear our driver. Our goal should be to harness AI's power to amplify human potential, not replace it. In this AI era, our uniquely human qualities - empathy, creativity, ethical reasoning - will become more crucial than ever. We have the power to create a future where technology serves humanity's highest aspirations. A future where progress is measured not merely in teraflops, but in the flourishing of human spirit and society. The challenges before us are formidable, but so is our capacity to overcome them.

I invite you to join me in this critical exploration. Together, let's chart a course that honors our humanity while embracing the transformative power of AI. In doing so, we align perfectly with our conference's theme, striving for innovation and sustainability in equal measure.

With unwavering determination and hope,

Chaklam Silpasuwanchai, Ph.D.
Assistant Professor
Asian Institute of Technology, Thailand.

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MESSAGE FROM THE GENERAL PRESIDENT SLAAS (EASTERN CHAPTER)

It is a great honour and delight for me to extend my compliments on the occasion of the 4th International Conference on Science and Technology (ICST 2024) of the Faculty of Technology, South Eastern University of Sri Lanka, which is jointly organized by the Sri Lanka Association for the Advancement of Science (SLAAS) – Eastern Chapter, under the theme of "*Exploring Innovative Horizons through Modern Technologies for a Sustainable Future.*"

It is noteworthy that ICST 2024 has ten technical tracks and covers a number of interesting areas of research related to the Conference Theme, which are topical in the present context. I fervently wish that this International Conference will provide an excellent forum to the national and international students, academicians and research scholars to interact and exchange ideas on their latest innovations and findings, and in building productive collaborations for cutting-edge research in their chosen field of work.

I thank very much to Mrs. A. R. Fathima Shafana and members of the organizing committee for their gracious invitation to write up this message for the ICST 2024. I sincerely express my warmest best wishes to the organizing committee of the ICST 2024 and all others who have provided their immense support to make this event a grand success. The painstaking efforts and commitment of all the members of organizing committee in preparation for this Conference is truly appreciated.

Finally, I extend my appreciation to the presenters for enriching the conference with your contributions, and congratulate them for successfully publishing their research findings. I wish sincerely that the ICST 2024 will be a resounding success.

Prof. A. G. Johnpillai
General President
Sri Lanka Association for the Advancement of Science -SLAAS (Eastern Chapter)
Sri Lanka.

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ABSTRACT OF KEYNOTE SPEECH

Perceptions Towards Communication Modes of Multi-Hazard Early Warning in Sri Lanka: Community Perspective

Dilanthi Amaratunga

Global Disaster Resilience Centre, University of Huddersfield, UK

The climate emergency is the biggest ever economic, social and environmental threat facing the planet and humanity. The global and interconnected risk landscape, therefore, requires integrated solutions that address cascading and interrelated risks. A multi-hazard early warning system is such a solution and is a key element of a comprehensive DRR strategy. Early warning messages about impending hazards that could or may cause disasters must reach all citizens, including emergency response organizations, communities at risk, public safety organizations, and others. Information and Communication Technologies (ICTs) are an important and integral component of Multi-Hazard Early Warning Systems (MHEWS), that manage and deliver alerting messages to those in affected areas and wider at the national or international level which allows them to take action to mitigate the impacts of the hazard. MHEWS has the ability to address several hazards and/or impacts of similar or different types in situations where hazardous events may occur alone, simultaneously, cascading or cumulatively over time, and taking into account the potential interrelated effects. To be effective, multi-hazard early warning systems should include the participation of different stakeholders and actively involve the people and communities at risk in order to ensure that the system has an enabling environment which incorporates the appropriate technology, regulatory and legal frameworks, adequate operational capacities, as well as to clearly defined roles and responsibilities for all participating agencies including communities. ICT accessibility is important in developing MHEWS. Vulnerable groups, including persons with disabilities, older adults, people in marginal or remote areas without access or connectivity, women and girls, individuals with low literacy levels, Indigenous people, and migrants, are often in a higher risk during the disaster; thus their needs should be taken into careful consideration when disseminating the alerts through mixed channels. However, there is lack of having effective and efficient communication modes and resistance of the community to adapt to novel technologically based communication modes. In order to identify the community-level perception of the existing communication modes in Sri Lanka, including the current status, gaps and barriers in the existing Technological applications, and thereby develop strategies to bridge the existing gap, a field survey was carried out across several local entities. Over 1400 responses were collected. As per the results obtained under the response analysis, traditional modes of communication were highlighted as the most effective communication mode both at urban and rural levels, amongst several other key findings, which will be the basis of this keynote speech. It further highlighted the need to raise awareness about the importance of risk knowledge, facilitate public education, disseminate messages and warnings efficiently and ensure that there is a constant state of preparedness and that early action is enabled.

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ABSTRACT OF KEYNOTE SPEECH

Will AI Replace Jobs? A Human-First Perspective

Chaklam Silpasuwanchai

Computer Science and Information Management, Asian Institute of Technology, Thailand.

As AI models scale in size and are supplied with increasing volumes of data, they approach levels of intelligence that could surpass human capabilities in various domains, a milestone often referred to as Artificial General Intelligence (AGI). This development could revolutionize industries, driving unprecedented economic growth, enhancing productivity, and accelerating advancements in fields such as healthcare and technology.

However, alongside these potential benefits, the widespread adoption of AI poses substantial risks to the job market, particularly for individuals whose skills involve reasoning, writing, and mathematics. Jobs traditionally considered secure within the middle and upper-middle classes are increasingly vulnerable to automation, as AI systems outperform human workers in cognitive tasks. The presentation highlights that while new job opportunities will emerge, they will primarily favor individuals with exceptional cognitive skills, leading to heightened inequality within professional and knowledge-based fields.

This poses critical societal challenge: the erosion of job security for those with median cognitive skills, resulting in broader social issues such as reduced self-worth and increased mental health concerns. There is a need for a human-centric approach that emphasizes skills AI cannot replicate, such as imagination, deep understanding of human behaviour, and ethical reasoning. Imagination, defined as the ability to conceive novel ideas and solutions, remains a uniquely human trait that AI, despite its creative capabilities, cannot authentically replicate. Similarly, the deep, holistic understanding of other humans—encompassing empathy and nuanced perception—poses a significant challenge for AI, as it involves complexities of the human mind that are not fully understood. Ethical reasoning, which guides human instincts about right and wrong, further highlights the limitations of AI, as it is rooted in values that are difficult to codify. Forward-thinking strategies such as the advocating for targeted investments in education that promote imagination, ethical reasoning, and a deep understanding of human nature are proposed to address these challenges. Additionally, AI literacy has to be enhanced to provide individuals with a comprehensive understanding of the capabilities and limitations of AI. By fostering a balanced approach that values and cultivates distinctly human skills, societies can better navigate the evolving job market and ensure that technological advancements contribute to sustainable growth without compromising social stability or human worth.

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TRACK - AGRICULTURE ECONOMICS & ENTREPRENEURSHIP

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Consumer Expenditure Elasticity and Value of Household Food Waste: A Case Study in Kurunegala District

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Abstract

Household food waste is driven by consumer habits and behaviour, varying with demographic, social, and economic factors. This study aims to determine whether household food waste is a luxury good and identify how demographic and socioeconomic factors affect household food waste. A Quadratic Almost Ideal Demand System (QUAIDS) model was used, augmented with demographic, socioeconomic, and expenditure controls. Data from 195 respondents via an online survey in the Kurunegala district (October 2022) covered food habits and waste. Food categories included rice, cereals, pulses, fruits, vegetables, meat, fish, dairy, eggs, and miscellaneous foods. The value of Household food waste was estimated using a proxy value derived from multiplying waste amounts by monthly grocery expenditures. The demand system estimation showed that all food waste categories were normal goods. Rice, cereals, pulses, fruits, vegetables, and miscellaneous foods were necessity goods, while meat, fish, dairy, and eggs were luxury goods. Expenditure share on household food waste varies with residence area and income level, and most households practice waste management and have positive attitudes toward minimizing waste.

Keywords: Household food waste, Almost ideal demand system, QUAIDS, Expenditure elasticity

I. INTRODUCTION

According to estimates, nearly one-third of the food produced worldwide is wasted. In Sri Lanka and other developing nations, food loss and waste play a crucial role in reducing hunger, raising incomes, and strengthening food security. When crops are produced, harvested, and processed, there is a loss of food, both in terms of quantity and quality. Developing nations are more likely to experience this. Food loss includes food waste, which is the act of discarding edible food at the consumer and retail levels. Food waste is particularly prevalent in industrialized nations, where it accounts for more than 40% of all food losses and waste at the retail and household levels (FAO, 2015).

Household Food waste (FW) means all edible food and beverages grown at home or purchased from outside but discarded at home, because of spoilage or with an expired date. Usually after a meal at home, edible food and beverages are thrown out as FW. Bones, shells, peels, curry leaves like un-edible parts and any food or beverages that are eaten away from home are not included as household FW. That represents a major component of all food waste. Typical household features are more or less likely to influence food waste. One food waste for one household may not be food waste for another household, it depends on a broad range of categories. It varies on a wide range of cultural, social, and economic factors. There is a personal dimension linked to socio-demographic factors, knowledge about food waste, and personal beliefs which are also influenced by cultural context and social norms (Gjerris and Gaiani, 2013).

Quantifying the amount of food waste during each step of the food supply chain significantly reduces food waste. But quantifying the amount of household food waste is QUAIDS-specified, not easy due to the lack of standard methodologies. Therefore, this is a problem with the reduction of household waste. Current consumer FW research concurs with the food categories that are most often wasted at home. Vegetables, fruits, and bread are the top wasted products, even though prevalence among these categories depends much on the household's dietary preferences. Limited information about inedible parts of food discarded at the household level is available. Because most studies focused on avoidable FW (Vargas-Lopez et al., 2022).

Demand estimation describes changes in consumer behavior concerning the price of the

product, consumer income, or any other factors that affect or impact demand. One of the most popular consumer demand measures is the income or expenditure elasticity in classical microeconomic theory. During this study, expenditure elasticity is used to determine whether household FW is a luxury good or not. That means changes in consumer behavior related to the diverse types of food waste of main food categories concerning monthly expenditure on each food category. Our approach contributes to the relevant literature by supplying a first attempt to quantify FW within households in the Kurunegala district. Moreover, by evaluating and studying household FW value and consumer responsiveness, we provide proxy value for FW at the household level. The definition of demand-side perspectives allows us to place FW in the context of elasticities and estimate its total expenditure changes, the value of waste produced, and price changes (Vargas-Lopez et al., 2022).

An almost ideal demand (AIDS) system is used to evaluate demand analysis related to household food waste. The flexible functional form of the property of the AIDS cost function shows that the demand functions are obtained from its first-order approximation to any set of demand functions acquired from utility-maximizing behavior. The set of demand equations is used to obtain values for parameters (Deaton and Muellbauer, 1980). The Quadratic Almost Ideal Demand System (QUAIDS) model is an extended form of the AIDS model, and it is developed by Banks, Blundell, and Lewbel (1997) and the introduction of demographics described in Poi (2012).

According to the AIDS model's Quadratic Almost Ideal Demand System (QUAIDS), expenditure elasticity for each FW of each food category is estimated. Based on the elasticity value of each home food waste of a chosen food category, it is determined whether a household produces luxury food waste. A luxury good is one for which demand grows more than proportionally as income rises in economics. The desire for luxury items is known to be highly income elastic. In other words, consumers will increasingly purchase luxury commodities as their income increases. Due to its extreme sensitivity to economic difficulties, consumer expenditure on luxury items is frequently influenced by the state of the economy. Consumer patterns, however, frequently support the economy as well. Materials and Methods

II. MATERIALS AND METHODS

A. Description of data collection

The primary data for this study were collected through a self-administered online questionnaire conducted in the Kurunegala district. The Kurunegala district was selected due to its well-defined city planning and the clear demarcation of rural, semi-urban, and urban residential areas, which allowed for a comprehensive analysis of income level differences across these regions. The research design adopted a cross-sectional time horizon.

B. Sampling Method

This study employed a random sampling method to select participants from the Kurunegala district. The district's diverse residential areas, including urban, semi-urban, and rural regions, provided a comprehensive representation of varying income levels and household behaviors. Respondents were recruited through social media platforms such as Facebook, LinkedIn, and Twitter, ensuring broad accessibility.

The data collection process was executed through an online survey. The questionnaire, crafted using established scales adapted from previous literature, was initially prepared in English and then translated into Sinhala to ensure accessibility for all respondents. A back-translation process was employed to verify the accuracy of the translation, ensuring that all respondents could understand and accurately complete the survey. To ensure the reliability and validity of the questionnaire, it underwent a pre-testing phase. Feedback from this phase was utilized to refine the questionnaire, enhancing its clarity and understandability. The final sample consisted of 195 respondents, who provided detailed information on their household's socio-demographic characteristics, food expenditure, food-wasting behavior, and waste management practices.

Data collection occurred in October 2022, with respondents from the Kurunegala district recruited via social networks such as Facebook, LinkedIn, and Twitter. The questionnaire comprised four main sections: 1. Household Socio-Demographic Information, 2. Food Expenditure Information, 3.

Food-Wasting Behavior, and 4. Waste Management Practices and Attitudes. The final section delved into the waste management practices adopted by households and their attitudes towards reducing food waste.

Respondents were instructed to provide answers reflecting their household's behavior and practices. The questionnaire targeted ten specific food categories:

- Rice
- Other cereals
- Pulses
- Fruits
- Vegetables
- Meat (beef, chicken, and pork products)
- Fish and shellfish
- Dairy products (milk, yogurt, etc.)
- Eggs
- Miscellaneous food

Prices for each food category were obtained from the different markets located in respondents' areas. Respondents were asked to report their monthly expenditure on each food category and the corresponding percentage of food waste. This comprehensive data collection approach enabled a detailed analysis of household food waste patterns and behaviors.

C. Method of Data Analysis

1) Model Specification

In their influential work, Deaton and Muellbauer developed the Almost-Ideal Demand System (AIDS) to analyze consumer spending patterns. Banks et al. later refined this model by incorporating a quadratic term in log expenditure, addressing the limitations of the original log-linear specification, which did not fully capture consumer behavior for certain goods. This enhanced model is referred to as the Quadratic Almost-Ideal Demand System (QUAIDS). Banks et al. demonstrated that AIDS is a special case of QUAIDS, with the quadratic specification offering a more general and flexible framework.

For our analysis of food waste, we consider both the AIDS model by Deaton and Muellbauer and the QUAIDS model by Banks et al. However, the results presented in the following sections focus exclusively on the QUAIDS specification. The demand function, as originally defined by Deaton and Muellbauer, takes the following form:

$$\omega_i = \alpha_i + \sum_j^k \gamma_{ij} \log p_j + \beta_i \log\left(\frac{m}{a(p)}\right)$$

Where α_i γ_{ij} and β_i are vectors of parameters, w_i is the expenditure share for good i, m is the total expenditure, the price index a(p) is defined as:

$$\log a(p) = a_0 + \Sigma_k a_k \log_{p_k} + \frac{1}{2}\Sigma_j \Sigma_k \gamma_{k_j} \log_{p_k} \log p_j$$

Alternatively, the quadratic model proposed by Banks et al. [31] describes the indirect utility function as follows:

$$\ln V(p,m) = \left[\left\{\frac{\ln m - \ln a(p)}{b(p)}\right\}^{-1} + \lambda(p)\right]^{-1}$$

Where ln a(p) denotes the transcendental logarithm function:

$$\ln a(p) = \alpha_0 + \sum_{i=1}^{k} \alpha_i \ln p_i + \left(\frac{1}{2}\right)\sum_{i=1}^{k}\sum_{j=1}^{k} \gamma_{ij} \ln p_i \ln p_k$$

Where p_i represents the price of good i for i=1… k. Additionally, in the indirect utility function, b(p) serves as the Cobb-Douglas price aggregator:

$$\mathrm{b(p)} = \prod_{i=1}^{k} p_i^{\beta^i}$$

and

$$\lambda(\mathrm{p}) = \sum_{i=1}^{k} \lambda_i \ln p_i$$

To adhere to economic theory, it is required to impose or test the conditions of aggregation, homogeneity, and symmetry, which leads to the following implications:

$$\sum_{i=1}^{k} \alpha i = 1 \qquad \sum_{i=1}^{k} \beta i = 1 \qquad \sum_{i=1}^{k} \gamma ij = 0$$
$$0 \qquad \gamma ij = \gamma$$

2) Elasticity

Since the estimated parameters themselves are not the main focus of our analysis, they are not

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presented in the subsequent sections. Instead, we concentrate on discussing the estimated expenditure and uncompensated price elasticities, which provide the economic insights we aim to explore. The expenditure elasticities are calculated using the following equations:

$$\mu_i = 1 + \frac{1}{\omega_i}\left[\beta_i + \eta_i' z + \left(\frac{2\lambda_i}{b(p)c(p,z)}\right)\ln\frac{m}{m_0(z)a(p)}\right]$$

3) Interpretation and Insights

By analyzing the estimated elasticity values, we can derive insights into household food waste patterns:

Expenditure Elasticity**:** Indicates whether a good is considered a necessity (Ei<1) or a luxury (Ei>1). This helps in understanding how changes in total expenditure influence the demand for different goods, thereby shedding light on the economic behaviour underlying food consumption and waste patterns. This analysis contributes to economic theory and promotes sustainable consumption practices.

III. RESULTS

A. Descriptive results

The demographic distribution of the respondents shows that the majority, 39% (n=76), reside in urban areas. A further 37.4% (n=73) live in rural areas, and 23.6% (n=46) are from semi-urban areas. Among the surveyed households, 84.6% (n=165) of the household heads are aged between 56 and 70 years, indicating a significant representation of older individuals in leadership positions within these households. This demographic factor likely influences household decision-making processes. The survey also revealed that households with four members are the most common, constituting 41.1% (n=80) of the sample. Households with five members represent 21.0%, reflecting diversity in household sizes within the region (Table 01).

Table 01: Demographic characteristics

Demographic characters	Value (%)	Std. Err.	Obs.
Age of HH head (% of respondents)			
Below 20 years	2.1	0.01	04
25-40 years	21.0	0.29	41
41-55 years	31.3	0.03	61
56-70 years	43.1	0.03	84
Above 71 years	2.5	0.01	05
Household head Male (% of respondents)	84.6	0.02	165
Household size (% of respondents)			
1	2.1	0.01	04
2	10.3	0.02	20
3	13.3	0.02	26
4	41.1	0.03	80
5	21	0.02	41
6	8.2	0.01	16
7	1.5	0.00	03
8	1.5	0.00	03
9	1.0	0.00	02
Residence area (% of respondents)			
Rural	37.4	0.03	73
Semi-urban	23.6	0.03	46
Urban	39.0	0.03	76

Participants were asked about their monthly expenditure on groceries, which averaged 43,305.62 LKR per household (SD = 20937.51). In terms of food waste, the average monthly expenditure was 2,604.40 LKR per household (SD = 2,054.05). This indicates considerable variability in household spending on both groceries and food waste (Table 02). Monthly household incomes were categorized into three groups: low income (≤35,000 LKR), middle income (35,000 LKR - 100,000 LKR), and high income (>100,000 LKR). Analysis revealed that 39% of respondents are in the high-income category, indicating a significant presence of economically affluent individuals. Additionally, 38% belong to middle-income households, suggesting a substantial middle-class presence, while 23% are categorized as low-income, highlighting economic challenges faced by a portion of the population. Examining the food purchasing habits, the highest food waste expenditure was reported by individuals who purchase raw food daily. Following this, those who buy raw food 3-5 days per week also exhibited high food waste expenditure. Households purchasing raw food monthly had lower food waste expenditure, with the lowest observed among those who buy raw food monthly. Food safety practices were also assessed. Among the 195 respondents, 93% consistently check the expiration dates when purchasing food, 5% do so sometimes, and 2% do not consider expiration dates at all. Furthermore, 83.59% (n=163) of respondents regularly freeze fruits and vegetables to minimize waste, while 16.41% (n=32) do not engage in this practice.

The impact of COVID-19 and the economic crisis on food waste behaviors was also examined. None of the respondents reported an increase in household food waste due to these conditions.

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Conversely, 63.59% (n=124) indicated a reduction in food waste during this period, while 36.41% (n=71) reported no change in their household food waste practices. These findings provide valuable insights into the demographic and economic factors influencing household food waste and the practices employed to manage and reduce waste within the study population.

B. QUAIDS Estimation Findings

Rice emerges as the dominant category with the highest expenditure share among all households. Vegetables also exhibit a substantial expenditure share across all household food waste (FW) categories. In low-income households, higher expenditure shares are observed for rice, other cereals, pulses, fruits, and miscellaneous FW, with lower shares for meat, fish, eggs, and dairy products compared to high-income households. Conversely, high-income households show elevated expenditure shares for meat, fish, eggs, and dairy products, alongside lower shares for rice, cereals, pulses, fruits, and miscellaneous FW.

Urban households exhibit higher expenditure shares for vegetables, meat, fish, eggs, and dairy products, while displaying lower shares for rice, cereals, pulses, fruits, and miscellaneous FW. In contrast, rural households have elevated expenditure shares for rice, cereals, pulses, fruits, and miscellaneous FW, with lower shares for vegetables, meat, fish, eggs, and dairy products. The following table summarizes the QUAIDS estimation results along with their significance levels:

Semi-urban households show the highest expenditure shares on rice waste and miscellaneous FW (Table 03).

Table 03: Expenditure shares on household food waste

Food category	Elasticity	Standard error	Significance level
Rice	0.942	0.061	***
Other cereals	0.928	0.104	**
Pulses	0.805	0.156	*
Fruits	0.712	0.082	**
Vegetables	1.001	0.069	***
Meat	1.658	0.082	***
Fish	1.312	0.116	**
Dairy products	1.297	0.125	**
Eggs	1.273	0.143	**
Miscellaneous foods	0.870	0.104	*

Elasticity values of Food Waste

The QUAIDS model was used to estimate expenditure elasticities for various household food waste categories. The results indicate that rice, cereals, pulses, fruits, and miscellaneous foods are considered necessities, with expenditure elasticity values below 1. Conversely, vegetables, meat, fish, dairy products, and eggs were classified as luxury goods, with elasticity values exceeding 1.

Table 02: Average monthly expenditure on food and FW at the household level

Expenditure share on FW	All households	Low-income	Middle-income	High-income	Rural	Semi-urban	Urban
Rice	0.250	0.257	0.227	0.210	0.258	0.260	0.237
Other kinds of cereals	0.059	0.075	0.065	0.047	0.083	0.064	0.031
Pulses	0.048	0.043	0.054	0.039	0.062	0.058	0.026
Fruits	0.153	0.229	0.164	0.130	0.198	0.178	0.095
Vegetables	0.198	0.153	0.175	0.238	0.148	0.187	0.253
Meat	0.090	0.034	0.068	0.129	0.048	0.059	0.150
Fish	0.044	0.016	0.037	0.057	0.044	0.030	0.052
Dairy products	0.023	0.004	0.019	0.031	0.018	0.016	0.032
Eggs	0.190	0.017	0.020	0.018	0.016	0/010	0.027
Miscellaneous food	0.114	0.170	0.120	0.099	0.122	0.133	0.095

***p < 0.01; **p < 0.05; *p < 0.1

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Table 04: Expenditure elasticity of household FW categories

FW categories	All households	Low-income	Middle-income	High-income	Rural	Semi-urban	Urban
Rice	0.942 (0.061)	1.070 (0.054)	0.958 (0.058)	0.825 (0.099)	1.008 (0.052)	1.006 (0.052)	0.831 (0.096)
Other cereal	0.928 (0.104)	1.197 (0.082)	0.985 (0.097)	0.607 (0.185)	1.075 (0.064)	1.075 (0.084)	0.371 (0.288)
Pulses	0.805 (0.156)	1.055 (0.123)	0.792 (0.148)	0.601 (0.267)	0.935 (0.104)	0.933 (0.112)	0.342 (0.413)
Fruits	0.712 (0.082)	0.564 (0.066)	0.662 (0.080)	0.892 (0.138)	0.653 (0.056)	0.641 (0.062)	0.903 (0.196)
Vegetables	1.001 (0.069)	1.057 (0.098)	1.032 (0.069)	0.975 (0.083)	1.055 (0.082)	1.029 (0.06)	0.975 (0.081)
Meat	1.658 (0.082)	2.468 (0.242)	1.645 (0.081)	1.555 (0.082)	2.085 (0.135)	1.876 (0.109)	1.473 (0.072)
Fish	1.312 (0.116)	1.479 (0.212)	1.339 (0.117)	1.250 (0.126)	1.292 (0.102)	1.425 (0.147)	1.286 (0.145)
Dairy products	1.297 (0.125)	1.442 (0.204)	1.310 (0.137)	1.249 (0.134)	1.348 (0.140)	1.404 (0.156)	1.237 (0.134)
Eggs	1.273 (0.143)	1.097 (0.224)	1.242 (0.110)	1.377 (0.212)	1.243 (0.152)	1.348 (0.236)	1.270 (0.147)
Miscellaneous	0.870 (0.104)	0.810 (0.094)	0.867 (0.095)	0.919 (0.173)	0.844 (0.086)	0.853 (0.079)	0.914 (0.186)

These findings suggest that households in the Kurunegala District tend to classify staple foods like rice and pulses as necessities, while luxury food items like meat and dairy products see higher food waste levels as income increases.

IV. DISCUSSION

Throughout this study, household food waste (FW) was estimated using a proxy value derived from multiplying waste amounts by monthly grocery expenditures. This approach introduced a total expenditure "proxy" in the QUAIDS model at the household level, providing a focused method for identifying meals that significantly contribute to the overall economic value of food waste.

Expenditure Share Analysis

The expenditure share analysis revealed that rice waste constituted the highest among household food waste categories across all households. This is particularly noteworthy in a sample where 98% of respondents were Sinhalese, as rice is a staple food in Sri Lankan households. Additionally, lower expenditure shares were identified for other cereals, pulses, meat, and fish, which might be influenced by elevated prices during an economic crisis, leading to reduced consumption of these categories. High-income households demonstrated higher expenditure shares on meat, fish, eggs, dairy products, and vegetables. This trend can be attributed to inflationary effects on food prices, causing lower spending by low-income households in these categories.

Residential Area-Based Analysis

The analysis based on residential areas revealed higher expenditure shares for rice, cereals, pulses, fruits, and miscellaneous food in rural areas. This reflects the agrarian nature of the Kurunegala district, a major rice-producing region. In contrast, urban households exhibited higher expenditure shares for vegetables, meat, fish, eggs, and dairy products, indicating different consumption patterns influenced by urban living conditions.

Expenditure Elasticity values

Expenditure elasticity values were calculated using the QUAIDS model, revealing positive values for all food categories and confirming them as normal goods. By distinguishing between necessity and luxury goods based on elasticity values, the study identified rice, cereals, pulses, fruits, and miscellaneous foods as necessities. Conversely, vegetable, meat, fish, dairy products, and egg waste were classified as luxury goods. Fruit waste, despite being perishable, was considered a necessity due to lower consumption levels in Sri Lanka. The study highlighted the perishability and cultural factors contributing to vegetable, meat, fish, dairy products, and egg waste being categorized as luxury goods. Rural

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areas exhibited higher wastage for all food categories except fruits and miscellaneous food, possibly due to factors such as limited space for disposal in urban areas and different separation habits in rural households. Urban households and those in high-income defiles allocated a higher percentage of their food budget to fruits, emphasizing higher expenditure elasticity for fruits in urban areas. Additionally, low-income households exhibited higher expenditure elasticity values for most categories except for fruit, dairy, eggs, and miscellaneous food, indicating higher consumption by wealthier individuals.

Food Waste Behavior

The study also considered food waste behavior, revealing that attitudes such as cooking skills and consciousness of expiration dates significantly influenced waste reduction. Moreover, responses indicated a reduction in household food waste during the COVID-19 period and the prevailing economic crisis. This finding aligns with similar observations in Mexico during the pandemic, underscoring the importance of individual and household-level factors in minimizing food waste during challenging economic conditions. These findings suggest a notable trend toward decreased household food waste among the surveyed population amidst the adversity of the COVID-19 pandemic and economic instability. This emphasizes the critical role of economic and cultural factors in shaping food waste patterns and highlights the potential for targeted interventions to reduce waste across different income levels and residential areas.

V. CONCLUSION

According to our findings, all categories of household food waste (FW) were classified as normal goods, as evidenced by positive elasticity values. Specifically, waste of rice, other cereals, pulses, fruits, and miscellaneous food items were identified as necessity goods, while waste of meat, fish, dairy products, eggs, and vegetables fell under luxury goods. The expenditure elasticity values of food waste varied across household income levels and residential areas. Notably, all FW categories exhibited higher expenditure elasticity values in rural areas, except for fruits. Low-income households generally showed higher expenditure elasticity values compared to other income groups, with exceptions noted for fruit, dairy products, and eggs. The study suggests that management practices, attitudes, and behaviors towards reducing household FW can be discerned from these observations.

VI. LIMITATIONS OF THE STUDY AND SUGGESTIONS FOR FUTURE RESEARCH

The primary limitation of this study was the absence of directly collected food waste data. Instead, household food waste (FW) was estimated using a proxy value derived from multiplying waste amounts by monthly grocery expenditures. While maintaining food diaries would have provided more precise results, time constraints rendered this approach impractical. The study relied on an online survey, thus analyzing self-reported data. Such methods introduce potential measurement errors due to respondents providing inaccurate information or opting out of participation. Data collection occurred exclusively in October 2022, which may limit the generalizability of findings since household FW can fluctuate seasonally, such as during holidays like Christmas or New Year, impacting waste patterns. Furthermore, the rapidly changing economic conditions posed challenges in maintaining consistent food prices throughout the study period.

Future research should consider integrating food diaries with online surveys to enhance data accuracy and account for seasonal variations in household FW. Additionally, investigations should explore how expenditure on food, price dynamics, and demographic factors influence variations in FW at the household level.

VII. IMPLICATION

Based on the analysis results, household food waste (FW) categories were classified as luxury goods and necessity goods solely based on expenditure elasticity values, without considering price elasticity values. Future research endeavors should focus on determining price elasticity values within the household food category.

This study was conducted exclusively in one district of Sri Lanka, suggesting a need for broader geographical representation across all districts for comprehensive insights. The findings are crucial for identifying which goods are considered luxury or necessity in Sri Lankan households, pivotal for developing effective strategies to minimize FW at the household level.

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Understanding the dynamics of different FW categories across various income levels and expenditure patterns is essential for addressing household food waste effectively. Such insights are invaluable for policymakers and decision-makers seeking to implement targeted measures for FW reduction, particularly in the context of ongoing economic challenges.

Ultimately, this study provides vital information to ensure continuous fulfillment of food requirements amidst the current economic crisis, underscoring its relevance and potential impact on policy formulation and decision-making.

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Engagement in an Entrepreneurial School Garden Project: Impact of Gardening on Students' Environmental Attitudes

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Abstract

This study explores the impact of the "Entrepreneurial School Garden Program" on students' environmental attitudes, using a mixed-methods research approach. This program integrates practical gardening activities with the school's co-curriculum to enhance knowledge and skills in food and nutrition, agriculture, and entrepreneurship. Quantitative data were collected through a survey on a sample of 214 students in the Jaffna district, where 22 schools had completed the program. Qualitative data were gathered through interviews with 5 groups of teachers, observations, and document analysis. The results revealed significant improvement in environmental attitudes (M=4.0494, SD= 0.7538). Students perceived improvements in their environmental awareness (M=3.9745), positive attitudes toward environmental sustainability (M=3.9185), and adaptability to environmental changes (M=4.195). The frequency of engagement in gardening activities influenced students' attitudes, while female students exhibited greater improvements than male students. Qualitative data analysis revealed improvements in a sense of responsibility and achievement, enhanced social skills and teamwork, and increased environmental awareness and stewardship. The frequency and duration of engagement have an influence on motivation. Students are perceived to be more responsible and capable of dealing with environment-related problems through their improved problem-solving skills, goal-setting abilities, and self-awareness. They developed better communication skills, empathy, and teamwork to adapt themselves to the environment. The engagement in gardening resulted in an improved consciousness of sustainability and commitment to environmental stewardship.

Keywords: Environmental well-being, Entrepreneurial school garden program, Behavioural attitudes, Food security, Experiential learning

I. INTRODUCTION

In recent years, there has been a growing interest among the curriculum designers and educational researchers on the effectiveness of extracurricular activities for developing social and emotional competencies in school students. Thus, attention is focused on the role of school-based gardening programs as a means of enhancing students' educational experiences and personal development. These programs are increasingly recognized by educators for their potential to foster a range of positive outcomes, including improved academic performance, greater environmental awareness, and enhanced social and emotional well-being (Childs, 2011). The schools in Jaffna district, with their unique cultural and environmental contexts, provide an intriguing setting to explore these potential benefits.

Since January 2023, the Food and Agriculture Organization of the United Nations (FAO), Australian Aid, Sri Lanka (Common Wealth Union) have supported entrepreneurial school gardens for students in over 200 schools spread across three provinces in Sri Lanka: Uva, Central, and North, in honor of the International Day of Education. The goal of the project is to assist awareness of school-based nutritional health and food security during the post COVID-19 and economic crisis led malnutrition and food insecurity crisis that Sri Lanka was experiencing. As part of the program, to develop skills in food security, nutrition, agriculture, and entrepreneurship, 505 school teachers from the three provinces were selected and provided training in the discovery-based teaching and learning techniques in agriculture. In addition, an awareness program was organized for students through practical activities in the selected schools for three weeks.

Then, the Entrepreneurial School Garden Program was implemented for one year in selected schools, integrating practical gardening activities into the educational curriculum. It was implemented to

enhance the knowledge, and skills among students on basic concepts of food nutrition, agriculture and entrepreneurship to improve their resilience to the food shortage that have emerged with economic crisis in Sri Lanka, while motivating students to have interest in agricultural entrepreneurship**.** This initiative is further intended to teach students about agriculture and sustainability and to encourage the development of positive environmental attitudes. By engaging directly with nature, students can learn the values and various skills of taking responsibility, problem solving , goal setting, stress management, critical thinking, spirituality, relationship building, team work, empathy, and positive attitude toward the environment.

This study investigates how participation in the Entrepreneurial School Garden Program has influenced the development of the environmental attitudes of students who participated in the programme. Specifically, it investigated the changes perceived in the environmental wellbeing of the students by examining the three dimensions identified through though the literature **(**Milfont, & Duckitt. 2010): environmental awareness, positive attitudes toward sustainability, and adaptability to environmental changes. The research is grounded in the belief that hands-on, experiential learning opportunities can significantly impact attitudinal growth and development of interpersonal skills of the students.

II. BACKGROUND OF THE STUDY

The role of co-curricular activities in developing positive attitudes in students has been a major area of focuss in several research studies (Waliczek, Bradley, & Zajicek, 2001). School gardening is one of the co-curricular activities which develops students' knowledge, skills and attitudes (Waliczek, & Zajicek, 1999) In recent years, innovative searches in education are increasing on a daily basis. Especially with the emergence of the Covid-19 pandemic, it became evident that a change in the direction and form of education is a must.

Despite the recognized benefits of school-based gardening programs. there remains a gap in understanding how these initiatives specifically impact the environmental attitudes of school students, particularly in diverse cultural and environmental contexts (Dilip, Thomas, & Malik, 2020). In the Jaffna district of Sri Lanka, where economic challenges and post-COVID-19 recovery efforts have heightened concerns about food security and nutritional health, the introduction of the Entrepreneurial School Garden Program presents a unique context to explore the impacts of the engagement in school gardening on students' attitudes.

While previous research has highlighted the potential of school gardening to improve academic performance and social and emotional well-being, there is limited empirical evidence on how such programs influence environmental attitudes in a comprehensive manner. Moreover, the specific context of the Jaffna district, with its unique socio-economic challenges, adds another layer of complexity that has not been thoroughly examined.

Therefore, this study seeks to investigate the participation of students in the Entrepreneurial School Garden Program and its impact on the environmental attitudes of students. It attempts to answer the overarching question: How does involvement in gardening activities of students enhance environmental awareness, positive attitudes toward environmental sustainability, and adaptability to environmental changes?

The study attempts to describe the behavioral impacts of school gardening programs, and offer valuable insights for educators, policymakers, and education leaders. This will help in making informed decisions regarding the implementation and expansion of such initiatives in future to maximize the benefits for holistic development of students, especially in regions facing economic and nutritional challenges.

The Objectives of the Study

1. To identify the impacts of school garden on students' attitudes in terms of their environmental well-being.
2. To identify the factors contribute to the attitude development through school gardening engagement of school.
3. To examine the significant differences in attitudinal development through engaging in school garden among different socio-demographic characteristics of students.

III. LITERATURE REVIEW

The relationship between school gardening programs and students' environmental attitudes has been extensively studied, reflecting the growing emphasis on experiential learning in

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education. School gardens serve as practical platforms where students can connect with nature, learn about environmental sustainability, and develop a sense of responsibility towards the environment.

Research studies have consistently shown that participation in school gardening activities positively influences students' environmental attitudes. According to Skelly and Bradley (2007), gardening programs can significantly enhance students' awareness and appreciation of environmental issues. Similarly, studies by Dirks and Orvis (2005) have demonstrated that hands-on gardening experiences lead to improved environmental knowledge and a stronger commitment to sustainability. Previous research also suggests that female students often exhibit greater environmental concern and engagement compared to their male counterparts. This is supported by Li et al., (2022) who found that females are generally more inclined towards environmental protection and sustainability.

Beyond environmental attitudes, school gardening has been linked to the development of social skills, teamwork, and a sense of achievement. Klemmer, Waliczek, and Zajicek (2005) highlighted that gardening activities foster collaboration among students and improve their communication skills, empathy, and ability to work in teams. These findings align with the current study's results, where students reported enhanced social skills and teamwork through gardening.

The integration of gardening into the school curriculum, particularly in subjects like food and nutrition, agriculture, and entrepreneurship, has been shown to enhance students' motivation and engagement. A study by Blair (2009) found that students who participate in garden-based learning are more motivated and perform better academically. The connection between frequency of engagement and improved environmental attitudes observed in this study echoes this, emphasizing the importance of sustained involvement in such programs. This body of literature underscores the multifaceted benefits of school garden programs, supporting the idea that they not only foster environmental stewardship but also contribute to the holistic development of students.

IV. RESEARCH METHODOLOGY

This study employs a mixed-methods research design, integrating both quantitative and qualitative approaches to describe the impact of the Entrepreneurial School Garden Program on behavioral attitudes of students. This design allows for a robust analysis by combining numerical data with detailed personal insights, thus providing a holistic understanding of the program's effects**.**

The study was conducted in the Jaffna district where eleven schools had completed Entrepreneurial School Garden Program successfully from 2022 to 2023 after the pandemic of Covid-19. Five schools were purposively selected for this study considering the gender, number of students who participated from the schools and number of presently available teachers who participated in the Entrepreneurial School Garden Program. A questionnaire survey approach was used for collecting the quantitative primary data from 214 grade nine students. A purposive sampling approach was employed to ensure a representative sample across different socio-economic backgrounds and school types.

The review of the literature revealed few instruments for measuring student attitudes from the impact of a school garden on students' attitudes. After through contemplation a self – prepared and validated questionnaire was administered to students after the implementation of the programme, at its completion. These surveys measured the perceived changes in three areas of environmental well-being..

In-depth interviews were conducted with a subset of 10 students, and 5 teachers. These interviews provided qualitative data on experiences and perceptions of the Entrepreneurial School Garden Program. Group discussions were held with five groups of parents having 5 members in each group .Observational data was collected during gardening activities and related classroom sessions. Student Journals and Project Reports, Analysis of students' written reflections and project reports offered additional insights into their learning experiences and attitudinal changes

Quantitative data Analysis was conducted using the techniques of descriptive statistics: Basic statistical measures were employed to summarize the survey data. Qualitative thematic technique was used to analyze interview and focus group

transcripts, along with observational and document data. This helped in identifying common themes and patterns in the perceptions.

V. FINDINGS OF THE STUDY

The study found that engagement in school gardening significantly improved their overall environmental attitudes, with a mean score of (M=4.0494, SD= 0.7538**).** Additionally, the number of days students engaged in school gardening had a positive impact on improving their attitudes (β=0.082). The most significant improvement was observed in environmental well-being. Students developed greater environmental awareness, positive attitudes towards the environment, and adaptability to environmental changes.

The study revealed significant differences in attitudinal development based on gender. Female students had a greater improvement in attitudes (M=4.0396, SD=0.63558) compared to male students (M=3.8523, SD=0.68411), with a notable improvement difference (0.1872). This suggests that female students were more positively influenced by participation in school gardening activities. Parent's occupation, family income, and religion of the participant were not found to have significant differences.

Several factors were identified as contributing to the development of attitudes through engagement in school garden programm The frequency of engagement in school gardening activities was a critical factor. Increased days of participation were positively correlated with improvements in attitudes. This highlights the importance of consistent involvement in gardening activities to foster attitudinal growth.

Students with more experience in gardening activities showed greater improvements in their attitudes. This aligns with previous findings by Williams, & Dixon, (2013), which indicated that increased experience in gardening enhances knowledge, attitudes, and overall experience.

As mentioned, female students exhibited more significant attitudinal improvements compared to male students.

Although the overall time spent on gardening activities in schools was limited, with 47.6% of students spending 30 minutes and 24.1% spending one hour, the consistent engagement played a crucial role in attitude development. Long-term involvement in school gardening activities positively impact on active engagement, both at school and at home. The sustained interest and participation were key to the positive attitudinal changes observed.

The Entrepreneurial School Garden Program significantly enhances environmental well-being. The findings underscore the value of regular, hands-on gardening activities in fostering positive behavioral attitudes and highlight the importance of considering demographic factors such as gender in program implementation.

Through the qualitative analysis of interviews, discussions, observations, and document studies, several key themes emerged, providing a nuanced understanding of how engagement in school gardening influenced attitudes**.**

Sense of Responsibility and Achievement: Students developed a strong sense of responsibility and achievement. Interviews revealed that students felt proud and accomplished when they successfully nurtured plants. Teachers noted increased self-esteem and a proactive attitude in students, particularly when they solved gardening-related challenges. Students' journals frequently mentioned their sense of responsibility and pride in their gardening achievements.

Gardening activities significantly enhanced social skills and teamwork which indirectly improve the environmental attitudes. Discussions indicated that students learned to collaborate and appreciate mutual contributions . There was a visible improvement in teamwork and empathy among students. They were observed supporting each other during gardening tasks. Project reports highlighted collaborative efforts and the development of strong peer relationships.

Participation in gardening fostered a deep sense of environmental awareness and stewardship. Interviews showed that students became more environmentally conscious. Students took the initiative in promoting sustainable practices, such as recycling and composting, in the school garden. Reflective essays indicated a significant increase in understanding of environmental issues and their commitment to sustainability.

Female students exhibited greater engagement and attitudinal improvements compared to male students. Interviews with female students highlighted their sense of empowerment and confidence gained through gardening. Female students were more engaged and took on leadership roles in gardening activities.

Regular and frequent engagement in gardening activities was crucial for attitudinal development. Teachers and students emphasized the importance of consistent participation. Frequent participants demonstrated greater improvements in responsibility and teamwork. Journals and project reports supported the idea that regular engagement was key to positive attitudinal changes.

Long-term involvement in gardening activities sustained interest and motivation. Interviews revealed that many students continued gardening at home, showing sustained interest. Students remained motivated and enthusiastic about gardening activities throughout the program. Reflective essays and journals showed ongoing commitment and enthusiasm for gardening beyond the school environment.

The integration of regular, hands-on gardening activities fosters positive behavioral attitudes, emphasizing the importance of frequency, experience, and gender considerations in program implementation. These insights provide valuable guidance for educators, policymakers, and community leaders in expanding and refining school gardening initiatives. Being engaged in school gardening helps students to improve their behavioural attitudes positively in the three identified dimensions: personal wellbeing, social wellbeing and environmental wellbeing.

VI. IMPLICATIONS AND RECOMMENDATIONS

The findings of this study have important implications for educators, policymakers, and community leaders. The positive impacts of the Entrepreneurial School Garden Program on behavioral attitudes highlight the value of integrating experiential learning opportunities into the educational curriculum. School gardening programs can serve as a powerful tool for holistic development, addressing not only academic needs but also fostering personal growth, social skills, and environmental consciousness. To maximize the benefits of such programs, the study recommends increasing the frequency of engagement, tailoring programs for inclusivity, sustaining long-term involvement, and integrating environmental education into the curriculum.

In conclusion, the Entrepreneurial School Garden Program has demonstrated significant positive impacts on environmental well-being. By providing hands-on, experiential learning opportunities, the program has cultivated a range of positive behavioral attitudes, equipping students with essential life skills and fostering a sense of responsibility towards themselves, their peers, and the environment. These findings underscore the importance of school gardening programs as a valuable component of holistic education, offering insights that can guide the implementation and enhancement of similar initiatives in diverse educational contexts.

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A Study of the Existing Knowledge and Practice of Small and Medium-scale Agricultural Entrepreneurs on the Export Market

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Abstract

As a developing country, it is important for Sri Lanka to consider the export sector in achieving the desired economic goals and still, Sri Lanka is a country that has prioritized the export of agricultural products. Entrepreneurship plays the most important role in achieving the economic development of a country, and considering Sri Lanka, small and medium-scale agricultural entrepreneurship makes a remarkable contribution to it. When considering the export sector, the contribution of small and medium-scale agricultural enterprises is at a very low level. Therefore, this research aimed to gain an understanding of the knowledge and practices of small and medium-scale agricultural enterprises about the export market and to assist in the development of the export market accordingly. Out of 1,376 small and medium-scale entrepreneurs registered in the Galgamuwa and Giribawa Divisional Secretariats of the Kurunegala District, 250 were selected as a sample using a simple random method. A principal component analysis was conducted to identify the main factors affecting it, in which the factors of literacy, financial ability, management ability, government policies and marketing capability were identified as internal factors that have a high impact on the export market and existing knowledge regarding the export market, and utilization of knowledge of the export market were identified as external factors. Accordingly, proper policies and practical programs are necessary to empower small and medium-scale agricultural enterprises. Further, entrepreneurs can be encouraged to remove the obstacles to access the export market and achieve the desired economic development goals for Sri Lanka.

Keywords: Small-scale business, Medium-scale business, Export market, Agriculture, Entrepreneurs

I. INTRODUCTION

The contribution of the export sector to the economy of a country is very special by dint of globally, every country is trying to increase its export revenue. For this, there is a strong competition between powerful states. Especially China, USA, Germany, Japan and South Korea are leading countries in the export sector respectively (world market figures, 2019).

Although this is the world market situation, Sri Lanka has earned 15.0 billion in export revenue in 2023 (Sri Lanka Central Bank report, 2023) and it ranks 86th in the world's export revenue ranking. When looking at Sri Lanka with domestic and global development, low growth in the export sector continues to be seen. Due to this, an exchange deficit has been created in the country for almost a decade.

In finding solutions for this, there are very few studies on the contribution of small and medium agricultural entrepreneurs to the export market and the knowledge and practice they have about the export market. Accordingly, it is important to study this as a matter that needs special attention. According to Mayneris & Poncet (2015), the nature of the knowledge of the business community regarding the demand in the foreign market related to their business affects the export process. Also, it has been confirmed in the investigations that the awareness and trust in the business community regarding the availability of related institutions and their services in the export process has an impact on the nature of knowledge for the export process (Filatotchev & et al, 2009). This study aims to identify the obstacles that prevent businesses from entering the export market and to highlight how addressing these challenges can contribute to uplifting Sri Lanka's economy. By examining the interest and attitudes of the current youth and business communities towards the export market, the study seeks to foster a greater inclination toward exporting. Furthermore, it explores the new market opportunities highlighted by the Export

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Development Board, particularly those beyond Sri Lanka's traditional export products. The study also assesses the level of awareness, knowledge, and attitudes within the local business community regarding the procedures for becoming an exporter, as well as the challenges they face in utilizing these opportunities (Sri Lanka Export Development Board Annual Report, 2019).
Accordingly, the primary objective of this study is to gain an understanding of the existing knowledge and practices of the small and medium scale agricultural entrepreneurs about the export market.

II. METHODOLOGY

The main target of this research is to study the gain an understanding of the existing knowledge and practices of the small and medium scale agricultural entrepreneurs about the export market. When studying the contribution of them in the export market, considering the expansion of the small and medium scale agricultural entrepreneurs in Sri Lanka, the expansion of the small and medium scale agricultural entrepreneurs can be commonly identified in the districts of Colombo, Gampaha and the Kurunegala district of the North-West Province, with the Western Province leading. Thus, in the selection of the sample used in the study, small and medium scale agricultural entrepreneurs registered in the Galgamuwa and Giribawa Divisional Secretariat Divisions of Kurunegala District was used. 250 entrepreneurs were selected for this purpose from the registered small and medium scale business in Giribawa and Galgamuwa areas using simple random sampling method.

Both the primary and secondary data methods were used to collect data. Under these two methods, both quantitative and qualitative data were classified and in order to obtain data relevant to the two methods, primary and secondary technical methods inherent to that were used for the collection of data. o obtain primary data, questionnaire was used, and using it a principal component analysis (PCA) was conducted to identify the factors affecting the knowledge and practice of SMEs in export markets.

III. RESULTS AND DISCUSSION

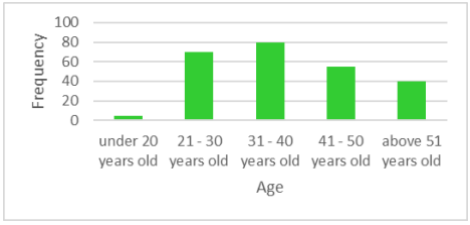

Figure 01: Responders Age level

Most of the respondents in the sample are people in the age group of 31-40 years. That is, when this group is expressed as a percentage of the entire sample, it is about 32%. Secondly, when classified according to the age structure of small and medium scale entrepreneurs, most people belong to the age group of 21-30 years. They are 28% when taken as an overall fixed percentage. In the sample, there are only five small entrepreneurs under 20 years of age, which is 2%.

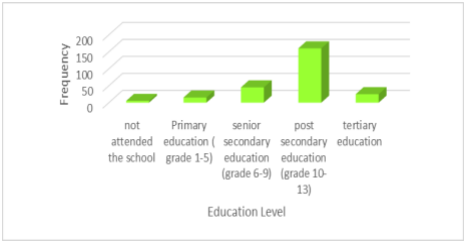

Figure 02: Responders Education level

Considering the educational level of the studied small and medium scale entrepreneurs, the highest percentage represents the post-secondary level of education. That is, the people who studied advanced level and ordinary level. It is a percentage of 64% in the entire sample. 18% percent had higher secondary education which is 45% of the total sample. The business community with college and university education as tertiary education constitutes 10% of the sample. Those with primary education represent 6% and the uneducated represent 2%.

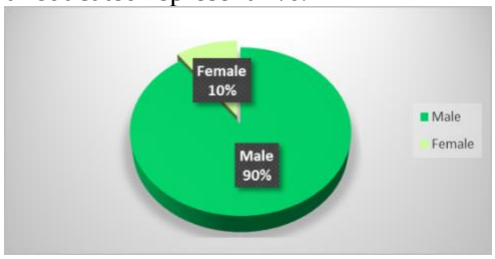

Figure 03: Gender Disparities

92% of the total respondents are represented by males which is 225 out of the total sample.

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Females represent 10% which is 25% of the total sample.

Table 01: Component Score Coefficient Matrix

	Component	
	1	2
Literacy	.208	-.110
Utilization of Knowledge of Export Market	.092	.380
Financial Ability	.243	-.056
Management Ability	.242	-.003
Government Policies	.223	-.143
Marketing Capability	.182	.155
Knowledge of the Export Market	-.114	.844

Source: Authors generated using SPSS

Here, the contribution of variables to each component can be indicated through Score coefficients. The results presented are based on a Principal Component Analysis (PCA), which was employed to reduce the dimensionality of the data and identify the key factors (components) that contribute to the variability among the variables studied. The method used to extract these components was PCA with Varimax rotation to ensure that the components are orthogonal (uncorrelated).

The score coefficients represent the contribution of each variable to the respective components. These coefficients were calculated using the factor loadings obtained from PCA. The higher the absolute value of a score coefficient, the greater the contribution of the corresponding variable to that component. For the first component, variables such as Literacy, Financial Ability, Management Ability, Government Policies, and Marketing Capability showed the highest contributions, indicating that these factors are the most influential in this component. The second component is primarily influenced by the Knowledge of the Export Market and the Utilization of Knowledge of the Export Market.

The above factors could be identified as internal factors affecting the export market. Among the internal factors affecting export market access, financial ability can be identified as one of the most influential factors. According to the data obtained from the entrepreneurs, the problems of financing the working capital for internationalization, the lack of funds for investment for internationalization, the lack of insurance for internationalization can be identified as internal barriers affecting export market access.

Management ability as an internal barrier to the export market can also be identified as the second influencing variable. Accordingly, strong management is required for export market performance. The study identified that there is insufficient knowledge in the small and medium scale entrepreneurs. Based on that, it was identified in the study that it is necessary to provide knowledge about the management process for management.

It was identified in the study that government policies affect export markets as internal barriers. Accordingly, it was recognized that market behavior is influenced by tax policies and government agreements followed by the government.

The second component has the highest contributions are, Utilization of Knowledge of Export Market and Knowledge of the Export Market.

According to the study, external factors affecting the export market can be identified as the second component. It was identified in the study that existing knowledge regarding the export market as a variable that has a strong impact on it. Analyzing the information of the entrepreneurs in the questionnaire, it appears that the information is inefficiently channeled into the businessmen.

Another factor affecting external factors was found in the study to be the problem in practical use of the export market. The second extracted component, the impact of the external factors affecting the export market, score is 0.388.

Thus, it can be concluded that internal factors have a greater impact on the export market and it is important to pay attention to external factors to maintain the performance of the export market. It can be concluded on the basis of the component score that the variable of small and medium scale entrepreneur's use of knowledge about the export market has a higher impact than all other variables. It was recorded as 0.844. Accordingly, the knowledge of small and medium scale entrepreneurs about the export market can be identified in the study as the variable that has the greatest impact on the export market.

IV. CONCLUSION

The study identifies several critical internal and external factors that influence the participation of small and medium-scale agricultural

entrepreneurs in Sri Lanka's export market. Internal factors such as financial ability, management capability, and literacy play a significant role in determining the success of these enterprises in the export market. Specifically, financial challenges, such as inadequate working capital, lack of investment funds, and insufficient insurance for international trade, are major barriers to market entry. Additionally, gaps in management skills highlight the need for enhanced training and knowledge transfer to strengthen the operational capacity of these businesses.

External factors, particularly the entrepreneurs' existing knowledge of the export market and their ability to utilize this knowledge, were found to be crucial for successful market participation. The study revealed that inadequate information flow between export development agencies and entrepreneurs significantly hampers their ability to navigate the export process effectively. To address this, there is a need for robust organizational programs that ensure consistent and accessible information dissemination, leveraging digital platforms, social media, and traditional media outlets.

Moreover, the study underscores the importance of a sustainable and supportive government policy framework. Policies that facilitate access to financial resources, provide tax incentives, and promote effective foreign agreements are essential for creating a conducive environment for export market growth. The findings suggest that empowering young entrepreneurs, particularly those between the ages of 21 and 30, through targeted education and support programs, could further enhance their participation in the export market.

In conclusion, a comprehensive approach involving the enhancement of internal capacities, improvement of external information channels, and the establishment of supportive government policies is essential for encouraging small and medium-scale agricultural entrepreneurs in Sri Lanka to engage more actively in the export market. These measures are vital for achieving the broader economic development goals of the country.

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Factors Influencing the Fast-food Consumption Frequency among Undergraduates of Faculty of Agriculture, Eastern University of Sri Lanka

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Abstract

Fast food has been revolutionized by modernization and globalization, and Sri Lankans, particularly young people with busy schedules, embrace it for its convenience. This could reduce their nutritional status and increase their risk of diet-related noncommunicable diseases. This study aims to relate the factors that influence the frequency of fast-food consumption among undergraduates of the Faculty of Agriculture, Eastern University, Sri Lanka (EUSL). A structured questionnaire was used to gather primary data from 100 randomly chosen students in five batches at the EUSL Faculty of Agriculture. The collected data were analyzed using the SPSS software package. Descriptive statistics were used to explain the study variables, and a chi-square analysis was done to find out the factors influencing fast-food consumption frequency. The results revealed that more than half of the students (82%) were female from various districts of Sri Lanka. When it came to choosing fast food items, the majority of students gave preference to taste. However, when it came to the diversity of the menu, they gave preference to taste when they consumed fast food on a weekly basis. Almost half of the students consume fast food 1-2 times per week. Additionally, the menu's variety and the time allotted for preparation, tasting, and dining with loved ones affected how frequently they consumed fast food each week. The study reveals that most students prefer fast food for snacks, which could be beneficial for undergraduate health care and promote healthier dietary choices.

Keywords: Fast food, Food choice, Health impacts, Nutritional status

I. INTRODUCTION

The fast-food industry has grown dramatically throughout the world (Jia et al., 2021; Lim et al., 2018; Mertens et al., 2022). Fast food is linked with restaurant chains that provide a bound menu of standard choices such as pizza, hamburgers, sandwiches, chips, sodas, and other related foods that are made quickly and intended to be consumed immediately (Mazidi and Speakman, 2017; Thornton et al., 2009). These dishes are distinguished by their quick availability, simple preparation method, and emphasis on efficiency, allowing customers to receive their cuisine in minutes of placing an order (Fulkerson, 2018).

Fast food consumption has become a public health concern due to its association with a poor diet. (Jia et al., 2021). It ended up with the risk of certain chronic diseases such as diabetes, cardiovascular diseases (Elizabeth et al., 2020; Jardim et al., 2021), and obesity (Elizabeth et al., 2020; Jardim et al., 2021; Ipparraguirre et al., 2021).

Fast food consumption has grown significantly among higher education students. These amounts may vary from around three times per month. (Didarloo et al., 2022) to two or more times a week (Shaban and Alkazeme, 2021; Mwafi et al., 2021). Varied factors have shown significant impacts on continual fast-food consumption, including attributes like higher socioeconomic status, gender, age group (Didarloo et al., 2022; Saha et al., 2022), and high-rise body mass index (Hojjati et al., 2023). Further, factors like price, brand reputation, taste, accessibility, favourable location, Promotional incentives and rapid service play an important influence in increasing fast-food consumption among higher education students. (Saha et al., 2022). Undergraduates are an especially vulnerable group, as they are in a period of life marked by various changes, which include spending prolonged periods away from home and residing at university campuses. This change considerably influences eating habits, frequently resulting in unlikely weight gain (Shatwan et al., 2022). This may have significant consequences in the future, as weight increase during the young adulthood stage is identified as a significant risk factor for the development of obesity in the later periods of adulthood (Sparke et al., 2021). Because it is regarded as the young generation, its well-being is important to the country's future

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economy. Due to their busy lifestyles and limited time for meal preparation, university students are frequently seen as a huge customer base for fast food. People in the adolescent and teenage years are the most regular consumers of fast food. (Lee, 2007). There is a lot of well-researched evidence that consuming fast food daily can be harmful to one's health. This is due to the elevated sugar, salt, saturated fat, trans fats, processed components, and calories in fast foods. It is also deficient in antioxidants, fibre, and a variety of other nutrients (Jerlyn Jones, 2023). University students who spend most of their time out of home usually consider factors like accessibility, comfort, and eating preference when determining how to meet their energy and dietary needs. This may lead to an unbalance in their dietary habits and increase their chance of getting diet-related non-communicable diseases (NCDs).

Few studies have been conducted on Sri Lankan undergraduates' fast-food consumption patterns. (Jayawickrama et al., 2020). Public knowledge of youngsters' fast-food eating is relatively low, and there are very few resources and studies accessible on the subject, particularly on undergraduates' food consumption patterns (Arya and Dubey, 2023). As a result, an empirical gap in fast-food consumption patterns and factors influencing the choice of fast-food among university students has been established. Based on this background, a study was conducted among undergraduates of the Faculty of Agriculture, Eastern University, Sri Lanka, to determine the factors influencing their fast-food intake. By having a better understanding of these variables, more efficient strategies for encouraging people to choose environmentally friendly and healthier food choices can be developed.

II. METHODOLOGY

This study further attempted to identify the most preferred fast foods and their consumption patterns; ten fast food items were listed among the respondents, and preference level was asked. The ten fast-food items included were burger, pizza, cakes, short eats, biscuits, juices, energy drinks, fried chicken, kothu, and ice cream.

A. Location of study

The research was conducted among the students in the Faculty of Agriculture at the Eastern University, Sri Lanka. The study looked at the Agriculture faculty students of Eastern University, Sri Lanka. The study's sample size was limited to 100 students from the Faculty of Agriculture at Eastern University in Sri Lanka.

B. Sample selection

Undergraduates from the Faculty of Agriculture at Eastern University of Sri Lanka were the intended audience. There were five batches of students under the Faculty of Agriculture, EUSL, during the study period, and the total number of students was 318. The survey included 100 students randomly selected from the five batches. The number of students selected from each batch was proportional to the total number of students in that batch. For the study, students from each batch were picked by simple random sampling technique.

Table 01 gives the sample size of the study.

Table 01: Sample size of the study
(Source: Field Survey, 2023)

Batches	Total Students	Sample size
1st year 1st Semester	76	24
2nd year 1st Semester	69	22
2nd year 2nd Semester	73	23
3rd year 2nd Semester	54	17
4th year 2nd Semester	46	14
Total	318	100

C. Data collection

In this study, a questionnaire survey was the principal primary data collection method. A structured questionnaire was used to measure the variables. The study also gathered secondary data from various sources, including textbooks, published sources, statistics handbooks, libraries, websites, and more. Additionally, data pertaining

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to the current study were gathered from the literature through empirical proof, real-world instances, and other research findings.

D. Data Analysis

The data gathered were analyzed using the IBM SPSS Statistics software, version 23.0 (Statistical Package for the Social Sciences). In addition to the absolute (n) and relative (%) frequencies, the mean and standard deviation (SD) were calculated for the statistical description. The chi-square analysis was performed to test the association among different variables.

III. RESULTS AND DISCUSSION

This study consisted of 100 participants, most of them were females (82%) and from 20 different districts of Sri Lanka. Most of the students, nearly 63 per cent, live in urban areas. About 95% of Students reported eating fast food one or two times a week, and they preferred and had become used to it. This indicates a moderate frequency of consumption. However, a more recent study conducted among students from higher education in Portugal found that students consumed fast food one to six times per week, with a high frequency of fast-food consumption (Oliveira and Raposo, 2024). Usually, fast-food items are taken as breakfast, lunch, snacks, dinner, or other periods. From the study, it was found that most of the students (more than 50%) preferred to take fast food as snacks. According to their consumption time, they prefer to grab fast food between 2 pm and 6 pm. More than half of the students (63%) preferred to consume both restaurant-made and home-made fast foods, followed by restaurant-based (20%) and home-made (12%).

A. Factors considered by the students during the selection of fast foods

The respondents were asked to rank the key factors considered when selecting fast food at a restaurant or home. The factors mentioned include healthy food, taste, calories, price, quantity, satisfaction, and variety. The responses are discussed below.

Taste: 80% of the students considered taste to be an important factor when purchasing fast food. A similar result was also observed by Pinnagoda (2017) and Kaushik et al. (2011), indicating that taste was the primary factor (50.3%) in consuming fast food. Most of the respondents in this study considered fast food tastes when making their selections.

Healthy food: Around 78% of the students considered healthy food a key factor when selecting a fast-food, indicating awareness of food and health choices. A likely result was observed by Oliveira and Raposo (2024) in their study among higher education students in Portugal, where students considered healthy food during the selection of fast-food and were concerned about their body weight management.

Calories: Almost 66 per cent of respondents considered calories to be an essential priority when selecting fast food.

Price: The results show that 70% of respondents considered price an essential priority when selecting fast foods, indicating the students considered cost as a significant factor when deciding what to eat.

Quantity: The results show that 50 per cent of respondents considered quantity of food as an essential priority while selecting fast foods.

Satisfaction: According to the results, 68 per cent of respondents considered consuming fast food for satisfaction.

Variety of menu: According to the results, 49 per cent of respondents highly prioritized the variety of fast-food items while selecting fast foods. Similarly, Harris et al. (2010) discovered that a diverse menu encouraged restaurant visits for specific eating occasions.

Among the factors such as health, calories, taste, price, quantity, satisfaction, and variety, students were asked to rank their important priorities when selecting fast foods. Most students preferred to consider taste as their foremost priority, followed by healthy food, price, satisfaction, the calorie content of fast food, quantity, and variety of food. The lowest number of students preferred to consider the variety of fast-food items. Table 02 gives the mean and standard deviation of the priority factors.

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Table 02 : Mean and standard deviation values of factors considered during the selection of fast-food

Factors	Mean	Std. Deviation
Taste	6.0698	1.42903
Health	4.7473	1.94132
Price	4.2706	1.73472
Satisfaction	3.9176	1.96524
Calories	3.4125	1.91393
Quantity	3.2785	1.45828
Variety	2.8077	1.77323

(Source: Field Survey, 2023)

B. Factors associated with fast-food Consumption frequency per week

A chi-square test was carried out with the variables: Advertisement, good taste (liking & enjoying the taste), limited time for cooking, cost, variety of menu, and eating with friends or family to identify their association with fast-food consumption frequency. Here, fast food consumption frequency was studied under four categories: 0 times, 1-2 times, 3-4 times, and 5 times or more per week. Table 03 gives the c Chi-square analysis between fast-food consumption per week and selected variables.

Table 03 : Chi-square analysis between fast-food consumption per week and selected variables

Factors	Chi-square Value [X^2]	*p-value*
Advertisement	17.849[a]	0.466
Good taste	29.980[a]	0.038[*]
Limited time for cooking	25.683[a]	0.041[*]
Cost/price	19.123[a]	0.384
Variety of menu	32.377[a]	0.020[*]
Eating with friends or family	29.384[a]	0.044[*]

Means with different letters represent significant differences at $p<0.05$

This chi-square test between the variety of menus and fast-food

frequency per week shows that the corresponding p-value is less than 0.05 ($p=0.020$; $X^2=32.377$). This implies that the two variables have an association between them. When testing the good taste, it was shown that two variables are associated ($p<0.05$; $X^2=29.980$). This highlights the importance of palatability in food consumption. The same was observed for the association between limited time for cooking and fast-food consumption frequency per week ($p<0.05$; $X^2=25.683$). University students are generally loaded with study-related activities and find very little time for cooking. This situation results in obtaining fast food from restaurants or preparing it at home. In addition, a significant association ($p<0.05$; $X^2=29.384$) was also observed between the frequency of fast-food consumption per week and eating with friends or family. Advertisements on fast foods were found not to be associated with the fast-food consumption frequency per week ($p>0.05$; $X^2=17.849$). Similarly, the study results reveal that fast-food consumption frequency per week was not influenced ($p>0.05$; $X^2=19.123$) by the cost/price of fast-food. Accordingly, advertisement and cost were not influenced fast food consumption frequency, and the variety of menu, limited time for cooking, teste factor, and eating with friends or family were found to be influenced by the fast-food consumption frequency pe r week.

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IV. CONCLUSION

It is concluded from the study that most of the students in the Faculty of Agriculture, Eastern University, Sri Lanka, preferred to consume fast food. Among the fast foods, most students preferred to consume short foods like samosa, rolls, and pastries, and their least preference was energy drinks. While selecting fast food, most students considered the taste of fast-food items an important factor, and the least considered factor is the variety of fast-food items. The study further concluded that there is a significant association between the frequency of fast-food consumption per week and the menu variety, limited cooking time, good taste, and eating with friends or family. Accordingly, these factors influence the fast-food consumption pattern of the Faculty of Agriculture, Eastern University, Sri Lanka undergraduates. The findings of this study have significant consequences for college students and offer guidance for creating stronger approaches to promote healthy eating choices.

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Physico-chemical and Consumer Preference Analysis of Novel Herbal Soap Enriched with Aloe vera (*Aloe barbadensis*)

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Abstract

Herbal soaps are popular products at a homemade scale worldwide, but innovative and commercialized local formulations are rare. Sri Lanka has a rich herbal diversity, and several plant extracts have been scientifically proven to show bioactivities such as anti-inflammatory, antibacterial, and antifungal properties. An instance of this is a herbal soap formulation that is useful for treating microbiological infections and regular use. The current study aimed to develop a novel herbal soap enriched with extracts of aloe vera (Aloe barbadensis), citronella oil (Cymbopogon nardus) and black tea (Camellia sinensis), evaluate the physico-chemical properties, and gauging consumer preference for the finished prototype while advancing the technology of the current saponification process. The soap base was produced by saponifying coconut oil with NaOH at 40°C, subsequently value added by incorporating 8% aloe vera gel, 4% citronella oil, and 4% black tea extract, and allowed to age for 72 hours at 32°C. The physico-chemical properties were determined as follows: density was 0.95 mg/ml, NaOH ratio was 4.16, free alkali content was 0.028% (0.007 mol/dm³), and Total Fatty Matter (TFM) was 79.6%. These metrics comply with the SLS 34:2009 standards and align with previous research findings, thereby classifying the product as Grade 1. Consumer assessment considered colour, aroma, texture, washing quality, and overall acceptability, revealing a brownish-golden hue, pleasant fragrance, a soft, consistent texture and gentle hand impact. Consumer preference was assessed across diverse socio-economic groups, revealing a high overall acceptability rating of 8.65 out of 10. The study advances soap technology, emphasizing compatibility with existing standards and consumer satisfaction.

Keywords: Herbal soap, Aloe vera, Tea, Total fatty matters, Saponification

I. INTRODUCTION

Soap is a commodity that is commonly used for hygienic practices such as washing and cleaning. The soap is generated through a process known as Saponification. In this process, triglycerides, free fatty acids (FFA), and fatty acid methyl esters react with an alkaline (NaOH or KOH) to produce soap (Bahl and Arun, 2017). There are several fatty acids that have been involved in the production of soap such as lauric acid, myristic acid, palmitic acid, stearic acid, and oleic acid (Arasaretnam and Venujah, 2019). In commercialization, colourants and fragrances are added to soap as value addition (Rahman and Paramita, 2021; Nchimbi, 2020).

Different scientific studies have proven that aloe vera gel can be used as a moisturizer for hydrating the skin due to its antiviral, antibacterial, and antioxidant properties (Mishra et al., 2023). Hence, the novel soap developed under this study was prepared with the incorporation of aloe gel. Moreover, the colour and fragrance of the novel soap were intended to be taken from natural ingredients. Citronella oil (*Cymbopogon* nardus) was used as the fragrance agent which imparts with addition of pleasant herbal smell to the developed soap and contributes to numerous actions such as antimicrobial, antioxidant, anticonvulsant and wound healing (Singh and Kumar, 2017) in addition to giving the fragrance for the developed aloe vera enriched soap. Hence, these properties have generated additional value for the developed soap further (Sharma et al., 2019).

Black tea (*Cameliia sinensis*) was imparted for the addition of natural colour which has been

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recognized as containing natural antioxidants such as catechin and has shown the antimicrobial, anticancer, and antifungal biological activities which generate more value to the developed soap product (LIczbiński, and Bukowska, 2022; Wang et al., 2022). Thus, when selecting the ingredients for the value addition, the aforementioned properties were considered (Pratama et al., 2021). This novel soap product was developed with enhancements to the technology of the existing saponification process to be easily adoptable in small and medium-scale enterprises. Nowadays, many novel herbal developments are carried out within the local university community, but the major drawback of these studies is the lack of commercial viability. In addressing this issue, the novel herbal soap enriched with aloe vera gel, citronella oil, and tea extract was assessed for compatible physico-chemical properties of a common soap product and acceptable consumer preference. In addition to the mere development of the product, in designing this study the concept of incorporation of aloe vera into several possible productions that could be carried out within the island is intended.

II. METHODOLOGY

A. Soap Production

Soap was made by saponification, filtering, and incorporation of herbs. For saponification, coconut oil and 20% NaOH were mixed and stirred in a beaker at 40°C for 40 minutes at 800 rpm, under controlled environmental conditions (23 ± 2^0C). As the next step, saturated sodium chloride (NaCl) was added into the soap base in an ice bath. The NaCl-soap mixture was filtered through a muslin cloth. Then, the filtered soap base was washed with ice-cold water and 0.05 M Citric acid respectively until the washouts gave a pH below 8. The resulting soap base was weighed and then melted in a 90 ^{0}C water bath until the desired melted texture. Then, the soap was enriched with the herbal incorporations and herbal formulations were taken according to a scientific design based on the trial-and-error method. The product optimization was done to the selected final formulation with regard to the organoleptic properties. Then, the herbal soap mixture was set to the moulding and the final product was obtained after 72 hours of holding time.

B. Physico-Chemical Characterization

The physico-chemical characterization comprised visual observations on product quality, including colour, texture, and aroma, alongside the mole ratio of coconut oil to NaOH (Rahman and Paramita, 2021), which were basically observed during its storing period and final stage of optimized soap at room temperature (32 ± 2 C^0).

Furthermore, density, pH, free alkali content (Betsy et al., 2013), and total fatty matter (TFM) (SLS 34:2009) were measured in triplicate to assess the formulation and quality of the novel herbal soap product.

C. Consumer Preference Evaluation

Consumer preference of the developed novel herbal soap was analyzed involving a 50-member consumer panel, recruited through careful screening from a pool of volunteers from the University staff to representing all defined social classes. In this consumer preference evaluation, the panelists were provided with a questionnaire and asked to rate the product regarding the attributes; colour, texture, odor, washing quality, and overall acceptability by using a ranking scale of 1 to 10, 10 being the highest value an attribute can obtain. Further, they were asked a few multiple-choice questions on their demographic details and preference perception.

D. Statistical Analysis

Data was analyzed using Microsoft Excel Professional plus 2016 and Minitab -17 statistical software to get the mean rank value and the standard deviation of each mean rank value for the consumer preference and each physico-chemical data regarding the newly developed herbal soap with the incorporation of aloe vera.

III. RESULTS AND DISCUSSION

As shown in Table 01, panelists have shown a higher preference, above the acceptable range in each attribute for the developed novel herbal soap. With the acceptance of 96% of consumer panelists, the developed herbal soap product has obtained overall consumer acceptability with 8.65/10 mean rank value. The panelists were specifically invited to represent a cross-section of the general public, encompassing a range of socio-economic backgrounds. Therefore, the received consumer preference score is comprehensive in defining the quality of the developed novel herbal soap.

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Table 01 : Mean rank values of the evaluation of consumer preferences

Consumer Preference (n=48)	Mean rank value (out of 10)
Color	8.06±0.96
Texture	8.27±1.25
Odor	9.98±0.94
Washing Quality	9.31±0.97
Overall acceptability	8.65±0.92

The final aloe vera incorporated herbal soap has given the observations as shown in Figure 01. It was brownish gold in colour and found to have a soft consistency. The citronella aroma existed after the solidification and the smell remained throughout the storing time at room temperature. In herbal value addition to the novel soap, aloe vera was used as the major value-adding ingredient, due to its antimicrobial activities, antioxidant activities, wound healing, moisturizing and beauty care properties.

The high antioxidant content of aloe vera slows down the ageing process of the skin while stimulating proper blood saturation via the vitamin and minerals present in aloe fillets. Also, due to its Additionally, though the citronella oil was used for the fragrance, and the tea extract was intended for imparting color, the antioxidants, flavonoids, and polyphenols compositions had enhanced the medicinal properties (antimicrobial, insecticidal, antioxidant, and dermatotoxicity activities) of the soap (Wany, et al., 2013; Sharma et al., 2019).

The weight of the prepared trial samples was between 7.6 ± 0.5 g. As shown in Table 02, the physico-chemical properties of the final sample, pH value was measured as 7.03 which represented the neutralized chemical nature. Although the resulting pH value is less than the standard value (pH 8.0 -10.0), the neutralized pH value represents that the developed herbal soap is ideal for the prevention of skin irritation due to the incorporation of aloe vera gel while advancing the soothing effect. Thus, it is suitable for body washing, and cleansing purposes further.

hydrating effect, aloe vera is beneficial in masking the dehydration that may be caused by the coconut oil-based soap. The most common oil used in soap production is coconut oil which is known to cause skin dryness evident in a wealth of previous studies (Ngan et al., 2020). Further, aloe gel has the ability to remove dead skin cells and has a good penetrating power, which aids in the transportation of healthy substances through the skin (Liang et al., 2021).

Figure 01 : Prototype of developed Aloe vera incorporated novel herbal soap

The density of the soap and the molar ratio between coconut oil and NaOH used in the saponification process were calculated as 0.95±0.006 g/mL, and 1:4.16 respectively. Those values were proved to be compatible compared to the previous study of Rahman and Paramita, (2021).

Table 02: Results of determined physicochemical properties of the final porotype

Physico-chemical Property	Amount	Reference values	Reference
pH	7.03±0.01	8.0 – 10.0	Das et al., 2024
Density (g /mL)	0.95±0.006	1.02	Rahman and Paramita, 2021

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Mole ratio (Coconut oil: NaOH)	1:4.16±0.006	1:5	Rahman and Paramita, 2021
Free caustic alkali content (Percent in mass)	0.028%±0.000	0.06% (max.)	SLS 34:2009
Total Fatty Matter (TFM) content	79.6% ±0.058	76.5 (min.)	SLS 34:2009

The free alkali content of the sample was given a value of 0.028% (0.007 moldm-3) with standard 0.1 moldm-3 HCl solution under the phenolphthalein indicator. The alkalis used to make soap are KOH (potassium hydroxide) and NaOH (sodium hydroxide). The most popular toilet soaps are sodium carboxylates. The fatty acids that are bound to glycerol in the precursor triglycerides play a crucial role in determining the molecular makeup of soap. Specifically, the proportion and type of these fatty acids determine the resulting sodium or potassium carboxylates formed during saponification, and this relationship governs the physicochemical properties of the soap (Moody et al., 2004).

Total Fatty Matter (TFM) content was 79.6% which is higher than the estimated TFM content of the previous study of Ahmed et al., (2021) (Ahmed et al., 2021). TFM value denotes one of the most important factors in terms of the quality of soap. According to the TFM value, the soap is graded into three categories such as grade 1 (above 76%), grade 2 (above 60%), and grade 3 (above 50%) (Betsy et al., 2013). Further, the TFM value is a metric for calculating how much fatty matter is present in soaps and the quality of the soap improves with a higher TFM content. High moisture concentrations in soap are caused by TFM%. Other elements that may affect the TFM value include the forms and amounts of fatty materials employed, as well as potential variations in the saponification process. Additionally, the resulting TFM value of the novel soap represents the lack of the presence of unreacted NaOH. Hence, the determined result of the TFM value of the prepared organic soap belongs to grade 1. That is associated with high quality, less hardness, and increased moisturizing properties of the soap (Betsy et al., 2013).

IV. CONCLUSION

The production of the aloe vera-enriched herbal soap, incorporating citronella as a fragrance agent and tea extract as a colouring agent, demonstrated compatible physico-chemical properties—such as pH, density, molar ratio between coconut oil and NaOH, free alkali content, and total fatty matter (TFM)—with commercial products. Additionally, the soap achieved favourable consumer acceptance, indicating a successful development at the laboratory scale.

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ABBREVIATIONS

Sodium hydroxide (NaOH), Potassium hydroxide (KOH), Sodium chloride (NaCl), Total fatty matter (TFM), Sri Lanka standard (SLS)

TRACK - ANIMAL SCIENCE & AQUACULTURE TECHNOLOGY

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Financial Impacts and Epidemiological Characteristics of Lumpy Skin Disease in Cattle in Ampara District of Sri Lanka

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Abstract

Cattle farming is a major economic sector in the Ampara district of Sri Lanka, yet there is limited information on lumpy skin disease (LSD) in the region. This study addresses this gap by investigating the prevalence, mortality rate, distribution, and age-related factors of LSD, as well as assessing the financial impacts of outbreaks. Data of LSD from nineteen government veterinary offices were collected through surveys and interviews. The data was analysed using Microsoft Excel 2021 and Minitab 19. Findings indicate that LSD had spread to nineteen out of twenty ranges in the Ampara district. The highest prevalence was observed in the Irakamam range (20.77%), while the lowest was in the Alayadivembu range (3.81%), with an overall prevalence of 8.59%. Nintavur and Addalaichenai had significantly higher mortality rates of 6.5% and 3.5%, respectively, compared to other regions in the Ampara district, where the mortality rate was much lower at 1.7%. Statistical analysis revealed that the affected animals were predominantly under one year of age. Financial impact assessment showed that 78% of affected farms experienced reduced growth rates in their cattle, while 22% faced infertility issues. Major risk factors for LSD spread included animal transportation, communal grazing lands, and presence of ticks. These findings provide valuable insights into the epidemiology and economic burden of LSD in Ampara, offering a basis for developing targeted interventions to protect livestock farmers' livelihoods and sustain the local economy.

Keywords: ***Lumpy Skin Disease (LSD), Cattle, Financial impacts, Ampara district of Sri Lanka***

I. INTRODUCTION

Lumpy Skin Disease (LSD) is a severe systemic illness in cattle caused by the Lumpy Skin Disease virus, which belongs to the Capripoxvirus genus within the Poxviridae family. Key symptoms of LSD include fever, nodular lesions on the skin and mucous membranes, and lymph node enlargement (Molla et al., 2017). Morbidity rates can range from 10% to 85%, depending on factors such as regional differences, cattle population density, and the effectiveness of control measures. While LSD generally has a low mortality rate of 1% to 5%, it can still cause significant economic losses due to reduced milk production, weight loss, and secondary infections, particularly in regions with high morbidity (Sherrylin et al., 2013; Namazi & Khodakaram Tafti, 2021).

Ampara District of Sri Lanka, where livestock farming plays a crucial role in the local economy, the spread of LSD has raised concerns due to its potential impact on dairy farmers' livelihoods. The variation in morbidity and mortality rates during LSD outbreaks depends on several factors, including geographic location, climate, cattle management conditions, and the virulence of the virus. Reported morbidity rates range from 5% to 45%, with mortality rates typically between 1% and 5%. However, higher rates have been observed in certain regions, such as in Oman, where a 2009 outbreak in a Holstein cattle population saw morbidity and mortality rates of 30-45% and 12%, respectively (Sherrylin et al., 2013).

LSD primarily affects cattle and buffaloes, with all breeds being susceptible, although imported breeds with thinner skins, such as Bos Taurus, are more vulnerable than indigenous breeds. Young calves are particularly susceptible, developing characteristic lesions within 24 to 48 hours of infection. In rare cases, wild species like impalas, Thomson's gazelles, and giraffes have also developed LSD lesions following experimental inoculation (Ali et al., 1990; Greth et al., 1992; Young et al., 1969).

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The exact transmission mechanism of LSDV is not fully understood, but it is believed to be mechanically spread by flying insects, with epidemics often coinciding with periods of high insect activity. Variations in attack rates, ranging from 10-15% to nearly 100%, may be attributed to differences in vector species across regions. Blood-sucking ticks have also been implicated in the transmission of LSDV in sub-Saharan Africa (Lubinga et al., 2013). While transmission through semen has not been experimentally confirmed, the virus has been isolated in the semen of infected bulls, suggesting potential intrauterine infection. The movement of animals from infected herds has frequently introduced the virus to new areas, with old skin lesions serving as a source of infection (Weiss, 1968; Kitching & Mellor, 1986; Carn & Kitching, 1995).

Pathologically, the acute stage of LSD is characterized by thrombosis, vasculitis, perivascular fibroplasia, and infarction, with inflammatory cells infiltrating affected areas. Gross pathology includes edema, congestion, and enlargement of lymph nodes, as well as nodular lesions in fascia and musculature. The incubation period for LSD is approximately 28 to 35 days in natural infections and 4 to 7 days in experimental settings (Al-Salihi, 2014; Mulatu & Feyisa, 2018; Ratyotha et al., 2022).

Clinically, LSD manifests as anorexia, fever, salivation, nasal discharge, enlarged lymph nodes, weight loss, and decreased milk production. The most distinctive sign is the presence of firm, raised skin nodules that appear on the legs, neck, back, and tail. These nodules can lead to complications such as myiasis, abortion, mastitis, and orchitis. Postmortem examinations often reveal lung edema, congestion, and nodules throughout the lungs and gastrointestinal tract (Namazi & Khodakaram Tafti, 2021).

The objective of this study is to assess the prevalence and mortality of LSD in the cattle population of Ampara district of Sri Lanka, analyze the risk factors contributing to the spread of LSD, and relate the occurrence with age, and evaluate the economic impact of LSD on livestock farming in the Ampara district.

II. MATERIALS AND METHODS

A. Study area and Study Population

The study focused on cattle farms affected by Lumpy Skin Disease (LSD) in the Ampara district over three months from September to December 2023. Data was collected from 19 selected Veterinary ranges within the district, based on the number of reported LSD cases in each farm. The Veterinary ranges included in the study were Addalaichenai, Akkaraipattu, Alayadivembu, Ampara, Dehiattakandiya, Irakkamam, Kalmunai, Karaitivu, Lahugala, Mahaoya, Navithanveli, Nintavur, Padiyathalawa, Pottuvil, Uhana, Sainthamaruthu, Sammanthurai, Damana, and Thirukkovil. These ranges were specifically chosen to provide comprehensive data from farms significantly impacted by LSD.

B. Data Collection

Epidemiological data were systematically gathered, focusing on cattle demographics, clinical signs of LSD, vaccination status, and management practices. This information was obtained through a combination of veterinary records and on-site farm visits. During sampling, details such as the sex, age, and management system of the cattle were meticulously recorded.

To assess the financial impact, data collection involved conducting surveys and interviews with farmers. These methods provided insights into production losses, veterinary expenses, and other economic consequences associated with LSD.

A well-structured questionnaire was prepared and completed to gather detailed information. This questionnaire covered various aspects including the owner's particulars, herd composition, management practices, and the health, disease, and vaccination status related to LSD.

In addition, an interview guide was meticulously developed and utilized. This guide focused on gathering insights about experiences with LSD, identifying which types of animals were affected, and assessing production losses.

C. Statistical Analysis

Qualitative data were analysed using a cohort study design to evaluate the independence of various epidemiological factors. Quantitative data were processed and analysed using Microsoft Excel. For the financial impact analysis, survey data and interview responses were meticulously examined in combination to provide a comprehensive assessment.

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Figure 01: Jerzy Crossbreed Cow in Kalmunai Infected with LSD Exhibiting Multiple Skin Nodules

Figure 02: Jerzy Crossbred Calf in Ampara infected with LSD reveals multiple skin nodules

III. RESULTS

A. Prevalence of Lumpy Skin Disease (LSD) in Ampara District

The data on LSD prevalence in the Ampara district is illustrated in Figure 03. The highest prevalence of LSD was observed in the Irakamam veterinary range, with a rate of 28.46%. The second highest prevalence was reported in the Samanthurai veterinary range at 20.77%. Overall, the prevalence of LSD in the Ampara district from September to December 2023 was 8.59%.

B. Mortality Rate of Lumpy Skin Disease

The highest mortality rate was reported in the Ninthavur veterinary range at 6.50%, followed by the Addalaichenai range with a mortality rate of 3.46% (Figure 04). The overall mortality rate in the Ampara district for the same period was 1.70%.

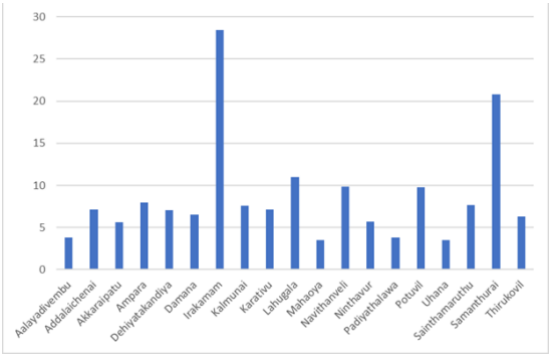

Figure 03: Prevalence (%) of Lumpy Skin Disease in Cattle in Ampara district: September to December 2023

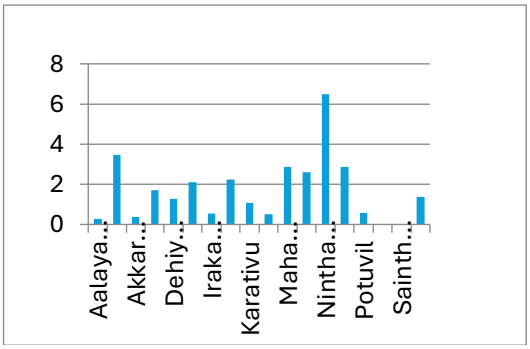

Figure 04: Mortality rate (%) of Lumpy Skin Disease in Cattle in Ampara district: September to December 2023

C. Age Distribution of Affected Animals

The analysis, as illustrated in Table 01, reveals that the highest percentage of Lumpy Skin Disease (LSD) cases were observed in animals under one year of age, while the lowest number of affected animals were in the over one-year age category.

D. Financial and Production Impacts

Figure 05 shows the impact of Lumpy Skin Disease (LSD) on farms in the Ampara district. The data indicate that 78% of LSD-affected farms experienced a reduction in growth rates among the affected animals. In contrast, 22% of the affected farms reported issues related to infertility in their livestock.

Table 01: Reported LSD in Two Age Groups: "Animals below one year and Animals above one year in cattle in Ampara district'' (September to December 2023)

Affected Ranges	**No. of cattle below one year**	**No. of cattle above one year**
Aalayadivembu	265	95
Addalaichenai	277	70

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Akkaraipatu	206	64
Ampara	196	36
Dehiyatakandiya	86	16
Damana	117	62
Irakamam	68	36
Kalmunai	307	50
Karativu	107	78
Lahugala	310	75
Mahaoya	565	65
Navithanveli	582	30
Ninthavur	89	34
Padiyathalawa	188	20
Potuvil	302	58
Uhana	289	58
Sainthamaruthu	24	6
Samanthurai	760	117
Thirukovil	987	113

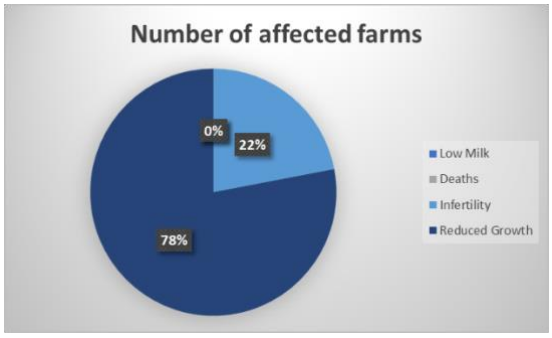

Figure 05: Financial Impact of Lumpy Skin Disease in Cattle on affected Farms in Ampara district of Sri Lanka

IV. DISCUSSION

This study, conducted across nineteen veterinary ranges in the Ampara district from September to December 2023, provides a comprehensive assessment of the prevalence, mortality, and impact of Lumpy Skin Disease (LSD) in cattle. The data collected from this three-month survey, along with interviews with local farmers, highlights significant variations in LSD prevalence and mortality rates across different ranges. The study corroborates previous findings that the morbidity rate for LSD ranges from 5 to 45% (Sherrylin et al., 2013). same as this study found notable differences in LSD prevalence across veterinary ranges in the Ampara district. The Irakamam range had the highest prevalence at 20.77%, while the Alayadivembu range had the lowest at 3.81%. The overall prevalence of LSD in the district was 8.59%. These figures suggest substantial regional variability, which may be influenced by local environmental, management, and biosecurity factors. Conversely, the mortality rate due to LSD varied significantly, with the highest rate observed in the Nintavur range (6.50%) and zero mortality recorded in the Sainthamaruthu and Uhana ranges. The total mortality rate across the district was 1.7%. Like that, the previous study reveals that mortality rates of 1 to 5% are considered more usual (Sherrylin et al., 2013). The absence of mortality in some ranges indicates effective local management or lower virulence of the virus in those areas, while higher mortality in other ranges suggests more severe outbreaks or less effective control measures.

The study corroborates previous findings that younger animals are more susceptible to LSD (Badhy et al., 2021). The data revealed that the majority of affected cattle were below one year of age, consistent with the heightened vulnerability of younger animals to the disease. In contrast, older cattle were less frequently affected. This age-related susceptibility underscores the need for targeted vaccination and preventive strategies for younger cattle to mitigate the impact of LSD.

The economic consequences of LSD on farms include not only direct losses from animal deaths but also secondary impacts such as reduced growth rates and infertility (Namazi & Khodakaram Tafti, 2021). In this study, 78% of LSD-affected farms reported reduced growth in affected animals, while 22% experienced infertility issues. The lack of reported issues with milk production suggests that milking animals were not significantly affected by LSDV during the study period, which may be due to the timing of the outbreak or effective vaccination coverage in dairy herds.

The spread of LSD is influenced by several known risk factors, including insect populations, communal grazing, the introduction of new animals, and vehicle movements (Ratyotha et al., 2022). According to government records and farmer interviews, the initial introduction of the LSD virus in the Ampara district is believed to have occurred through animal transportation from the Batticaloa district. Subsequent spread likely occurred via arthropod vectors, communal grazing, and shared watering sources. These findings emphasize the importance of controlling vector populations and managing communal resources to prevent the spread of LSD.

The findings of this study highlight the need for targeted control strategies tailored to the specific conditions and risks of different veterinary ranges. Effective vaccination programs, vector control measures, and improved biosecurity practices are essential to reducing both the prevalence and mortality of LSD. Additionally, farmer education on the importance of early reporting and prompt treatment of affected animals can help mitigate the spread of the disease.

In conclusion, the study underscores the significant regional variability in LSD prevalence and impact within the Ampara district. Addressing these variations through targeted interventions and enhanced management practices will be crucial for controlling future outbreaks and minimizing the economic impact of LSD on local cattle populations.

V. CONCLUSION AND RECOMMENDATION

The LSD outbreak in the Ampara district resulted in high morbidity but low mortality among the cattle population. The primary modes of transmission included the transportation of animals from affected areas, as well as further spread through ticks, communal grazing, and shared water sources. Calves under one year of age were particularly vulnerable, resulting in significant financial losses due to stunted growth and infertility. To control the outbreak effectively, we recommend implementing vaccination programs, restricting animal movement, and culling infected animals. Strategic government policies should be developed, alongside further research on vector insects and robust quarantine practices. Educating herd owners about prevention measures and prioritizing vaccination efforts are also essential for mitigating future outbreaks.

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How Broiler Meat Quality Influenced by Halal and Kosher Slaughtering Methods?

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Abstract

The increasing global demand for broiler meat has highlighted the significance of religious slaughtering methods, such as Halal and Kosher, due to their impact on meat quality and consumer preferences. This study examines the effects of these methods on the quality of broiler meat, focusing on nutritional composition, physicochemical properties, and sensory attributes. A total of 25 birds were slaughtered using each method, and the resulting meat samples were analysed for moisture, ash, fat, protein content, pH, colour, texture, and sensory qualities. The results showed no significant differences between Halal and Kosher methods in moisture, ash, fat, and protein content. However, Halal meat exhibited higher pH and lightness values, which could influence its appearance and shelf life. Sensory evaluation revealed no significant differences in consumer preference, although Halal meat scored slightly higher in aroma, taste, and overall acceptability. While these findings align with some previous studies, the small sample size limits the generalizability and credibility of the results. Future research with larger sample sizes is necessary to validate these findings and provide a more comprehensive understanding of the differences between Halal and Kosher slaughtering methods. Ultimately, the choice between these methods may be driven more by religious and cultural beliefs than by significant differences in meat quality. This study affirms that both Halal and Kosher methods are effective in producing high-quality broiler meat, reflecting the diversity of dietary practices and the importance of respecting consumer preferences in the global market.

Keywords: Halal, Kosher, Slaughtering, Meat quality, Broiler

I. INTRODUCTION

The global demand for meat products has steadily increased, driven by a growing population, rising incomes, and changing dietary preferences. Among the various types of meat, broiler chicken remains one of the most consumed worldwide due to its affordability, versatility, and nutritional value (Nusairat, 2022). As consumers become more conscious of food safety, animal welfare, and religious dietary laws. Two religiously prescribed methods, Halal and Kosher, have been particularly scrutinized and debated for their impact on meat quality and ethical considerations (Nakyinsige et al., 2012). Halal and Kosher slaughtering methods, which are required by Islamic and Jewish dietary laws, respectively, have gained significant attention in recent years due to the growing demand for religiously-compliant meat products (Bang, 2016; Farah, 2020). Traditionally, Halal and Kosher slaughtering have been the subject of debate, with concerns raised about animal welfare, pre-slaughter handling, and the potential impact on meat quality (Aghwan et al., 2016). Both methods emphasize the importance of humane treatment of animals and the ritualistic aspect of the slaughtering process. Halal, derived from Islamic law (Sharia), requires that the animal be healthy at the time of slaughter, a prayer be recited, and the blood be fully drained (Sukardi et al., 2022). Kosher slaughter, dictated by Jewish law (Kashrut), similarly mandates a swift cut to the throat, complete blood drainage, and adherence to specific handling protocols (Regenstein et al., 2003). These practices are not only rooted in religious traditions but are also believed to affect the physical and chemical properties of the meat.

The quality of broiler meat is assessed based on various attributes, including tenderness, juiciness, flavor, shelf life, and microbiological safety. Factors influencing these attributes encompass the animal's health, handling, slaughtering method, and post-slaughter processing (Pogorzelski et al., 2022). Even though, the quality of broiler meat is

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a key consideration in the global food industry, as it directly influences consumer satisfaction, industry profitability, and public health (Marchewka et al., 2023). Given the distinctive procedures involved in Halal and Kosher slaughter, there is a growing interest in understanding how these methods impact meat quality compared to conventional slaughtering techniques (Farouk et al., 2014). The scientific community has undertaken numerous studies to evaluate the implications of religious slaughtering on meat quality. These studies often focus on parameters such as pH levels, water-holding capacity, color, texture, and microbial load (Lambooij et al., 2014; Sukardi et al., 2022; Farah, 2020; Della et al., 2021). Broiler meat quality with slaughter methods yet to be study. Therefore, objectives of this study are to: compare the nutritional composition (moisture, ash, fat, protein content) of broiler meat obtained from Halal and Kosher slaughtering methods, Evaluate the physicochemical properties (pH, color, texture) of the meat from each slaughtering method and assess the sensory attributes (aroma, taste, overall acceptability). This comprehensive analysis will provide clear insights into the effects of Halal and Kosher slaughtering methods on broiler meat quality.

II. METHODOLOGY

A. Location

The research was conducted at Nelna Farm (Pvt) Ltd. slaughtering of broilers was done at Nelna Processing Plant, Meethirigala, Sri Lanka. Broiler breast meat samples were analyzed in the Animal Science Laboratory at South Eastern University of Sri Lanka (SEUSL).

B. Sample Collection

Breed of Arbor Acres plus broilers were slaughtered at the age of 38+ days with an average weight of 2.05 kg. 25 birds in each methods were selected randomly from cage and slaughtered. Availability of reagents and laboratory facilities; that sample size was limited to 25 birds per method.

C. Halal Method

Birds were shackled by their legs and hung vertically for easy bleeding, with sharp knife a person cut the neck in jugular vein area (just below the gullet and the core of the neck); saying Bismillah and Allahu Akber. Let the birds for bleeding and did the evisceration.

D. Kosher Method

Investigation was performed to check the abnormalities in the birds and individual slaughtering was performed in the presence of butcher called “Shochet”. Then carcass were soaked in clean water for 30 minutes. After soaking drip and dry in a downward position for a few minutes. After dripping, meat is salted and left to hang for 60 minutes to draw out any remaining blood, then did the evisceration.

E. Storing of Samples

Once the packed carcass’s temperature reaches -32 ^{0}C, which transferred into cold room (T -20^{0}C) and kept for 3 days for the travelling arrangements then transferred to Laboratory in SEUSL for the meat quality parameters’ testing and sensory evaluation.

F. Proximate Analysis

Moisture (Air Dry Oven), Ash (Muffle Furnace), Crude fat (Soxhlet apparatus) and Crude protein (Semi-Automatic Kjeldhal Machine) were analyzed through AOAC Analytical Methods (AOAC, 2006).

G. Physiochemical Properties Analysis

pH, Color and Texture parameters were analyzed in the sample.

1) pH

pH measured by 2 g of samples homogenized with 18 mL distilled water (60 s homogenized). The mixture was filtered by using filter paper then filtrate was determined by using a pH meter (Model: EUTECH) at room temperature (25 ^{0}C).

1) Color

Color was measured by using a KONICA MINOLTA Chroma meter (CR-410). The values of lightness (CIE L*), redness (CIE a*), and yellowness (CIE b*) were determined by deriving the average of the recorded measurements.

2) Texture

Texture was measured using a texture analyzer (Model: TA-XT2) and took the readings of hardness, cohesiveness and sponginess.

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H. Sensory Analysis

The sensory evaluation was conducted using the 9-point hedonic scale to assess various sensory attributes, including color, tenderness, aroma, texture, taste, and overall acceptability of fried chicken. The evaluation involved 30 untrained panelists who were randomly selected from students enrolled in the Biosystems Technology courses at the Faculty of Technology, South Eastern University of Sri Lanka.

The panelists were not provided with any prior training, as the goal was to reflect general consumer preferences. To minimize biases, the panelists were not informed of the exact purpose of the study or the specific parameters being tested. The samples of fried chicken were served in a consistent and controlled environment to reduce external factors that might influence the panelists' perception. Randomization of panelists and sample order was employed to avoid order effects. Each participant received the same piece of fried chicken to ensure uniformity in the evaluation process.

Additional measures to control for potential biases included standardized lighting, temperature, and presentation of the samples. Panelists were also instructed to cleanse their palate between samples, ensuring that previous tastes did not affect their subsequent evaluations

I. Data Analysis

Collected data were subjected normality test and identified as a not normal distribution of data. For that, Mann-Whitney U-Test for the comparisons between Halal and Kosher methods slaughtered meat quality parameters and sensory evaluation analyzed by Friedman test. All statistical analysis were performed by SPSS Ver. 25.0 at the significant level of 0.05.

III. RESULTS AND DISCUSSION

J. Nutritional Analysis of Poultry meat

The proximate analysis was conducted to evaluate the nutritional composition of broiler meat obtained through Halal and Kosher slaughtering methods. The analysis focused on determining the moisture, ash, fat, and protein content of the meat samples. The results are presented in Table 01. There is no significant difference between Halal and Kosher slaughtering methods ($p > 0.05$) in all proximate parameters. Moisture content was high value in Kosher method (77.78 %) and least value for Halal (73.53 %). The mean moisture contents for Halal meat and Kosher meat were in close range to the values (74.16%, 77.42% respectively) reported by Rahman et al. 2019. The moisture content of meat is primarily influenced by factors such as the technique of slaughter, the type of meat, the pH value, and the amount of drip loss. During the slaughtering process, the moisture levels in the meat decrease slightly as a result of the dipole forces acting on the tissues (Varnam & Sutherland, 1995). Due to the greater amount of blood extracted during Halal slaughtering compared to other procedures, the moisture level in Halal meat is slightly lower than in meat from other slaughtering methods (Rahman et al., 2019). Ash content of Halal meat was 3.09 % which higher than Kosher meat (3.18 %). Highest crude fat was recorded in Halal meat (2.07 %) and lowest in Kosher meat (2.05 %). In protein highest value recorded in Halal meat (21.23 %) followed by Kosher meat (21.09 %). According to Rahman et al. 2019 that, the decreased value of non-Halal slaughtered meat may be attributed to protein degradation caused by elevated stress levels. During the process of slaughtering, animals and birds experience significant stress, leading to the release of muscle glycogen into the bloodstream and the creation of lactic acid in the muscles. This mechanism leads to the acidification of muscles and triggers several biochemical changes in muscles after death (Bender, 1992). These alterations result in a reduction in the ability to extract protein, leading to an increase in the loss of nitrogen from muscles and ultimately causing protein degradation. In addition, muscle proteins begin to break down shortly after death as a result of several microbial and enzymatic processes. Due to its preference for efficient blood drainage, the Halal method exhibited lower levels of protein degradation compared to alternative slaughter procedures.

K. Physicochemical Properties

3) pH

The highest pH value was observed in the Halal method (6.03 ± 0.02), while the lowest pH was recorded in the Kosher method (5.91 ± 0.01). And there is a significant different between two methods ($p < 0.05$). The pH of meat is mostly determined by the metabolic condition of the muscle at the moment of slaughter. The levels

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fluctuate correspondingly at the beginning and after the last phase of severity mortis. The elevated pH levels observed at the time of slaughter may be attributed to the tension experienced by the muscles during the struggling of birds following the severing of their necks. During the exertion, the glycogen stores were exhausted, leading to a decrease in the generation of lactic acid in the muscles, which in turn caused an increase in pH levels (Grashorn, 2010).

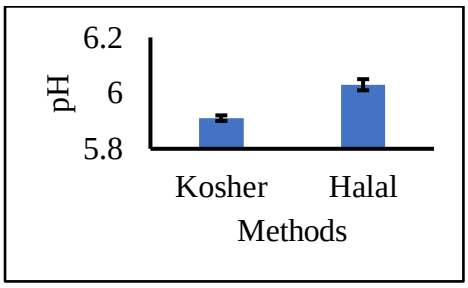

Figure 05: pH of meats

1) Color

The color of meat is strongly associated with the concentration of haem-containing substances, such as myoglobin, hemoglobin, and cytochrome C. Among these three molecules that include haem iron, myoglobin has the most impact on the color of poultry meat (Froning et al., 1968). The myoglobin level in the breast muscle was substantially lower compared to the leg/thigh muscle (Fletcher, 1999). Based on the research there was no significant difference in the redness (8.91 ± 0.57, 9.05 ± 0.44) and yellowness (10.83 ± 0.43, 10.73 ± 0.47) values between the Halal and Kosher slaughtering methods ($p > 0.05$). But significant difference was observed in the lightness of the meat ($p < 0.05$) and Halal slaughtered meat's lightness was 59.62 ± 0.82, Kosher method was 58.39 ± 0.82 (Table 2). The difference in lightness can be attributed to the variation in meat pH; and higher pH level associated with lighter meat color (Wattanachant, Benjakul, & Ledward, 2004). In this research Halal method have high pH (6.03) and lightness than Kosher method.

2) Texture

Texture is the primary sensory attribute that has the most impact on the evaluation of overall quality (Fletcher, 2002). Texture analysis of the meat samples, including measurements of hardness (93.00 ± 1.08, 94.00 ± 1.02), cohesiveness (0.65 ± 0.03, 0.60 ± 0.01) and sponginess (1.49 ± 0.07, 1.58 ± 0.05) revealed that no significant differences between the Halal and Kosher slaughtering methods ($p > 0.05$) (Table 02). These results justified that the slaughtering method does not have a substantial impact on the texture attributes of broiler chicken meat and but get high value of texture in Halal slaughter meat (Rahman et al., 2019). However, it is important to note that other factors such as breed, feed, and pre-slaughter handling, in addition to water-holding capacity and pH, can also influence meat texture (Mir et al., 2017).

L. Sensory Evaluation

The sensory evaluation revealed that (Figure 02), there is no significant different between Halal and Kosher method slaughtered meats ($p > 0.05$); aroma, taste and overall acceptability were recorded high hedonic scale for Halal method (Figure 02). Other parameters except tenderness remain same hedonic scale in both methods. Blood retention and the subsequent development of volatile compounds during cooking has influenced on aroma and taste of the meats that, blood retention negatively effects on aroma and taste (Farouk et al., 2014). Blood retention of poultry meats influenced by pre-slaughter stunning (Gregory, 2005). In this research stunning performed in Kosher method before slaughtering that may influenced the meat quality. Even though both methods were slaughtering by associate humane, that may give same hedonic scale for color and texture; which justified by Kua et al. 2022; Martuscelli et al. 2020, suggesting that consumers may associate humane slaughtering practices with better visual quality of the meat.

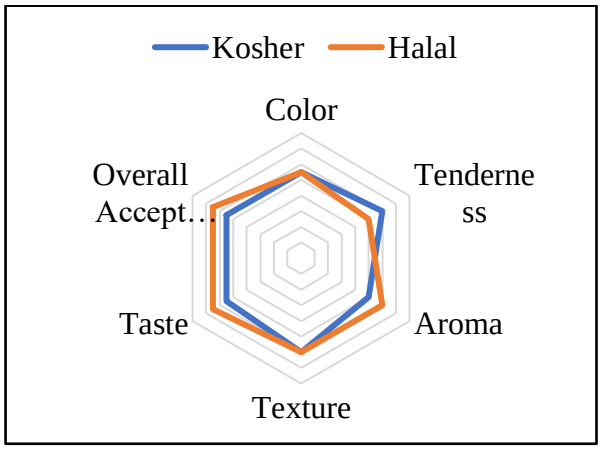

Figure 06: Sensory Evaluation of meats

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IV. CONCLUSION

The findings from this study reveal that both Halal and Kosher slaughtering methods produce broiler meat of comparable quality across most parameters analyzed, including proximate composition, texture, and sensory attributes. While the proximate analysis showed no significant differences in moisture, ash, fat, and protein content, slight variations were observed, with Kosher meat having marginally higher moisture levels and Halal meat showing slightly elevated protein content. These differences are likely due to the specific blood drainage techniques employed in each method. The higher pH and lightness observed in Halal slaughtered meat could influence both the visual appeal and the shelf life of the meat, suggesting potential implications for marketing and storage practices. Sensory evaluation results, where Halal meat scored marginally higher in aroma, taste, and overall acceptability, indicate that subtle differences in meat processing can impact consumer perception and preference.

The small sample size, specific conditions under which the research was conducted, and potential biases inherent in the evaluation processes may have influenced the results. Acknowledging these limitations provides a more balanced view and Indicates the need for further research to confirm these findings across larger samples and different environments. Additionally, the study did not compare Halal and Kosher methods with conventional slaughtering techniques, which could provide a more comprehensive understanding of how these methods stack up against mainstream practices in terms of meat quality and consumer preference.

For the poultry industry and policymakers, these findings suggest that both Halal and Kosher methods are effective in producing high-quality broiler meat, aligning with humane slaughter principles while satisfying consumer expectations. The minor differences observed may be leveraged for targeted marketing strategies that emphasize specific sensory attributes preferred by certain consumer groups. This study contributes to the existing literature by highlighting the subtle but potentially market-relevant differences between Halal and Kosher slaughtering methods, offering valuable insights that can inform product differentiation and consumer choice in a culturally diverse market landscape. These insights underline the importance of considering both religious and cultural practices alongside scientific evidence when shaping industry standards and policies.

Table 01 : Proximate analysis of Halal and Kosher slaughtering methods

[a]

Methods	Moisture%	Ash%	Fat%	Protein%
Kosher	77.78 ± 5.38[a]	3.18 ± 0.51[a]	2.05 ± 0.10[a]	21.09 ± 0.28[a]
Halal	73.53 ± 3.87[a]	3.09 ± 0.53[a]	2.07 ± 0.11[a]	21.23 ± 0.22[a]

superscript, similar superscript not significantly different in column wise at the level of 0.05

Table 01: Color and Texture Parameters of meats from Halal and Kosher slaughtering methods

[a, b]

Methods	Color		
	L*	a*	b*
Kosher	58.39 ± 0.82[a]	9.05 ± 0.44[a]	10.73 ± 0.47[a]
Halal	59.62 ± 0.82[b]	8.91 ± 0.57[a]	10.83 ± 0.43[a]
	Texture		
	Hardness	Cohesiveness	Sponginess
Kosher	94.00 ± 1.02[a]	0.60 ± 0.01[a]	1.58 ± 0.05[a]
Halal	93.00 ± 1.08[a]	0.65 ± 0.03[a]	1.49 ± 0.07[a]

superscript, similar superscript not significantly different in column wise at the level of 0.05

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Development and Evaluation of Low-cost Automatic Incubator that Applied Inverter Technology

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Abstract

An incubator is a device that is used to turn the fertile eggs hatching successfully at suitable environmental conditions by regulating the temperature and humidity of the enclosure. To meet the high demand of poultry production artificial egg hatching is needed. So temperature controls are an important factor for the incubation process. The source of power in an incubator is electrical energy. Energy is limited on earth. So proper use of energy is an important factor. By controlling the temperature and humidity efficiently we can reduce the electrical energy consumption. In this paper, we have discussed energy-saving techniques in hatching incubators which can save energy. The possibility of hatching egg is about 35-40° centigrade but the optimum temperature should be kept at 37.5° centigrade for 21 days and Below 35° centigrade and above 40.5° centigrade no embryo can be survived for hatching. Cooling eggs for short periods says 30-40 minutes out of 24 hours regularly with no harmful effect during incubation and probably profit. So to reduce energy consumption we introduced a power-saving mood that keeps the system shut off for 15-20 minutes within 24 hours during incubation. Using the inverter, we have simulated the backup system which has improved the temperature rise time and settling time compared to the conventional egg incubator. Calculation shows that this system is energy efficient.

Keywords: fertile, temperature, hatching, survived, embryo, simulate,

I. INTRODUCTION

An incubator is most important part of the poultry production process (hatching) and protects the environment conditions. Incubator an insulated enclosure in which temperature, humidity, and other environmental conditions can be regulated at levels optimal for growth, hatching, or reproduction. There are three principal kinds of incubators: poultry incubators, infant incubators, and bacteriological incubators. Incubators are core actors in entrepreneurial ecosystems. Incubator is a device used to grow and maintain microbiological, cell cultural practices. [Boleli, I.C. et al. (2016)]

Incubator based on the working principle that organisms require a particular set of parameters for their growth and development with the optimal condition (under artificial conditions) of temperature, humidity, oxygen, and CO2 levels. Avian incubation is a technique that keeps eggs warm in an artificial environment. An incubator is used for the artificial hatching of eggs; it lets the foetus grow inside without the presence of the mother to provide the conditions for growth and hatching. [J.A. Oluyemi and F.A. Robert,1982.]

The high cost of incubators is a major factor restraining the growth of this market. The higher cost of machines is due to the costly raw material required for egg incubators. Additionally, the energy cost is another hampering factor to this market in the forecast period. [E.A.O. Laseinde, Woye and Sons, 1994] Poultry farming has to face other challenges associated with high vaccination costs, and veterinary care services. [M.E. Ensminger, Poultry Science (Animal Agricultural Series)] The non-availability of credit is another issue affecting this industry. The growing population and increasing consumption of processed food along with government initiatives promoting the consumption of protein-rich diets are expected to increase the demand for eggs. Increasing the hen population would be required to meet the growing demand for eggs. [Hsieh, H. F., and Shannon, S. E., 2005.]

The ability of an incubator to improve the hatchability of eggs further assists the increase of hen population thereby grows up the demand for automatic incubators. [S. Sansomboonsuk, "An Automatic Incubator," J. Energy Research,] At a global level, the market growth for poultry

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consumption will be in-line with the global GDP in the long-term forecast. The increasing disposable incomes and lifestyle standards are further flourishing this industry. [Audretsch, D. B., 2007.] The equipment runs on solar energy and has an efficiency of around 90% for hatching chicken eggs. Such innovations for sustainable products will prevail in the egg incubator market. [Lamine, W., Mian, S., Fayolle, A., Wright, M.,Klofsten, M. and Etzkowitz, H., 2016] Most small-scale egg incubators are domestically fabricated with simple incubation technology and it leads to several complications and less hatching percentages. Egg incubators available in market have not the inverter technology. Hence development of low-cost small-scale incubator with improved technology has become very important Hence, this was an attempt to develop an automatic egg incubator with inverter technology. [Barbero, J. L., Casillas, J. C., Ramos, A., & Guitar, S., 2012.]

II. MATERIALS AND METHODOLOGY

Research was conducted in the School of Agriculture, Kundasale, Sri Lanka and the incubator obtained here was prepared using the following materials and equipments.

A. Materials

Temperature controller, Timer, 220v current indicator, DC fan, holder, bulb, TT wire, 3 core wire, 13A plug top, 12v power supply, 12v to 220v ac inverter, reform box small, tape, turning motor, Switch, Aluminums bar. Measurement tape, Paper cutter, wrench, Screw driver, lighter, Glue gun, Glue stick, revert gun, Bouth Machine, soldering iron.

C. Methodology

The measurement was taken of a regiform box by first (18.5 inches long, 15.7 inches, width, and 14.1 inches Height) was prevented, giving beauty fully covered by yellow color cello tape. The temperature controller, timer, switch, humidity meter, current indicator, and inverter were Arranged and fixed by a plastic tray and lid of the regiform box. Then put some holes on the side of the plastic tray to make air ventilation.

The wires of all devices were connected by the tray. Then fixed the 12-volt DC fan under the lid in the central position (DC fan 4-inch-long and wide,1-inch thickness), (fixing bolt and nut 8mm thickness and 8 inches long). The heat bulb was a fixed lid on the Regiform box between the fan and the lid (We used a motorbike head bulb for a heating source). The PVC pipe bulb holder was fixed by the center of the regiform lid and a small hole in the lid inserted the wire fixed bulb. Power was supplied and the incubator (All controlling devices are connecting the control panel) finally fixed the controlling unit on a regiform box (Take the measurement and fix the middle of the lid) using a 6mm wall plug and glue to fix the control panel.

Figure 01: Regiform box with tools

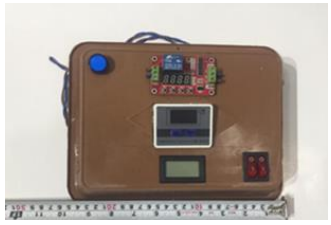

Figure 02: Control panel

Table 01: Cut the entire Aluminum bar for the automatic system with the measurement

Aluminium Bar Type	**Length of the bar**	**Need Quantity**
0.75:0.75 inch L bar	17.7 inches	2 pieces
0.75:0.75 inch L bar	15.7 inches	2 pieces
0.75:0.75 inch L bar	3.5 inches	4 pieces
0.75:0.5 inch L bar	12.9 inches	4 pieces
0.75:0.5inch L bar	13.7 inches	2 Pieces
0.75:0.5 inch L bar	5.9 inches	1 pieces
0.5:0.5 inch u bar	12.5 inches	5 pieces
0.5:0.5 inch u bar	4.7 inches	1 pieces

To develop the automatic system for an incubator, bind 11.7 inches 2 pieces of L bar along with 15.7 inch 2-piece L bar like rectangular shape by rivet gun. It acts as the outer tray of an incubator. Then bind the 12.92 inch 2 pieces of L bars with 13.7

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inch 2 pieces of L bars by rivet gun. It acts as an incubator tray and, after that binds 12.9inch 2 pieces of L bar with 3.5 inch 2 pieces of L bar like before. It's a water-content tray. Connect for H runner with inner tray and joint 12.5-inch U bar 5 pieces with inner tray at 5cm spacing. Fixed the bold and nut in the middle of the motor shaft (1.5-inch-long, 2 inch 3mm thickness bold and nut were used).

III. RESULT AND DISCUSSION

Table 02: Hatching detail

Trail		HATCHING 1 Trail-1		HATCHING 2 Trail-2		HATCHING 3 Trail-3	
Eggs	BOVEN BROWN	15	14	30	27	-	-
	DEKALB WHITE	15	12	-	-	30	27
Total		30	26	30	27	30	27
Percentage (100%)		86.6%		90%		90%	
Average Percentage		88.8%					

This Table 02 was illustrated of three trail hatching percentage of egg, were used to two type varieties of eggs first trail half of percentage brown and white eggs used to measure the percentage of hatching then trail 2 only used to brown eggs, trail 3 only used to white egg and make the calculation.

Table 03: Comparison between My incubator and Company product

.

No	Data	Company Product	New Research Product
1	Incubator Body Material	Out Site Stainless Steel inside Aluminium sheet	Out Site insulation tape inside Regiform
2	Temperature Controller Model	XM -18 E Computerized controlling system 220V AC	W-300 temperature controller 12V-DC
3	Heating Material	electrical heater (500w)	motor bike head bulb
4	Air Ventilation System	AC-220 v 12inch fan	DC - 12 v 4 inch fan
5	Automatic Turning System	45 angle rotation method	rolling type rotation method
6	Automatic Turning System Material	Iron steel	Aluminium bar
7	Electricity consumption	90 unit (21days) 150 watts hour per day	4.2 unit (21days) 0.2 watts hour per day
8	Hatching rate	90-92%	85-90%
9	Hatching time	21days	21days
10	Chicks Quality	Good	Good
11	Cost of Product	75000/=	12500/=
12	Used Technology	Recommendation method	Reducing electricity consumption inverter technology
13	Egg Candler Method	manual egg Candler	manual egg Candler
14	Humidity control	automatic motor	manual hand sprayer
15	Power Source	220V direct current AC/single phase	AC DC 220V-12V inverter 220V AC single phase
16	Egg Capacity	60	30

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17	Total Weight of the Machine	35 Kg	1.8 Kg
18	Incubator Model	AP incubator (India)	My own product
19	Used Parameters		
20	1 – Temperature	37.5C	37.5C
21	2 – Humidity	1-18days 60-65% 18- 21 days 80%	1-18days 60-65% 18- 21 days 80%
22	3 - Turning Time	1 hour interval per 1 turning	1 hour interval per 1 turning
23	4 - Candling time	10-18 days	10-18 days
24	Suitability	large scale farmers	Small Scale Farmers
25	Total Watts	0.2 Kw / hr	0.0083 Kw/hr

This Table 03 was illustrated compared to the marketing products and our research products. The research products low cost and highly efficiency of small scale farmers,

A. Sensory Analysis

Above the quality & quantity parameters are used to develop incubators collection among small-scale farmers. According to their response, 20 customers were selected and given the incubators for trial and data collection. Then collected data were compared with standard incubators using parametric and nonparametric procedures. A 5 point Likert scale was used to evaluate the compatibility of the incubator.

B. Data Analysis

Data analysed by SPSS Software, VERSION – 25, mean separation method is turkey. The Kruskal-Wallis Test analysed all the non-paramedic data.

C. Questionnaire Survey on Developed Tool

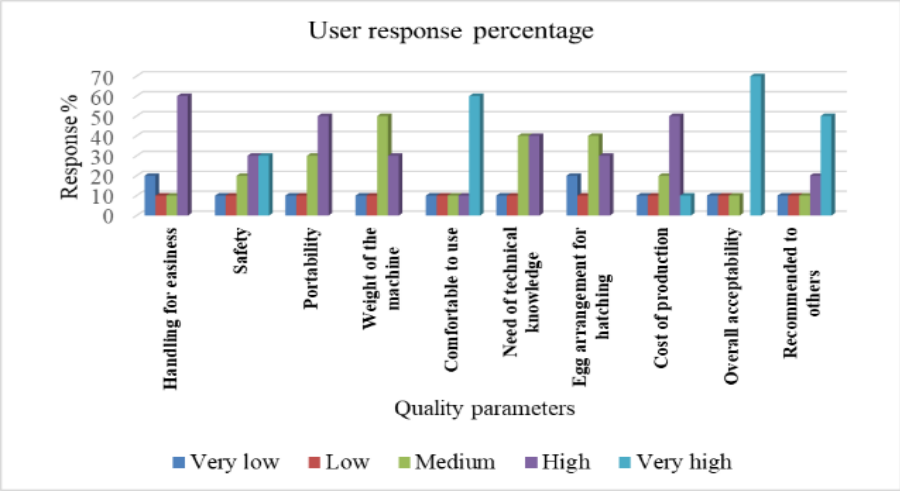

Figure 04: User responses collected through a survey

It was observed that the highest percentage (60%) of respondents highly accepted the handling for easiness, the lowest percentage (10%) of respondents low & medium level accepted and 20% of respondents very lowly accepted the handling for easiness.

An equal percentage of (30%) respondents were highly accepted and very highly accepted (30%) of the safety of the incubator and an equal percentage of respondents were lowly (10%) and very lowly (10%) of the safety and 20 % of respondents were medium level accepted the safety.

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The highest percentage of (50%) respondents highly accepted the portability comparatively lower percentages (10%) of respondents were very slowly and lowly accepted the portability and the remaining 30% of respondents accepted the portability medium level.

The highest percentage of (50%) respondents accepted the weight of the machine as medium level comparatively lower percentage (10%) of respondents accepted the weight of the machine as very low &low level

The highest percentage of (60%) respondents were very highly accepted the comfortable to use. From the remaining 40% of respondents, 10% of respondents accepted the very low level, 10% of respondents accepted the low level, 10% of respondents accepted the medium level & final 10% of respondents accepted the high level comfortable to use.

The highest percentage of (40%) respondents highly and medium level accepted the need for technical knowledge and the lower percentage (10%) of respondents very low & low level accepted the need for technical knowledge

The highest percentage of (40%) respondents were medium level accepted the egg arrangement for hatching and the lowest percentage (10%) of respondents lowly accepted 30% of respondents were high level accepted the egg arrangement remaining 20% of respondents were very low-level accepted.

The highest percentage of (50%) respondents highly accepted the cost of production, a lower percentage (10%) of respondents were very low, low, and very high levels of acceptance and the remaining 20% of respondents were medium level accepted the cost of production.

The highest percentage of (70%) respondents very highly accepted the overall acceptability 10% of respondents accepted very low level, 10% of respondents accepted low level and 10% of respondents accepted medium level

The highest percentage of (50%) respondents very highly accepted the recommendation 20% of respondents highly accepted and from the remaining 30% of respondents; 10% of respondents very low level accepted, 10% respondents accepted low level and 10% of respondents accepted medium level of recommended to others.

D. *Performance of the Machine*

Table 04: Mean value for treatments

Data	Ranks Treatments	No	Mean rank	P-value
Easiness	My incubator	20	15.05	0.000
	Market product	20	5.95	
Safety	My incubator	20	13.30	0.019
	Market product	20	7.70	
Portability	My incubator	20	15.50	0.000
	Market product	20	5.50	
Weight	My incubator	20	5.50	0.000
	Market product	20	15.50	
comfortable	My incubator	20	14.20	0.002
	Market product	20	6.80	
Need of technical knowledge	My incubator	20	5.95	0.000

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	Market product	20	15.05	
Egg arrangement	My incubator	20	10.50	1.000
	Market product	20	10.50	
Cost of production	My incubator	20	5.50	0.000
	Market product	20	15.50	
Overall acceptability	My incubator	20	10.50	1.000
	Market product	20	10.50	
Recommendation	My incubator	20	15.50	0.000
	Market product	20	5.50	

The value represents 5 point Likert scale. The $p<0.05$ is significant for easiness, portability, safety, comfort, weight need of technical knowledge, cost of production & recommendation of the machine, according to fried man test. The $p<0.05$ is not significant for egg arrangement, overall acceptability.

IV. CONCLUSION AND RECOMMENDATION

Performance evaluation of the incubator reveals the above average results; from 30 fertile eggs the average hatchability rate is 88.6%. Cost evaluation of incubator with minimal electricity consumption 4.2 units per 21 days Cost of production also very low compared with market product. So this incubator is highly accepted by farmers. Data collection from farmers also highly satisfied and accepted all the features therefore can highly recommend this incubator applies on inverter technology according to hatchability percentage, electricity consumption, cost of production, and easiness of handling.

In the future, there is a chance to modify the incubator to hold large numbers of egg capacity. Can use batteries instead of current. Can minimize the amount of electricity consumption than now. Can change the heating source and temperature controller instead of the XM -18 computerized controller. Energy storage solutions such as battery or renewable energy sources. Examine the possibility of establishing networks of incubators connected by the Internet of Things to exchange information and insights. Based on the power source renewable energy options are likely to gain attention in forecast years owing to manufacturers' focus on eco-friendly production and cost-effectiveness. With the renewable option, companies can decrease their carbon emission and aid in sustainability development

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TRACK - BIOSYSTEMS ENGINEERING AND AUTOMATION

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Role of Ecological Floating Beds in Nutrients Removal from Polluted Surface Water: A Systematic Review and Bibliometric Analysis

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Abstract

An in-depth understanding of the remediation of polluted water via Ecological Floating Beds (EFBs) is essential, as they are a popular bioremediation technology. The present study intends to identify the existing knowledge on the application of EFBs for nutrient pollutants removal and to provide insights to enhance the efficiency of EFBs performance. By following Preferred Reporting Items for Systematic Review and Meta-analysis (PRISMA) guidelines, 55 articles were retained after an automatic, manual screening and eligibility assessment. The selected articles were subjected to descriptive analysis and keyword co-occurrence analysis using Biblioshiny R and VOSviewer software to identify knowledge in terms of pollutant type, removal mechanism, and performance enhancement means. Accordingly, the key knowledge identified is (1) the main nutrient pollutants removed by EFBs are nitrogen and phosphorous, (2) the promising pathways of nutrient removal are microbial degradation and plant uptake, (3) Proteobacteria is the most abundant bacterial phyla that are involved in nitrogen removal via denitrification (4) the performance of EFBs can be enhanced with the addition of various materials, whereas Zeolite showed profound effects in nutrient removal. The knowledge identified in this study would serve as a source for scholars and many stakeholders who are interested in implementing EFBs for pollution remediation

Keywords: Ecological floating bed, Denitrification, Nitrogen, Phosphorous, Removal efficiency

I. INTRODUCTION

Mineral nutrients primarily nitrogen (N) and phosphorous (P) enter the surface water systems via various routes such as surface runoff that carries dissolved surplus agrochemicals (Huang et al., 2017), eroded soils and sediments from agricultural lands, discharge of secondary effluents and wastewater from wastewater treatment plants and industries (Sun et al., 2020; Sun et al., 2021a, b, Meng et al., 2021), disposal of animals' and birds excretes and feces etc. The resulted higher concentrations of these nutrients cause eutrophication (Beusen et al., 2016; Ahmed et al., 2017; Gao et al., 2017) and water quality deterioration, which is obviously visible with algal blooms, proliferation of aquatic flora and unpleasant odour and colour. Consequently, it results loss of ecological integrity, decreased aquatic biodiversity, disappearance of submerged vegetation, potential production of toxins (Moal et al., 2019) and may end up with the threatening of human health.

To address these adverse effects caused by eutrophication and subsequent pollution, it is necessary to remove the causal nutrients (N and P), which is carried out with many methods and techniques including physical (e.g. filtration, flotation, coagulation, sediment dredging, mechanical aeration) (Chen et al., 2018; Pereira et al., 2018), chemical (flocculation settling, chemical algal killing) (Wu et al., 2011) and ecological (macrophyte remediation, constructed wetland, floating bed) (Walaszek et al., 2018). The Ecological Floating Beds (EFBs), have received much attention and become popular for pollutants removal. This is because, it is a low cost, simple method for construction and maintenance (Li et al., 2018). Moreover, it requires no land and water depth (Gao e t al., 2018) and beautifies the environment (Zhu et al., 2023). Meanwhile the other methods have many drawbacks including low efficiency, short duration, large investment, wide occupation of land (Li et al., 2015), low

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adaptability and stability (Yang et al., 2021) and pollution acceleration through resuspension (Chen et al., 2021).

Even though the EFBs are superior in pollution remediation, their performance is not stable and satisfactory always. In particular, limited biomass and growth of plants subjecting to seasonal changes affects the performance of EFB (Sun et al., 2009; Wang et al., 2018) and they are vulnerable to lower temperature (Cao et al., 2016). Furthermore, the constituents of water being treated are also influence the performance of EFBs. Notably, the higher concentrations of nutrients especially ammonium nitrogen (NH_4^+) (>10 mg/L) cause toxicity to plants, inhibit nitrifying and heterotrophic bacteria (Li et al., 2020), while lower organic carbon content affects the denitrification process. As a result, the traditional EFBs have been found inefficient for treating hyper eutrophic water (Yan, et al., 2021), secondary effluent and wastewater with low C/N ratio (Huang et al., 2020; Sun et al., 2020; Sun et al., 2021a, b). Thus, there is a necessity to improve the performance of EFBs, hence, the scholars have been trying with numerous approaches. In this context, addition of various materials including external carbon source (Huang et al., 2020), biofilm carriers (Yang et al., 2020; Hu e t al., 2020) and electron donors (Sun et al., 2021a, b) are notable approaches that have been found successful in strengthening of EFBs' performance. Specifically, addition of carbon source, prepared by mixing the reed straw powder and polycaprolactone, to the traditional EFB with *Iris wilsonii* increased the average removal efficiencies of Total Nitrogen (TN) (57.6%) and Total Phosphorus (TP) (46.7%) when used to treat the effluent from municipal wastewater treatment plant (Huang et al., 2020). An EFB integrated with tubular reactors, which are filled with biofilm carriers and agricultural waste carbon source (bagasse), showed a stable removal efficiency of 82% for a period of 7 months during treating secondary effluents of wastewater treatment plants (Yang et al., 2020). Sun et al. (2020) stated that denitrification efficiency was nearly 100% with the addition of sufficient electron donors while it was 4-43% without electron donors. EFBs established with complementary substrates (zeolite and sponge iron) efficiently and stably removed N from tail water and the effluent concentration for NH_4^+-, nitrate (NO_3^-) and TN were lower than 1, 1 and 1.5 mg/L respectively (Meng et al., 2021).

Besides, researchers have found that coupling of other technologies such as electrochemical technologies also improved the performance of EFBs. Notably, Yan, et al. (2020) designed an electrolysis integrated EFB with the Mg-Al alloy anode and graphite cathode, placed in the middle of biochar filled polyethylene. This system showed an improvement in removal rates from 26% to 53% and 10% to 76% respectively for TN and TP. The greater removal in integrated EFBs was achieved due to the improved the growth and reproduction of hydrogen autotrophic bacteria and flocculation of PO_4^{3-} with the internally formed Mg^{2+} and Al^{3+} ions. Similarly, EFBs coupled with microbial fuel cell (comprises a biocathode) improved the removal efficiency of NH_4^+ (2-16%) and TN (3-17%) (Yang et al., 2021). These research findings indicate the potential of EFBs for pollution remediation, particularly alleviation of nutrient pollutants. Hence, an in-depth understanding of existing knowledge would be helpful in EFBs related researches to support implementation of this technology. Further, to the best of our knowledge, it is noted that the systematic reviews conducted in this context are limited. Therefore, we attempted to carry out a systematic literature review with the research question; how does an EFB alleviate nutrient pollutants from surface water and two objectives were set. They were (1) to identify the prevailing knowledge on EFBs-based removal of nutrient pollutants from surface water (2) to provide an insight for the means to enhance the performance of EFB for nutrients removal.

II. METHODS

The study used Systematic Literature Review (SLR) process, which consists of three key stages (1) planning (2) conducting review and (3) reporting findings.

A. Article Selection Process

Prior to selecting articles, a clear research question was identified in planning stage, followed by a review protocol was developed and validated. The review protocol developed for this study is given in the Table 01. As the "Preferred Reporting Items for Systematic Reviews and Meta-Analyses" (PRISMA) are preferred for SLRs (Liberati et al., 2009) article selection was carried out as per the PRISMA standards through a series of steps

including identification, screening and inclusion. Flow chart depicted in the Figure 01 describes the article selection process performed according to PRISMA guidelines. Briefly, the databases Scopus and Web of Science were used as information sources to identify the studies to be reviewed in SLR.

Table 01: Review protocol

Article selection method	PRISMA guidelines (PRISMA 2020 checklist)
Search term	Ecological Floating Bed
Inclusion criteria	Year range (2010-2023)
	Document type (Research article)
	Source type (Journal)
	Subject area (All)
	Language (English)
Databases	Scopus (Sc), Web of Science (WoS)
Analysis method	Keyword co-occurrence analysis
Reporting structure	PRISMA guidelines (Overall: PRISMA 2020 checklist, Abstract: PRISMA 2020 checklist for abstract)

The search strategy used in our study was "ecological floating bed". Screening, a crucial step in article selection process for SLR, was performed two times. Automatic screening was carried out primarily with the titles of articles immediately after identification with the existing limiting options of databases. For this purpose, we choose the year range (2010-2023), document type (article), source type (journal), language (English), subject area (all) as inclusion criteria. Subsequently we retrieved 67 articles from Scopus and 48 from Web of Science. Articles remained after automatic screening were exported into MS Excel sheet which contains a list of information including title, abstract, keywords, journal name, authors name, publication year, number of citations etc. Before performing manual screening, information retrieved in different Excel sheets by database wise, were compiled together and checked for duplicates with the conditional formatting option of MS Excel and then identified duplicates were removed. Then, manual screening was carried out with the exported abstracts against the inclusion criteria and the articles that do not meet the inclusion criteria were excluded. After that, full texts of remaining articles were downloaded and assessed for eligibility to be included in the SLR. During eligibility assessment, the articles that are out of scope, non-relevant and unable to access were excluded. Eventually, the articles found to be sound enough in answering the research question were considered and included for the present study.

B. Study risk of bias assessment

Researchers' bias in selection and analysis of articles affect the quality of review (Kitchenham and Charters, 2007). This was eliminated in the present study by adopting a few measures such as designing and following a protocol briefing the inclusion criteria and analysis methods and systematic, objective selection procedure (Xiao and Watson, 2019; Priyashantha et al., 2022) and independent parallel assessment by more than one researcher (Brereton et al., 2007).

B. Methods of analysis

The information in Excel sheet exported from databases were subjected to analysis. Bibliometric analysis was the method of analysis used in the present study, as it is a scientific technique for examining scientific activity in a study (Paule-Vianez et al., 2020). It was performed through Biblioshiny and VOSviewer software. Bibliometric analysis provides scientific maps, commonly known as bibliometric networks. VOSviewer was used to create such maps, where the keywords were considered as the unit of analysis. The relationship between the keywords resulted from their co-occurrences, indicated by the numerous links in the network. VOSviewer visualize this feature in "Keyword co-occurrence network visualization".

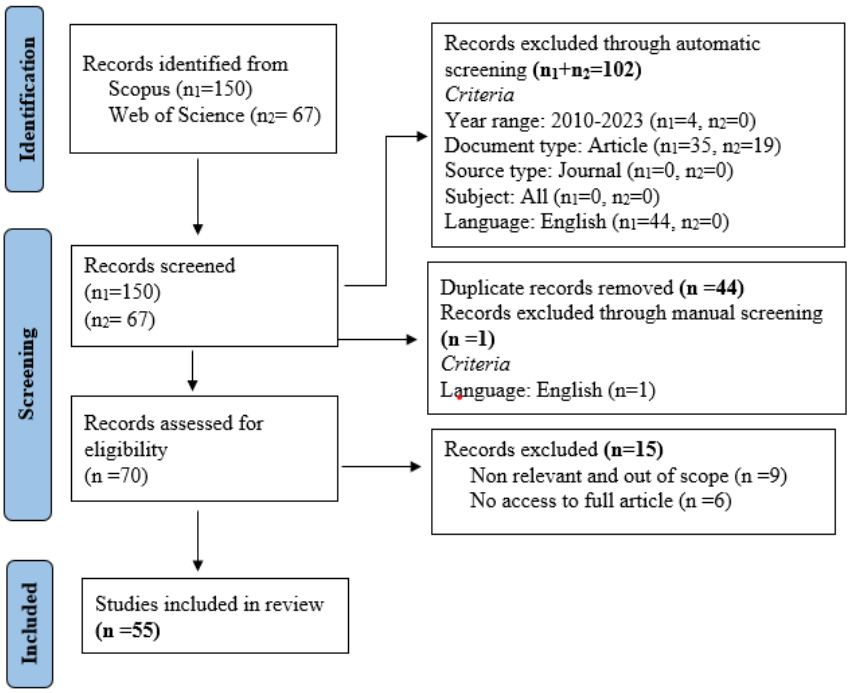

Figure 01: Article selection process

It is necessary to normalize the network visualization so as to gain valuable insight into the area of investigation. So, by default, the VOSviewer produces a two-dimensional network using the association strength normalization. Nodes close to each other indicate strongly related keywords, while nodes far from each other indicate weakly related keywords (Van Eck and Waltman, 2014). A network of clusters was then constructed using the VOSviewer, with nodes related to each other tending to be placed in the same cluster (Chen et al., 2016). Nodes assigned to clusters are indicated by colours in VOSviewer. A cluster may therefore represent a common theme. Since the objectives of our study were to identify the prevailing knowledge and to provide an insight related to application of ecological floating bed in remediation of nutrient pollutants from surface water, the keyword co-occurrence analysis was utilized. In addition, Biblioshiny R software was used to generate preliminary information about the articles included in the review. This includes "year wise published articles", "country wise published articles", and "sources of publication".

III. RESULTS

A. Study selection

With the search term "ecological floating bed" 150 and 67 articles were identified respectively from Scopus (Sc) and Web of Science (WoS) databases. Immediately after identification, 4 articles were excluded from Sc identified article set, as they were not in the range of 2010-2023 and no articles were excluded from WoS article set. Then, as per the 2nd inclusion criteria (document type=research article), 35 (conference papers=26, review=7, erratum=1, retracted=1) and 19 articles (proceeding papers=15, review=4) were respectively excluded from Sc and WoS articles' set. As a result, 111 and 48 articles were respectively retained. Further, as per the 3rd and 4th inclusion criteria, none of the articles were excluded and with the 5th inclusion criteria (language =English), 44 articles were excluded as they were in Chinese language, thus 67 and 48 articles were retained from Sc and WoS articles' set. Thereafter, a number of duplicated articles (n=44) were removed from whole article set (67+48) and one article was removed during manual screening as it was not in English language. Thus, 70 articles were retained and passed for eligibility assessment, during which full text of each article was independently read by the authors. The articles that are not relevant to the study objectives and unable to obtain full text of articles were excluded. Accordingly, 15 articles were excluded and by the end 55 articles were retained for the review.

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B. Study characteristics

This section presents the descriptive information of articles used in the review. The Figure 02 shows how the relevant studies are published over the years. It indicates that a very few articles were published till 2017, and afterwards there was an increasing trend in publication and reached the peak in 2021. Then, there was a decline in the publication of articles related to EFBs based pollution remediation. Furthermore, as shown in the Figure 03, the journal named "Science of The Total Environment" is the most popular platform to publish the studies related to EFBs, followed by the journals "Ecological Engineering" and "Bioresource Technology" provided equal opportunities for publishing this kind of studies. studies, many are considered least popular as they have just published a single article.

Though a number of journals (31) published EFBs based

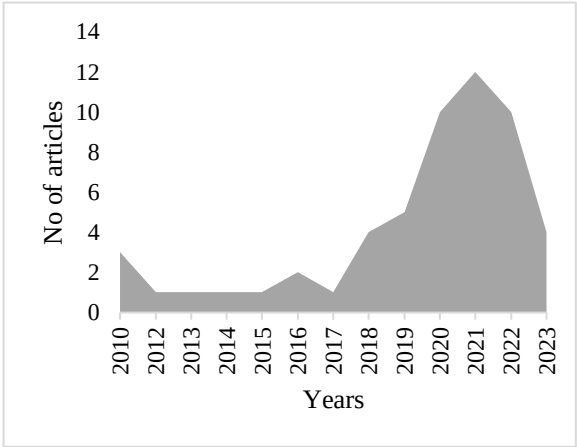

Figure 02: Annual production of articles

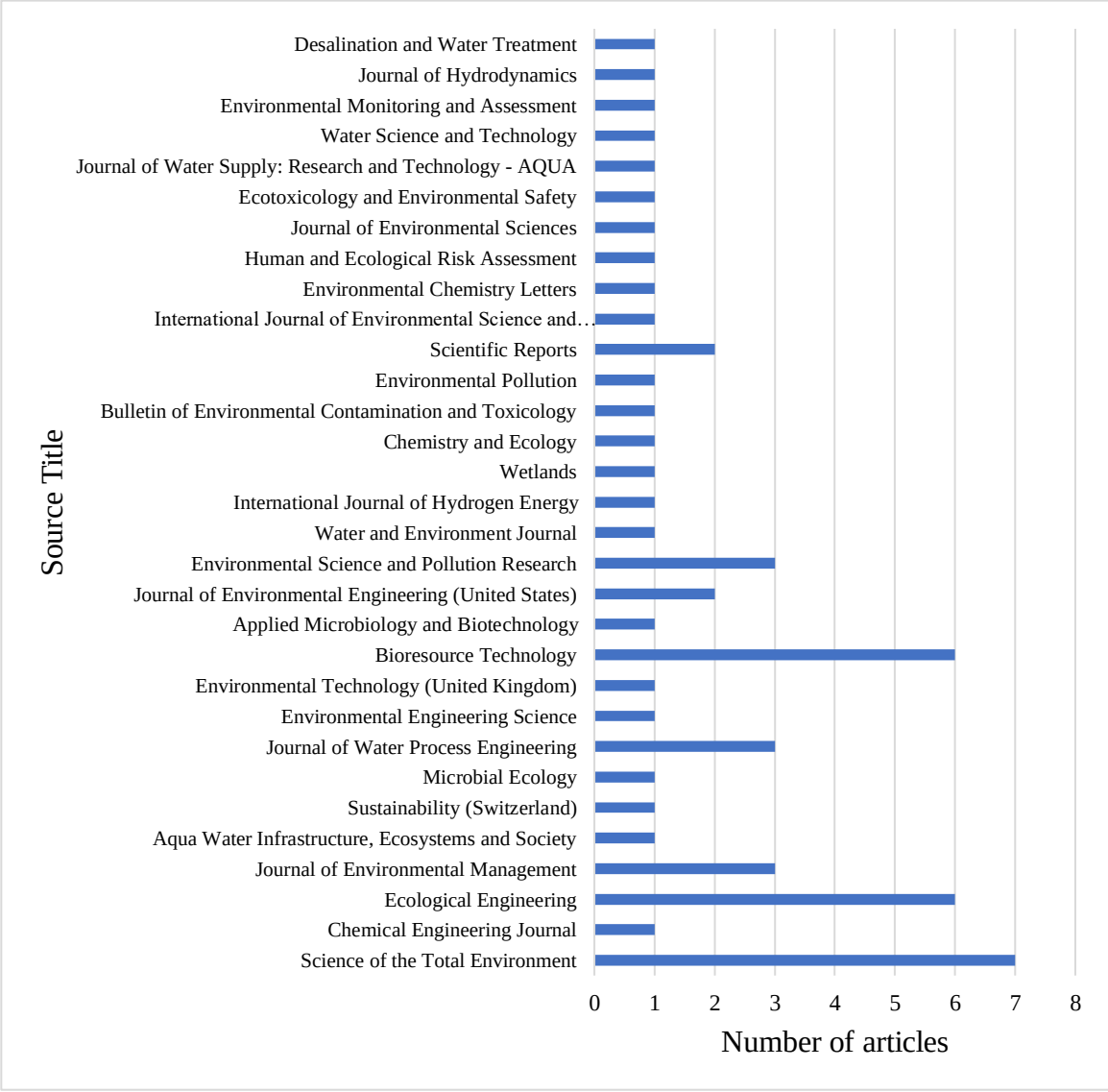

Figure 03: Articles published across different journals

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C. Results of studies

This section reports the findings of bibliometric analysis primarily performed with VOSviewer. Results of analysis help addressing the objectives of the study. Thus, the keyword co-occurrence network visualization map (Figure 04) created with the keywords' occurrences, helps addressing the first objective, which was identifying the prevailing knowledge on application of EFBS for remediation of nutrient pollution in surface water. Keyword co-occurrence network visualization map 1 (Figure 04) created with the minimum occurrences of three provide knowledge on certain aspects. The keywords with their respective occurrences are shown in the Table 02. Out of 13, the keywords "nitrogen, ecological floating bed and phosphorous" are the top three frequently occurred, indicated by larger nodes (Figure 04). These keywords have stronger relationship between them and represented by thicker connection line between the nodes. This is justifiable, because N and P are the most promising nutrient pollutants removed by EFBs from the polluted water.

Table 02: Keywords with the corresponding occurrences

Keywords	Occurrences
Absorption	3
Bacteria	12
Denitrification	12
Ecological floating beds	33
Eutrophic water	8
Nitrate	3
Nitrification	5
Nitrogen	36
Phosphate	4
Phosphorus	25
Plant	5
Total nitrogen	3
Total phosphorus	5

Furthermore, the 13 threshold selected keywords are classified into three clusters and denoted in different colours such as green, red and blue. The keywords fall under one cluster are closely related to each other and represent a common theme. Thus, green, red and blue clusters reflect the themes of "nutrient pollutants removed by EFBs", "removal mechanism of N" and "removal mechanism of P" respectively.

The green cluster comprises five keywords namely nitrogen, phosphorous, eutrophic water, total nitrogen and total phosphorous. N and P are the two key nutrient pollutants present in the eutrophic water (Bao 2015; Wu et al., 2016; Yan et al., 2020; Pan et al., 2021; Zhang, T et al., 2021). EFB, as an eco-friendly water treatment technique restores the surface water quality by removing these nutrients to a certain level. The eutrophic water either natural (Li et al., 2010; Zhang et al., 2012; Bao 2015; Wu et al., 2016; Zhang, T et al., 2021) or synthetic (Cui et al., 2018; Yan, et al., 2021; Cheng et al., 2022; Zhao et al., 2022) were successfully treated with this technique. Removal performance of EFBs is investigated by analyzing various forms of these nutrients, whereas the concentrations of TN and TP in polluted water were the more focused ones (Hu et al., 2010; Sheng et al., 2013; Sun et al., 2017; Gao et al., 2020; Huang et al., 2020; Liu et al., 2020).

Red cluster consists of five keywords including ecological floating bed, denitrification, nitrification, nitrate and bacteria. Ecological floating beds, as a bioremediation technique, have been widely employed to remediate various kinds of polluted water including wastewater (Cao and Zhang, 2014; Gao et al., 2020; Peng et al., 2021), secondary effluents (Yang et al., 2020; Sun et al., 2021a, b; Sun et al., 2022) and eutrophic water (Lyu et al., 2020; Zhu et al., 2023). Microbial nitrification and denitrification are the primary pathways of nitrogen removal in EFB systems (Cui et al., 2018; Song et al., 2019; Peng et al., 2023), where the microorganisms especially bacteria, serving as ecological factor, convert the NH_4^+ into NO_3^- and then into N_2 and N_2O, in turn reduce the N load from polluted water.

The blue cluster comprises three keywords such as plant, phosphate and absorption. Nutrients dissolved in water like phosphate are taken up by plants directly. Subsequently, plant absorption is considered as one of the main P removal mechanisms in EFB systems (Samal et al., 2019; Kumwimba et al., 2022; Sun et al., 2022; Zhang et al., 2023).

Ultimately, the network visualization map 1 disclosed the knowledge primarily about the main pollutants removed by EFBs and their mechanisms. There was no information identified regarding objective 2. Thus, the minimum occurrences of keywords were changed into two and keyword co-occurrence analysis was again performed. As a result, 20 threshold keywords were selected and utilized to create the keyword

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co-occurrence network visualization map 2 (Figure 05), which helped addressing the second objective. The keywords were categorized into three clusters of red, green and blue. The Table 03 shows the keywords grouped into different clusters with their respective occurrences.

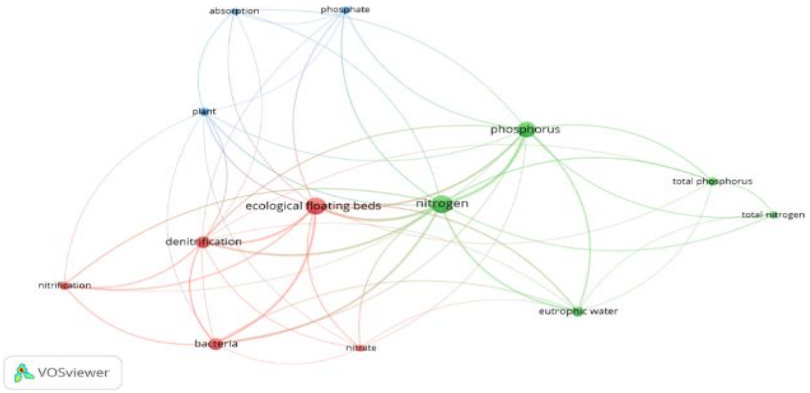

Figure 04: Keyword co-occurrence network visualization map 1

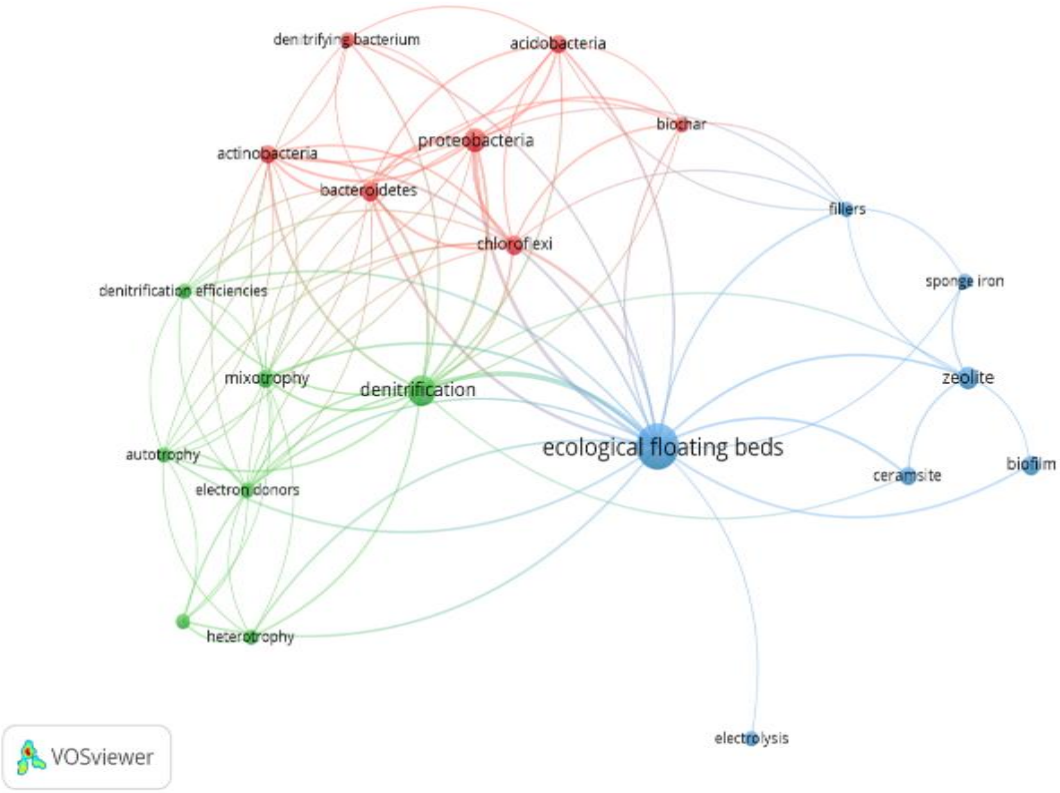

Figure 05: Keyword co-occurrence network visualization map 2

Since denitrification is a main microbial process associated with pollution remediation by EFBs and contributed greatly for N removal from polluted water, keywords related to denitrification are categorized into one cluster (Green). However, inadequate supply of electron donors from organic matters limits the denitrification in EFBs, therefore it is necessary to add electron donors externally to improve denitrification efficiency. Denitrification that occurs in the EFBs are of either autotrophic (Sun et al., 2020; Yan, et al., 2020; Sun et al., 2021a, b) or heterotrophic (Sun et al., 2020; Sun et al., 2021a, b; Cheng et al., 2022; Peng et al., 2023; Qiu et al., 2023) or mixotrophic

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(Sun et al., 2020; Sun et al., 2022; Peng et al., 2023), depending on the electron donors involved in denitrification process. Iron scraps, as an autotrophic electron donor, added into the conventional EFBs enhanced the N removal by improving mixotrophic denitrification processes (Sun et al., 2020; Sun et al., 2022; Peng et al., 2023).

Meanwhile, keywords belonging to red cluster reflect the common theme of abundant bacterial phyla. As denoted by larger node in the Figure 05, proteobacteria was found to be the most dominant bacterial phyla involved in N and P removal processes when EFBs are used in bioremediation (Nandy et al., 2022; Kumwimba et al., 2022; Qiu et al., 2022; Liu et al., 2022; Song et al., 2022; Zhang et al., 2023). The other bacterial phyla abundantly present in EFB systems are Bacteroidetes, Chloroflexi, Acidobacteria, Actinobacteria (Nandy et al., 2022; Kumwimba et al., 2022; Zhang et al., 2023).

Though, EFBs are successful in bioremediation, their removal performances were restricted by the growth rate and limited stand biomass of plant (Sun et al., 2009; Wang et al., 2018) and low temperature (Cao et al., 2016). Thereby, inclusion of various physical, chemical and biological materials in EFB systems helped enhancing the performance of EFBs in nutrient pollutants alleviation. Keywords fall under blue cluster namely zeolite (Kumwimba et al., 2022; Zhu et al., 2022), biofilm (Sheng et al., 2013; Pan et al., 2021), ceramsite (Song et al., 2019; Zhao et al., 2022), sponge iron (Wang et al., 2018; Meng et al., 2021; Zhu et al., 2023), fillers (Wu et al., 2016; Song et al., 2022) and electrolysis (Yan et al., 2020; Yan, et al., 2021) are the mostly used materials and processes in EFBs performance enhancement. As these keywords share a common theme, reflecting the means for improving the performance of EFB, those can be regarded as "performance enhancers" of EFBs.

Table 03: Keywords with corresponding occurrences

Cluster	Keywords	Occurrences
Red	Acidobacteria	3
	Actinobacteria	3
	Chloroflexi	4
	Denitrifying bacterium	2
	Bacteroidetes	4
	Biochar	2
	Proteobacteria	6
Green	Autotrophy	2
	Electron donors	2
	Mixotrophy	3
	Heterotrophy	2
	Denitrification	12
	Denitrification efficiencies	2
	Iron scraps	2
Blue	Biofilm	4
	Ecological floating beds	33
	Electrolysis	2
	Ceramsite	3
	Fillers	2
	Sponge iron	2
	Zeolite	5

III. DISCUSSION

The present study was centered answering the research question; how does EFBs remediate nutrient pollutants from surface water? Thus, the first objective was set to identify the prevailing knowledge on EFB-based remediation of nutrient pollutants while second was to provide an insight for the means to enhance the performance of EFB for nutrient pollutants removal from surface water. We identified six themes complying the objectives of the study with the keyword co-occurrence analysis from the keyword co-occurrence network visualization maps 1 and 2 (Figure 04-05). The knowledge identified with
the themes is discussed below in different sub titles.

***Types of pollutants*:** As reflected by the theme 1 (Green cluster in keyword co-occurrence network visualization map 1) the most common nutrient pollutants removed by EFB systems are N and P. Remarkably, 89.7% and 81.2% of TN and 94.4% and 75% of TP were reduced in EFBs planted with water spinach and sticky rice respectively from a polluted tidal river (Sun et al., 2017). EFBs planted with *Canna* and *Calamus* (Cao and Wang, 2014) and *Oenanthae javanica* (Zhou and Wang, 2010) decreased TN concentration respectively from 17 mg/L to 5.23 mg/L and from 12.58 mg/L to 1.16 mg/L. Hence, Zhang, T et al. (2021) reported that EFBs with *Ipomea aquatica* removed TP at a rate of 0.021 mg/L/day. Other than the TN and TP, EFBs were found successful in alleviating the other forms of nitrogen including NH_4^+, NO^{3-}

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and PO_4^{3-} (Dai et al., 2018; Lv et al., 2019; Yan, et al., 2021; Ni et al., 2022)

***Removal mechanisms*:** The researchers have declared that volatilization, sedimentation, adsorption, plant uptake and assimilation and microbial degradation and or assimilation are the most promising pathways for nutrient pollutants removal via EFBs (Gao et al., 2017; Sun et al., 2020; Sun et al., 2022). Amongst, microbial degradation (nitrification/denitrification) and plant absorption were found to be the main mechanisms, as reflected by the themes 2 and 3 (Red and blue clusters in keyword co-occurrence network visualization map 1) in traditional as well as functional EFBs. However, in general, contribution of plant absorption for nutrients removal is less (<30%) compare to microbial transformation, especially for N removal. For instance, N removal by plant uptake accounted for 29.3% and 27.8% respectively in floating bed zone and strengthened floating bed zone (Wang et al., 2018). Similarly, the aquatic plants (*Ipomea aquatica*) in the integrated EFBs took up 9.6% of TN to increase their biomass, while it was 8.3% for TP (Zhang, T et al., 2021). These findings confirm the smaller contribution of plant absorption in N removal. However, contradictory results also were observed, in particular, Cui et al., (2018) reported that plant absorption was the main pathway for N removal in conventional (80.5%) and enhanced EFBs (46.3%) with *Cyperus alternifolius* during treatment of hyper eutrophic water. Furthermore, Zhang et al. (2023) recorded a removal of 0.3 kg of P via plant assimilation when treating the rural river with *Oenanthae javanica* planted EFBs. *Oenanthae javanica* plants in EFB absorbed the P from the system and 1.85 g/m^2, 1.65 g/m^2 and 2.11 g/m^2 of TP were accumulated into stem, leaf and root tissues respectively (Zhou and Wang, 2010). Hence, Wang et al. (2018) observed 27.79% removal of P in the floating bed zone of via plant uptake. The nutrient removal via plant uptake primarily depends on plant characteristics (e. g. growth rate) and initial concentration of nutrients (Cui et al., 2018)

On the other hand, microbial degradation played major role in nutrient removal. Especially, N in the polluted water is removed through the processes of nitrification and denitrification, depending on the available N form. For instance, microbial degradation accounted 19.5% and 23.2% for N and P removal in conventional EFBs, while it was 49.9% in enhanced EFBs respectively (Cui et al., 2018).). Furthermore, it was noted that N removal via microbial degradation occurs to a greater extent in EFBs than that of other removal mechanism like plant assimilation, sedimentation etc. For an instance, the N removal via microbial transformation was found to be greater (0.5 $g/m^2/d$) than the removal via plant uptake (0.02 $g/m^2/d$) in EFBs with *Myriophyllum aquaticum* (Kumwimba et al., 2022). Similarly, microbial degradation and assimilation accounted 57.2% for N removal in the lake when EFB coupled with microbial electrochemical system was employed, while plant uptake accounted only 1% (Qiu et al., 2023). Out of the two processes of microbial transformation, denitrification is prominent for N removal. Notably, denitrification accounted 72.5% in an integrated EFB, comprised of aquatic plant (*Ipomea aquatica*), aquatic animal unit (*Hyriosis cumingii*) and bacteria-algae unit that used to treat eutrophic water (Zhang, T et al., 2021). Hence, Saunders and Kalff (2001) also stated that 80% of N is removed via denitrification. It is an anaerobic process that occurs at the Dissolved Oxygen (DO) level below 1 mg/L (Tallec et al., 2008) and mediated by denitrifying bacteria either autotrophic or heterotrophic.

***Ecological factors involved in nutrients removal*:** Plants and microorganisms are referred to ecological factors in EFBs responsible for removal of nutrient pollutants from polluted water (Wu et al., 2016). According to the literature available, a wide range of plants have been used in EFBs. *Acorus calamus, Canna indica, Cyperus alternifolius, Ipomea aquatica* and *Iris pseudacorus* are a few widely employed plants in EFBs due to their unique characteristics such as higher removal capacity, cold resistance and landscaping effect (Yang et al., 2020; Nandy et al., 2022; Song et al., 2022; Peng et al., 2023). On the other hand, microbes present in the water, rhizosphere and other materials added into the EFB systems take part in the nutrient removal. As the microbial transformation is being the main route for nutrient removal, various N and P cycling bacteria including ammonifying, nitrifying, denitrifying, oxidizing bacteria involved for N and P removal in EFBs. These bacteria can be of either heterotrophic or autotrophic depending on the source that use to derive the energy (Reflected by the theme 4 in green cluster in network

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visualization map 2). Furthermore, researchers have investigated how nutrient removal is achieved in EFBs by these microbes. Accordingly, it has been found that the abundance of microbial communities has increased during pollution mitigation accompanied with EFBs (Nandy et al., 2022; Kumwimba et al., 2022; Zhang et al., 2023). As reflected by the theme 5 (red cluster in network visualization map 2), microbes primarily bacteria belonging to phylum "Proteobacteria" were abundantly present in EFBs (Wu et al., 2016; Zhang et al., 2023). This is because the nitrogen cycling bacteria belong to proteobacteria (Chu and Wang, 2016) since microbial degradation (nitrification/denitrification) is the main pathway for N removal. Next to Proteobacteria, Bacteroidetes, Chloroflexi, Actinobacteria and Acidobacteria were found to be the abundant bacterial phyla in EFBs. EFBs not only improve the abundance of microbial communities, but also the richness (Kumwimba et al., 2022), stability (Liu et al., 2022) by providing the essential matters (e. g. oxygen, carbon source and attachment site) for their growth and proliferation and these facets of microbial community are influenced by the season, location, hydraulic properties like flow velocity (Song et al., 2022; Zhang et al., 2023) and physiochemical water quality attributes such as temperature, pH and DO (Read et al., 2015; Mu et al., 2021).

Means to enhance performance of EFB: Since the traditional EFBs rely on aquatic or terrestrial plants, they have certain limitations during bioremediation, primarily their performance is less due to poor growth rate and limited stand biomass of plants (Cui et al., 2018; Liu et al., 2019) and low temperature (Cao et al., 2016). Researchers have studied the alternatives to enhance the performance of EFBs. It was found that various materials added into the conventional EFBs serve as either substrate for growth of plants and microbes or electron supplier, carbon source or attachment site for biofilm growth, in turn increased the pollutant removal (Table 04). Different materials have different capabilities due to their specific characteristics.

As reflected by the theme 6 (Blue cluster in network visualization map 2), zeolite was the frequently investigated material (Cui et al., 2018; Wang et al., 2018; Song et al., 2019; Lin et al., 2019; Zhu et al., 2022; Meng et al., 2021; Kumwimba et al., 2022) for their effect on pollutant removal enhancement. Zeolite as an adsorbent due to its cation exchange, coprecipitation and interception abilities (Wang et al, 2020a, b), showed a good removal of NH_4^+ and PO_4^{3-}. For example, EFB integrated with zeolite and limestone has increased the removal efficiency to 63.5%, 59.3% and 68% respectively for TN, TP and NH^{4+} (Cui et al., 2018). Likely, EFBs suspended with zeolite had a highest purification efficiency of 92.8% for NH_4^+ than the conventional EFBs (46%) (Kumwimba et al., 2022). Meng et al. (2021) also noted the superior effect of EFBs with zeolite for NH_4^+ removal than the traditional EFBs during treating simulated tailwater. Potential of zeolite in EFBs enhancement is extensive as it acts as a biofilm carrier and a filler too and the corresponding applications are discussed in below sections.

Followed by zeolite, biofilm occurred frequently, thus integration of biofilm either inert or biodegradable carriers is considered effective in strengthening the performance of EFBs. In particular, a semi-soft assembly medium (combination of molded plastic ring and polypropylene rayon fibers) as a biofilm carrier was integrated into EFBs with *Ipomea aquatica* and freshwater bivalve and reported to have higher mean removal efficiency of 45.1% and 47.3% for TN and TP respectively (Li et al., 2010). An EFB consisted of hydroponic *Chlorophytum comosum* and biofilm attached to the polymeric fibrous carrier removed 50% of TN and 57% of TP (Pan et al., 2021). In addition to the inert biofilm carriers such as plastics, fibers, elastomeric fillers (Meng et al., 2021) biodegradable or substrate-based biofilm carriers (e.g., rice straw, zeolite, ceramsite, sponge iron, plant litter) found potential in EFBs performance enhancement, as they play multiple roles. These include (i) accommodate the microbes on to their inner and outer surfaces and form biofilm mass (Li et al., 2018; Xiao et al., 2015) (ii) provide organic substrate (C) for microbial metabolism (Nandy et al., 2022) (iii) support plant growth by providing nutrients (Bi et al., 2019). Notably, addition of zeolite helped removal of NO_3^- even at lower temperature (5-15°C) due to higher adsorption of microbes over its larger specific surface area (Meng et al., 2021).

According to the literature, ceramsite, sponge iron and filler materials also received attention to be utilized in strengthening the performance of EFBs. Ceramsite is a material, prepared with direct

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crushing and burning of natural mineral or industrial waste as raw main material. Li et al. (2018) studied the effects of Ceramsite based Ecological Floating Beds (CFBs) utilizing ceramsite as substrate for macrophytes in aquaculture water quality improvement and reported lower concentration of NH_4^+, TN and TP in CFBs applied ponds than the control ponds without CFBs. Additionally, ceramsite used in EFBs found potential for not only nutrient pollutants alleviation but also in the removal of heavy metals such as V, Cr and Cd (Lin et al., 2019).

In terms of fillers, various types of fillers either organic or inorganic (e. g. biochar, drinking water treatment residual, sponge iron, stereo elastic packing, wood chip, zeolite) have been employed in EFBs through suspending them (Wang et al., 2018; Song et al., 2019; Kumwimba et al., 2022). Recently, it is evident that combination of more than one filler enhanced the performance of EFB rather using single filler due to their complementary effects. For instance, N and P concentrations were lower in the water in the Strengthened Ecological Floating Bed zone (SFB), which was treated with SFB with zeolite and sponge iron (Wang et al., 2018). As reported by Guo et al. (2020), a mixture of zeolite and biochar fillers significantly improved N and P removal. Similarly, EFBs with the combined fillers of zeolite, biochar, woodchip, stereo elastic packing, water treatment residual had highest purification efficiencies for NH_4^+ (99.8%), TN (99.2%) and TP (98.4%) (Kumwimba et al., 2022). In addition to the above-mentioned materials, electrolysis technique also become popular for enhancing the performance of EFBs. Noticeably, lower concentrations of NH_4^+, NO_3^- observed in closed circuit (connected Microbial Electrochemical System (MES)) than those of open circuit, implied that MES enhanced the nutrient removal via EFBs due to enrichment of functional bacteria in a short time during treating urban water in black odorous artificial lake (Qiu et al., 2023).

Table 04 : Materials used to improve the performance of EFB

	Removal Efficiency/Removal Rate (%)					
Materials	**Nitrate**	**Ammonia**	**Total Nitrogen**	**Phosphate**	**Total Phosphorous**	**References**
Freshwater bivalve (*Corbicula fluminea*) and semi soft assembly medium (Biofilm carrier)			45.1		47.3	Li et al., 2010
Dredged sludge		44.3	36.3		35.7	Hu et al., 2010
Fiber fillers	69.5 (62.4)	49.2 (35.3)	49.3 (29.8)			Wu et al., 2016
Zeolite and Sponge iron	72.96 (63.58)	89.98 (77.39)	80.76 (75.80)	92.49 (79.55)	84.44 (73.93)	Wang et al., 2018
Elastic plastic fillers	24.67 (12.04)	77.64 (58.13)				Dai et al., 2018
Mixture of Zeolite and limestone		91.5 (83.2)	82.8 (70.7)		73.9 (67.5)	Cui et al., 2018
Efficient Phosphorus Removal Composite (EPRC) (Prepared with fly ash and steel slag)				0.97(0.87)	0.93(0.83	Liu et al., 2019
Rice straw biocarrier	93.18 (34.54)	93.5 (24.67)	76.94 (34.76)			Cao and Zhang, 2014

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Plastic filling (Polymethyl methacrylate)	75.24 (34.54)	19.83 (24.67)	43.94 (34.76)			Cao and Zhang, 2014
Mixture of Iron scraps and Plant biomass	29.14					Peng et al., 2023
Calcium peroxide, Sponge iron	54.72 (9.43)	52.23 (27.27)	59.83 (33.05)	96.55	89.09	Zhu et al., 2023
Rice straw	78	82				Nandy et al., 2022
Zeolite		92.8				Kumwimba et al., 2022
Water treatment residual		88.6				Kumwimba et al., 2022
Biochar		84.2				Kumwimba et al., 2022
Fiber fillers		32.19-55.99	33.89-54.26			Song et al., 2022
Alum sludge ceramsite		58.1 (32.4)	46.7 (27.2)		53.2 (25.8)	Zhao et al., 2022
Embedded pellets of a heterotrophic nitrification aerobic denitrification bacteria (*Pseudomonas* Y1)			73.58 (33.82)			Cheng et al., 2022
Iron scraps (Zero Valent Iron)	50.9 (34)		47.6 (31.2)			Peng et al., 2021
Sodium acetate, Sodium thiosulfate	>90%	15-40%	70-85%			Sun et al., 2021a
Electrolysis (Mg-Al Alloy Anode)		91.2	87.1	96.4		Yan, et al., 2021
Biofilm attached to polymeric fibrous carrier			50		57	Pan et al., 2021
Iron scraps			57-79% (46-56)			Sun et al., 2021b
Electrolysis (Mg-Al alloy anode, graphite cathode)		96.5 (94.5)	53.1 % (26.7)	74.5 (8.9)	76.5 (10.54)	Yan et al., 2020

IV. SUPPLIMENTARY INSIGHTS

A. Factors influencing nutrient removal in EFB

1) Temperature

Temperature is one of the extrinsic factors that influences nutrient removal performance of EFBs, as the physiological and biochemical activities of plants and microorganisms are temperature dependent. In terms of N removal, both nitrification and denitrification are temperature sensitive. The conducive temperature for nitrification is 25-30°C (Wang et al., 2018), where the survival of nitrite oxidizing bacteria is optimum. Temperature shows positive correlation for denitrification (Sun et al., 2020), and 20-30°C was found to be optimum for denitrification (Sun et al., 2020; Sun et al., 2022; Peng et al., 2023) as it is conducive for growth and activity of denitrifying bacteria. The extremes of temperature (low and high) affect these microbial processes and lead to reduced N removal. For example, higher temperature (>30°C) observed during stage II impaired the nitrification and resulted lower NH_4^+ and TN removal in EFBs coupled with microbial fuel cells (Yang et al., 2021). Further, lower temperature (<25°C) observed in phase V, resulted lower TN removal efficiencies in traditional EFBs and functional EFBs with electron donors due to reduced denitrification (Sun et al., 2021b). Likely, poor denitrification due to limited growth and activity of denitrifying

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bacteria was observed in EFBs at lower temperature (<20°C) (Sun et al., 2022; Peng et al., 2023). Sun et al. (2021a) also observed a decline in TN removal efficiencies in EFBs enhanced with electron donors at lower temperature (<20°C), even though the Hydraulic Retention Time (HRT) was 3 days. Furthermore, temperature indirectly affects the DO and both are inversely proportional to each other. Thus, denitrification become poor at lower temperature due to higher DO as it competes with NO_3^- for electrons during reduction process, where denitrification is strictly anoxic (<1 mg/L DO) (Tallec et al., 2008). Poor denitrification at lower temperature as a result of higher DO was observed by Peng et al. (2023) and Sun et al. (2021a, b). To cope up these adverse effects of temperature, addition of many materials including iron scraps (Sun et al., 2021b), sponge iron (Meng et al., 2021), porous carriers like zeolite (Song et al., 2019; Meng et al., 2021) and extension of HRT (Yang et al., 2021), have been found possible means to improve the nitrogen removal.

2) *HRT/ Water Exchange Period*

HRT simply refers to the time interval over which the water is retained without changing inside the reactors/containers/digestors. This influences nutrient removal by affecting the contact between the nutrients in the water and microbes. The effects of HRT on nutrient removal in EFBs were studied by a few numbers of researchers. In particular, Li et al. (2010) evaluated the effects of water exchange on purification efficacy of an integrated EFBs (IEFBs) employing plant, fresh water clam and biofilm carrier. They evidenced an increase in removal efficiency for TN (26.3-52%) NH_4^+ (19.7-33.7%) and TP (32.8-54%) with the increase in water exchange period from 3 to 5 days. This is because that the assimilation of nutrients (N and P) by plants, microbes and bivalves, microbial degradation of N and inorganization of particulate P could be enhanced in prolonged water exchange period. Similarly, TN removal efficiencies of EFBs suspended with fillers such as iron scraps and plant biomass also increased by 20% when the HRT extended to 3 days from 2 days (Peng et al., 2023). Moreover, a decline in effluent concentrations for NH_4^+, NO_3^- and TN was observed from 1.4-0.3 mg/L, 6.5-2.6 mg/L and 8.2-3.2 mg/L respectively with the increase in HRT 1-3 days and highest TN removal occurred at 3 days HRT in iron based EFBs (Sun et al., 2022). Sun et al. (2021a) also noted that regardless of the electron donor used, more N removal occurred in 3 days HRT than that of 2 days HRT. These findings imply that HRT of 3 days is conducive to complete denitrification and higher N removal can be achieved at this HRT at a temperature around 21°C, if the influent has a good mixture of NH_4^+ and NO_3^-.

On the other hand, it was found that the higher nutrient removal is possible even at shorter HRT when other physiochemical parameters especially temperature and DO substantially influence the effects of HRT. For instance, the higher water temperature (26.8°C) observed during 1 day HRT, resulted more N removal due to increased denitrification when NO_3^--N was the main constituent in influent (Sun et al., 2021a). Hence, Sun et al. (2021b) also reported the similar effects of HRT on performance of EFBs for N removal, which means effluent NO_3^- content was low (2.74 mg/L) at 3 days HRT in EFB supplemented with iron scraps. However, due to higher water temperature, effluent $NO_3^-$was low (6.55 mg/L) at 1 day HRT than at HRT of 2 days (7.18 mg/L).

3) *Forms of influent N*

N in the raw water comprises of NO_2^-, NO_3^-, NH_4^+ and each form of N is removed via different routes, primarily NO_3^- via denitrification and NH_4^+ either via nitrification or plant uptake. A very few studies focused investigating the effects of influent N form on its removal performance of EFBs. In particular, Sun et al. (2021b) observed higher TN removal when the main influent N was NO_3^-, implying that NO_3^- nitrogen removal via denitrification contributed more for TN removal. Further, with the decrease in influent NO_3^- (vice versa in NH_4^+), there was a decline in TN removal efficiency in both traditional (56-46%) and functional EFB (79-57%) due to reduced NO_3^- load for denitrification. A decline in NO_3^-removal was observed by Sun et al. (2022) with the decrease in influent NO_3^-. Similarly, Sun et al. (2021a) also observed a decrease in TN removal in EFBs added with different electron donors such as sodium acetate (79-49%), sodium thiosulfate (81-46%) and iron scraps (79-46%) with the increase and decrease of influent NH_4^+- and NO_3^- respectively. Further, with the increase in influent NH_4^+-, N removal pathway changed to nitrification and ammonium nitrogen removal increased. A higher NH_4^+ removal resulted a higher TN removal (35% higher than that of NO_3^--based influent) when the main influent nitrogen was NH_4^+ (Dai et al., 2018). From these results, it is noteworthy to conclude that, depending on

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influent forms of N, different N removal routes dominate and contribute to TN removal. Accordingly, denitrification is the dominant pathway when the influent has higher NO_3^-, while nitrification dominates in the influent with higher NH_4^+ for TN removal. In general, TN removal occurs via the combination of nitrification and denitrification and to achieve a good TN removal efficiency, there should be a mixture of NH_4^+ and NO_3^-in water. Moreover, in addition to N load, the operational conditions including pH, temperature and DO influence the contribution of each pathway.

VI. CONCLUSION

The nature-based bioremediation technique called EFBs removes the nutrients pollutants especially different forms of N and P from various polluted water sources. As the plants and microbes are the two main ecological factors involved in EFBs, the plant assimilation and microbial degradation processes dominate the removal mechanisms of these nutrients and contributed to a greater percentage of removal. The performance of EFBs is not consistent always and exhibit a wider range of efficiency for pollutants removal subjecting to variation in the type of water being treated, type of plants employed in EFBs and the operation conditions such as temperature, DO level, HRT etc. Furthermore, inclusion of various materials has found enhancing the performance of EFBs, whereas the zeolite is the widely utilized material. Besides, during this study, secondary pollution from decaying plant components and sediment and plant lodging were identified as the major challenges in EFBs based water treatment. This can be minimized through the frequent harvesting of plant biomass and stabilization of nutrients in sediments.

Even though, this study has comprehensively expressed the existing knowledge of EFBs, restricted article search for open access and two databases are considered limitations of this study which open an avenue for future studies. Further, it was noted that EFBs have not been utilized well by the developing countries in water treatment due to lack of community awareness, knowledge, skills, facilities and responsible authorities. Therefore, considering the potential benefits of EFBs in pollution remediation, it is advised to promote their applications though the awareness campaigns at smaller and larger levels. Further, young generation should be motivated and provided with in-hand training for efficient designing and handling of EFBs. By addressing the limitations and challenges, application of EFBs as well the benefits attained from this kind of study can be expanded in future.

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TRACK - CROP SCIENCE & TECHNOLOGY

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Beetle Pests in Sri Lanka: Current Challenges, Knowledge and Emerging Threats to Agriculture and Biodiversity

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Abstract

Beetles represent a significant portion of Sri Lanka's biodiversity, with 115 families (ca. 3,033 species) documented, making them the largest faunal group on the island. The larval and adult phases of about 75% of beetle species are phytophagous and considering their significant damage to economically important crops for agriculture. Substantial agricultural yield is lost each year due to rapid insect infestations could significantly impact national food availability. It is extremely necessary to document insect pests in the country fundamental to pest management strategies. This review focuses on enhancing the understanding of major beetle pest species that affect crops such as vegetables, fruits, grains, coconut, rubber, rice and tea. The review encompasses 60 species from 14 families, with a predominant presence of pests from the Chrysomelidae, Scarabaidae, Curculionidae, Cerambycidae and Meloidae families. Recent field observations suggest significant damage to cashew plants in Wanathawilluwa. Phytophagous beetles significantly impact vegetable crops in the Solanaceae and Cucurbitaceae families by feeding on soft tissues. Larvae contribute to damage by attacking roots and stems, causing necrosis. Within families Coccinellidae, Carabidae, and Cicindelidae, many beetles exhibit predatory behaviours, while some demonstrate phytophagous tendencies as opportunistic feeders. Beetle pests in families Curculionidae, Cerambycidae, and Scolytidae are predominantly associated with woody crops. Understanding the economic pest status of these beetles and their sporadic population dynamics is crucial due to past outbreaks in neighbouring countries, highlighting potential risks to agriculture and ecosystems.

Keywords: Beetle, Pests, Agriculture, Crops, Phytophagous

I. INTRODUCTION

Coleoptera commonly known as Beetles are the most diverse group of animals on earth. They encompass almost 25% of all defined animals (Powel, 2009; Sharma, et al., 2019). The diversity of beetles is very wide with a cosmopolitan distribution; they are found in all habitats with a few in marine settings, except in extreme environments (Banerjee, 2014; Springer, 2009). Sri Lanka, a tropical island exhibiting remarkable biological diversity thus is designated as one of the world's biodiversity hotspots along with the Western Ghats of India (Myers et al., 2000). According to the numerical records, 3,033 species of coleopterans belonging to 115 families are documented from Sri Lanka (Bambaradeniya, 2006).

The larval and adult phases of about 75% of beetle species are phytophagous (Gullan & Cranston, 2010). Since most beetles are herbivores, and then considering their significant damage to economically important crops for agriculture, forestry, and household settings, are often deemed as one of the most destructive groups of pests worldwide (Gilliott, 1995; Patole, 2017; Kailash, et al., 2015). The percentage of beetle species that are pests is relatively low. However, they are particularly significant in tropical countries like Sri Lanka, where the environment and cropping conditions favor their development. The country's agricultural sector accounts for approximately 7% of the national Gross Domestic Product (GDP), with more than 30% of the country's population employed within the agriculture sector (ITA, 2024). Addressing the increasing food demand driven by population growth is a paramount global concern, but the substantial agricultural yield is lost each year due to rapid insect infestations (Bandara & Harshana, 2019). Insect pests inflict damage on crops at different growth stages, leading to annual losses ranging from 25% to 30%, which could significantly impact national food availability (Bandara & Harshana, 2019). Thus,

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research must focus on major insect pests and their outbreaks which is fundamental for the implementation of pest management strategies (Bandara & Harshana, 2019).

The fall armyworm (*Spodoptera frugiperda*) (Order Leoidoptera) was the worst pest infestation in the country's history which led to a substantial yield loss in 2018 over six months in corn (Hettiarachchi, et al., 2024; Wijerathna, et al., 2021; Perera, et al., 2019). Over 50% of the cultivation (54,416 hectares) has been infested in Uva, Eastern, and North Central provinces (Perera, et al., 2019). In 2020, a sporadic increase in crop-damaging yellow-spotted grasshoppers (*Aularches miliaris*) was recorded in the North Western Province in coconut and rubber cultivations (Rodrigo, 2020). A similar outbreak was reported on coconut plantations in Gampaha, Kegalle, Kandy, Kalutara, Colombo, Kurunegala, Ratnapura, Puttalam, and even the southern province of *Aleurodicus dispersus* (Spiralling whitefly) in 2019, resulting in considerable net yield loss (Silva, 2022). Rice, the primary food crop grown in Sri Lanka, is predominantly affected by the brown plant hopper (*Nilaparvata lugens*), leading to annual imports of milled rice ranging from 20,000 to 600,000 tonnes (Bandara & Harshana, 2019). There is an equal tendency to spike the beetle population to an endemic proportion in terms of past experience with the sudden emergence of some beetle species and the sporadic increase of the population in regional countries during past decades. Nevertheless, this scenario is expected to further intensify mainly due to climate change (Bentz et al., 2010; Jakoby et al., 2019). Recent researches have shown that such outbreaks have increasingly challenged traditional responses, and highlight the need for a more comprehensive management framework (Hlásny et al., 2021). Therefore, it is extremely timely and necessary to document insect pests in the country, starting with a particular class or order and then expanding to other classes and orders. This review focuses on efforts made to understand some of the major coleopteran pests in the country, providing detailed accounts of their host plants, distribution, and the nature of the damage they cause.

II. COLEOPTERAN PESTS OF MAJOR CROPS

The faunal communities within the Chrysomelidae, Cerambycidae, and Curculionoidae families are frequently deemed pests, primarily targeting agriculturally vital vegetable crops. Beetles of the family Scarabaeidae exhibit phytophagous tendencies with a diverse array of feeding behaviors. For instance, Dynastinae primarily feed on stems or roots, Cetoniinae consume sap, fruit, and flowers, Rutelinae target foliage, fruit, and flowers, while Melolonthinae feed on foliage. The soil-dwelling larvae of chafers predominantly consume live roots and have the potential to kill seedlings, mature plants by reducing the drought tolerance (Jackson & Klein, 2006). The prevailing observation indicates that the majority of species in coleopteran families, Coccinellidae, Carabidae, Cicindelidae primarily engage in predation, preying upon other insects and associated organisms serving as natural enemies. While numerous species exhibit phytophagous tendencies, many are opportunistic feeders, consuming a diverse array of food sources, damaging by sucking the sap from the flowers, buds, pods, tender shoots and reduce the market value of the products (Carvalho, et al., 2010; Cornelisse, et al., 2013).

A. Coleopteran Pests of Vegetables, Fruits, and Grains

Leafy vegetables constitute a vital element of the Sri Lankan diet and have been subjected to commercial cultivation. Flea beetle, *Chaetocnema* spp. (Chrysomelidae) has been recorded as an economically significant pest of green leaves (Table 01), serving as a primary threat to Mugunuwanna (*Alternanthera sesilis* L.) (Wahundeniya et al., 2005; Marasinghe and Nishantha, 2018). Flea weevil, *Tachyerges* spp. (Curculinoidae), has been identified as a new pest of leafy vegetables, Mukunuwenna (Hackston, 2020). This pest has been identified as an occasional threat to leafy vegetables across three districts, with particularly high leaf damage observed in the Gannourwa area during July-August 2017. Laboratory studies show that it can also damage various other leafy vegetable crops (Table 01) (Kumari, et al., 2022). A sweet potato flea beetle, *Chaetocnema confinis* Crotch. (Chrysomelidae) was discovered, causing extensive damage to Kankun (*Ipomoea aquatica*) in

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the Gannoruwa area during January-February 2018, reaching 100% crop loss. The damage initially appeared as whitish streaks on the leaves, progressing to yellow and brown discoloration, ultimately resulting in the complete destruction of the crop. Feeding studies confirmed that this species did not damage Mukunuwenna. These findings validate the existence of the invasive flea beetle species, *C. confinis*, within Sri Lanka, that not previously been documented (Kumari, et al., 2022).

Mohamedsaid (1979), studied the taxonomy of blister beetles (Meloidae) together with seasonal and geographic distribution and compared the meloid fauna of the island with rnainland India. *Mylabris pustulata* (Thunberg) is recorded as the most commonly collected species of Meloidae in Sri Lanka (Mohamedsaid, 1979). The species are geographically distributed throughout the island with the greatest abundance in regions receiving between 50-100 inches of rainfall annually, with peaks of abundance in April, June, and August (Mohamedsaid, 1979). According to Singh, et al., (1968) adult beetles recorded as a serious pest of cucurbitaceous crops and soybeans. Bhagwat (1995), surveyed Pigeon pea variety pests in Sri Lanka, covering six districts in farmers' fields and on Mahailluppallama research station and observed *Mylabris* sp. and Jewel beetles (*Sphenoptera* sp.) (Buprestidae) damaging pigeon pea stems seriously. Thuvaraka and Pakeerathan (2023), studied on eco-friendly management of hadda beetle, (*Henosepilachna* spp.) (Coccinellidae) which is a significant insect pest in brinjal cultivation across northern Sri Lanka. This polyphagous pest targets economically vital crops of the Solanaceae and Cucurbitaceae families (Table 01). *Epilachna vigintioctopunctata*, another phytophagous coccinellid, commonly known as the Epilachna beetle or cucurbit beetle, is a significant pest of cucurbitaceous and solanacaeous crops in Sri Lanka. Both the adult and larva of this beetle feed on the epidermal tissues of leaves, often stripping them down to the midrib, which can lead to the death of the plant (Karunaratne & Arukwatta, 2009). Mayadunnage, et al. (2007), conducted an extensive survey of predatory coccinellid beetles in vegetable-growing areas in the Mid Country, Sri Lanka, and recorded 15 different species belonging to 12 genera.

Abeywardhana and Dangalle (2021), conducted a survey on Arboreal Tiger Beetles (Cicindelidae) in Lowland Crop Cultivations in Sri Lanka, marking the first documentation of such beetles in crop cultivations in the country. Among the notable findings, *Derocrania scitiscabra* was the most commonly encountered species in betel leaf cultivation in the dry zone of Aralaganwila. Additionally, other species of the genus *Derocrania* were found in fruit farms in Vellankulam, and were observed in cinnamon and pepper cultivations in Waulpane (Table 1). Furthermore, observations by Jaskula (2013), indicate that tiger beetles may exhibit vegetarian feeding behavior during periods of low prey availability, admitting both suitable prey and vegetarian food sources. Additionally, reports indicate that species of the *Neocollyris* and *Tricondyla* genera lay their eggs on young branches of Arabic coffee and Liberian coffee trees, suggesting a potential reliance on specific plant species in Sri Lankan crop cultivations for their life cycle completion (Abeywardhana, et al., 2021). The larval stage of *Holotrichia serrata*, (sugarcane white grub), is recognized as a significant threat to sugarcane crops in Sri Lanka. In September 2012, an epidemic of this beetle was noted in soybean, cotton, and pigeon pea environments in Vidarbha, India (Dadmal, et al., 2013). Besides sugarcane, it poses a significant threat to various vegetables (Table 1). Observations in Sri Lanka have revealed that the grubs feed on the tap roots of teak seedlings, causing affected plants to wither and eventually perish, widely recorded from Sabaragamuwa province (Bandara, 1990; Bunalski, 1995). *Holotrichia reynaudi*, *Holotrichia rufoflava*, species of dung beetles recorded from the island, especially from Western and North Western provinces, and is considered as major pests on Peanuts, *Arachis hypogaea* in India (Kumar, et al., 2020; Bunalski, 1995). *Adoretus versutus*, commonly referred to as the rose beetle, originates from Oriental regions and is prevalent in numerous Asian countries, including Sri Lanka. The larvae of these beetles pose a threat to the roots of wild turmeric. Capable of triggering outbreaks, this pest can cause extensive defoliation across various crops (Table 01). A notable case occurred in Vanuatu, where the rose beetle was introduced in 1982 on Efate Island and inflicted significant damage in 1988 and 1989 on Espiritu Santo Island (Beaudoin, 1992). The Sri Lankan weevil, *Myllocerus undecimpustulatus*

undatus Marshall (Curculionidae), native to Sri Lanka, was initially recognized as causing damage to the leaves of winged bean, *Psophocarpus tetragonolobus* (Shanthichandra et al., 1990). The weevil considered as a pest of more than 20 crops. The larvae feed on plant roots for approximately one to two months. It is unclear which plants serve as hosts for the larvae, but they have been successfully reared in laboratory conditions using pepper, eggplant, cotton, carrot, and sweet potato roots. The leaf-feeding adults exhibit a wide host range, including native, ornamental, vegetable, and fruit species (Neal, 2013) (Table 01). Another *Myllocerus* species, *Myllocerus viridanus*, grey weevils, (Curculionidae), constitute a significant pest native to Sri Lanka and India, with a broad spectrum of host plants (Table 01) (Butani, 1979). Thangavelu et al. (1974), documented severe outbreak on *Corchorus olitorius* L., a type of green leaves used in Ayurveda, originating from Tamil Nadu. Additionally, it has been established as a pest of Moringa (*Moringa pterygosperma* Gaertn) (Kotikal & Math, 2016).

B. Coleopteran Pests of Coconuts

The coconut is an economically significant crop that plays a crucial role in social and cultural activities in Sri Lanka. It is cultivated in 92 countries globally, with Sri Lanka ranked as the fourth-largest producer (Winotai, 2014). Beetle pests have emerged as a significant threat to coconut cultivation by damaging flowers, feeding on nuts, roots, and seedlings (Table 01). The coconut leaf miner (*Promecotheca cumingii*) (Hispidae), first recorded as a beetle pest of coconuts in Sri Lanka in 1970 (Perera, 1979), was initially observed in Dehiwala but soon spread to other areas in the Western, Southern, and Northwestern Provinces. Although it is controlled by natural enemies, occasional outbreaks have been recorded. Apart from coconuts, *P. cumingi* has been reported to attack arecanut, swamp palm, sago palm, royal palm, and oil palm, although in Sri Lanka it has only been detected on coconut, oil palm, and royal palm (Perera, 1979) The Plesispa beetle, scientifically known as *Plesispa reichei* (Chrysomelidae), was first reported in 1997 from Badalgama in Gampaha District, and it has since become widespread throughout the coconut triangle (CRI, 2006). The Red Palm Weevil was first discovered in the early 20th century in South and Southeast Asia. In Sri Lanka, it is a significant pest that causes severe damage to young coconut palms aged 3–10 years. Reports indicate that around 10% of young coconut palms in the country are lost each year due to its attacks (Table 01) (Kumara, et al., 2015). The *Oryctes rhinoceros*, (Scarabaeidae), commonly known as the rhinoceros beetle or coconut black beetle, targets developing fronds of tropical palms across Asia (Kumara, et al., 2015).

C. Coleopteran Pests of Tea

Xyleborus fornicatus Eichh., a twig-boring ambrosia beetle (Scolytidae), was first documented as a tea pest in 1868. It inflicts two types of damage: primary injury through the construction of galleries in stems, which can cause branch breakages, and secondary injury from wood rot, ultimately weakening the tea plants (Walgama, 2012). *Euwallacea perbrevis* Schedl, known as the shothole borer (Curculionidae), has been a significant pest of tea in Sri Lanka and India for more than a century. It is also economically important as a pest of avocado. Since the early 1900s, Sri Lankan tea growers have been plagued by this insect, which creates galleries inside the wood of the terminal branches of the tea crown (Liao, et al., 2023).

D. Coleopteran Pests of Rubber

The larvae of the Cockchafer beetle, *Melolontha* spp. (Scarabaeidae), pose a significant threat to rubber cultivation by feeding on rubber roots. Grub infestation reached endemic propotions during 2002 in Awissawella area destroying young rubber clearings which have spread to the Ratnapura, Kegalle and Kalutara districts presently. They consume lateral roots and can also damage the cortex of the taproot, leading to shoot dieback (Gurusinghe, 2019).

E. Coleopteran Pests of Rice

According to Perera and Karunaratne (2015), grain losses during storage, primarily caused by various agents of grain deterioration, range from 4% to 6%. Among these losses, 80% are attributed to insect infestations (Table 1). In Sri Lanka, rice weevil (*Sitophilus oryzae*), grain moth (*Sitotroga cerealella*), and red flour beetle (*Tribolium casteneum*) are identified as highly damaging pests of stored paddy and rice, and *Sitophilu* spp., is recognized globally as the most significant pest affecting stored paddy and rice (Perera & Karunaratne, 2015) which two species have been recognized in Sri Lanka (DOA, 2024). Pathak and Khan (1994), listed *Coccinella repanda*

(Thunberg) (Coccinellidae), a ladybird beetle as feeding on rice plants in Sri Lanka (Table 01).

Table 01: Coleopteran pests of major Agricultural crops in Sri Lanka

Species Name	**Family**	**Host Plants**	**Nature of Damage**	**Reference**
Protaetia alboguttata (Vigors)	Scarabeidae	Karonda (*Carissa carandas)*, Star fruit (*Averrhoa carambola)*, Brinjal	Feed on the flesh of the fruit by gouging with the horn in the front of the head and burying 3/4th of mouth parts into the fruit, Feed on tender shoots, flowers and flower buds during early morning,	(Jayanthi, et al., 2017)
Red pumpkin beetle *Aulacophora foveicollis* (Lucas)	Chrysomelidae	Cucumber, Bitter gourd, Sponge gourd, Ash gourd, Pumpkin, Melon	Feed on the leaf blade, perforate giving appearance of lace, eventually defoliated, Flowers and fruits are eaten and cut, larvae attack the roots and stems causing necrosis	(Khursheed and Raj, 2020)
Coccinella transversalis	Coccinellidae	Beans, Cotton, Mustard, Brinjal, Groundnut, Cabbage	Adults and nymphs cause damage by sucking the sap from the flowers, buds, pods, tender shoots	(Mayadunnage, et al., 2007), (Rajan, et al., 2018)
Rose beetle *Adoretus versutus*	Scarabeidae	Cashew, Taro (*Colocasia esculenta*), *Citrus* sp., Ginger, Cowpea, Radish	Perforate the leaf lets starting from the middle without destroying the ribs, make depressions in the border of the areas eaten, feed in the early hours of the night	(Beaudoin, 1992)
Mango ash weevil *Myllocerus discolor*	Curculionidae	Maize, *Citrus* sp., *Sorghum bicolor*, Brinjal, Soyabean	Feed on leaves, nibbling the leaves from the margins and eaten away small patches of leaf lamina	(Das and Das, 2016)
Myllocerus subfasciatus	Curculionidae	Brinjal	Damage leaves forming characteristic leaf notch symptoms, The grubs are subterranean and cause root damage resulting in wilting, drying and death	(Shanmugam, et al., 2018)
Apogonia blanchardi	Scarabeidae	Greengram, Cocova	Feed on the leaf from the peripheral region	(Calcetas, et al., 2021)
Pulse beetle *Callosobruchus chinensis*	Chrysomelidae	Bean, Black gram, Chickpea, Pigeonpea, Pea, Cowpea	Lay eggs on green pods and the larva bore through pod and feed on the developing seed, the insects continue to feed, emerge to adults and cause further infestation in harvested yields	(Arora, 1977; Singhal, 1986; Sirinivasan, et al., 2008)

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Xyleborus perforans	Curculionidae	Jackfruit, Citrus spp., Cashew, Coconut	Bore into the xylem of the plant, and carry with them symbiotic fungi which grow in the galleries, and upon which the adults and larvae feed	(Rabaglia, et al., 2020; Winotai, 2014)
Scymnus latemaculatus	Coccinellidae	Mustard, Cabbage, Cauliflower, Potato, Turnip, Bottle gourd, Brinjal, Okra, Wheat	Both grubs and adults feed on upper surface of the leaves	(Janakiraman and Booth, 2021), (Ali, et al., 2018)
Henosepilachna septima	Coccinellidae	Bitter gourd , Ribbed gourd, Bitter Melon	Both grubs and adults feed on leaves, stem and fruit throughout the crop stages and results in skeletonizing the leaves	(Naz and Inayatullah , 2013), (Ganga, et al., 1985)
Sri Lankan weevil *Myllocerus undecimpustulatus undatus Marshall*	Curculionidae	*Citrus* sp., Pepper, Strawberry, Eggplant, Cotton, Carrot, Sweet potato	Feed on leaves inward from the leaf margins causing the typical leaf notching. When the leaf material is almost completely defoliated, where the weevil has fed along the leaf veins	(Neal, 2013)
White grub *Holotrichia serrata*	Scarabaeidae	Peanut, Pegion pea, Arecanut, Potato, Jack fruit, Soybean, Sugarcane, Tobacco, Rubber, Rice	Feed on plant roots, causing yellowing, do not show immediate symptoms of damage resulting lifespan yield losses	(Bhattacharyya *et al.*, 2017)
Grey weevil *Myllocerus viridanus*	Curculionidae	Cashew, Ranawara *(Cassia auriculata L.)*, Tora (*Cassia tora* L.), Key lime (*Citrus aurantifolia)*, Sweet Potato, Drumstick, Curry leaves, Eggplant	Feed on leaves nibbling the margin and eating away small patches of leaf lamina and larvae feeds on the fibrous rootlets of the host plant	(Rajan and Ghosh, 2019) (Butani, 1979)
Flea beetle *Chaetocnema spp.*	Chrysomelidae	Mugunuwanna, (*Alternanthera sessilis linn*.) Thampala (*Amaranthus candatus*), Nivithi (*Spinacia oleracea*), Koora thampala	Damage upon the leaves by chewing, resulting formation of small round holes which appears as windows due to the presence of epidermis	(Kumari, et al., 2022).
Flea weevil *Tachyerges spp.*	Curculinoidae	Mugunuwanna, Thampala, Koora thampala	The adult prefers younger leaves for feeding, while the larvae create mines in mature leaves	(Kumari, et al., 2022)
Flower feeder *Mylabris pustulata*	Meloidae	Wax gourd , Field pumkin, Chinese Okra, Sponge Gourd (*luffa aegyptiaca*), , Peanuts, beans, Pumpkin, Okra, Zea mays, Mango	Feeding on buds, flowers, fruits, pollen tender leaves which leads to affect the fruit setting	(Rao, 1954), (Sharma and Singh, 2016), (Raju, et al., 2016) (Joshi and Gaur, 2019)

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Mylabris thunbergii	Meloidae	Okra, peanut, Pigeon pea, Ceylon spinach (*Talinum fruticosum),* Blackgram (Vigna mungo), Cowpea (*Vigna unguiculata*), Greengram	Feeding on leaves, floral parts; petals, pollen, stigma secretions, and tender developing pods	(Durairaj and Ganapathi, 2003)
Hadda beetle *Henosepilachna vigintioctopunctata* F.	Coccinellidae	Tomato, Potato, Eggplant	Both the adult and larval stages feed on the epidermal tissues of leaves, flowers, and fruits	(Jamwal *et al.*, 2017) (Thuvaraka and Pakeerathan, 2023)
Cashew-tree borer *Plocaederus ferruginea*	Cerambycidae	Cashew	Grubs feed on cambium tissues stopping sap flow	(Wijetunge, et al., 2016)
Stem boring grey beetle *Apomecyna saltator*	Cerambycidae	Minor pests of cucurbitaceous vegetable crops	Grubs bore the stems and make tunnel inside, Adults feed on the soft portions of the stem	(Fernando & Abhayawardena, 1991; Kumar, et al., 2022)
Mango stem borer *Batocera rufomaculata*	Cerambycidae	Mango, Durian, Jackfruit, Mulberry, Papaya, Apple	Grubs enter stems, creating tunnels that dry shoots and entire trees, resembling burned foliage in severe cases, significantly reducing yield	(Atapattu, 2015; Magar, et al., 2022)
Banana pseudostem weevil *Odoiporus longicollis* Oliver	Curculionidae	Monophagous pest of Banana plants	Larvae feed on pseudostem by tunnelling. In most of the cases the larvae goes deep into the pseudostem, adults are found to feed under the leaf sheaths	(Justin, et al., 2008)
Cherry stem borer *Aeolesthes holosericea* Fabricius	Cerambycidae	Cherry, Mulberry Apricot, Crab apple, Guava, Peach, Pear, Plum and Walnut etc.	Newly hatched grubs consume bark and create zigzag galleries before boring into and feeding on the sapwood.	(Patole, 2017)
Derocrania scitiscabra	Cicindelidae	Coconut cultivation mixed with pepper, Betel cultivation	Exhibit vegetarian feeding behavior during periods of low prey availability	(Abeywardhana, et al, 2021; Jaskula, 2013)
Derocrania concinna Derocrania schaumi Tricondyla granulifera	Cicindelidae	Fruit farm consisting of Mango and Cashew		Abeywardhana, et al, 2021)
Coffee stem borer *Xylotrechus quadripes* Chevrolat	Cerambycidae	Coffee	The larvae bore into the coffee stem, killing the young plants	(Patole, 2017)
Coffee-berry borer *Hypothenemus hampei* Ferrari	Scolytidae	Robusta and Arabica Coffee	Adult female attacks coffee berries and bore a hole into the coffee berry and then make galleries in the seeds where the eggs are deposited	(Patole, 2017)

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Adoretus celogaster	Scarabaeidae	Coconut	Attack seedling leaf	(Winotai, 2014)
Phyllognatus dionysius F.	Scarabaeidae	Coconut	Attack mature plant leaves	(Winotai, 2014)
Oryctes rhinoceros L.	Scarabaeidae	Coconut, Oil palms, Date palms, Screwpine (*Pandanus*), Ornamental palms	Mature plant leaf eaters, reduced leaf area which influences nut production, with attack greater on tall, mature trees, from about 5 years of age onwards.	(Kumara, et al., 2015; Winotai, 2014)
Rhabdoscelus obscurus	Curculionidae	Coconut	Bore into the stem	(Winotai, 2014)
Asiatic red palm weevil *Rhynchophorus ferrugineus* Olivier	Curculionidae	Serious pest of Coconut, oil palms, date palms, sago, other species of Palmae	Feeding larvae bore into the crown of coconut and destroy it, outer leaves turn chlorotic and die, this gradually spreads to the innermost leaves, the trunk becomes tunneled and weakened	(Kumara, et al., 2015; Winotai, 2014)
Coconut leaf palm hispid *Plesispa reichei*	Chrysomelidae	Minor pest of coconut	Attack young palms around 3-4years old. both adults and larvae feed on young unopened leaflets and make feeding scars paralleled to the main vein, attack the tips of recently unfolded leaflets of mature plants	(Winotai, 2014)
Coconut weevil *Diocalandra frumenti* Fabricius	Curculionidae	Coconut palm, Date palm, Oil palms and Sorghum	The grubs attack all parts of the coconut palm particularly the roots, the leaves, and fruit stalks. As a result there is premature fruit fall	(Patole, 2017)
Rice root weevil *Echinocnemus oryzae*	Curculionidae	Rice	Both grubs and adult consume rice plants, grub stage reduce production by feed on roots. Adults in flooded or unflooded rice fields feed on young paddy leaves, leaving distinctive scars that run nearly parallel to the leaf veins.	(Mahala, et al., 2022)
Paddy black beetle *Heteronychus lioderes*	Scarabaeidae	Rice, Maize	Adult eat the subterranean stems and roots, impacted plants wilt and pass away. Upland rice is severely under attack.	(Mahala, et al., 2022; Sarkar, et al., 2014)
Rice Hispa *Dicladispa armigera*	Chrysomelidae	Rice	Grubs tunnel towards the leaf sheath, Adults initially remove chlorophyll in parallel white streaks along the main leaf	(Mahala, et al., 2022)

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			axis, starting from the leaf tips. Mature beetles prefer the leaf's upper surface, each adult consume approximately 25 mm^2 of leaf daily.	
Coccinella repanda Thunberg	Coccinellidae	Rice pollen, panicle	In the absence of prey, feed on leaves, panicle, leaving small chewed areas, and frequently damage developing grains.	(Pathak and Khan, 1994)
Grain weevil *Sitophilus granerius Sitophilus oryzae*	Curculionidae	Rice, Grain products	Infestation starts in the field. Eggs laid on rice seeds, hatch into tiny grubs which feed the grain	(DOA, 2024)
Red flour beetle *Tribolium castaneum*	Tenebrionidae	Grain products	Secondary pests, feed on dust and fines of stored grains by constructing tunnels	(Wijayaratne and Egodawatta, 2021)
Cowpea weevil *Callosobruchus maculatus*	Chrysomelidae	Grain products, Stored legumes and seeds	Infestation starts in the field, larvae bore into the pulse grains and feed on endosperms	(Anuradha, et al., 2023)
Rusty Grain Beetle *Cryptolestes ferrugineus*	Laemophloeidae	Barley flour, Oats, Sorghum, Wheat flour, Maize, Corn	Both larvae and adults feed on stored nuts by boring inside, spreading fungal infection	(Thube, et al., 2017; Bharathi, et al., 2023)
Cigarette Beetle *Lasioderma serricorne*	Anobiidae	Stored Tea, Herbal Products, Arecanut	Larvae feed directly on nuts and in severe infestation nuts can be pulverized. Infestation of this pest can be detected by noticing larval cocoons, dead adult beetles in stored products	(Wijesinghe, et al., 2016; Thube, et al., 2017)
Coffee bean weevil *Araecerus fasciculatus*	Anthribidae	Coffee berries, Cocoa, Arecanut	Recorded from fresh stored nuts containing moisture, Both adult and grub damage the nuts by making holes of 1.5-2.5 mm diameter	(Thube, et al., 2017)

III. CASE STUDY OF A BEETLE OUTBREAK IN A CASHEW PLANTATION IN WANATHAVILLUWA, SRI LANKA

Severe leaf damage to cashew plants was reported in Wanathawilluwa in late 2023. Sampling of adult beetles was carried out in two different sites (Acre 2 Area and Acre 10 Research Area) in the Cashew plantation, Wanathawilluwa in December 2023. Beetles were captured using two UV-light traps from dusk to sunrise (6:00 pm to 7:00 am). Beetles that were attracted to the light traps were stopped by transparent polystyrene plates and fell into a container where they were preserved (96% ethanol).

Approximately 500 adult beetle specimens were collected from two sites and identified majority as *Apogonia* sp. (ca. 432 specimens) (Figure 02), *Sophrops* sp (ca. 27 specimens) and few Sericini chafers (Figure 01). The damage was observed as eating of the cashew leaves from the edges, resulting in round-shaped margins (Figure 02). Fortunately, the population increase does not

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significantly affect cashew production in the area (personal communication).

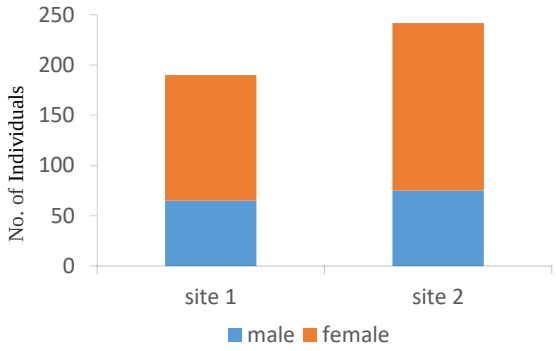

Figure 01: Beetle individuals sampled from site 1 and site 2

A B

Figure 02: **A**, Cashew leaf damage displaying distinctive round-shaped margins due to feeding, **B**, *Apogonia* sp. collected from Wanathawilluwa

IV. CONCLUSIONS

The review documents 60 beetle species from 14 families that are significant pests in Sri Lanka's agriculture, affecting crops like vegetables, fruits, grains, coffee, tea, rubber, and coconut. Notable families include Curculionidae (12 species), Scarabaeidae (9 species), Chrysomelidae (7 species), Coccinellidae (6 species), and Cerambycidae (5 species), along with Meloidae, Scolytidae, Cicindelidae, Anthribidae, Buprestidae, Anobiidae, Laemophloeidae, Tenebrionidae, and Hisphidae. Vegetable crops from the Solanaceae and Cucurbitaceae families are particularly vulnerable, while Curculionidae, Cerambycidae, and Scolytidae primarily target woody crops like cashew, fruits, coconut, tea, and stored grain products. A specific case study highlighted an outbreak of beetles in a cashew plantation in Wanathavilluwa, where the majority of identified pests were *Apogonia* species, followed by *Sophrops* species, and a few Sericini chafers. Beetles occur frequently in crop cultivations, highlighting their significant ecological role in the agricultural landscapes of Sri Lanka. Therefore, understanding their dynamics within these ecosystems is essential. Although most beetle genera are documented, the gaps in knowledge regarding their status as economic pests and the patterns of their sporadic population increases remain significant. This knowledge gap is particularly concerning given the tendency for beetle populations to spike to endemic proportions, as evidenced by past outbreaks in regional countries over recent decades. Thus, further research is crucial to develop effective management strategies and mitigate potential economic impacts on crop production in Sri Lanka.

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Effects of Fertilizer and Irrigation on the Growth and Yield of Bush Pepper (*Piper nigrum* L.) Intercropped under Coconut

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Abstract

This research was conducted at the Intercropping and Betel Research Station of the Department of Export Agriculture, Sri Lanka, to assess the impact of different irrigation levels (6 L or 8 L per day) and amounts of inorganic fertilizer mixture (660 kg, 1320 kg, or 1980 kg per ha) consisting of Urea, MOP, and Eppawala Rock Phosphate, on the growth and yield of bush pepper planted under coconut. The study was a factorial experiment in a randomized complete block design with three replicates. Data on growth and yield were collected for five years. The findings didn't reveal significant differences in canopy diameter or branching. However, after 20 months, plants irrigated with 8 L per day exhibited a higher percentage of flowered plants, indicating that increased irrigation can accelerate flowering. Nevertheless, more spikes were observed under low fertilizer application, suggesting that low nutrient supply positively influences the anthesis of bush pepper. Although the increased irrigation and fertilizer application improved the spike filling rate, it showed a decrease in spike production. Nonetheless, no interaction between the two factors has been identified. Moreover, the decline in yield from the third to the fifth year was observed which can be attributed to the mutual shading of growing plants. However, these results do not support the feasibility of field cultivation of bush pepper, as the dry yield achieved in this experiment (maximum 660 kg/ha/year) falls short when compared to traditional climbing pepper.

Keywords: Bush pepper, Flowering, Fertilizer, Growth and yield, Irrigation

V. INTRODUCTION

Black pepper (*Piper nigrum* L.) is an important spice crop for Sri Lanka, with a significant contribution to the country's economy and the livelihoods of small-scale farmers. In 2022, the black pepper extent in Sri Lanka was 42,152 ha and production reached 24,029 MT. Pepper exports in 2022 were 11,416 T valuing Rs. Million 23,464 (Raby & Hettiarachchi, 2023). Black pepper is grown as a climbing vine, which requires stakes or support structures for vertical growth. However, propagating black pepper plants using plagiotropic branches (fruiting/side branches) results in bush-shaped plants, commonly known as "bush pepper" which is mostly suitable for pot cultivations. According to some studies, a bush pepper pot plant produces about 1.5 kg of green (fresh) pepper in 2-3 years, under average management conditions (TNAU, 2022; Priyadarshani et al., 2018). It is common in houses as an ornamental plant which delivers black pepper for family requirements (Kavindi, 2013).

The compact growth habit of bush pepper plants allows for higher plant densities and more efficient use of space. Additionally, bush pepper plants are easier to maintain than climbing pepper plants, as it needs no support or trellises, require less labour, and are quick to produce yield (Thankamani et al., 2002; Ngawit, Wangiyana, & Farida, 2022). However, Bhattacharya (2017) has reported that bush pepper plants of some varieties did not reach to bearing stage until 3 years.

According to these details, bush pepper can be considered as a potential intercrop for small-scale coconut farmers in Sri Lanka. Adopting bush pepper cultivation under coconut could increase land productivity, diversify income and improve resilience to changing climate. Research conducted by Priyadarshani et al., (2018) in Sri Lanka under coconut identified 1.8 m x 1.2 m as the suitable spacing for bush pepper which results in around 3000 plants per ha. Moreover, this study confirmed the potential of achieving nearly 750 kg/ha/year of dry pepper yield from the fifth year onwards but also notes the superiority of orthotropic plants (climbing pepper) in long-term results. Further, considering the possible differences in the root system and growth habits, bush pepper management should differ from climbing pepper. However, as most of the bush

pepper studies are confined to pot experiments, the effect of agronomic practices like irrigation and fertilizing under field conditions remains unclear. Thankamani & Ashokan, (2011) showed 8 L drip irrigation during October – May is best for bush pepper under coconut in Kerala. Indian Institute of Spice Research has recommended the application of NPK at 10, 5, 20 g per bush at three months interval for field-grown bush pepper while recommending a lower dose for potted plants.

In Sri Lanka, the Department of Export Agriculture (DEA) recommends an annual application of 2380 kg/ha of a fertilizer mixture for climbing pepper vines. This mixture consists of Urea, Eppawala Rock phosphate (ERP), Muriate of Potash (MOP), and Kieserite in a 4:5:3:1 weight ratio. Additionally, DEA advise a seasonal application of 1400 kg/ha/year of the same mixture, applied twice a year (Anon, 2019). Yet, there is no specific fertilizer mixture recommended for bush pepper in Sri Lanka. Therefore, this research aimed to identify the effects of irrigation and inorganic fertilizer application on bush pepper plants grown under coconut in Sri Lanka.

VI. METHODOLOGY

This research was conducted at the Intercropping and Betel Research Station of the Department of Export Agriculture, Narammala, which is situated in the Low Country Intermediate Zone (IL1a) of Sri Lanka (7°24'19.0"N, 80°12'15.2"E). Annual average rainfall during the study period of 2016 to 2020 was 1904.8 mm. A coconut field over 20 years old was selected as the research site and divided into five blocks. The whole field was being managed according to the recommendations of the Coconut Research Institute, Sri Lanka, including the application of 3.3 kg of APM-W fertilizer mixture with 1 kg dolomite per palm once a year during September to October. Bush pepper plants were prepared from two-nodal cuttings of plagiotropic branches. After approximately four months, during the 2015-16 Maha season, these potted plants were planted into five blocks, with three plants per plot at 1.8 x 1.2 m spacing, following the previous research outcome (Priyadarshani et al., 2018). The experiment was conducted as a two-factor factorial experiment in a randomized complete block design with three replicates.

After establishment, the application of treatments was started. Treatments include two levels of irrigation and three levels of inorganic fertilizer. Two irrigation levels of 6 L and 8 L thrice a week were selected (Thankamani & Ashokan, 2011). The irrigation was halted during rainy days until the soil became visibly dry.

Since there was no specific recommendation for bush pepper in Sri Lanka, three levels of a fertilizer mixture used by some farmers in the Kurunegala district were selected. This fertilizer mixture, applied once in three months, consists of Urea, Eppawala Rock Phosphate (ERP), and MOP in a 2:5:4 ratio (w/w). The tested amounts were 660 kg/ha/year, 1320 kg/ha/year, and 1980 kg/ha/year, corresponding to 55 g, 110 g, and 165 g per plant every three months. These amounts were selected considering the DEA recommendations for pepper cultivation.

Table 02: Treatments of the experiment

Treatment	Irrigation Amount	Fertilizer application (kg/ha/year)	Fertilizer (g/plant/3
T1	6 L	660	55
T2	6 L	1320	110
T3	6 L	1980	165
T4	8 L	660	55
T5	8 L	1320	110
T6	8 L	1980	165

The Growth data like canopy diameter, number of plagiotropic branches, and number of spikes in a bush, were collected in monthly intervals throughout the study period. Further, the yield data including the fresh and dry weight of peppercorn, and fruit filling rate were recorded at irregular intervals depending on the availability of mature spikes.

The collected data were statistically analysed using the SAS OnDemand for Academics statistical application. Data were tested for normality, then the Kruskal-Wallis test was performed for nonnormal data, while analysis of variance was conducted for normally distributed data which includes, canopy diameter, percentage of flowered plants and spike filling rate. Mean separation was done using Duncan's Multiple

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Range test. The analysis revealed no interaction effect between irrigation and fertilizer levels in this experiment. Thus, the results are discussed as single-factor effects.

VII. RESULTS & DISCUSSIONS

The statistical analysis of monthly records confirmed that none of the treatments had any significant effect on the canopy diameter of the plants during the study period, except 15 months after planting (MAP) between three different fertilizer levels, as shown in Table 02.

Table 03: Canopy diameter of bush pepper plants N=90

Dose of fertilizer	Canopy diameter (cm)		
	09 MAP	15 MAP	18 MAP
165 g	58.1 [a]	83.4 [ab]	92.2 [a]
110 g	56.0 [a]	77.5 [b]	86.5 [a]
55 g	64.5 [a]	90.1 [a]	92.5 [a]
CV %	35.78	24.70	26.44

Note: The means followed by the same letters are not significantly different at $\alpha = 0.05$. MAP = months after planting.

This finding contradicts the majority of previous studies, which have highlighted the effect as well as the interaction between irrigation and fertilization in relation to plant growth and yield. Since, there were no significant differences in the most of canopy diameter data, indicating plants in this experiment have not suffered water or nutrient stress, the 55 g fertilizer and 6 L irrigation level is adequate for comparable growth of bush pepper plants. Therefore, further research is necessary with lower doses of fertilizer and irrigation to identify the optimum amounts for the growth of bush pepper plants.

No significant difference in the number of plagiotropic branches was identified. Also, the coefficient of variation of these data was over 50% which minimises the certainty of results. Therefore, it can be suggested that these irrigation or fertilizer application levels had no significant effect on the branching of bush peppers.

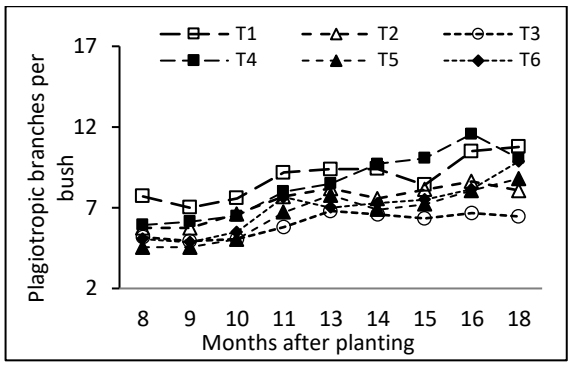

Figure 01: Plagiotropic branch formation of bush pepper under different irrigation and fertilizer levels. T1 to T6 denote daily irrigation and quarterly fertilizer application levels.

The results also showed that the percentage of plants with flowers was higher in 8 L irrigation compared to those irrigated with 6 L. The difference was statistically significant up to 20 months after planting. However, flowering under three fertilizer levels was not statistically significant (Table 03).

Table 04: Percentage of plants with flowers, 20 months after planting (MAP)

Dose of fertilizer	Plants with flowers (%)	Irrigation level	Plants with flowers (%)
165g	85.1 [a]	8 L	94.2 [a]
110g	80.0 [a]	6 L	77.9 [b]
55g	93.7 [a]		
CV %	22.52		

Note: Means followed by the same letters are not significantly different at $\alpha = 0.05$

According to the results, higher irrigation levels can advance the flowering of plants even when the growth of plants remains unchanged. Unclear changes due to better water and nutrient availability might have caused this progress in 20 months. These results are consistent with previous research which has shown that irrigation can significantly influence the growth and development of pepper plants (Thankamani & Ashokan, 2011). The absence of significant differences between the three fertilizer levels is not consistent with previous studies that have reported a positive effect of fertilizer on flowering in pepper plants (Swarnapriya, 2020). Thus, while these results emphasise the importance of soil moisture for early flowering, further investigation

is required to evaluate the effect of fertilizer on bush pepper flowering.

The data in Figure 02 represents the number of spikes in bush pepper plants, which measures the potential yield. It shows that the use of 55 g of fertilizer has resulted in a higher spike production in bush pepper plants. However, based on the data analysis, neither irrigation level nor fertilizer amount have significant effects on spike production.

Flowering can be enhanced either by high amounts of fertilizer which promote vegetative growth at the expense of spike production or insufficient fertilizer levels that trigger flowering as described by Wada & Takeno (2010). As no significant impact had been observed on plant growth, flowering of bush pepper might have been induced by fertilizer imbalance after the initial growth stage. This indicates the fertilizer level sufficient at the early growth stage may not be adequate at the latter stages, especially after anthesis. Hence, more studies should be conducted to determine the nutrient requirements at different stages of the bush pepper plant.

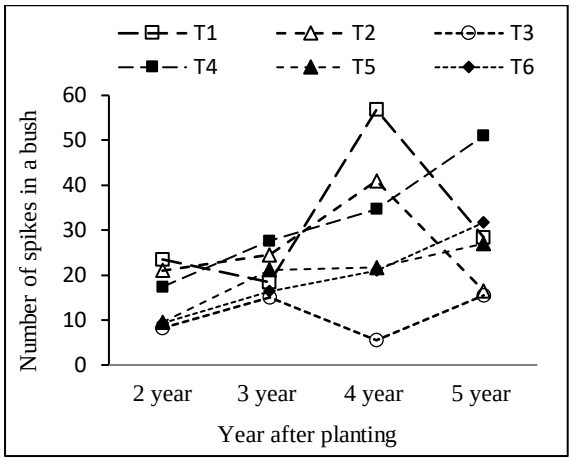

Figure 02: Number of spikes in a bush pepper plant.

The data on spike filling show the increase in the amount of fertilizer and water applied to the plants leads to a higher filling rate of bush pepper spikes (Table 04). This indicates that proper fertilizer application plays a crucial role in the growth and development of pepper fruits. Thus, emphasizing the importance of providing more water and fertilizer to the plants after flowering.

Table 04: Filling percentage of bush pepper spikes after 4 years of planting

Fertilizer level	Spike filling rate (%)	Irrigation	Spike filling rate (%)
165 g	78.3 [a]	8 L	76.6 [a]
110 g	73.2 [ab]	6 L	68.1 [b]
55 g	66.8 [b]		
CV	16.82		

Note; Means followed by the same letter are not significantly different. T1 to T6 denote daily irrigation and quarterly fertilizer application levels

Nevertheless, the spike length of bush pepper has been consistent through the treatments. Data shows that 84.1% of spikes had a length greater than 10 cm, while 19.5% had a length higher than 14 cm. Thus, nearly two-thirds of spikes had a length between 10 to 14 cm with an average of 11.9 cm.

According to the data in Table 05, which shows yield from the third year to the fifth year under different fertilizer and irrigation levels, bush pepper yield shows a reduction with time. Thus, it needs to be evaluated further in the field for a longer cultivation period. Also, the yield of bush pepper compared to traditional pepper is not adequate.

Table 05: The yield of bush pepper (dry yield kg per ha per year) under different irrigation and fertilizer levels

Treatment	3rd year	4th year	5th year
Fertilizer			
165 g	456.2 [a]	323.9 [a]	231.5 [a]
110 g	447.2 [a]	418.3 [a]	216.3 [a]
55 g	661.2 [a]	511.0 [a]	266.3 [a]
Irrigation			
8 L	520.7 [a]	319.3 [b]	247.3 [a]
6 L	547.0 [a]	555.1 [a]	227.7 [a]
CV	73.29	75.01	84.32

Note; Means followed by the same letter are not significantly different.

This kind of decline or fluctuation in yield is common in some bush pepper experiments (Priyadarshani, et al., 2018; Bhattacharya & Bandyopadhyay, 2017). Therefore, it can be a typical characteristic of black pepper plants of plagiotropic origin. But also, the effect of mutual shading of growing plants cannot be underestimated. Bush pepper plants naturally

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produce overlapping branches due to limited vertical growth. Its uncontrolled growth can reduce photosynthetic efficiency affecting the yield over time. Hence, pruning of bush pepper plants can be beneficial for a consistent yield for a long period. Therefore, further research on appropriate punning practices must be conducted.

In addition, the fertilizer formula used here (Urea: ERP: MOP; 2: 5: 4) is different from the recommended fertilizer mixture for black pepper in Sri Lanka (Urea: ERP: MOP: Kieserite; 4: 5: 3: 1). Therefore, plant growth and yield might have been affected by the imbalance of nutrients. Further, this demonstrates that applying fertilizer overdoses is pointless, thus emphasising the importance of providing a proper fertilizer recommendation for bush pepper in Sri Lanka. Since bush pepper has a comparatively small root system, its efficiency in nutrient uptake may not be similar to climbing pepper plants. Hence, bush pepper will be benefitted by providing readily available fertilizer mixtures. Therefore, replacing Eppawala rock phosphate (ERP) with more soluble triple super phosphate fertilizers should be considered in future bush pepper research (Srinivasan et al., 2008).

In conclusion, irrigation with 6 L or 8 L per bush thrice weekly or 660, 1320, and 1980 kg/ha/year of fertilizer mixture at three-month intervals shows no significant difference in the growth of bush pepper plants as measured by canopy diameter and number of plagiotropic branches. However, 8 L irrigation can bring plants into the flowering stage earlier than 6 L, though it can affect the production of spikes and final yield. Under these conditions, no interaction between fertilization and irrigation was observed. According to the results of this experiment, the use of 660 kg/ha/year of fertilizer has provided the plants with an adequate amount of nutrients for growth. Yet, the spike filling rate can be improved with higher irrigation and fertilizer application. Bush pepper in this experiment has produced around 660 kg/ha/year dry pepper yield at best, which is not satisfactory compared to about 5000 kg/ha/year yield of traditional climbing black peppers.

Finally, further research with irrigation and fertilizer levels less than 660 kg/ha/year, and changing with the growth phase of the bush pepper plants i.e., increased amount after the flowering, can be recommended.

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Cost-Effective Potting Media for Efficient Betel (*Piper betle* L.) Propagation

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Abstract

Betel (Piper betle L.) is a popular intercrop with coconuts in Kurunegala and Gampaha districts, mainly grown as a cash crop. To ensure selection of high quality, vigorous plants, growers often use potted betel plants for transplanting. The traditional potting media for betel consists of equal parts topsoil (TS), sand (S), cow dung (CM) and coconut flour (CD). However, due to the high cost and limited availability of sand and coir dust, using partially burned paddy husk as a substitute is a more economical option. A study was conducted to determine the cost-effective potting mixture using a combination of different potting materials. Seven treatments included the combinations of top soil, sand, cattle manure, coir dust, and partially burned paddy husk (PBPH). The poly bags were filled with a plotting mixture and three nodal cuttings were planted. A propagator was used to raise the plants for 21 days. The small plants were then kept in 70% shade. According to the results, the highest root dry weights were in the T2(TS:CM:S:CD:PBPH 2:1:1:1:3) and T7 (TS:CM:PBPH, 1:1:3). The highest shoot dry weight, shoot length, and number of leaves were all observed in T4 (TS:CM:S:CD 2:1:1/2:1:1). Therefore, treatments T4, T2, and T7 can be recommended for betel propagation. The cost per plant in the T4, T2, and T7 treatments was Rs 13.50, Rs 11.50, and Rs 9.30, respectively, which is lower than the cost of the conventional potting mixture at Rs 18.00.

Keywords: betel,Cost effective potting media, paddy husk

I. INTRODUCTION

Betel (*Piper betle*) is a perennial climbing plant from the Piperaceae family that is widely cultivated and highly valued for its economic and cultural significance in South and Southeast Asia. The leaves of the betel plant are commonly chewed with areca nut and slaked lime, a traditional practice across several Asian countries (Rani & Singh, 2017). Successful cultivation of betel requires specific soil and climatic conditions, making the selection of a suitable potting mix crucial for effective propagation and growth (Manjunatha, 2016). Betel is particularly popular as an intercrop in coconut plantations, serving as a significant cash crop in regions like Kurunegala and Gampaha districts of Sri Lanka (Silva et al., 2018). Many growers prefer to use potted betel plants for transplanting, as this allows them to select high-quality, vigorous plants for field planting (Senanayake & Wijesundara, 2019). In producing these potted plants, the cost, applicability, and availability of the potting media are key factors to consider (Das et al., 2020).

The conventional potting mixture used for raising betel planting materials typically contains a mixture of topsoil, sand, cow dung, and coir dust in a 1:1:1:1 ratio (V/V/V/V) (Wijeratne et al., 2017). However, the use of sand and coir dust has become increasingly uneconomical due to rising costs and limited availability (Kumar et al., 2018). A cost-effective alternative is the substitution of sand and coir dust with partially burned paddy husk, which offers a more affordable and accessible option. To address this, a study was conducted to determine a more economical potting mixture using a combination of different growing materials.

II. METHODOLOGY

The experiment was carried out from July to November 2020 at the Dampellessa Intercropping and Betel Research Station Narammala, located in the low country intermediate zone of (IL1a) of Sri Lanka (7°24'19.0"N, 80°12'15.2"E). Five different potting materials were used: topsoil (TS), cow dung (CM), sand (S), coir dust (CD) and partially burnt rice husks (PBH). These materials were combined in different ratios to

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create seven potting media mixture treatments (Table 01) with each treatment forty replicates.

Table 01 The different combinations of potting materials (Volume basis)

Treatment	TS	CM	S	CD	PBPH
T1 (Control)	1	1	1	1	0
T2	2	1	1	1	3
T3	1	½	1	1	1
T4	1	1	½	1	1
T5	1	1	1	½	1
T6	1	1	1	0	2
T7	1	1	0	0	3

Healthy semi-mature orthotropic three-node betel branches were obtained from the same variety of mother plants maintained at Narammala Intercropping and Betel Research Station. The potting mixture was filled in polythene bags 20 cm ×12 cm in size, which had perforated at the bottom for drainage. After watered hourly and selected cuttings were planted in polyethylene bags and watered. Stem cuttings were dipped in copper-based fungicide solution before introducing them into the potting mixture to prevent fungal infection at the cut end.

Isolated stem cuttings were placed in a humidity chamber to minimize air circulation and provide 70% shade. After 21 days, the cuttings were transferred from the humidity chamber to a net house with 60% shade, where moisture levels were maintained. Pest and disease control measures were applied as needed. Five plants were randomly selected from each replicate. Starting 35 days after planting, data on the number of shoots, number of leaves, shoot length, number of

roots, root length, shoot dry weight, and root dry weight were collected biweekly.

Data was recorded at two weeks intervals at 35 days after planting. The number of shoots, the number of leaves, the shoot length, the number of roots, the root length, the shoot dry weight and the root dry weight were recorded. Newly emerged shoots were separated from the plant and placed in paper bags. The shoot samples were oven-dried at 70°C until a constant weight was achieved, and the weight was recorded using an analytical balance. The vines were uprooted and thoroughly washed. Afterward, the roots were separated from the plant, placed in paper bags, and oven-dried at 70°C until reaching a constant weight. The weight was also measured using an analytical balance. Roots were carefully washed and separated using surgical scissors. Root samples were spread over a 1 cm grid, and root length was measured by counting the number of root intersections with the grid lines, following the method of Tennant (1975). The data were analyzed using ANOVA and statistical analysis was performed with Minitab 17 software. The least significant different (LSD P = 0.05) was used to compare the treatment means.

III. RESULTS & DISCUSSIONS

Table 02. The growth parameters of betel plant under different potting media

Treatment	Root dry weight (g)	Shoot dry weight (g)	Root length (cm)	Shoot length (cm)
T1	0.08^{c}	0.64^{bc}	83.38^{c}	27.07^{c}
T2	$\mathbf{0.16^{a}}$	0.75^{b}	120.04^{ab}	$27.96b^{c}$
T3	0.09^{ab}	0.56^{c}	98.69^{bc}	$28.44b^{c}$
T4	0.12^{ab}	$\mathbf{1.04^{a}}$	112.63^{ab}	$\mathbf{44.60}^{a}$
T5	0.10^{ab}	0.65^{bc}	100.46^{bc}	33.80^{b}
T6	0.11^{ab}	0.72^{b}	113.04^{ab}	$30.28b^{c}$
T7	$\mathbf{0.16^{a}}$	0.75^{b}	$\mathbf{131.81^{a}}$	$31.20b^{c}$
CV %	27.31	20.95	14.59	18.93

Note: means followed by the same letters are not significantly different

The highest root dry weights were observed in treatments T2 and T7 (0.16 g), which was significantly higher than T1 (0.08 g) but not significantly different from T3, T4, T5, and T6. The root dry weights of the treatments followed the order of T7=T2>T4>T6>T5>T3>T1 and treatment T1 being the lowest. There was no significant difference between treatments T_7 and T_2.

According to the statistical analysis, there were significant differences ($p<0.05$) between treatments with respect to shoot dry weight. The highest shoot dry weight was recorded at T4 (1.04 g), which was significantly higher than the other treatments and T_3 had the lowest. Shoot dry weights followed the order as $T_4>T_2 =T_7 >T6>T5$

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$>T_1$ $>T_3$ respectively. Treatment T_4 was the highest.

The higher root and shoot dry weights in treatments T2, T4, and T7 can be attributed to the optimal combination of organic components, which provided adequate nutrients and improved soil structure. The high root dry weight in T2 and T7 (with higher proportions of PBPH) suggests that PBPH may enhance root biomass by improving soil aeration and moisture retention. Hossain and Islam (2020) reviewed various agricultural waste residues and concluded that materials like partially burnt paddy husk can improve soil physical properties, including aeration and moisture levels, thereby benefiting root growth and overall plant health. Research indicates that the application of rice husk ash improves soil structure by reducing soil compaction and increasing porosity, which leads to enhanced root growth due to better aeration in maize(Channabasappa et el. 2002*).*

T7 had the longest root length (131.81 cm), significantly longer than T1 (83.38 cm), which had the lowest. Root length followed the order as T_7 $>T_2$ $>T_6>T_4>T_5>T_3$ $>T_1$ There were no significant differences among the treatments T_2, T_6, T_4, T_5 and T_3. There were significant differences ($p<0.05$) among treatments for shoot length. T4 had the significantly longest shoot length (44.60 cm). Shoot length followed the order of as T_4 $>T_5>$ T_7 $>T_6>T_3>T_2>T_1$ respectively.
There was no significant differences among treatments T_1,T_7,T_6,T_3 and T_2.(Figure.1) here was no significant different among treatments. Treatment T_4 had the highest average number of leaves with respect to other treatments. T_3 had the least average number of leaves.

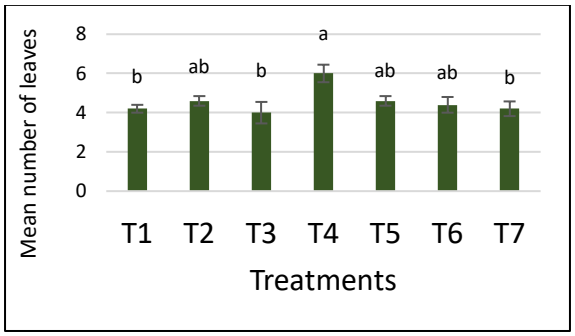

Figure 01. Effects of potting media on the number of leaves of betel plants during 60 days after plating.

Note: means followed by the same letters are not significantly different

T7 exhibited the longest root length, indicating that a higher proportion of PBPH in the mixture may promote root elongation. PBPH is known for its excellent aeration and drainage properties, which can facilitate deeper root growth. T4, with the longest shoot length, suggests that a balanced mixture of coir dust and sand can significantly enhance shoot development.

The positive effects of organic amendments like cattle manure and coir dust on plant growth have been well-documented. The cattle manure significantly improve soil fertility by increasing organic matter content and microbial activity, leading to enhanced plant growth (Ribeiro et al.2016). Similarly, coir dust, a by-product of the coconut industry, has been recognized for its high water-holding capacity and ability to improve soil aeration, which benefits root and shoot development (Awang et al. 2009).

The role of PBH in promoting root growth aligns with findings by *De Costa et al.* (2012), who reported that PBH enhances soil physical properties, such as porosity and permeability, thereby facilitating better root penetration and growth.

Though the sand and coir dust are traditional components of potting mixtures, their high cost and limited availability can be prohibitive. PBPH is a cost-effective alternative with good aeration properties. Studies have shown that PBPH can improve root growth due to its porous nature, which facilitates better oxygenation and drainage

For instance, research by Reddy et al. (2018) found that the incorporation of burnt paddy husk into soil significantly increased root biomass and plant growth by enhancing soil porosity and water management. Additionally, Sharma and Kumar (2020) highlighted that the use of paddy husk in soil amendments led to better oxygenation, which is critical for healthy root development and reduces the risk of root diseases.

The study revealed that different potting mixtures significantly influence the growth parameters of Betel. Treatment T4, comprising a mixture of topsoil, cattle manure, sand, and coir dust, showed superior performance in shoot dry weight and

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shoot length, indicating its potential as an effective potting mixture for Betel propagation. The maximum production cost (Rs. 18.00) was observed in the T1. Other treatments T2, T3, T4, T6, and T7 cost of production were Rs.11.50 ,Rs. 17.75, Rs.13.50, Rs.17.80, Rs. 15.75 and Rs 9.30. The cost of a plant in the T2, T4 and T7 treatments were Rs.11.50, Rs.13.50, Rs. 9.30 respectively lower than the cost of the conventional potting mixture (T1) Rs18.00.

IV.CONCLUSION

The findings indicate that the inclusion of partially burnt paddy husk (PBPH) in potting mixtures enhances the growth of betel plants, with mixtures containing higher PBPH levels (T2 and T7) demonstrating significant increases in root biomass and length. Additionally, the mixture with a reduced proportion of sand and coir dust (T4) was found to optimize shoot growth. Among the tested combinations, the T4 mixture (1:1:0.5:1:1) emerged as a cost-effective option for betel propagation, providing a balanced blend of nutrients and physical properties that support both root and shoot development. Further research should investigate the long-term impacts of these potting mixtures on plant health and productivity, as well as their cost-effectiveness for large-scale betel cultivation.

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Morphological and Yield Performance of Chinese and Rangoon Ginger (*Zingiber officinale* Roscoe) Accessions Cultivated as Intercrops under Coconut Cultivation in the Low Country Intermediate Zone of Sri Lanka

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Abstract

Ginger (Zingiber officinale) belongs to the family Zingiberaceae. Chinese, Rangoon and Local are the commonly cultivated ginger types in Sri Lanka. Local ginger is rich in fiber, uses in Indigenous and Ayurveda medicinal purposes, and amount of yield is comparatively low. Chinese and Rangoon are moderately in pungency, amount of yield is comparatively high and use in beverage industry likes for production of ginger beer and for culinary purposes also. Ginger can be grown either as a mono-crop or inter-crop under coconut plantation. This research was carried out at Inter-cropping and Betel Research Station, Narammala where the area belongs to Kurunegala district is under the coconut triangle. Coconut plants are generally spaced in 26 ft x 26 ft, hence 75% of area under the coconut plants are remaining unproductively. Underutilized area is high when the age of the coconut plants is below 5 years and over 20 years. Climatic conditions in Kurunegala district is more favourable for ginger cultivation. After the three years field experiment, the highest fresh yield of rhizome per clump for Chinese ginger accessions was given by the accession of G33 (949.2 g/clump) in Low Country Intermediate Zone under coconut cultivation. The highest fresh yield of rhizome per clump for Rangoon ginger accessions was given by the accession of G28 (754.2 g/clump) in low country Intermediate zone under coconut cultivation. The G28 and G33 accessions can be used to cultivate under coconut plantation as an intercrop to increase the productivity of coconut lands.

Keywords: Chinese ginger accessions, Rangoon ginger accessions, Evaluation

I .INTRODUCTION

Ginger is scientifically known as *Zingiber officinale* Roscoe and belongs to the order *Zingiberales* and the family *Zingiberaceae*. It is common in Southeast Asian countries and primarily cultivated in India. Ginger is a perennial herbaceous plant. The true stem of the plant lies underground and the above ground part is called the pseudo stem.

There are three main types of ginger grown in Sri Lanka: Chinese ginger, Rangoon ginger and native ginger. In addition, different types of ginger are cultivated around the world. Local ginger is high in pungency, rhizome is rich in fiber, uses in Indigenous and Ayurvedic medicinal purposes, and yield is comparatively low. Chinese and Rangoon are moderately in pungency, amount of yield is comparatively high and are often used in beverage industry likes for production of ginger beer and for culinary purposes.

Total cultivated extent of ginger in year 2022/2023 was 2,383 ha and the total production was 19,375 mt. Kurunegala, Gampaha, Kandy, Badulla and Rathnapura were the major growing districts of ginger in year 2022 / 2023 cultivated extent of these districts were 774, 280, 188, 142 and 129 ha respectively .Ginger production in the districts of Kurunegala, Gampaha and Kandy were 7,352, 2,662 and 1,692 ha respectively (Anonymous, 2023). Ginger can be grown either as a mono-crop or inter-crop under coconut plants. Coconut plants use a large volumes of air space and it limits to increase the crop density. Efficient utilization of air space is important. Coconut palms are generally spaced 8 m x 8 m resulting in 75% of area remaining unproductive. Underutilized area is high when the age of the coconut palm is below 5 years and over 20 years. Therefore, coconut based intercrops farming systems is important to increase the productivity of the land (Liyanege *et al.*, 1986).

There were no identified high yielding ginger accessions. For that cultivation of Chinese and Rangoon ginger is more profitable due to high yield rather than that of Local ginger.

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The objectives of the study were to evaluate the morphological characteristics and identify high-yielding accessions of Chinese and Rangoon ginger (*Zingiber officinale* Roscoe) for cultivation as intercrops under coconut cultivation in the Low Country Intermediate Zone of Sri Lanka.

II. MATERIAL AND METHOD

A. Collection of ginger accessions-

Field surveys were done to collect ginger accessions and survey information like farmers' details, information on crop management practices were recorded on questionnaires. Different accessions of ginger were collected from the districts of Kurunegala, Gampaha, Kalutara, Galle, Matara, Hambantota, Monaragala, NuwaraEliya, Matale, Kegalle, Jaffna, Ampara, Kandy, Badulla, Rathnapura, Anuradhapura, Polonnaruwa, Puttalam and Colombo. Germplasm were collected from the different Extension Officers' rangers level within the district.

B. Multiplication of ginger accessions-

Collected ginger accessions were established in the research field, at Intercropping and Betel Research Station (IBRS), Department of Export Agriculture, Dampelessa, Narammala, Sri Lanka for further growth of ginger rhizomes. It is situated in Low country Intermediate zone, agro-ecological region IL1a Longitude is 80.22^0E and Latitude is 7.43^0N. Elevation is 63m from mean sea level. Average day time temperature is 28-30^0C. Narammala typically receives about 1900 mm of precipitation and has around 192 rainy days annually. Mean humidity is 76.8% (Weather and Climate, 2020).

C. Evaluated ginger accessions-

1) Evaluated Chinese type ginger accessions-

Altogether there were 14 Chinese type ginger accessions were collected by field surveying. One wild type ginger accession was also found. That was more or less similar to Chinese type ginger. Out of the collected all Chinese ginger accessions, 5 accessions were considered for the evaluation. Because of the amount of the rhizomes of the rest of the Chinese type ginger accessions, were not sufficient for establishment of a 3 replicates of field experiment. These Chinese type ginger accessions were numbered as G1, G2, G3, G17 and G33.

2) Evaluated Rangoon type ginger accessions-

Altogether there were 18 Rangoon type ginger accessions were collected by field surveying. Out of the collected all Rangoon ginger accessions, 7 accessions were considered for the evaluation, because the amount of the rhizomes of the rest of the Rangoon type ginger accessions were not sufficient for establishment of a 3 replicates of field experiment. These Rangoon type ginger accessions were numbered as G6, G9, G27, G28, G29, G30 and G34.

D.Establishment of ginger accessions evaluation fields and management practices- .

This research was carried out during the period of 2015-2023, at Intercropping and Betel Research Station (IBRS), Department of Export Agriculture, Dampelessa, Narammala, Sri Lanka. Evaluation for ginger was done as an intercrop under the coconut cultivation. Experimental design for evaluation field was Randomized Complete Block Design (RCBD) with 3replicates. The field was ploughed up to 35 cm-40 cm in depth and tilling of soil was done. Raised beds of 3.05 m x 1.22 m (10 ft x 4 ft) were prepared. Field establishment was done in *Yala* season in month of April. Five Chinese type ginger accessions, and seven Rangoon type ginger accessions were taken for the evaluation. These considered accessions had sufficient amount of rhizomes for 3 blocks. There is no any recommended ginger accessions given by the Department Export Agriculture for cultivation. Thirty grams of rhizomes weight for each accession was used for planting of Rangoon ginger and 40g of rhizomes weight from each accession was used for planting of Chinese ginger . Spacing between rows and between plants were 25 cm x 25 cm. Sprinkler irrigation was practiced for ginger cultivation. Department recommended management practices were followed for evaluation. One hundred kilograms of Triple Super Phosphate was applied as basal dressing per hectare. Eighty two kilograms of Urea and 42 kg of Muriate of Potash were applied for a hectare, at 45 days after establishment of ginger rhizomes. Eighty two kilograms of Urea and 42 kg of Muriate of Potash were applied for a hectare, at 90 days after establishment of ginger rhizomes. Always ginger beds were covered by using a mulch. Harvesting was done at nine months after the planting when the leaves become like straw.

E. Collection of ginger data-

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Both morphological and yield data were collected. Height of the pseudo-stems, number of pseudo-stems per clump, number of leaves per pseudo-stem, leaf length and leaf width were measured at the 8 month after the planting. Nine month old matured fresh ginger rhizomes of each accessions were used for the weight evaluation. Cross sections of rhizomes were compared for colour using a Munsell Colour Chart (Plant). Fresh yield for each accessions was taken by randomly selecting 10 clumps per each replicates.

F. Analyzing of data-

Three consequent years, yield and morphological data were countered. Three year mean values were taken for the analysis. Mean separations were practiced using Statistical Analyzing Software (SAS) package. Leased Significant Difference (LSD) technique was used for the mean separation of the treatments.

III. RESULTS AND DISCUSSION

A. Evaluation of morphological characters-

Morphological characters of height of the pseudostem, no. of pseudostem per clump, no. of leaves per pseudostem, leaf length and leaf width were measured at the 8 month after the planting. Height of the pseudostem was measured from bottom of the plant to the top of the plant. Number of pseudostems per clump was taken by the counting. Number of leaves per pseudostem was also taken by the counting. Leaf length was measured from base to tip of the leaf. Maximum width of the leaf was taken as the leaf width.

1) Morphological characters of Chinese ginger

Mean values of morphological characters of Chinese ginger are shown in Table 01.

If the height of the pseudo-stem is higher it has more advantage, to capture penetrated sunlight through the coconut plants. The highest significant mean value for height of the pseudo-stem was recorded by the Chinese type ginger accession of G3 (59 cm) and the lowest value recorded by the accession of G17 (32.7 cm). There were no significant differences among the ginger accessions of G1 (33.8cm), G2 (32.8cm), G17 (32.7cm) and G33 (33.7cm) for height of the pseudo-stem.

Normally if a clump has higher number of pseudo-stems it will enhances the level of photosynthesis. There were no any significant differences among the accessions for number of pseudo-stems per clump. Number of pseudo-stems per clump varied from 7 to 5. Although they were not significant the highest value for number of pseudo-stems per clump was recorded by the Chinese ginger accession of G3 (7) and the lowest value recorded by the Chinese ginger accessions of G2 and G17 (5). According to a study done by Hossain *et al* (2019) higher number of pseudo-stems per clump during harvesting was observed in "deshi" variety (V1) (4.19) and lower number of tiller per plant was observed in china variety (V2) (3.70).

Number of leaves per pseudo-stem varied from 18 (G3) to 8 (G2). The highest significant number of leaves per pseudo-stem was given by G3 (18). There were no significant differences among the other accessions of G1, G2, G17 and G33.

Leaf lengths of Chinese ginger accessions varied from 21cm (G3) to 12cm (G1 and G33). There are no any significant differences of leaf length among the accessions of G1, G2, G17 and G33. The reason may be the these accessions are genetically somewhat similar.

Table 01: Mean values of morphological characters of Chinese ginger (At 8 months after the planting)- Means within a column with the same letter are not significantly different at P<0.05

Accession No.	Pseudostem height (cm)	No. of Pseudostems/ clump	No. of Leaves / Pseudostem	Leaf length (cm)	Leaf width (cm)
G6	35.2 bc	**10 ab**	9 b	14b c	1.9 cd
G9	38 b	5 b	**16 a**	12 c	1.8 d
G27	32 bc	2 b	9 b	13.3 bc	**2.2 ab**
G28	28 c	3 b	10 b	14 bc	2 bcd
G29	36.2 b	**11 ab**	**15 a**	16.5 b	2.1 bc

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G30	32.7 bc	**15 a**	10 b	13.2 c	2 bcd
G34	**55.2 a**	**15 a**	**15 a**	**21.2 a**	**2.4 a**
CV%	17	44	26	19	10

Leaf width varied from 2.5cm to 1.9cm . The highest significant different value for leaf width was indicated by the accession of G3(2.5 cm) and the lowest leaf width was indicated by the accession of G2 (1.9 cm).

If the leaf length and leaf width are higher values, leaf area of the accession is also high. Among the considered Chinese accessions, G3 was the most predominant accession for the morphological characters.

2) Morphological characters of Rangoon ginger- Mean values of morphological characters of Rangoon ginger are shown in Table 02.

Table 02: Mean values of morphological characters of Rangoon ginger (At 8 months after the planting)- Means within a column with the same letter are not significantly different at P<0.05

Accession No.	**Pseudostem height (cm)**	**No. of pseudostems per clump**	**No. of leaves / pseudostem**	**Leaf length (cm)**	**Leaf width (cm)**
G1	33.8^{b}	**6^{a}**	10^{b}	12^{b}	2^{b}
G2	32.8^{b}	**5^{a}**	8^{b}	14^{b}	1.9^{b}
G3	**59^{a}**	**7^{a}**	18^{a}	**21^{a}**	**2.5^{a}**
G17	32.7^{b}	**5^{a}**	9^{b}	14^{b}	2^{b}
G33	33.7^{b}	**6^{a}**	9^{b}	12^{b}	2^{b}
CV%	21	43	22	16	11

The height of the pseudo-stem was varied from 55.2cm to 28cm. The highest significant different value for height of the pseudo-stem was recorded by the Rangoon type ginger accession of G34 (55.2 cm) and the lowest value recorded by the accession of G28 (28 cm).

Number of pseudo-stems per clump varied from 15 to 2. The highest value for number of pseudo-stems per clump was recorded by the Rangoon ginger accession of G30 and G34 (15). But there were no any significant differences among the accessions of G6, G29, G30 and G34.The lowest value recorded by the Rangoon ginger accessions of G27 (2). Number of leaves per pseudo-stem varied from 16(G9) to 9 (G6 and G27). Leaf lengths of Rangoon ginger accessions varied from 21.2cm (G34) to 12cm (G9). Leaf width varied from 2.4cm (G34) to 1.8cm (G9). Among the considered Rangoon accessions, G34 was the most predominant accession for the morphological characters. Normally Chinese ginger has, higher pseudostem height and less number of pseudostems per clump than that of Rangoon ginger.

B. Evaluation of the colour of the rhizomes of ginger accessions -

Nine month matured fresh ginger rhizomes were used for the evaluation. Cross sections of rhizomes were compared with a Munsell Colour Chart (Plant) (Figure 01).

Figure 01: Cross Sections of Rhizomes of Ginger Accessions

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Table 03 shows the Munsell colour notations for rhizome of Chinese ginger accessions and Table 04 shows the Munsell colour notations for rhizome of Rangoon ginger accessions.

Table 03 : Munsell colour notations for rhizome of Chinese ginger accessions

Accession No.	Colour notation of the rhizome [according to Munsell Colour Chart (Plant)]
G6	5Y 8/6 to 8/8
G9	5Y 8/4
G27	5Y 8/4 to 8/6
G28	5Y 8/6 to 8/8
G29	5Y 8/8
G30	5Y 8/6 to 8/8
G34	5Y 8/6 to 8/8

Water, protein, lipids, fibres, starch, minerals and vitamins are the components of ginger rhizomes (Ginger, 2015).

Normally, the ginger rhizome is pale yellow in colour. A study was done for identify, what are the compounds that responsible for the yellow colour. In this study, 62 kinds of ginger rhizomes originating from different cultivars or different cultivation locations were collected for analysis of yellow pigment compounds. Ultra-performance liquid chromatography profiles at 420 nm for each sample were used for principal component analysis. Curcumin, demethoxy curcumin, and 6- dehydrogingerdione were identified as the main common compounds contributing to the yellow colour (Yoko I. *et al, 2014*).

Commonly cross sectional colour of core area of rhizome of Chinese ginger is bright yellow. All the colour notations of Chinese ginger accessions were differ from each other. That means their pigment compositions were differing from each other.

Commonly cross sectional colour of core area of rhizome for Rangoon ginger is light yellow. Most of the Rangoon ginger accessions (G6, G28, G30, G34) show 5Y 8/6 to 8/8 colour notation for cross section colour of rhizome.

Table 04 : Munsell colour notations for rhizome of Rangoon ginger accessions

Accession No.	Colour notation of the rhizome [according to Munsell Colour Chart (plant)]
G1	5Y 8/8
G2	5Y 8/6
G3	5Y 8/4 to 8/6
G17	5Y 8/8 to 8/10
G33	5Y 8/6 to 8/8

C. Evaluation yield of ginger accessions-

1) Fresh yield of the Chinese ginger-

Mean values of fresh yield of Chinese ginger is shown in Table 05.

Table 05: Mean values of fresh yield of the Chinese ginger

Accession no.	Fresh weight of the rhizome /clump (g)			
	1st year cultivated ginger	2nd year cultivated ginger	3rdyear cultivated ginger	Mean values of 3 years
G1	**1265.5^{a}**	**877.2^{a}**	546.1^{d}	896.3^{b}
G2	1219.8^{abc}	723.8^{ab}	596.5^{c}	846.7^{c}
G3	1245.5^{ab}	697^{ab}	557.2^{d}	833.2^{c}
G17	1113.6^{c}	565.3^{b}	648.5^{b}	775.8^{d}
G33	1113.5^{c}	627.7^{b}	**1106.4^{a}**	**949.2^{a}**
CV%	30.4	13.9	20.3	13.5

Means within a column with the same letter are not significantly different at P<0.05

In first year, the highest fresh yield was given by the accession of G1 (1265.5 g/clump). But it was not significant different with the accessions of G3 (1245.5 g/clump) and G2 (1219.8 g/clump). The lowest fresh yield was given by the accession of G33 (1113.5 g/ clump).

In second year, fresh yield for all the accessions were lower than the yield of first year. It is may be

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the unfavourable weather condition of the second year. The highest fresh yield was given by the accession of G1 (877.2 g/clump). But it was not significant different with the accessions of G2 (723.8 g/clump) and G3 (697.0 g/clump). This is more or less similar to first year yield. The lowest fresh yield was given by the accession of G17 (565.3 g/ clump).

In third year, the significant highest yield was given by the accession of G33 (1106.4 g/clump). The lowest yield was given by the accession of G1 (546.1 g/clump). Besides the yield of G33, yields of the rest of the accessions in the third year, were lower than that of first year. The reason may be the weather conditions gave a negative impact on the yield of the accessions of G1, G2, G3 and G17 but not an adverse effect on the yield of G33, in third year due to some genetical reason.

Three year mean values for fresh yield of rhizome varied from 949.2 to 833.2 g per clump. When considered three years average yield of Chinese ginger, G33 accession gave the highest yield of 949.2 g/clump (10,441 kg/Ac). Therefore G33 accession is more suitable for cultivate under coconut plants as an intercrop.

The vegetative growth and development of ginger are divided into two phases. First phase is the rapid growth phase, that is increased growth rate of plant height followed by rhizome development phase. Throughout the second phase, enlargement and expansion of ginger rhizome is happened (Soni J. K., *et. al*.,2022).

Although the predominant vegetative growth was indicated by the Chinese accession of G33, the highest fresh yield was given by G33 accession. The reason for this type of situation may be the large amount of synthesized food was utilized for vegetative growth, and remaining only a small amount of synthesized food for the storage in rhizome.

Table 06: Mean values of fresh yield of the Rangoon ginger

Accession no.	Fresh weight of the rhizome /clump (g)			
	1st year cultivated ginger	**2nd year cultivated ginger**	**3rdyear cultivated ginger**	**Mean values of 3 years cultivated ginger**
G6	**749.4^{a}**	538.5^{d}	538.8^{d}	608.9^{d}
G9	671.8^{b}	543.3^{d}	552.8^{d}	589.3^{d}
G27	681.4^{ab}	703.3^{abc}	720.2^{b}	701.6^{b}
G28	**729.5^{ab}**	**801.3^{a}**	731.8^{b}	**754.2^{a}**
G29	696^{ab}	**764.3^{ab}**	**749.8^{a}**	**736.7^{ab}**
G30	**690^{ab}**	644.3^{bcd}	589.1^{d}	641.1^{c}
G34	**684^{ab}**	590.3^{cd}	658.6^{c}	644.3^{c}
CV%	35.4	11.7	20.6	11.7

Means within a column with the same letter are not significantly different at P<0.05

2) Fresh yield of the Rangoon ginger

Mean values of fresh yield of Rangoon ginger is shown in Table 06

In first year, the highest fresh yield was given by the accession of G6 (749.4g/clump). But it was not significant different with the accessions of G27, G28, G29, G30 and G34. The lowest fresh yield was given by the accession of G9 (671.8 g/ clump).

In second year, the highest fresh yield was given by the accession of G28 (801.3 g/clump). But it was not significant different with the accessions

of G29 (764.3 g/clump) and G27 (703.3g/clump). The lowest fresh yield was given by the accession of G6 (538.5 g/ clump).

In third year, the significant highest yield was given by the accession of G29 (749.8 g/clump). The lowest yield was given by the accession of G6 (538.8 g/clump).

Mean fresh yield of rhizome varied from 754.2 to 589.3g per clump. When considered three years average yield of Rangoon ginger, G28 accession gave the highest yield of 754.2 g/clump (4,977.7kg/ ac).

Commonly Chinese ginger yield is higher than Rangoon ginger yield. Although the predominant vegetative growth was indicated by the Rangoon accession of G34, the highest fresh yield was given by G28 accession. The reason for this type of situation may be the large amount of synthesized food was utilized for vegetative growth, and remaining only a small amount of synthesized food for the storage in rhizome.

IV. CONCLUSIONS

This research was carried out at Inter-cropping and Betel Research Station, Narammala. This area belongs to Kurunegala district. Kurunegala district is under the coconut triangle. Coconut plants are generally spaced in 26 ft x 26 ft. Due to this reason in 75% of area under the coconut plants are remaining unproductively. Underutilized area is high when the age of the coconut plants is below 5 years and over 20 years. Climatic conditions in Kurunegala district is more favourable for ginger cultivation. After the three years field experiment, the highest fresh yield of rhizome per clump for Chinese ginger accessions was given by the accession of G33 (949.2 g/clump) in Low Country Intermediate Zone under coconut cultivation. The highest fresh yield of rhizome per clump for Rangoon ginger accessions was given by the accession of G28 (754.2 g/clump) in low country Intermediate zone under coconut cultivation. The G28 and G33 accessions can be used to cultivate under coconut plantation as an intercrop to increase the productivity of coconut lands. Further research is required to identify the performances of this accession in other agro-ecological regions besides low country intermediate zone.

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Plant-derived Semiochemical Strategy for Sustainable Management of Coconut Whitefly (*Aleurodicus cocois*) using Trunk Injection Techniques

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Abstract

In Sri Lanka, the coconut industry, which is a major contributor to the national economy, is under severe threat from the recently introduced pest, the coconut whitefly (Aleurodicus cocois). This pest's resistance to conventional pesticides combined with the height of coconut trees has highlighted the need for sustainable management alternatives. The aim of this study is to develop and evaluate a plant semiochemical-based strategy for coconut whitefly control, using stem injection as a systemic alternative to chemical pesticides. The approach offers a sustainable solution by reducing pest populations without negatively impacting the ecosystem. Plant extracts of seeds and leaves of Strychnos nux-vomica (Goda kaduru), neem, mint and clove oil were formulated and tested. Four successful formulations were identified and initially tested by direct spraying. Building on these results, the formulations were combined with systemic recipients such as urea, NaCl, KCl and citric acid and evaluated by strain injection methods. Field trials showed significantly higher mortality rates (68%, 95.85%, 93.27% and 94.66%) for formulations 1 to 4 compared to the untreated control ($p < 0.005$). Stem-injected palms showed a gradual decline in whitefly populations, although adverse weather conditions prevented continuous monitoring. These findings suggest that repeated applications are necessary for long-term success.

Keywords: Alternative pesticides, Coconut whitefly, Plant semiochemicals, Trunk injection, Sustainable pest management.

I. INTRODUCTION

In Sri Lanka, the coconut palm, also known as *Cocos nucifera*, serves not only as a symbol of the country's thriving agricultural sector but also as a symbol of the country's cultural identity and its ability to recover economically. The sector, which spans around 410,000 hectares, serves as the foundation of rural economies, providing employment opportunities for thousands of small-scale farmers and making a substantial contribution to the economy of the country. Many aspects of everyday life are influenced by its products, including the gastronomic pleasures that are enjoyed all throughout the country, its function in traditional medicine, and the manufacture
of coir, which is a versatile material that is used in a broad variety of applications (Al-Ballaa, 2023). However, this essential sector is confronted with a severe challenge in the form of the coconut whitefly, also known as *Aleurodicus cocois*, a pest that puts the health of crops and their output at risk. The effect of this disease goes beyond the immediate harm it does to the coconut palms; it also affects the livelihoods of farmers, the supply of coconut-based goods, and the price of those items, and it upsets the ecological balance that is necessary for sustain\able agriculture. The current circumstance shows the urgent need for creative and effective ways for pest control, such as the semiochemical-based strategy that was developed in this study.

The current strategies employed to combat the coconut whitefly in Sri Lanka are riddled with limitations. Chemical pesticides, the most common method, pose significant environmental hazards, threatening non-target species and potentially leading to the development of pest resistance. These chemicals also pose health risks to the farmers and consumers. Manual removal of the pests, while non-toxic, is impractical and labor-intensive, especially considering the scale of infestations and the height of mature coconut palms. Yellow sticky traps, another method, provide limited control and are ineffective in large-scale infestations. (Abeysekera, 2019).

This prevailing situation underscores the urgent need for an innovative, sustainable, and practical

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solution to manage the coconut whitefly menace effectively. The limitations of existing pest control methods highlight the necessity for a strategy that is not only environmentally responsible but also economically viable and easy to implement on a large scale. (Maniania and Ekesi, 2016).

The purpose of this study is to establish a unique approach of pest management that is both successful and ecologically sustainable and develop a semiochemical-based strategy, utilizing trunk injections, to manage the coconut white-fly infestation. This approach promises to be a targeted, environmentally responsible, and potentially more effective method compared to the current practices.

II.MATERIALS AND METHODOLOGY

A.Extraction of Plant Compounds

The extraction of insect repellent compounds was carried out using a systematic distillation method. Selected plant materials were placed into a distillation flask, and the distillation apparatus was set up according to proper guidelines. Distilled water was added to the flask, ensuring it covered three-fourths of the plant material to prevent overflow during boiling.

Upon heating the distillation flask, the water began to boil, releasing steam that carried the insect repellent compounds from the plant materials. The steam was then passed through a condenser, where it was cooled and converted back into a liquid. The resulting liquid consisted of a mixture of water and the extracted insect repellent compounds (Irzhad et al., 2023).

B.Isolation and Purification of Extracted Plant Compounds

The isolated plant compounds underwent a systematic isolation and purification process in the well-equipped laboratories of the Microbiology and Crop Science Departments at the Faculty of Technology, South Eastern University of Sri Lanka. Firstly, the extracted plant compounds were transferred to a separation funnel, where petroleum ether was added and thoroughly mixed. The mixture in the separation funnel was allowed to settle, resulting in two distinct phases: an upper organic phase (containing the plant compounds) and a lower aqueous phase (water). Sodium sulfate was then added to remove any residual water. The petroleum ether was subsequently evaporated using a rotary vacuum evaporator at 40°C.

Once refined, the compounds underwent rigorous testing to determine their purity and concentration, ensuring that the pesticide formulation contained only the most effective and consistent components. This meticulous purification process is essential for developing a pesticide solution that is both effective and safe for managing the coconut whitefly (Skoog et al., 2013).

C. Preparation of Semiochemical Pesticides

The selected plant materials were dried to reduce their moisture content and then cut into small pieces. These were ground into a fine powder using a blender and placed into flasks. Hexane and methanol were added to the flasks as solvents, and the mixtures were shaken overnight at 1600 rpm. The polar and nonpolar compounds in the plant materials were extracted by the respective solvents. The resulting mixtures were filtered using filter papers, and the filtrates were collected in separate flasks for further analysis.

The final stage of this process involved homogeneously mixing all the pesticide compounds. Strychnos nux-vomica was identified as a promising compound. Additionally, neem oil, clove oil, and mint oil were incorporated. An ultrasonic mixing machine was used to ensure thorough mixing. The ultrasonic mixer effectively disperses nano-sized particles into liquids, such as water, oil, and solvents. Four types of formulations were prepared for mortality testing (McMurry, 2016).

Table 2.1: The percentages of **Strychnos nux-vomica, clove oil, mint oil,** and **neem oil** in each formulation.

Formulation	Strychnos nux-vomica	Clove oil	Mint oil	Neem oil
1	5%	5%	5%	5%
2	10%	5%	5%	5%
3	15%	5%	5%	5%
4	20%	5%	5%	5%

A. Tested the Efficacy of the Prepared Formulation Against Whitefly Through Laboratory Bioassays.

The pesticide was tested for its efficacy in controlling whiteflies through direct spraying prior to trunk injection. High-pressure spraying and mist spraying techniques were used to minimize fly

dispersal and ensure effective application. Before spraying, the whitefly population on each sample was roughly counted. After spraying, the number of dead whiteflies was recorded at various time intervals, such as 10, 20, 30, 60, and 120 minutes. The treated leaf area remained free of whitefly infestation for approximately seven days following pesticide application.

B. Trunk injection solution compounds

During direct spraying, mortality was recorded positive way. Formulation of the highest mortality recorded, further incorporated with systemic carrier materials and tested for trunk injection. The first step of this process was the preparation of trunk injection formulations. Mainly four types of formulations were used.

Figure 01: Prototype trunk injector

Table 2.2: Components of Trunk injection formulations

Formulation	Components	Water (ml)	Pesticide
1	Citric Acid	40	Yes
2	Urea, KCl, and NaCl	40	No
3	Pesticide, Water, Citric Acid, and Salt	40	Yes
4	Pesticide, Citric Acid, and Salt	40	Yes

Drilled 3 inches and made two holes in the coconut trunk, and set a 20ml needle for each hole. Then pesticide and translocation mixture were inserted into each needles. Four coconut trees were used for four mixtures. Then monitored the absorption condition of the mixtures. All the mixtures were absorbed within one day.

Leaf samples were methodically collected at 2, 4, and 7 days post-application marking key intervals for evaluation. As well these collected samples were subjected to GC-MS analysis as per the procedure with the goal of evaluating the translocation design and the effectiveness of the mixtures along the trunk to the leaves over the specified time intervals.

VIII. RESULTS & DISCUSSION

A. Evaluating Mortality Rates Induced by Formulated Semiochemical Pesticides

Table 3 1: Formulation 1 mortality rate results

Plant 01 Sample Nos	Alive (before spray)	Alive (after spray)	Number of dead whiteflies
2	98	27	71
5	63	29	34
1	38	11	21
3	250	80	170
3.1	140	30	110
Total	589	177	406
			68.93%
	Morality rate		

The Table 01 illustrates that the number of coconut whiteflies that were alive before and after the application of formulation 1, along with the calculated mortality for each sample. The sum of white flies alive before the spray across all samples was 589, and the sum of those alive after the spray was 177. This resulted in a total of 406 dead. The mortality rate, presumably calculated as (Total dead / Total live before Spray) * 100, is approximately 68.93%. This indicates that, on average, about 68.93% of the coconut white flies were killed by formulation 1 across all the samples.

Table 3.2: Formulation 2 mortality rate results

Plant 02 Sample Nos	Live whiteflies (before spray)	Live whiteflies (after spray)	Number of dead whiteflies
18	338	19	319
10	178	7	171
12	244	0	244
10	156	12	144
Total	916	38	878
	Morality rate		95.85%

Sample No 18: Initially had 338 white flies alive, and after spraying, 19 remained alive, resulting in 319 mortalities. Sample No 10: Started with 178 white flies alive, with 7 surviving post-spray,

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leading to 171 mortalities. Sample No 12: Had 244 white flies before the spray, with none surviving afterward, thus 244 mortalities. Sample No 10: Had 156 were alive before the spray, and 12 remained after, resulting in 144 mortalities.

Summing up the figures, there were initially 916 white flies alive across all samples, and post-spray, 38 remained. This resulted in a total of 878 white flies being mortally affected by formulation 02.

The mortality rate for formulation 2 is calculated to be approximately 95.85%, as derived from the formula (Total dead/ Total Alive Before Spray) * 100. This suggests a very high efficacy of formulation 2 in causing mortality in the coconut whitefly population across the samples tested.

Table 3.3: Formulation 3 mortality rate results

Plant 03 Sample Nos	Alive (before spray)	Alive (after spray)	Number of dead whiteflies
7	38	4	34
8	89	3	86
16	106	13	93
18	208	14	194
Total	441	34	407
			93.26%
Morality rate			

The mortality rate for formulation 3 is calculated to be approximately 93.26%, as determined by the formula (Total dead/ Total Alive Before Spray) * 100. This rate suggests that Mixture 3 is highly effective, resulting in the death of a large majority of the coconut white-flies across the samples tested.

Table 3.4: Formulation 4 mortality results

Plant 04 Sample Nos	Live whiteflies (before spray)	Live whiteflies (after spray)	Number of dead whiteflies
2	197	4	193
6	141	8	133
3	69	13	56
10	268	11	257
Total	675	36	639
Morality rate			94.66%

The mortality rate for Formulation 4 is approximately 94.67%, calculated by the formula (Total dead / Total Alive Before Spray) * 100. This mortality rate is quite high, indicating that Formulation 4 is very effective in killing coconut white-flies across the tested samples.

Comparing formulations 4 to the previous formulations: Formulation 1 had a mortality rate of 68.93%, followed by Formulation 2 at 95.85% and Formulation 3 at 93.27%.Formulation 4's effectiveness is slightly less than that of Formulation 2 but is still considerably high and is more effective than Formulation 1 and slightly higher than Formulation 3. To determine the best mixture, one should consider not only the mortality rates but also factors such as environmental safety, cost-effectiveness, ease of application, and any non-target effects. Formulation 4 seems to be a strong candidate based on efficacy; however, a comprehensive evaluation including these additional factors is necessary for a conclusive decision.

IX. CONCLUSION

In conclusion, the experimental study on the effectiveness of different formulations for controlling coconut whiteflies in this preliminary study has shown promising results, especially with formulation 2 (10% Strychnos nux-vomica + 5% clove oil + 5% mint oil + 5% neem). oil) and formulation 4 (20% Strychnos nux-vomica + 5% clove oil + 5% mint oil + 5% neem oil). These formulations achieved high mortality rates of 95.85% and 94.67%, respectively, indicating their potential as effective pest control solutions. However, further research, including additional experiments and field trials, is essential to validate these results, ensure systemic properties of the coconut palm, and evaluate the effectiveness and sustainability in practice. The promising results of Formulations 2 and 4 highlight the need for further research to support their practical application in sustainable agricultural practices.

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The Foliar Application of Sea Lettuce (*Ulva lactuca*) Liquid Extract on Growth and Quality of Groundnut (*Arachis hypogaea* L.)

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Abstract

*At present there is a significant demand for environmentally sustainable agriculture to produce high-quality, nutritious food for the growing global population. Research efforts are currently focused on sustainable crop production methods, utilizing organic fertilizers and botanical compounds derived from natural resources to enhance the yield of commercially valuable crops. A field study was conducted to investigate the effects of foliar application of seaweed (Ulva lactuca) liquid extracts (SLE) on the growth and yield of the 'Indi' cultivar. The foliar application of SLE was applied to the plant at one-week interval. As treatment, the seed extract was applied at different concentrations 10% SLE (T2), 20% SLE (T3), 50% SLE (T4), and 100% SLE (T5) (v/v). Control treatment consisted of foliar application of distilled water (T1). The results showed that there were significant differences($p<0.05$) among the tested parameters of the 'Indi' cultivar.Foliar application of seaweed extract at concentrations of 20% (T3) increased the ground nut plant height (49.44 cm), number of nodules (144) and pods (27), air dry pod weight (36.38 g), air dry seed weight seed yield (24.28 g), biological yield (2898.12 kg/ha), and harvest index (41.96 %). Seaweed extract with 100% foliar application reduced the above-mentioned parameters significantly compared to the control. Therefore, it could be concluded that the seaweed extract at a 20% concentration level can be used to enhance the growth and yield of 'Indi' groundnut cultivar.***

Keywords: Biostimulator, foliar application, Groundnut, Seaweed liquid extract

I. INTRODUCTION

Groundnut (*Arachis hypogaea* L.) is an economically important crop in Sri Lankan region. It belongs to the Leguminosae family and requires applicable quantities of nutrients at appropriate times to achieve better yield and quality. There is a growing need to enhance the environmentally friendly cropping system and reduce the negative environmental impacts (Zuma *et al*.,2023). In Sri Lanka, growers use chemical fertilizers to meet the added demand for food and prefer to gain a quick return. Additionally, the inordinate operation of agrochemicals and synthetic fertilizers has led to numerous environmental problems. Due to the runoff of synthetic fertilizers from agrarian lands, nitrate and phosphate concentrations were set up to be significantly more advanced than the admissible limits of the World Health Organization norms (Divya and Balagali, 2012). Hence, the indispensable nutrient operation is essential for overcomes the constraints prevailing in the eastern part of Sri Lanka. Seaweed extracts contain a large proportion of growth hormones such as (IAA and IBA), cytokinin, trace elements (Fe, Cu, Zn, Co, Mo, Mn, and Ni), vitamins, and amino acids that promote the growth, yield, and productivity of numerous crops (Kumar and Sahoo, 2011). Seaweeds are biodegradable, non-toxic, non-polluting, and safe for humans, animals, and livestock (Dhargalkar and Pereira, 2005). Several regions of the world must be explored and exploited to understand the richness of marine plants and macroalgae. Algal resource use has not yet been optimized, and there is a great abundance of potentially important species, similar to sea lettuce. It is a macroalga belonging to the phylum Chlorophyta that can grow attached, sessile, or free-floating. Sea lettuce has proven to be a useful fertilizer because it not only provides macronutrients such as nitrogen, phosphorus, and potassium but also contains numerous micronutrients needed by crops (Eyras *et al.*, 1998). In Sri Lanka, the utilize of *Ulva lactuca* as a biofertilizer or bio stimulant has not yet been adequately investigated and has been reported as

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a beneficial application for the growth of plants (Metting *et al*., 1990). The specific objective of the current study was to estimate the effects of different concentrations of seaweed foliar spray on the growth and yield of groundnut.

II. MATERIALS AND METHOD

A. Experimental site.

The experiment was conducted at the agronomy farm of Eastern University of Sri Lanka. The soil of the experimental area is sandy regosol. The latitude is 43' and the longitude is 81º 42'. During the growing periods, the average temperatures ranged between 26-35°C. The minimum and maximum rainfalls during the experimental season were 7 mm and 60 mm respectively. Certified seeds 'Indi' was obtained from the seed sales Centre of Karadiyanaru, Batticaloa, Sri Lanka. The experiment was laid out in randomized complete block design (RCBD) with four replications. Polythene bags were used to establish the plants. The diameter and height of polythene bags were 42 cm and of 36 cm respectively. The foliar spraying was done five times during the experimental period at one-week intervals from three weeks after planting. The recommended plant management practices (watering, fertilizer applications) were carried out based on the guideline of the Department of Agriculture, Sri Lanka.

B. Seaweed collection and seed weed extract preparation.

Seaweed was collected by the hands along the coastal waters of Passikudaha, Batticaloa and the sediment, epiphytes, and organic matter on the surfaces of seaweed were cleaned immediately with seawater. The seaweed was packed in polythene bags and transported to the horticulture laboratory.Inorder to remove excess dirt and salt, the seaweed was once again cleaned with tap water in the laboratory. The seaweed was air dried in a dark room for three days. After drying, it was cut to a size of 0.5 cm to 1 cm. The samples were weighed (1 kg) and boiled in 1 litter distilled water for an hour. The mixture was allowed to cool to room temperature and was filtered through muslin cloth. The seaweed extract was treated at a 100% concentration and diluted with distilled water at a rate of 1:5 (Bhosle *et al*., 1975). During each application, 10 ml of extract was applied to each plant. The treatment structures are as follows,

Table 01. Details of treatments for conducting groundnut cultivar trials using seaweed liquid extract

Treatments	**Seaweed liquid extract (SLE)Concentrations**
T1	Distilled water (Control)
T2	10 %
T3	20 %
T4	50 %
T5	100 %

C. Samples Collection for analysis

Five plants have been arbitrarily chosen from each replicate of treatments. The control plants too were selected for the measurement.

D. *Plant height*

The plants were pulled out, and their roots were rinsed with tap water. A measuring tape was used to record the heights of each plant from the base of the stem (at the soil surface) to top of the highest part of the plant by a measuring tape.

E. *Number of pods and number of nodules*

The plants were uprooted from each treatment and the roots were washed with tap water. The plant's pods and nodules were counted.

F. *Air dry pod*

The pods of each plant were removed and separated and sundried for five days and their dry weight was recorded using an electric balance.

G. *Air dry seeds*

Seeds were separated from the pods. Seeds were sundried for five days and their dry weight was recorded using an electric balance.

H. *Seed yields*

Seeds were collected from each pod and seed yield was calculated from each treatment

I. *Biological yield*

The biological yield was determined by weighing all pants harvested from each treatment.

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J. *Harvest index*

The harvest index (HI) was calculated to determine the fraction of economically useful products of a plant in relation to its total productivity (grain-to-straw ratio) using the following formula:

HI = (EY/BY) x 100

Where HI- Harvest index, EY- Economic yield, BY-Biological yield.

K. *Statistical analysis*

Data collected were subjected to analysis of variance (ANOVA) using Statistical Analysis System (SAS) software (SAS version 9.1, Institute INC., Cary, USA). Treatment means were compared according to Tukey's to find out the significance between the treatments at $p<0.05$.

III. RESULTS AND DISCUSSION

Foliar application of seaweeds affected the growth of groundnut plants and significantly ($p<0.05$) influenced plant height compared to the control treatment (Table2). The highest plant height was obtained from T3 (20% SLE) treatment, whereas the lowest average was observed in T5 (100 % SLE). The application of seaweed extracts may have contributed to the observed outcomes by tending to raise the total chlorophyll content of the leaves, which in turn affected the photosynthetic process's capacity and efficiency (Fan *et al.,* 2013) and enhancing nutrient availability and absorption (Mancuso *et al.,* 2006). These factors likely contributed positively to plant vegetative growth. This result is similar to the results of Sutharsan *et al*. (2017) who reported that a lower concentration of *Sargassum crassifolium* significantly increased the plant height of maize, while a higher concentration exhibited an inhibitory effect than control plants. Means followed by the same letter are not significantly different ($P<0.05$.) from each other according to Tukey's honestly significant difference test at 5% significant level. There was a noticeable difference ($P<0.05$) in the number of nodules between Seaweed Liquid Extract (SLE)-treated and untreated plants. The highest number of nodules (144.67) was recorded in 20% SLE (T3), which differed remarkably from T1, T2, T4, and T5. The lowest nodule number was observed at the highest SLE concentration (100 %). The results align with the findings of Sivashankari *et al*. (2006), who observed that higher concentrations of seaweed extracts hindered germination, while seeds of *V. sinensis* soaking in lower concentrations of the extracts showed higher rates of germination.. Additionally, they observed that certain growth-promoting compounds such IAA and IBA, Gibberellins, cytokinin, minerals (Fe, Cu, Zn, Co, Mo, Mn, and Ni), vitamins, and amino acids may be accountable for the higher germination percentage at low concentrations.

Table 02: Effect of foliar application of SLE on Plant height, pod and nodule numbers per groundnut cultivar.

Treatment	Plant height (cm)	Number of nodules/plants	Number of pods/ plants
T1	22.67± 0.12^{d}	99.53b±2.4 0^{d}	20.3±0.25 ^{d}
T2	36.65± 0.23^{b}	134.44±2.82 ^{b}	25.73 ± 0.88^{ab}
T3	49.44 ± 0.44^{a}	144.67± 0.43^{a}	27.00 ± 1.54^{a}
T4	31.97± 0.23b^{c}	131.54± 0.33^{bc}	22.27 ± 0.17^{ab}
T5	20.26± 0.15^{e}	91.14 ±2.73 ^{e}	14.34±0.38 ^{e}

Statistical analysis of data showed that application of a lower concentration (20%) of SLE (T3) significantly ($P<0.05$) increased the mean number of pods per plant (27) in treated plants compared to the control plants, whereas a higher concentration (100%) of SLE (T5) reduced the mean number of pods per plant (14). This could be because increased SLE concentrations have an inhibiting impact even if SLE contains higher concentrations of macro-and microelements. It was clearly indicated that foliar application of seaweed (*Sargassum crassifolium*) at lower concentrations favored tomato plant growth by increasing. photosynthesis through an increased leaf area, as reported by Rasheed *et al.* (2003). These results coincide with those of earlier studies on tomatoes, where the number of fruits of tomato remarkably increased at lower concentrations of *Kappaphycus alvarezii* sap of Zodape, since phytohormones, amino acids, and essential macro

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and micronutrients found in seaweed extracts enhance plant growth and development. Furthermore, he reported that fruit number per plant was significantly reduced at higher concentrations than in control plants. It was also in agreement with the findings of Vijayakumar *et al*. (2018) who stated that higher concentrations of seaweed liquid extracted from *Codium decorticatum* decreased chlorophyll content, which led to reduced plant growth as well as the number of pods in *Capsicum annum*. Means followed by the same letter are not significantly different (P<0.05.) from each other according to Tukey's honestly significant difference test at 5% significant level. The application of SLE treatments had a significant (P<0.05) effect on the air-dried weights of pods and seeds per plant compared to the control (Table 03). The highest air-dried pod weight (36.38 g) and seed weight (24.28 g) per plant were obtained in T3 (SLE 20 %), whereas 100% SLE exhibited an inhibitory effect on pods (13.12 g) and seeds (10.02 g) weight per plant.

Table 03: Effect of foliar application of SLE on air-dried pod weight and air-dried seed weight of the groundnut cultivar.

Treatment	Air-dried pod weight per plant(g)	Air-dried seed weight per plant(g)
T1	16.24 ± 0.41^{d}	12.91 ± 0.35^{d}
T2	24.87 ± 0.47^{b}	17.38 ± 0.29^{b}
T3	36.38 ± 0.41^{a}	24.28 ± 0.55^{a}
T4	21.03 ± 1.14^{c}	15.72 ± 0.14^{c}
T5	13.12 ± 1.23^{e}	10.02 ± 0.45 ^{e}

Polyphenols, polysaccharides, alginates, polyamines, pigments, free amino acids, betaines, vitamins, micro- and macronutrients, and naturally occurring phytohormones are among the biologically active compounds found in seaweed extract. These different chemicals found in seaweed extract may have a stimulatory effect, potentially influencing the cellular metabolism processes of treated plants and producing the positive effects of seaweed extract that have been reported (Khan *et al*., 2009).Additionally, the high magnesium and mineral content found in seaweed extracts may have contributed to the observed increases in total leaf chlorophyll and carotenoid concentrations, which in turn may have improved photosynthetic efficiency, nutrient availability, and absorption, ultimately leading to increased carbohydrate production (El-Din, 2015).

Our results are in line with the findings of other researchers applying the SLE of *Sargassum crassifolium* with 20% concentration as the foliar application significantly increased the average polar diameter per fruit of tomato by 12.31% compared to control plants (Sutharsan *et al*., 2014).

Means followed by the same letter are not significantly different (P<0.05.) from each other according to Tukey's honestly significant difference test at 5% significant level. Pod and seed yields were significantly (P<0.05) affected by the application of SLE (Table 04). It was noted that the addition of 20% SLE (T3) had a significant effect on economic yield than the other treatments. Maximum seed yield was obtained in T3 (2898.12 kg/ha) followed by T2 (2727.58 kg/ha) and T4 (2227.76 kg/ha) respectively. The harvest index is a consequence of the grain yield

Table 04: Effect of foliar application of SLE on pod yield, seed yield and harvest index of the ground nut plant during the harvesting stage.

Treatment	Pod yields (kg/ha)	seed yields (kg/ha)	Harvest index (%)
T1	2576.41 ± 106.40^{d}	2134.97± 232.66^{d}	30.89± 01.35^{d}
T2	3452.98 ± 105.53^{b}	2727.58 ± 111.40^{b}	36.12± 01.61^{b}
T3	4135.57 ± 123.14^{a}	2898.12 ± 134.01^{a}	41.96± 02.33^{a}
T4	3176.98 ± 117.21^{bc}	2227.76 ± 201.42^{c}	32.44± 02.33^{c}
T5	1796.23 ± 122.41^{e}	1978.55 ± 102.01^{e}	17.01± 01.31^{e}

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and biological yield. There was also a significant difference ($P< 0.05$) in the harvest index of the ground nut plants after the foliar application of SLE (Table 03). Maximum harvest index (41.96 %) was noticed under the foliar application of T3 (20% SLE) which was followed by the foliar applications of T2 (10 % SLE) and T4 (50% SLE), whereas T5 (100 %) had the lowest value of 17.01 % in the present study. The increase in harvest index percentage may be due to an increase in seed yield. Major and minor minerals, vitamins, cytokinins, auxins, and compounds that promote growth akin to abscisic acid are all found in seaweed extracts. Studies have shown that these nutrients can enhance plant growth and yield as well as help plants become more resilient to environmental stress (Khan *et al*., 2009; Zhang *et al*., 2003). An increase in yield with SLE application is associated with improved chlorophyll biosynthesis (higher SPAD index) (Yusuf *et al*., 2018)

IV.CONCLUSION

The present study determined that the foliar application of Seaweed liquid extract **(***Ulva lactuca*) improved the growth and yield of 'Indi' groundnut cultivar. Among the four concentrations tested, 20% of SLE performed better in terms of groundnut plant growth and yield. Hence, foliar treatment with *Ulva lactuca* at 20% may thus be recommended for improving the characteristics of pods and nodules and yield and yield components of the groundnut.

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ABBREVIATIONS

SLE – Sea weed liquid extract

TRACK - DATA SCIENCE & AI

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Classification of Sri Lankan Paddy Varieties using Deep Learning Techniques

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Abstract

Rice is a highly consumed staple food in Sri Lanka. From farming phase to distribution phase of paddy, classification of paddy is becoming vital as it provides efficiency to the planning, production, sales and consumption. In Sri Lanka, the evaluation of the classification of paddy varieties is typically overseen by the Rice Research and Development Institute (RRDI). Traditionally, paddy identification is done manually by human inspectors, ensuring some level of accuracy but requiring significant manpower, time, and subjective judgment. This research seeks to transform the categorization of paddy varieties in Sri Lanka. This paper provides an approach to identifying and classifying paddy variety in paddy sample with the help of image processing and CNN model. For this approach, 10 varieties of paddy samples were collected from Rice Research and Development Institute. With these samples a dataset of more than 10,000 images were captured and used in this research. Image preprocessing involved cropping, scaling, and noise removal to standardize the data. Experiments were conducted with nine different CNN models, iterating through various architectures and training parameters to optimize performance. The experiment was performed on ten rice categories to evaluate the suggested solution. The accuracy of classification is of 93.69%.

Keywords: Convolutional Neural Network (CNN), Depp Learning, Paddy Classification

I.INTRODUCTION

Rice is favorable and highly consumed food in Sri Lanka. Rice is one of the highly consumed and staple food of Sri Lanka. Around 3.1 million tons of rough rice (paddy) are grown every year to meet about 95% of the country's demand. Since more than 1.8 million farmers and their families depend on rice production, rice holds a unique importance compared to other agricultural products in Sri Lanka (Anon, n.d.).

The accuracy of identifying paddy is one of the most important factors when classifying rice varieties. The use of paddy varieties differs depending on the purposes. Different varieties of rice are used for the production of many value-added products, including food varieties. Therefore, rice variety identification is very important for consumers (Golpour et al., 2014). In addition, the price and grade of rice are decided by its commercial value, genetic characteristics, and quality factors, which depend on the type of rice variety.

Currently, the classification of paddy is performed manually, typically through visual inspection by experienced and well-trained individuals. However, this approach has significant drawbacks, including time consumption and unreliability due to inconsistencies and the involvement of unskilled technicians. Moreover, results may vary from person to person leading to subjective results. Therefore, there is a pressing need for a more efficient and accurate method of paddy variety classification. The review of literature shows that both Machine Learning (ML) and Computer Vision (CV) have been extensively employed across various domains, offering a fast, accurate, nondestructive, and cost-effective substitute for automated paddy classification processes. Deep learning techniques have superseded statistical methods in computer vision due to their enhanced accuracy in tasks such as object identification and image recognition (Kiratiratanapruk et al., 2020).

While research on the classification of paddy varieties is limited, the identification of rice varieties has been extensively studied using external parameters such as shape, size, color, and texture (Cinar, 2019). For example, Singh and

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Chaudhury (2020) classified rice grains based on morphology, color, texture, and wavelet features, using image pre-processing techniques followed by a cascade network classifier. Similarly, Nagoda and Ranathunga (2018) employed support vector machines (SVM) and image processing methods to classify rice samples based on physical properties like color and texture, achieving a segmentation accuracy of 96% and a classification accuracy of 88%. Cinar (2019) also identified seven morphological features for classifying two different rice species. Several machine learning models, including Logistic Regression (LR), Multilayer Perceptron (MLP), SVM, Decision Trees (DT), Random Forest (RF), Naïve Bayes (NB), and K-Nearest Neighbor (KNN), were tested for classification accuracy, with success rates ranging from 88.58% to 93.02%. Additionally, Chatnuntawech et al. (2018) proposed a deep CNN algorithm for classifying rice varieties, using spatial–spectral data from two datasets, and achieved a mean classification accuracy of 91.09%. Their study also employed hyperspectral imaging to examine rice seeds in a consistent orientation.

Despite the limited research on paddy classification, there is a clear need to focus specifically on classifying Sri Lankan paddy varieties. The review of existing literature highlights the scarcity of research on Sri Lankan paddy and the lack of application of emerging deep learning methodologies. Therefore, this study aims to evaluate the effectiveness of deep learning algorithms in classifying Sri Lankan paddy varieties.

II.LITERATURE REVIEW

Artificial Neural Networks (ANN) have significant role for rice classification. For instance, Pazoki et al. (2014) used ANN Multi-Layer perceptron (MLP) and neuro-fuzzy networks to classify five rice varieties in Iran along with UTA feature selection algorithm to fine-tune the classifiers. The analysis used 24 color features, 11 morphological properties, and four shape factors to classify rice grains. The screening is proved to have a rate above 99% for both approaches.

There are numerous ML techniques that are available for the classification purposes. Arora et al., (2020) used different image processing algorithms and ML algorithms for rice grain classification using various parameters of individual rice grains like major axis, minor axis, eccentricity, length, breadth, etc. Relevant features of the rice grains have been extracted using various image processing algorithms. The rice grain images have been classified using different machine learning algorithms, such as LR, DT, NB, KNN, RF and Linear Discriminant Analysis (LDA) classifiers. They proposed future directions for incorporating additional features like chalkiness and moisture content analysis to ensure good quality rice is delivered.

While various ML algorithms have achieved significant classification accuracy, ensemble learning approach is also gaining momentum for classification problems. Ensemble Learning can achieve better performance than a single model alone by combining various models. It can be applied to various ML tasks including classification. Setiawan & None (2024) used ensemble learning methods to classify rice grains based on image features. The study compared various machine learning algorithms, ultimately finding that Bagging meta-estimator improved classification accuracy by combining predictions from multiple base estimators. They utilized Bagging meta-estimator to aggregate decisions from multiple base classifiers, reducing model variance and improving classification consistency. By applying this approach to various grain features, ensemble method achieved consistent classification accuracy across different paddy varieties.

Most studies on image-based paddy classification have primarily focused on color, morphology, and shape features. By using near-infrared hyperspectral imaging technology, both spatial and spectral information, as well as morphological features, can be captured. Jin et al. (2022) combined near-infrared hyperspectral imaging with traditional machine learning methods and deep learning models to classify rice seed varieties. This non-destructive imaging technique captures high-resolution spectra, enabling the detection of even subtle differences in paddy grain features, which leads to accurate classification across various rice varieties. Among conventional machine learning methods, SVM performed well, while in deep learning, LeNet, GoogLeNet, and ResNet models showed effective identification. Deep learning methods significantly outperformed conventional machine learning algorithms, with

most models achieving classification accuracies exceeding 95%.

In another study, Qiu et al. (2018) employed a near-infrared hyperspectral imaging system with two different spectral ranges *(380–1030 nm and 874–1734 nm)* to classify four rice seed varieties. The study compared the performance of various discriminant models, including KNN, SVM, and CNN. Models utilizing the spectral range of 874–1734 nm outperformed those built with the 380–1030 nm range, with CNN outperforming both KNN and SVM.

Rajalakshmi et al. (2024) achieved 97% accuracy in classifying 13 southern Indian paddy varieties — such as *Yanaikomban, Swarna Masoori, Sivapu Kowuni, and Mapillai Samba*—using a Deep Neural Network (RiceSeedNet) combined with traditional image processing techniques. They also demonstrated RiceSeedNet's potential to achieve 99% accuracy in classifying eight paddy grain varieties from a public dataset. The study utilized two datasets: one containing 13,000 images of southern Indian paddy varieties (1,000 images per variety), and another with 8,000 images from an open-source benchmark dataset (1,000 images per variety). In the research of Paddy seed variety classification using transfer learning based on deep learning, Jaithavil, D. et al. (2022) used three pre-trained models VGG16, InceptionV3, and MobileNetV2 to classify three paddy varieties. Compared with various other two models Inception-v3 showed the highest accuracy and least test loss with 83.33% and 28.41% respectively

Few other recent studies have been successful in classifying paddy varieties. For instance, Ansari, N. et al. (2021), presented a rapid inspection method to classify three paddy varieties using color, texture and morphological features and k-nearest neighbors, support vector machine, and partial least squares-discriminant analysis (PLS-DA) algorithm. Where the classification accuracy using PLS-DA, SVM-C, and KNN model was 83.8%, 93.9%, and 87.2% respectively. In another study, Uddin, M. et al. (2021) proposed a computer vision-based system for non-destructive paddy seed variety identification, crucial for maintaining seed purity in agriculture and industry. To address challenges like illumination variations during image capture, the study introduced a modified histogram-oriented gradient (T20-HOG) feature. Combined with Haralick and traditional features, these were refined using the Lasso technique and used to train a feed-forward neural network (FNN) for accurate variety prediction demonstrated 99.28% accuracy in identifying paddy grain types.

Anami, B.S. et al. (2020) proposed a deep convolutional neural network (DCNN) framework for automatic recognition and classification of various biotic and abiotic stresses in paddy crops. The pre-trained VGG-16 CNN model was used to classify stressed images during the booting growth stage. The trained models achieved an average accuracy of 92.89% on the held-out dataset, demonstrating the technical feasibility of using the deep learning approach. The proposed work finds applications in developing decision support systems and mobile applications for automating field crop and resource management practices. The approach is applicable to 11 classes of biotic and abiotic stresses from five different paddy crop varieties.

III.METHODOLOGY

The methodology applied for this study is illustrated in Figure 01 below.

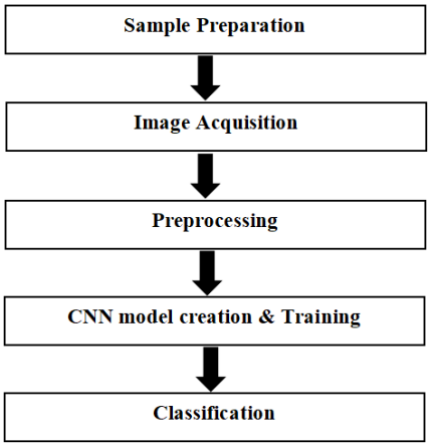

Figure 01: Applied Methodology

G. Sample Preparation

Although many different varieties of paddy are available today, ten common paddy grain samples were chosen for this study using a convenient sampling method. 100grams of paddy grain samples from eight common Sri Lankan Paddy varieties (At 309, At 362, At 373, Bg 300, Bg 352, Bg 359, Bg 374, Bw 367) and two Sri Lankan traditional varieties (Kahawanu, Madathawalu) were selected for the data set preparation. They

were obtained from Rice Research and Development Institute (RRDI), Bathalagoda, Ibbagamuwa (Figure 02).

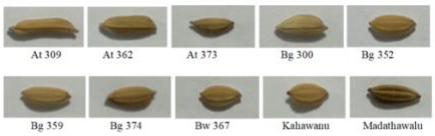

Figure 07: Samples images of ten paddy varieties

H. Image Acquisition

The paddy grains were first cleaned to eliminate impurities, and random samples from each variety were selected for image acquisition. 1000 images of each paddy varieties were captured in the same lightning condition and same fixed frame by an iPhone 14 pro camera. Each image of a paddy seed was acquired with the seed placed centrally and horizontally, with the seed body rotated along the horizontal axis.

I. Preprocessing

First, images of paddy were cropped and scaled to a uniform size of 500 x 250 pixels to standardize all the images and noise removal was done using bilateral and non-local filters where, bilateral filtering was effective for preserving edges and non-local filtering was effective for various noise types (Figure 03).

Figure 08: Preprocessed Images a) Raw image captured from camera b) Image after Cropping c) Image after Noise Removal

Bilateral filtering is an advanced image processing technique used to smooth images while preserving edges, making it ideal for applications where edge preservation is important. Bilateral filtering maintains the integrity of edges while reducing noise and smoothing the image.

Bilateral filtering is defined by:

$$BF[I]_P = \frac{1}{W_P} \sum_{q \epsilon S} G_{\sigma_s}(||p - q||)\, G_{\sigma_r}(I_p - I_q)\, I_q$$

where:
$BF[I]_P$ is the filtered image at pixel p
I_p and I_q is are the intensities at pixels p and q respectively.
S is the spatial domain of the image.
$G_{\sigma_s}(||p - q||)$ is the spatial Gaussian kernel.
$G_{\sigma_r}(||I_p - I_q||)$ is the range Gaussian kernel.
W_P is the normalization factor:

$$W_P = \sum_{q \epsilon S} G_{\sigma_s}(||p - q||)\, G_{\sigma_r}(I_p - I_q)$$

The bilateral filter operates by combining both spatial and range kernels, where the spatial kernel depends on the Euclidean distance between pixels p and q, with σ_s controlling the spatial extent of the filter and the range kernel depends on the intensity difference between pixels p and q, with σ_r controlling the range of intensity values that influence the filtering. The filtered image at a pixel is computed as a weighted sum of neighboring pixels, with the weights determined by both the spatial distance and intensity difference. This method effectively smooths regions with similar intensities while maintaining the sharpness of edges. Bilateral filtering provides better edge preservation than other filtering methods like Gaussian filtering, which often blurs edges, or median filtering, which can lose finer details. By reducing noise while retaining sharp edges, bilateral filtering ensures that important features are maintained, leading to more accurate classification.

J. Model Creation and Training

Since CNN has shown proven accuracy in various image-based classification problems due to their ability to capture spatial hierarchies of features through convolutional layers, this study employed CNN for the classification of paddy (Alzubaidi et al., 2021). Single paddy image was used to train the CNN model for the paddy classification. Dataset was split into three sets: training, validation and testing for accurate evaluation. Several own baseline CNN Models were created and trained on the training set, with performance tracking and hyperparameter optimization guided by the validation set. Iterative refinement was done using the validation set to consistently improve the model's performance.

In the development of a CNN model, the initial attempts utilized basic architectures with dropout layers to prevent overfitting, followed by the addition of batch normalization for improved training stability. The third iteration introduced preprocessed images with noise removal. Subsequent models incorporated further refinements, including dropout, regularization

techniques, L2 regularization, and a learning rate scheduler to enhance model robustness and performance. In the final models, the primary focus was on significantly expanding the dataset to improve the model's effectiveness.

The best-performing CNN model, as determined by our experiments, was composed of convolutional layers, each followed by activation functions, batch normalization, and pooling layers. Initially the input layer of the architecture processed images of size 500x250x3. The first convolutional layer applied 32 filters of size 3x3 with ReLU activation, followed by a 2x2 max pooling layer. This structure was consistently applied across subsequent layers, with the number of filters progressively increasing to 64, 128, 256, and finally 512, enabling the model to extract increasingly complex features. Batch normalization was used after each convolutional layer to enhance training stability, and dropout layers were incorporated to mitigate overfitting. The model concluded with a fully connected layer comprising 512 neurons, regularized with L2, and a dropout rate of 0.5. The final softmax output layer classified the input into one of 10 categories.

K. Evaluation

In the development of a CNN models, each model designed with different architectural complexities. The comparison of these models was conducted to identify the most effective paddy identification task. Performance evaluation was carried out using performance metrics, including accuracy, precision, F1 score, recall and AUC.

Accuracy: The percentage of correctly classified instances in the dataset is measured generally as accuracy. The number of true positives (TP), true negatives (TN), false positives (FP), and false negatives (FN) is used to calculate it.
The accuracy is defined by:

$$\text{Accuracy} = \frac{\text{TP} + \text{TN}}{\text{TP} + \text{TN} + \text{FP} + \text{FN}}$$

Precision: Defined as the percentage of correctly identified positive instances among all predicted positive instances. It is particularly important when the cost of false positives is high, as it indicates the reliability of the positive predictions.
The precision is defined by:

$$\text{Precision} = \frac{\text{TP}}{\text{TP} + \text{FP}}$$

Recall: quantifies the percentage of real positives that the model accurately detected. When ignoring positive cases (false negatives) is more crucial than mislabeling negatives as positives, it is extremely significant.
The recall is defined by:

$$\text{Precision} = \frac{\text{TP}}{\text{TP} + \text{FN}}$$

F1 score: The average mean of recall and precision combined.
The F1 score is defined by:

$$\text{F1 Score} = \frac{2 \times (\text{Precision} \times \text{Recall})}{\text{Precision} + \text{Recall}}$$

AUC: Area Under the Curve evaluates the model's ability to distinguish between positive and negative classes. It reflects the probability that a randomly chosen positive instance is ranked higher than a negative one. Higher AUC values indicate better performance, with 1.0 being perfect and 0.5 indicating no discrimination.

IV.RESULTS & DISCUSSION

A. Model 1

The global minimum of the loss function was reached at the 30th epoch. Despite this, the results were suboptimal; the validation accuracy was 74.2%. A significant oversight in this training phase was the use of raw data, rather than preprocessed data, which likely impacted the model's performance negatively. This experience underscores the importance of data preparation in building effective machine learning models, as preprocessing can significantly influence the accuracy and efficiency of the training process.

B. Model 2

The global minimum of the loss function was again reached at the 30th epoch. However, despite these adjustments, the results did not meet expectations. The validation accuracy was recorded at 62.5%. Similar to our initial attempt, the model was trained using raw data instead of preprocessed data, which adversely affected its performance. This experience further highlighted the critical importance of data preprocessing in training CNN models, as the lack of it can lead to significant discrepancies in performance metrics.

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C. *Model 3*

The global minimum of the loss function was achieved at the 80th epoch. Despite these improvements in data preprocessing, the performance metrics indicated that the training was not optimal. The validation accuracy was relatively low at 47.5%. This suggested issues in the model architecture or parameter settings that were not addressed merely by preprocessing the data. The significant loss indicates that further model evaluation and adjustments are necessary to improve its effectiveness.

D. *Model 4*

with the global minimum of the loss function being reached remarkably early at the 10th epoch. Despite these extensive changes, the training outcomes were highly unsatisfactory. The model achieved a validation accuracy of only 17%. This performance indicates a significant misalignment in the model's training process or architectural setup. These results underscore the need for a thorough review and recalibration of the model's configuration and training strategy.

E. *Model 5*

The model achieved a validation accuracy of 83%, indicating a substantial enhancement in its ability to generalize from the training data to unseen validation data. The improvements in image quality, along with careful preprocessing and effective model architecture, contributed to the much-improved performance metrics. This iteration demonstrates the critical importance of high-quality data and appropriate model tuning in developing effective deep learning systems.

F. *Model 6*

The results led to a notable improvement in the model's performance, achieving a validation accuracy of 76%. This represents a significant enhancement, confirming the effectiveness of the learning rate scheduler in optimizing the training process and the L2 regularization in improving the model's performance. This iteration underscores the utility of adaptive learning rate mechanisms and regularization techniques in boosting the accuracy and efficiency of machine learning models, especially in scenarios involving complex datasets and model architectures.

G. *Model 7*

The increase in dataset size proved to be highly beneficial, as reflected by a validation accuracy of 75.42%, the highest achieved across all above iterations.

H. *Model 8*

Finaly the same model 7 was trained using our whole dataset and the model achieved a validation accuracy of 93.69%. The substantial improvement in performance with the expanded dataset highlights the critical role of data volume in training machine learning models. A larger dataset provides a more comprehensive representation of the variability and complexity inherent in real-world data, thereby enhancing the model's ability to learn and generalize effectively. This milestone underscores the importance of both quality and quantity in dataset composition when aiming to improve model accuracy and robustness.

The performance of our models was affected by the quality of the dataset, image conditions, and the architectural choices made during model development. Models 1 and 2, which used raw, unprocessed images captured under varying lighting conditions and angles, struggled with noise and irrelevant features due to wide backgrounds and inconsistent image conditions, leading to poor identification and suboptimal results. In Model 3, preprocessing steps such as resizing and cropping were introduced, but the model still underperformed, indicating that the presence of wide backgrounds continued to overshadow the seeds. To address these issues, Models 5 through 8 utilized a standardized image capture process, where all images were centrally aligned, uniformly cropped, and preprocessed using bilateral filtering for edge detection and non-local means filtering for noise reduction. The architectural improvements in later models, including the addition of dropout, L2 regularization, and learning rate scheduling in Models 5 and 6, further helped to prevent overfitting and enhance generalization.

To ensure the trained model is correctly identifies the paddy seed, 30 paddy images were used for the prediction which are not used for train, test, or validate the model. The best performed model identified all images and other models identified few.

The result is summarized and presented below in Table 01 and Table 02.

Table 01: Summary of different CNN models which are trained using proper dataset

Model	Epoch	Learning rate	Validation Accuracy	Train Accuracy	Test Accuracy	F1 Score	Precision	recall	AUC
5	60	0.001	83%	99.5	78.25	0.11	0.14	0.11	0.51
6	60	Dynamically changed	76%	100%	55 %	0.1	0.18	0.11	0.47
7	60	Dynamically changed	75.42%	100%	82.25 %	0.11	0.11	0.12	0.51
8	60	Dynamically changed	93.69%	100%	89.75 %	0.94	0.95	0.94	0.99

Table 02: Summary of different CNN models which are trained using improperly captured images

Model	Epoch	Learning rate	Validation Accuracy
1	100	0.0001	74.2%
2	40	0.001	62.5%
3	100	0.0001	47.%
4	60	0.001	17%

Figure 03 illustrates the prediction of paddy seeds by Model 8.

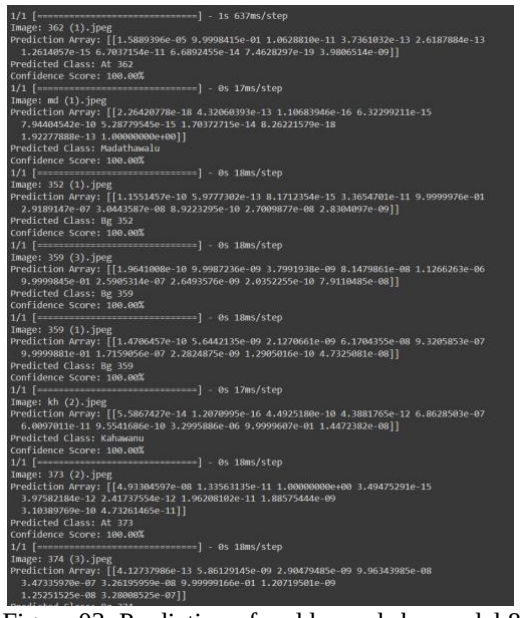

Figure 03: Prediction of paddy seeds by model 8

X. CONCLUSION

Deep learning technologies are now commonly used in various sectors of agricultural production and industrial food production. In this paper, we aim to develop CNN models to classify10 paddy varieties from a dataset of nearly ten thousand images of paddy seeds. We investigated nearly 1000 data samples in each paddy variety for training and testing models. Several CNN models were evaluated and compared in order to obtain a model that had the best performance. the highest classification accuracy obtained was 93.69%. The preliminary work presented in this paper could be further enhanced by focusing on clustering to identify and classify different paddy varieties in a single image.

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Leveraging Big Data and Advanced Analytics for Enhanced Decision-making: Insights and Applications

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Abstract

In today's era of exploding data volume, Big Data and its analytical tools are increasingly being embraced by organizations across various sectors to extract actionable insights for informed decision-making. This research paper investigates the critical role played by Big Data and analytics in driving strategic decisions across diverse domains. The multifaceted applications of Big Data analysis are examined in this paper, with a focus on customer behaviour analysis, marketing trend analysis, fraud detection and prevention, operational efficiency optimization, and risk management in decision-making. By organizations, deeper insights are gained into customer preferences, purchasing patterns, and consumer perceptions through the harnessing of Big Data, ultimately leading to an increase in customer loyalty. Big Data facilitates the identification of emerging market trends, enabling businesses to swiftly adapt their strategies, capitalize on new opportunities, and remain ahead of the competition. Anomalous patterns and suspicious activities are helped to be detected through advanced analytics techniques employed with Big Data, thereby fortifying organizations against fraud and minimizing financial losses. Additionally, operational processes are optimized through Big Data analytics, ultimately leading to cost savings and improved productivity. Furthermore, proactive risk identification, assessment, and mitigation strategies are enabled by Big Data analysis, empowering organizations to navigate uncertainties effectively and safeguard against potential threats. This paper sheds light on how valuable insights are provided for leaders seeking to leverage data for strategic decision-making and achieving sustainable success, with Big Data analytics transcending industries.

Keywords: Big data, Big data analytics, Decision making

I.INTRODUCTION

In today's increasingly interconnected and digitized world, the proliferation of data has been defined as a characteristic of our era. Big Data, characterized by its volume, velocity, and variety (the 3 Vs) (Elgendy, N. and Elragal, A., 2016), with some categorizing additional characteristics like value and veracity (5Vs) (Hiba, J. *et al*., 2015) and even further extended lists including virality, volatility, visualization, viscosity, and validity (up to 8 Vs) (Kapil, G. *et al*., 2016), has revolutionized how organizations operate and make decisions. The ability to harness and analyze vast amounts of data has been opened up by Big Data, from businesses and governments to healthcare and academia, for understanding complex phenomena, predicting trends, and driving innovation.

Big Data Analytics, a multifaceted discipline at the heart of the data revolution, refers to the process of large, complex datasets being collected, organized, and analyzed (Riahi, Y. and Riahi, S., 2018). It utilizes a range of techniques and technologies, including advanced algorithms, machine learning, and statistical methods, to unlock hidden value from these enormous datasets. This allows decision-makers to extract actionable insights from the vast amount of information available, empowering them to make informed choices (Elgendy, N. and Elragal, A., 2016). Across various domains and industries, a pivotal role is played by Big Data and its analysis in the realm of decision-making (Di Berardino, D. and Vona, S., 2023). Leveraging data-driven insights has become a cornerstone of success in the modern era, whether it's business strategies being optimized, customer experiences being enhanced, public services being improved, or scientific research being advanced.

Hidden insights from industrial data are unlocked by big data analysis in manufacturing, granting leaders a competitive edge through enabling

informed decisions in complex environments (Li, C. *et al.*, 2022). This aligns with findings from a separate study which highlights the link established between big data analytics and improved decision-making within businesses (Awan, U. *et al*. 2021). However, by the latter study, it is also suggested that a larger role may be played by business intelligence and data-driven insights than big data analytics capability itself.

Beyond manufacturing, big waves are being made by big data in healthcare. The potential of big data analytics in cardiology for improving the quality of care and reducing costs is pointed to by a study (Nazir, S. *et al*. 2019). Similarly, research on smart buildings explores how machine learning and big data analytics can be utilized to manage data and potentially improve decision-making (Qolomany, B. *et al*. 2019).

The importance of focusing on data quality over quantity for effective decision-making is emphasized by another study (Kościelniak, H. and Puto, A., 2015). A utilitarian decision-making model is proposed by this study, which considers the overall strategy of the enterprise, but acknowledges the need for further development in selecting important information from vast datasets.

Cloud computing and big data (Niu, Y. *et al*. 2021) emphasize the need for careful consideration before adopting cloud-based business intelligence. The entire+9 decision-making process can be potentially compromised by security risks associated with cloud storage and data transfer, if sensitive information is breached.

This literature review aims to comprehensively explore the pivotal role of big data and advanced analytics in enhancing decision-making processes. By examining the key applications, benefits, challenges, and best practices, this review seeks to provide valuable insights for organizations seeking to leverage these technologies for informed decision-making.

In Section II, we meticulously outline the methodology employed for our literature review, encompassing the search strategies, databases consulted, and the criteria for inclusion and exclusion. We also describe the data analysis techniques utilized to synthesize the reviewed literature. Section III elucidates the key findings in alignment with our research objectives, providing comprehensive insights into the impact of big data and advanced analytics on decision-making processes. In Section IV, we delve into the broader implications of these findings for both theory and practice. Finally, Section V presents our concluding thoughts and suggests directions for future research in this evolving field.

II.METHODOLOGY

A multi-database approach was employed to identify relevant sources for this literature review. Initially, a broad search of Google Scholar was conducted to capture the available publications on the topic. Titles and research data were then retrieved from Google Scholar based on a developed search strategy. Subsequently, additional searches were conducted in databases including IEEE Xplore, JStor, ScienceDirect, and others.

A two-stage selection process was implemented to ensure the included sources were relevant and credible. During the initial screening, articles were selected for their apparent relevance to the research question, based on keyword matching. This initial selection was further refined through a full-text screening process utilizing pre-determined inclusion/exclusion criteria. Here, the focus shifted to the depth and detailed relevance of the content to the research question.

For this review, a variety of scholarly sources were considered, including research articles, conference publications, established literature reviews, and other credible review articles.

The selection of sources prioritized both relevance and credibility. Included articles directly addressed the research topic and originated from trustworthy and reliable sources. Google Scholar's comprehensiveness was initially valuable due to its broad search capabilities. However, the focus ultimately shifted to specialized databases such as IEEE Xplore for its curated content in engineering and technology. Additionally, resources from JStor, ScienceDirect, and other established academic databases were included to ensure a well-rounded selection.

The initial analysis of the selected resources began with a general overview being conducted for each source. Introductions, conclusions, and methodology sections were skimmed to grasp the

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main points and research methods employed by the authors. This initial analysis will be followed by a more in- depth analysis involving a critical appraisal of each study. This appraisal will focus on the research methodology, potential biases, and the generalizability of the findings. Once each study has been critically evaluated, a process of synthesis will be undertaken. This synthesis will involve connections being drawn and patterns being identified across the studies, highlighting both agreements and contradictions. The goal of the synthesis is to provide a comprehensive understanding of the current state of knowledge on the research question.

III.BIG DATA ANALYTICS IN DECISION-MAKING

The power of big data analytics has led to a significant impact on the field of decision-making. The effectiveness of big data in this domain has been documented in numerous research articles. This review article focuses on identifying the key roles played by big data and big data analytics in decision-making. We will explore five key ways in which big data enhances decision-making processes.

I. Customer Behavior Analysis

The field of consumer behavior analysis is being revolutionized by the power of Big Data Analytics (BDA). Compelling evidence for BDA's ability to significantly enhance understanding of consumer behavior has been provided by numerous research frameworks. This has opened exciting opportunities for businesses to tailor their strategies and optimize customer experiences.

BDA is argued by Holmlund, M. *et al.* to be a useful tool for capturing and analyzing customer experience (CX) data (Holmlund, M. *et al*. 2020). However, improvement in CX is not solely achieved through having more data. Businesses need to focus on collecting the right data and utilizing it to generate actionable insights. The paper proposes a new framework for CXM that considers the various types of CX data and analytics that can be employed. The authors call for further research on how BDA can be used to improve CX in non-commercial settings, as well as how to develop better CX metrics and analytics tools.

BDA companies are becoming powerful allies for Consumer Goods and Retail Companies (CGRCs) in the realm of innovation (Mariani, M.M. *et al*. 2020). Faster innovation cycles for CGRCs can be fueled by BDA through bridging knowledge gaps. The research acknowledges limitations and emphasizes the need for further exploration across industries to solidify these concepts.

A promising Big Data application framework for analyzing consumer behaviors utilizes topological data structures, co-occurrence methodology, and Markov chain theory (Zin, T. T. *et al*. 2020). This framework operates in three layers: data organization, analysis and modelling, and prediction and inference. Studies have shown that this framework can effectively identify customer behaviors. For instance, it can be used to predict the most popular product combinations in a store, providing valuable insights into what products customers are most likely to buy together.

The proposed system addresses building decision trees for massive customer datasets using the C4.5 algorithm (Khade, A.A., 2016). Distributed processing for the ever-growing data volumes in today's cloud computing and big data world is catered to by leveraging the MapReduce framework. Traditional decision tree algorithms are simply not handled effectively by such large datasets.

Speed, reusability, and the familiar comfort of HTML elements alongside Scalable Vector Graphics (SVG) are offered by D3.js, which comes in for data visualization. The authors envision future improvements to be made to boost the system's efficiency and scalability, including the incorporation of realtime databases like Apache HBase or MongoDB, and the utilization of advanced distributed algorithms like ForestTree from Apache Mahout.

A mathematical and machine learning-based predictive model is shown to exist, with the capability to forecast consumer behavior using social media data from various platforms such as Facebook and YouTube (Chaudhary, K., *et al*. 2021). This model proves valuable for businesses by allowing them to understand how consumers might react to a product based on social media information. The findings demonstrate significant

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variations in consumer behavior across different social media platforms, with a maximum deviation observed at 99.51%. The model's accuracy was also measured, achieving a maximum of 0.98. It utilizes machine learning techniques and big data analytics to analyze social media data such as likes, followers, and downloads to predict consumer behavior on different platforms.

Customer segmentation based on the Time-Frequency-Monetary (TFM) value model and the establishment of loyalty tiers were previously employed (Wassouf, W. N., *et al.* 2020).

Classification algorithms were then applied, using loyalty levels as the classification categories and selected customer attributes as features. The results were compared to identify the most accurate classification model. Subsequently, rules for loyalty prediction were derived from this model. These rules revealed the correlations between behavioral characteristics and loyalty levels, providing insights into the drivers of loyalty within each customer segment. Targeted marketing efforts with appropriate offers and services for each segment were enabled by this approach. An additional benefit of using classification algorithms was the development of a precise predictive model for classifying new users based on their loyalty potential.

J. Trend Analysis

Valuable trends can be uncovered by analyzing the vast amount of data on Twitter (big data) (Rodrigues, A. P., et al. 2021). Big data analytics techniques like LDA (topic modelling) and K-means clustering go beyond simply counting hashtags. Hidden themes, user groups with specific interests are revealed by these techniques, providing a more nuanced understanding of what's trending. This empowers businesses to target customers effectively, politicians to understand public sentiment, and movie studios to gauge audience reception – all with improved accuracy compared to traditional methods.

Various preprocessing techniques are applied to the data before analysis, such as converting emoticons to text, removing hyperlinks, punctuation, and white spaces, removing stop words, stemming, and lemmatization. Hashtag counting was initially used in this study, but since it doesn't consider the actual tweet content for trend prediction, noun counting was also employed. Latent Dirichlet Allocation (LDA) was then used for clustering, followed by cosine similarity, K- means clustering, and Jaccard similarity for trend analysis. The analysis included both real-time and static data. Real-time streaming SPARK was utilized for real-time data analysis. In short, big data analytics unlocks a deeper level of trend analysis on Twitter, yielding actionable insights for a variety of stakeholders.

K. Fraud Detection and Prevention

The financial strain on healthcare systems in the US due to a growing elderly population and advancements in medical technology is highlighted in one of the articles (Herland, M. *et al*., 2018). The article focuses on Medicare fraud, a significant issue that wastes billions of dollars. Traditionally, fraud detection relies on manual auditing, which is inefficient when dealing with vast amounts of data. The increasing availability of big data, like electronic health records, opens doors for using machine learning to improve fraud detection in Medicare. The Centers for Medicare and Medicaid Services (CMS) plays a role by releasing big datasets to aid in identifying fraud and abuse. A method for using big data and machine learning to identify fraudulent activity in Medicare claims is proposed by the authors. They compare the effectiveness of using individual datasets (Part B (physician and other supplier utilization and payment data), Part D (prescriber utilization and payment data), and DMEPOS (referring durable medical equipment, prosthetics, orthotics, and supplies utilization and payment data)) and a combined dataset. Their findings show that the combined dataset with Logistic Regression delivers the best overall performance in detecting Medicare fraud. The study paves the way for further research using data sampling techniques to improve fraud detection accuracy.

Several ways auditors leverage big data analytics to detect and prevent fraud are identified in one of the papers (Rosnidah, A. P., *et al.* 2021). A framework that considers technological, organizational, and environmental factors (TOE) is presented. Technological factors include the specific data analytics tools used, while organizational factors encompass the audit firm's size and management's attitude towards this approach. Finally, environmental factors include

the industry, competition, and government regulations that the firm operates within.

Data mining, a broad concept used to find patterns and relationships within data, is highlighted as playing a crucial role. Text data mining is described as particularly valuable for fraud detection because much information is stored in text format. The paper goes on to explain that this process involves four key tasks,

- Classification: Sorting data into predefined categories.
- Clustering: Grouping similar data patterns together.
- Regression: Modeling data with minimal error.
- Association rule learning: Identifying how often specific patterns appear.

Fraud trends can be uncovered and the location's role in suspicious activity can be understood through geospatial analysis. Large datasets like insurance claims or burglary reports can be analyzed to proactively identify fraud by finding patterns and clusters that might indicate fraud rings. While data integration and using automated tools remain challenges, exploring new models and systems to aid fraud detection and support decision-making is crucial. For successful implementation, obtaining data from various sources in a consistent format for unified analysis is essential.

Computer-Assisted Audit Techniques (CAATTs) are identified as valuable tools for audits of all sizes, not just large firms. Even with basic computer skills, CAATTs can be leveraged to improve productivity, accuracy, and client relationships. There are two main types of CAATTs:

- Audit software: Analyzes client data for control weaknesses and record integrity.
- Test data: Created by the auditor to test the client's computer software controls.

The paper also identifies key barriers to integrating big data analytics into audit practice, such as data overload, data availability and relevance/integrity, pattern recognition ability, ambiguity, and a lack of training and expertise among auditors. Solutions to improve data analytics procedures for preventing and detecting fraud are proposed by the authors, including operational analysis, strategic analysis, and deep neural networks.

A framework and tools for analyzing retail fraud detection are highlighted in one of the other review papers (Jha, B.K. *et al*., 2020). This information is presented in Table 01.

L. Operational Efficiency Optimization

Systems to track employee performance and company success factors are being built by companies. These systems collect and analyze data to aid leaders in making informed decisions (Schläfke, M. *et al*., 2012). Performance management is being extended beyond financials, with new metrics and ongoing advancements being embraced. Data analysis is being used by businesses to improve performance management by identifying cause-and-effect relationships and utilizing various data sources to inform better decisions. This approach necessitates a strong IT infrastructure and data analysis skills, but it can be very effective. This paper argues that performance analytics can be significantly improved by performance management systems (PMS) through the use of data to validate cause-and-effect relationships.

Table 01: Font format for this publication

Author (s)	Method	Application
Gadal, S.M.A.M. and Mokhtar, R.A., 2017	k-means clustering , Sequential Minimal Optimization (SMO)	Retail fraud detection
Zuech, R., *et al*., 2015	Hadoop framework	Intrusion detection
Fan, Q., et al., 2009	Polar Histogram Feature (PHF), Bag-of-Features (BOF)	Intrusion detection
Hoang Trinh, *et al*., 2011	Finite State Machine (FSM)	Retail fraud detection
Coppolino, L., *et al*., 2015	SEPA Direct Debit system	Online payment
Cantabella, M., *et al*., 2017	Data gathering, investigation, imagination	Learning pattern analysis

Cui, H., *et al*., 2016	Graph Mining with Frequent Pattern (GM-FP)	Healthcare fraud detection
Xing, E.P., *et al*., 2015	Petuum framework	Large-scale Machine Learning
Kitts, B., *et al.*, 2013	Mix adjustment algorithm	Click fraud detection
Caldeira, E., *et al.*, 2012	Neural Networks, Random Fores	Transaction fraud detection
Leite, R.A., *et al.*, 2017	Financial Fraud Detection (FFD)	Banking fraud detection
Balasupramanian, N., *et al*., 2017	Big Data analytics	Online Fraud Detection

The use of BDA to improve the sustainability of the mining supply chain in South Africa is examined by one study (Bag, S., *et al*. 2020). The mining industry, while crucial to the South African economy, has social and environmental impacts. BDA can be utilized to optimize business processes such as procurement and logistics, resulting in cost savings, waste reduction, and improved sustainability. The study explores the positive correlation between BDA expertise and employee development. A link between employee development, an organization's human capital, and positive supply chain sustainability outcomes is suggested by their findings. It is argued that product innovation not only fosters employee development but also leads to improved employee performance and overall innovation levels. Managers play a key role in optimizing employee performance through the creation of a supportive learning environment. Employee performance is seen to improve with a greater managerial emphasis on innovation, particularly through the path of green product design, which ultimately leads to a sustainable supply chain. The researchers acknowledge that success in supply chain management, a sequence of activities, can be achieved through both human-driven and data-driven approaches. The development of these skills and the closing of any skill gaps among employees are identified as critical roles played by training. They emphasize that, in today's world, every activity is scrutinized through a technological lens, particularly Big Data Analytics.

The Logistics and Transportation industries are identified as prime candidates for utilizing Big Data (Borgi, T. *et al* , 2017). The constant movement of goods and people create massive datasets containing valuable information such as location, weight, and destination. These Big Data sets can be analyzed by logistics companies to improve service quality and efficiency. This study demonstrates the potential for big data technologies to be used in optimizing efficiency within logistics and transportation. By leveraging big data, several milestones can be achieved, including last-mile delivery, route optimization, crowdsourcing and social transportation, smart logistics, and anticipatory logistics.

M. Risk Management

Big data empowers organizations to comprehensively assess and manage risks by revolutionizing the entire risk management process (El Khatib, *et al*., 2023 & Doggalli, G., *et al*. 2024). Several studies have been conducted that demonstrate the use of BDA for mitigating risks in various sectors, including banking (Dicuonzo, *et al*., 2019), transportation, and healthcare (Choi, *et al*., 2017).

Big data analytics are shown to be beneficial for managing various risks, including financial, employee turnover, customer churn, and threats from partners, as evidenced by Apple's approach. Data from Siri and other sources are analyzed by Apple to identify, assess, and mitigate these risks before they occur. Additionally, this data is used to develop recovery plans and improve customer relationships. Due to its reliance on third-party vendors and various business operations, Amazon encounters a multitude of risks. However, these risks are effectively identified, assessed, and mitigated through the company's use of big data analytics. This big data is collected and analyzed through their cloud computing technology and AWS big data software, allowing data-driven decisions to minimize risks like fraud, employee churn, and operational issues. Similar to Apple and Amazon, Google utilizes big data analytics to manage internal and external risks. This big data, collected from various software sources, is analyzed to facilitate early identification and mitigation of risks. This allows Google to prevent fraud, manage risks from third-party companies, and reduce operational risks that could hinder its competitiveness (El Khatib, *et al*., 2023).

Operational Risk Management (ORM) is defined as the process of identifying and mitigating risks in business operations. A study explores existing literature on ORM frameworks and their applications in various sectors such as transportation, emergency management, and healthcare. The findings indicate that ORM is a growing area of interest, with a focus on power and energy, healthcare, supply chain operations, and information systems.

Big data introduces new challenges to ORM. The value of information assets can be difficult to determine, and storing big data can be expensive. Additionally, cultural and political risks are associated with collecting big data, such as privacy concerns. To address these challenges, companies can estimate the value of information assets, utilize tiered storage for data, and establish risk tolerance levels. Furthermore, new frameworks, such as the Bayesian Markov chain Monte Carlo (BMCMC) framework, have been developed to incorporate big data into ORM. Data mining techniques can also be employed to analyze big data and identify operational risks. For instance, data mining techniques have been used to develop financial early warning systems, forecast customer loyalty, and assess the risk of management fraud (Choi, T.-M *et al*., 2017).

IV.RESULT AND DISCUSSION

The findings of this literature review underscore the significant impact of Big Data Analytics (BDA) on decision-making across various domains. The analysis of existing research reveals that BDA enhances decision-making processes by providing organizations with deeper insights into customer behavior, emerging trends, fraud detection, operational efficiency, and risk management.

In customer behavior analysis, BDA allows organizations to understand and predict customer actions by analyzing vast datasets, enabling tailored strategies that improve experiences, loyalty, and satisfaction. In trend analysis, advanced techniques like topic modeling and clustering help identify subtle trends that traditional methods might miss, giving organizations a competitive edge in rapidly changing markets. BDA also significantly improves fraud detection and prevention, particularly in healthcare and finance, by using machine learning and data mining to identify anomalous patterns, reducing losses and enhancing security. Additionally, BDA optimizes operational efficiency by analyzing supply chain data to identify inefficiencies and streamline processes, leading to cost savings and productivity gains. Finally, BDA empowers organizations in risk management by proactively identifying and mitigating potential threats and vulnerabilities, a capability especially crucial in high-stakes sectors like finance and manufacturing.

BDA provides a nuanced understanding of customer behavior, allowing businesses to develop targeted strategies and improve customer satisfaction. Integrate multimodal data sources (e.g., text, images, and sensor data) to enrich customer insights and enhance predictive accuracy. Develop real-time analytics capabilities to promptly respond to changes in customer behavior and preferences. Advanced analytical frameworks, such as topological data structures and Markov chain theory, effectively predict customer behavior and identify popular product combinations. Future direction may focus on improving scalability and efficiency of these frameworks to handle increasingly large datasets. Explore the integration of emerging technologies like AI to refine predictive models and enhance decision-making processes. Techniques like Latent Dirichlet Allocation (LDA) and K-means clustering provide deeper insights into trends and user interests, surpassing traditional hashtag counts. Future studies may lead to Advance real-time trend analysis technologies by enhancing streaming data platforms and incorporating advanced preprocessing techniques. Address ethical considerations and biases in trend analysis to ensure fairness and accuracy.

Machine learning and data mining techniques improve fraud detection, particularly in sectors like healthcare and finance, by identifying anomalous patterns and reducing losses. In future it is necessary to develop robust data privacy and security measures to protect sensitive fraud-related data. Explore cross-industry applications of fraud detection frameworks and tools to enhance effectiveness in various contexts. BDA optimizes operational efficiency by analyzing supply chain data and identifying inefficiencies, leading to cost savings and productivity gains. Future researches may think of Integrating BDA

with emerging technologies like IoT to enhance supply chain management and operational efficiency. Focus on human-centric design to ensure that analytics tools support and enhance human decision-making. BDA revolutionizes risk management by providing advanced tools for identifying and mitigating risks, as demonstrated by companies like Apple, Amazon, and Google. There is a room for addressing challenges in operational risk management (ORM) by developing new frameworks and utilizing data mining techniques to identify and manage risks. Enhance scalability and efficiency in ORM processes to handle large volumes of risk-related data.

V.CONCLUSION

This literature review underscores the transformative impact of Big Data Analytics (BDA) on decision-making across diverse sectors. By offering profound insights into customer behavior, emerging market trends, fraud detection, operational efficiency, and risk management, BDA equips organizations with the tools to make more informed and strategic decisions. The integration of advanced techniques, such as machine learning, data mining, and multimodal data analysis, enhances the value of Big Data, allowing businesses to navigate and capitalize on the complexities of today's data-driven landscape.

Despite these advantages, several challenges persist, including issues related to data quality, integration, privacy, and security. To harness the full potential of BDA, organizations must invest in robust data governance frameworks and cutting-edge analytical tools. Future research should focus on addressing these challenges, exploring the application of BDA in emerging fields, and developing scalable solutions that integrate new technologies like AI and IoT.

Big Data Analytics represents not merely a tool but a strategic asset capable of driving innovation, enhancing competitiveness, and ensuring long-term success. Organizations that adeptly leverage BDA will be well-positioned to thrive in the digital era, transforming data into actionable insights and fostering sustainable growth

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Machine Learning-based Mobile Application for Weed Detection in Paddy Fields

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Abstract

In the context of Sri Lanka, where agriculture, particularly paddy cultivation, plays a crucial role, farmers face significant challenges due to weed infestation. Unlike some other countries that have embraced machine learning technologies to address these issues, Sri Lanka has yet to adopt such advanced solutions. To tackle the pervasive weed problem, a research initiative was undertaken to develop a mobile application capable of identifying weed types. The methodology involved utilizing Convolutional Neural Network (CNN) pre-trained models, namely ResNet-50, Inception-v3, and VGG16, along with the Google Colab platform for training the dataset. Among the three models, VGG16 demonstrated the highest accuracy, making it the chosen model to further the research. The primary goal was to achieve a superior level of accuracy in detecting weed species in rice fields. The research team focused on delivering a mobile application with a high level of accuracy to identify and classify weeds in paddy fields. The integration of advanced technologies, such as IoT and machine learning, aimed to provide Sri Lankan farmers with an efficient and effective tool to combat weed-related challenges in their agricultural practices.

Keywords: Weed detection, CNN, VGG16, ResNet-50, Inception-v3, Weed control methods

I. INTRODUCTION

Technology is being developed rapidly, constantly offering new solutions across various industries. Digital devices such as computers and smartphones have become essential tools in addressing everyday challenges. In the modern world, researchers and tech enthusiasts are continually creating systems and innovations by leveraging the latest technological advancements. As an agricultural country, in Sri Lanka, most of the farmers are struggling with the weed problem. The research is about the development of a machine learning based mobile application to identify the weed types in rice fields and provide weed controlling methods for the identified weed types. VGG16, InceptionV3, and ResNet 50 are the 03 Convolutional Neural Network (CNN) models that we used to train the image dataset. The mobile application was developed using the VGG16 model which gives the best accuracy in object detection. The research is based on the weed problem in Sri Lanka paddy cultivation and proposes a model with a higher level of accuracy for weed detection. In addition, it is planned to provide weed control methods for the identified weed species, and categorize weed control methods under organic (cultural, biological, physical, manual) and inorganic weed control methods with a short description of each weed species.

The target users are Sri Lankan farmers in both rural and urban areas, students, and the young generation interested in farming. In this research project, object detection accuracy is the key point and has the highest priority. Here, we used weed leaves in the image data set, and the accuracy level can be increased by using a large number of images.

In this work, the data set was collected by visiting the fields and capturing images of the found weed plants. The collected data set was trained on Transfer Learning technologies and three Convolutional Neural Network models (VGG16, Inception V3, ResNet 50) and found the best model as VGG16 according to the accuracy level and data loss.

Figure 01: Captured image data set

The technologies that were used for the project were Transfer Learning technologies, three

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Convolutional Neural Network models (VGG16, Inception V3, ResNet 50), Keras, etc.

A. Convolutional Neural Network (CNN)

CNN is a part of the Artificial Neural Network (ANN) in deep learning. CNN can recognize the patterns of objects. CNN is designed explicitly for processing pixel data and has a large number of neurons that can self-optimize via learning. CNN consists of 5 layers.

B. Transfer Learning

Transfer learning is the use of a pre-trained model (a model that was trained previously on one problem) in some way on another second problem. In deep learning, transfer learning is a technique where one previously trained neural network model is used to solve another similar problem. Keras is a powerful open-source Python library for developing deep learning models that run on top of the machine learning platform TensorFlow. So, many pre-trained models are available here. VGG16, Inception v3, and ResNet 50 are selected from them.

II. RELATED WORK

Research article shows that weeds reduce the yield and quality of the farm harvest (Kamath, Balachandra and Prabhu, 2020). But in most cases, weed management is not followed. The research contains a technique that can be used for automatic weed detection and identification. Their proposed system was a computer vision-based automatic weed detection. In their application, weeds can be detected and identified and classified from digital images. According to their review, computer vision can be defined as a process of analyzing images and videos into meaningful interfaces. The proposed system can be used in the agriculture sector to identify plant classification and crop disease identification. According to the paper, India lost INR 1050 million because of the harvest losses. They created the dataset according to types of weeds. They collected the dataset using two digital cameras facing down towards the ground. Images were acquired from a Raspberry PI (RP OV56647) camera and stored in RGB color space in JPEG format. They used MATHLAB (R2018) to process images. In their research, they used a sample of 300 datasets, dividing them into training and test sets. They predicted outcomes on the test data and measured diversity using Yule's statistic. The study developed two MCSS models to classify paddy crops and weeds from digital images. Their proposed system can be applied to publicly available paddy crop data and aims to recommend appropriate herbicides for different weed types based on the classification results.

Bai et al. (2020) conducted their survey on object detection recognition and robot grasping based on machine learning. As this research is in the image processing field, machine learning plays a major role there. Convolutional Neural Networks realize the training of large scale image datasets. In this research, they applied machine learning, and machine vision to various image processing tasks, such as image detection, target detection, etc. The article contains information about how they use CNN to analyze and process. When compared with other image processing algorithms, CNN gives the advantage of having no processing requirements for detecting the target. Rechay et al. (2021) have focused on neural networks to detect disease in maize due to its economic significance. Weeds are a major problem in agriculture yield management. They proposed a smartphone application to identify maize crop disease in plants by using the dataset. As they mention, the detection accuracy is 83%. The work shows that they used the image Net dataset as a benchmark for computer vision. That dataset contains above 1000 items. Their defined model was developed using Python. The holdout methodology is used to evaluate results to separate the dataset to 80% training data and 20% for validating data. They did the testing part on a Ryzen 5 1500 6-core workstation. They develop the neural network model by developing two classes, healthy and diseased. They used the library TensorFlow Google developing model to design a deep learning model. The source library was written using Python. The backend was developed by using the TensorFlow backend. It is an open-source deep learning framework for developing mobile devices. The IDE that they used is Android Studio.

According to Roahn et al. (2011) in Sri Lanka, 50% of crop yields are reduced because of the weeds. Their research article shows how weeds affected paddy harvest and weed types. As they mentioned in the paper, there are 16 weed species.

According to Szegedy, Toshev and Erhan (2012) Image processing using Deep Learning Neural Networks is the most commonly used method in object detection. In the research article, the authors proposed a system to object detection in various classes using a formulation. Their proposed system is high-resolution object

detection that can be used to detect images using DNN. The authors focused on DNN for object detection in a larger number of datasets and formulated a DNN based regression to get a binary mask as the result. They used DNN mask detection in a multiscale fashion to increase accuracy. CNN layers were used to detect images from the dataset. CNN regression layer was used to generate the binary mask. To get the most accurate output, the dataset images were divided into N number of pixels. The fixed size of the N is equal to d*d. According to the paper, the authors faced some challenges because of the image sizes and the limitation of the output cell size. If the image size with 400*400 and the d=24, the image can't be applied to the 16*16 cell. That problem was fixed using the multi-mask Robust localization. The proposed system was trained using 5 masks. The mask size is always larger than the image size. They used 1000 data sets for the model training, and the image set was divided into 60% negative and 40% positive datasets. The future work is to formulate the proposed system to use for a larger number of classes.

Sambolek and Ivasic-kos (2021) proposed system is a model that can be used in SAR operations to detect persons. Their research is based on an automatic person detection system using CNN and YOLO V4. According to the authors, the automatic object detection of images and person detection are commonly used. So the article is mainly focused on technologies such as R-CNN and YOLO V4. Related work shows that the YOLO V4 is the fastest and has high accuracy with small false detections. The researchers used CNN YOLOV4 to detect people, and as the dataset, they used the SARD data set. The paper describes that YOLO was selected as the tester because of its high accuracy. Also, the authors checked the transferring setting of YOLO V4 and used YOLO and Deep CNN to get the results. So the images in the dataset were divided into S*S frames and used the typical deep learning algorithms. The proposed system used a YOLO detector within a deep residual network with

53 layers. Also, the YOLO models were trained on the Google Colab service. In the experiment, they compared YOLOV4 with other testers, and the accuracy of the YOLO tester was 96%. Compared with the other testers, the best accuracy level is with the YOLO. So because of the accuracy level, they developed the system using the YOLO (SARD). The model was trained on 512*512 image resolution, but the 832*832 resolutions were used for the best results. For future work, they will develop a thermal camera to increase detection performance and recognize human activities.Zhang et al. (2021) proposed a system that can be used to GPR–B scanned images from rail infrastructure methods for object detection using faster RCNN, SSD, and YOLO V2. The system accuracy level is 97%. The authors have proposed a GAN-based deep learning framework to detect the hyperbolas automatically. The proposed framework has two parts: data generation and object detection based on deep learning. The main purpose of the system is to generate an image when the random noise is input. In the object detection part, the authors have proposed a one-stage detection model. The article shows that the CNN YOLO can be used as an object detection system to get more secure.Classification of a single pixel converts the problem of object detection into semantic segmentation (Lin et al., 2020). The authors mentioned that YOLO V3 has more accuracy than other test methods because it depends on multi-scale fusion. The proposed system is to remove anchors that detect objects based on two key points. One stage method is used because of the problem that occurs in the two stage object detection model. In this work, YOLO is used as the tester, and the image is divided into s*s cells. A cell center is called a grid cell. The grid cell was responsible for detecting the objects. Images were given with 511*511 size, and the output is 64*64 offsets. According to the authors CNN can be used to deep learning based well control object detection systems. The network framework that they used is like below.

From the research conducted by Kristo, Ivasic-Kos and Pobar (2020), they proposed a system of automatic person detection in thermal images. The used methodology to detect objects was CNN model training. According to this research, YOLO V3 was the fastest performance tester that can be used for object detection. To evaluate the best detection performance, they designed an original dataset and trained a deep learning model. The images were detected at the state of the art level. The proposed system was developed using an adaptive Boolean Based Saliency (ABMS) kernel with a YOLO detector. The data set was 4000 and the image size was 608*608 pixels. The system was trained without multi-scale training. The resulting output was a 90% person class with RGB images, and the model was trained on a 3000 training data image set. The performance of the model train was succeeded with the YOLO V3. And the trained dataset was COCORGB. In future studies, the authors will plan to develop an application to detect persons and non-human objects in different weather conditions.

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Ratnasekera (2015) Reviewed how weedy rice is a threat to rice production, distribution, and strategies for weedy rice management. The research identifies weedy rice as one of the four most harmful weeds affecting rice fields globally. In the mid-1990s, it was first recognized as a problem in the Vavuniya, Ampara, and Batticaloa districts. This paper is valuable for our research as it discusses the unique traits of weedy rice. It highlights that weedy rice is difficult to distinguish from cultivated rice at the seedling stage due to their similar appearance. The limitation of this research paper is it does not talk about the weedy rice management practices. But it gives a clear idea about how weedy rice has spread throughout Sri Lanka paddy fields and its morphological and genetic diversity. This research paper is not directly related to our research topic, but it is helpful to study weedy rice.

Even though many individuals have been trying to provide a solution in recognizing weeds in the crop using various methods for several years, no system has made a business breakthrough yet. Considering this situation, Jaiganesh et al. (2020) proposed a model for plant identification by plant leaves using a deep learning technique - CNN classifier. They have used a dataset that is available on Kaggle. The dataset includes around 960 distinct plants from 12 different species, captured at various growth stages. The model achieved an accuracy of 82% on the training set, with a validation accuracy (for plant identification) of 86%.

One of the best CNN algorithms, YOLO, is good at solving object detection in the most simple and highly efficient way (Du, 2018). The paper describes the new directions of the YOLO, YOLO versions (V1, V2, etc.), CNN, the layers of CNN, CNN algorithms, and the limitations of CNN. Classification and localization and detection are the tasks of the image processing technology. In image processing model training, the most occurring problems are accuracy, speed and cost. Until 2012, CNN reduced the error rate from 26% to 15.3%. Then CNN developed in two directions called normalization and optimization. Further, the researchers have compared Faster R-CNN and YOLO V2. The performance of the detection systems has been compared with mAP (mean average precision) and FPS (frames per second). Compared with Faster R-CNN, YOLO has more advanced applications in practice. Fast YOLO is the fastest general-purpose object detector. YOLO's FPS 155 and its mAP can also reach up to 78.6, surpassing the performance of Faster R-CNN greatly. The comparisons confirm that the YOLO is a suitable algorithm for object detection research, and its performance, accuracy levels are higher than other detection systems. The limitation of YOLO is that YOLO struggles to generalize to objects in new or unusual aspects of ration or configuration. And there are shortages with its loss function errors. But YOLO can achieve high precision and keep real time for pictures with high resolution. YOLO is a unified object detection model. YOLO V2 provides state-of-the-art with the best tradeoff between the best accuracy and real time speed for object detection than other detection systems.

Overuse of herbicides in paddy fields leads to increased production costs and environmental pollution. To address this, it's essential to detect the location of rice seedlings and weeds for targeted weed management (Ma et al., 2019). The researchers propose a fast and robust image segmentation method for identifying rice seedlings and weeds at the seedling stage using SegNet, where these plants often overlap. The study focuses on two main objectives: introducing a semantic segmentation method based on encoder and decoder architecture, and comparing its performance with classical segmentation models, specifically FCN and U-Net. SegNet, a deep Convolutional Neural Network, is utilized for image segmentation, offering lower computational cost and higher precision compared to FCN. For the study, 28 RGB images were captured around 20 days after the rice seedlings emerged. The images, taken in paddy fields with weeds in early growth stages, were divided into smaller tiles, totaling 224 images. Of these, 80% were used for training and 20% for testing. The SegNet model was trained using transfer learning.

The results showed that SegNet achieved higher classification accuracy, with an average accuracy rate of 92.7%. In comparison, the FCN and U-Net models had average accuracies of 89.5% and 70.8%, respectively. In Sri Lanka, more than 142 weed species have been identified in rice fields. (Rao et al., 2017) The paper speaks about the methods (Manual, mechanical, tillage, mulching) of weed control used in South Asian countries. Manual weeding and submergence were the main weed control techniques used in Sri Lanka until the early 1960s. Then herbicides became more popular. As the single weed control approach is inefficient, Integrate Weed Management is needed to keep weeds below an economic threshold level.

The system proposed by Kulkarni and Angadi (2019) is about detecting weeds and crops using CNN and IoT. The proposed method is to train a large number of images of weeds and crops using

CNN. The trained CNN model is trained by getting images from the camera sent to the Raspberry pi. Raspberry performs image segmentation by dividing the image into small cells. Each CNN model classifies as weeds or crops. The system was trained using 250 image data sets. The accuracy rate is 85%, and the false ration is 7%. The proposed system consists of a Raspberry pi and a camera. The camera was used for image processing and segmentation. The results of the system are obtained with an average accuracy of 85%. So the proposed framework can be used by farmers to check whether the growth of weeds. The article shows that CNN can be combined and implemented in weed controlling to get excellent results. In the research of Liu et al. (2015) they used an algorithm consisting of two dimensional image information. The algorithm is focused on two main processes like convolution and sampling. The authors used the CNN subsampling method by sampling by time or space. The subsampling structure by time space was used to achieve some degree of scale and deformation displacement. The designed algorithm is based on gray image as input of 96*96 size, that turned in to 32*32 size of the images. The model was trained on the 7 convolutional layers and the results were more accurate.

The system proposed by Islam et al. (2021) is a machine learning algorithm to weed detection. The paper is organized with an overview of machine learning algorithms that can be used to weed detection in Australian Chili fields. The proposed system aims to detect weeds by using image processing and machine learning. The used data set was preprocessed using image processing, KNN based studies. Weed detection is the purpose of the proposed system. According to the paper, KNN offers a 63% percentage of RF 96%, and the SVM offers 94% accuracy in the weed detection proposed system. Their future work will be a deep learning algorithm to increase the accuracy of weed detection

III. EXPERIMENTAL WORKFLOW

In this section, the problem under investigation is explicated, providing context and emphasizing the study's significance. The existing knowledge gap is outlined, and the research objectives are articulated. By framing the problem, a foundation is laid for the subsequent sections, highlighting the relevance of the research.

A. Problem

In the present world, technology has involved every industry making their work more accessible and speedy. But when comparing to other industries, we noticed that no significant change can be seen in the farming industry. Especially in the Asia countries like Sri Lanka. Sri Lanka is considered as an agricultural country, and rice is the staple diet and the single most important crop in Sri Lanka (Senanayake and Premaratne, 2016). However, weeds in the rice fields are one of the major problems the Sri Lankan farmers face (Perera and Dahanayaka, 2015).

There are more than 120 weed species that can be identified that belong to 32 families (Gunasena, 1992). It is a challenging task to detect the weeds and select suitable weed control methods for each weed species. So, weeds have become a major problem to reduce the harvest of paddy cultivation. Further, the Sri Lankan younger generation is also interested in farming but they are not familiar with many weed species and the past weed controlling methods, and they have no knowledge or experience to continue their farming. So, we have identified that not having enough knowledge on weed detection and weed control methods is a reason behind this situation and the spread of weeds. Even though the Sri Lankan farmers are facing this problem from the earlier days, there is not enough support from modern technology to overcome this situation. So, it is clear that there should be more support from the technology to the Sri Lankan farmers and young generation, students, and researchers to identify the weed species in rice fields and suggest suitable weed controlling methods. The research is based on the above problems and proposes a model with a higher level of accuracy to weed detection. In addition, it is planned to provide weed control methods for the identified weed species.

B. Data Set Creation

The dataset was created using a Redmi Note8 48mp camera, Samsung S7 12mp camera, Samsung m12 48mp camera, and Nikon D750 camera. There were 3933 images belonging to 20 weed types. The data set was 3933 images belonging to 20 classes. In the dataset training process, the same data set was trained with the same parameters with all the 03 models. Google Colab idle environment was used as the idle environment to train the data set. The data set was created by cropping all images as squares and setting the pixel size to 224 x 224 for all and setting to auto-arrange white balance and high ISO

normalisation. After that, the images were divided into 20 classes, and then those sets were divided into 2 groups as train and test datasets.

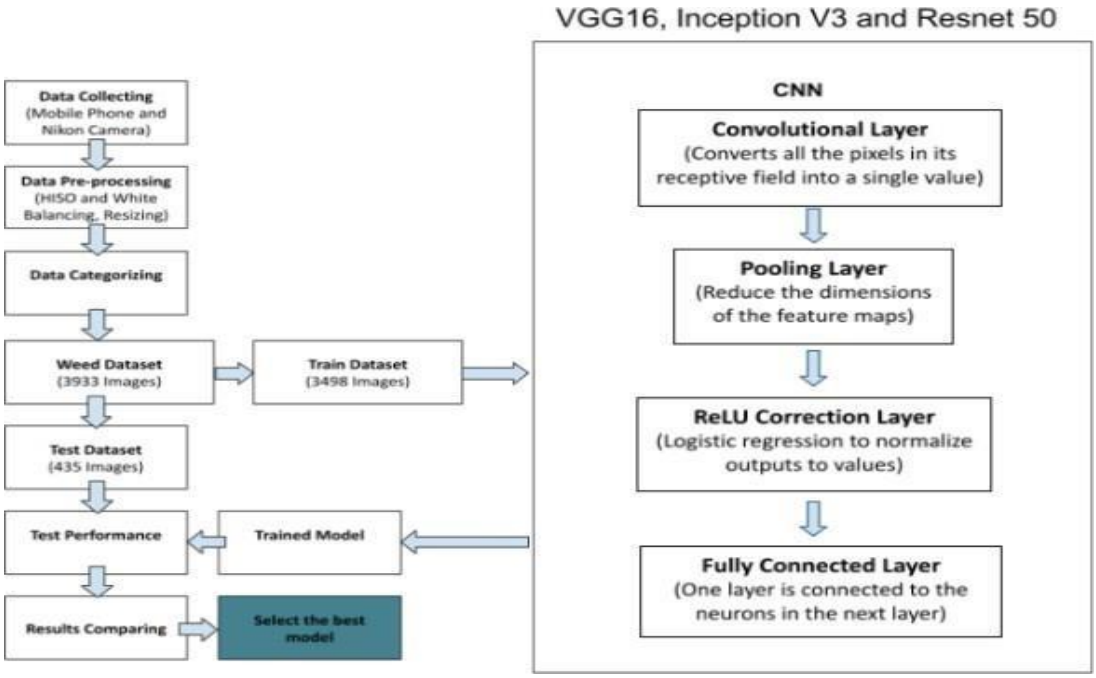

Figure 02: Model Training Flow Diagram

C. Data Set Training with Transfer Learning

VGG16

The selected data set was pre-processed before using this model as (224* 224 * 3). That model has 1,383 million trainable weights and 16 layers (convolution layers 3x3 filter, max pool layers 2x2 filter, 2 fully connected layers, and Softmax layer). The basic Architecture of a VGG16 is represented in Fig. 3.

Inception V3

Inception v3 is a pre-trained CNN model that Consists 48 layers deep{(Convolutional layers 4 [1*1], [3*3], [5*5]), MaxPooling layers[3*3], Fully connected layer 1} and 23,8 million trainable weights. It was trained on more than a million images in the ImageNet database. All images in the ImageNet database have a fixed size of 224*224 and have RGB channels (3) therefore we had to pre-process the images as we did in VGG16 (224 * 224).

ResNet 50

Microsoft introduced a deep residual learning framework (Resnet 50) to overcome the problem that occurs when adding more layers to a deep network may cause a higher training error rate. The [F(x)+x] formula makes shortcut connections to skip one or more layers. Then ResNets can get high accuracy when increased depth without training error.

IV. RESULTS

The image dataset was trained using the three models (VGG16, Inception v3, and ResNet50) two times. On the first try, only the VGG16 performed well and the other two models did not perform as expected. On the second try, both VGG16 and inception V3 performed well (accuracy of 98% and 99%), but the accuracy of ResNet 50 was not enough (75%). VGG16 was selected as the best model from VGG16 and Inception v3 by considering the accuracy and loss. Both models gave the best results but the validation loss of Inception V3 is higher than VGG16. And also the accuracy of the VGG 16

model was 100%. So VGG16 was selected as the best model for the weed detection system.

Data Training Results

Data training Results with VGG16

- Validation accuracy - 75%
- Validation loss - 0.69
- Model loss - 0.63
- Model accuracy - 77%

Data training Results with Resnet50

- Validation accuracy - 98%
- Validation loss - 0.0464
- Model accuracy - 100%
- Model loss - 0.0025
- Epoch - 15

Data training Results with Inception V3

- Validation accuracy - 99%
- Validation loss - 0.1076
- Model accuracy - 99%
- Model loss - 0.0053
- Epoch - 15

B. Primary Detection Results

After considering the data training results, VGG16 model was selected as the image dataset training model. Results are shown in the TABLE.I

Table 01: Data Training Results

Model Name	Model Accuracy	Model Loss	Validation Accuracy	Validation Loss
Resnet 50	77%	0.63	75%	0.69
VGG16	100%	0.0025	98%	0.0464
Inception V3	98%	0.0053	99%	0.1076

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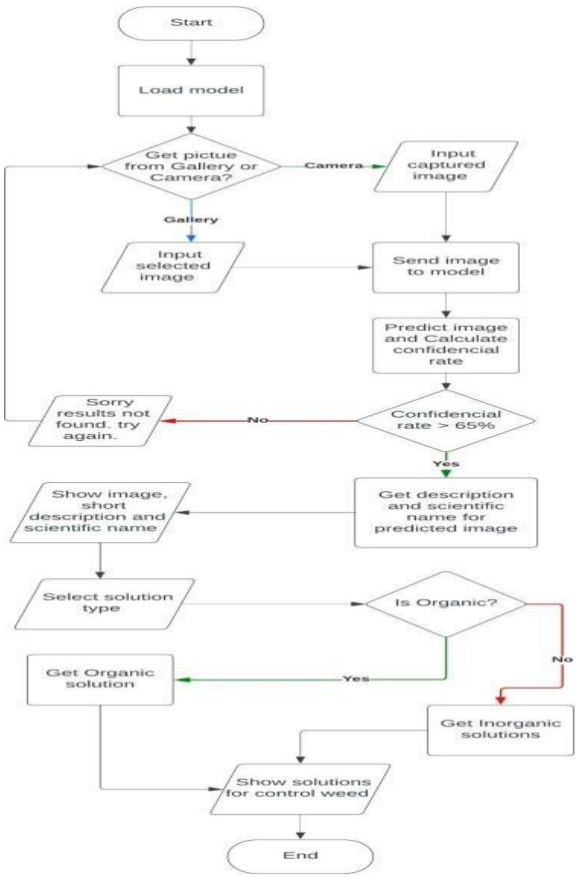

Figure 03: Mobile Application Data Flow Diagram

C. Mobile Application

In this research, we propose a mobile application designed to assist farmers in identifying weeds in agricultural fields. The app allows users to upload or capture images of weeds using their mobile devices. It employs image recognition technology to identify the weed type and provides detailed information on how it impacts the harvest, including potential yield loss. Furthermore, it offers step-by-step guidance on both chemical and organic methods to manage the weeds effectively. As paddy fields often lack internet connectivity, the dataset is stored locally within the application's database, ensuring farmers can access and use the app even in remote areas without a network connection. This solution aims to enhance farming efficiency by delivering real-time, actionable insights directly to farmers.

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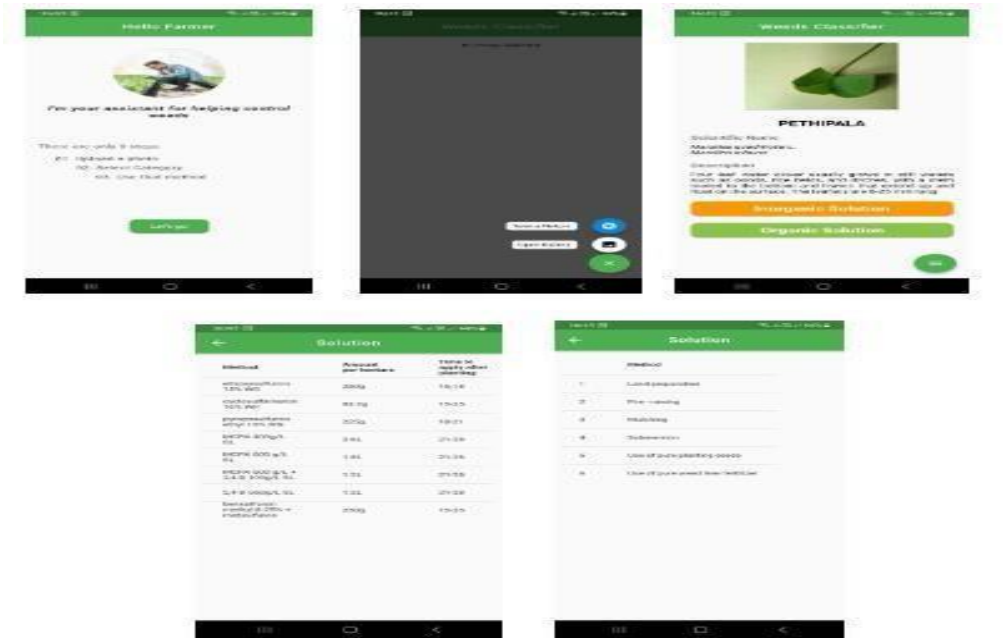

Figure 04: Mobile Application Interface

V. DISCUSSION

The primary objective of this project was to achieve accurate weed species detection in paddy fields. The developed mobile application, powered by the selected Convolutional Neural Network (CNN) model, successfully identifies six distinct weed types and offers tailored weed control methods for each. The literature review highlighted the longstanding challenges Sri Lankan farmers face in combatting weeds, with existing solutions relying heavily on traditional knowledge and experiences. The system created through this research serves as a significant support mechanism for farmers, the younger generation, students, and researchers engaged in weed detection and control methods. By leveraging advanced technology, the developed application not only addresses the immediate concerns of weed infestation in paddy fields but also contributes to the knowledge base within the agricultural community. This initiative represents a crucial step towards providing practical and efficient solutions to a persistent problem in Sri Lanka's agricultural landscape.

VI. CONCLUSION

In the course of this research, we proposed a machine learning-based system designed for the detection of various weed types in paddy fields, coupled with the provision of effective weed control methods. Drawing from pertinent literature, it became evident that Convolutional Neural Networks (CNNs) have proven success in object detection. In our study, the specifically employed VGG16 model demonstrated notable efficacy in identifying weeds in rice fields, achieving an impressive 97% validation accuracy, 0.0464 validation loss, 100% model accuracy, and a minimal 0.0025 model loss.

Through the developed application, we successfully implemented the VGG16 model to detect six selected weed types with high accuracy. Notably, the system can be further enhanced by expanding the range of detectable weed types. This involves refining the image dataset with higher-quality and more informative images. Subsequently, the dataset should undergo training with the VGG16 model, exploring optimal epoch sizes to maximize accuracy. This iterative process allows for the continuous improvement of the system's weed detection capabilities, making it adaptable to a broader spectrum of weed types in paddy fields.

VII. FUTURE WORKS

Here at this stage, the mobile application only shows 06 weed types from the selected weed types. The descriptions of those 06 weed types and the weed control solutions for them can be added within the same source code. For our future work, the application will be broadened by adding more weed types and we can create or link the application with external resources. But if the application was connected with such an external

server, the ability to work offline would be lost. In this stage, the developed mobile application can provide offline services. Further, trying to enhance the user experience by making some changes to the designed user interfaces. For now, the application is only compatible with the English language, but it will be developed as compatible with the other languages.

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Pioneering Disease Prediction in Cinnamon Leaves using Machine Learning: A Systematic Literature Review

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Abstract

The integration of Machine Learning (ML) in agricultural disease prediction has become increasingly prominent. This review paper explores the evolution of techniques used for predicting diseases in cinnamon leaves and analyzes common cinnamon leaf diseases, drawing on research conducted up to 2023. The paper highlights the evolution of ML methodologies, particularly in the areas of image processing, feature extraction, and classification algorithms. It provides an in-depth analysis of various approaches, such as Convolutional Neural Networks (CNNs), Support Vector Machines (SVMs), and Random Forests, evaluating their effectiveness in disease prediction. From an initial set of 100 studies, 22 were selected for detailed analysis based on their relevance and contribution to the field. Additionally, the review addresses the challenges associated with developing reliable ML models. Through the synthesis of findings from multiple studies, this paper offers a comprehensive overview of current research in cinnamon leaf disease and prediction, identifying existing gaps and proposing directions for future investigations to improve the precision and applicability of ML-driven solutions in agriculture.

Keywords: Cinnamon Leaf Diseases, Machine Learning, Agricultural Disease Prediction, Classification Algorithms

I. INTRODUCTION

In Cinnamon, known locally as "Kurundu" in Sri Lanka, has been a valuable commodity since antiquity, cherished for its unique aroma, flavor, and medicinal properties. Derived from the inner bark of various species within the Cinnamomum genus, cinnamon has a rich history intertwined with trade, culture, and culinary traditions. Among the many species, Cinnamomum verum, commonly referred to as Ceylon cinnamon or "true" cinnamon, holds a place of particular significance. Native to Sri Lanka, Ceylon cinnamon is distinguished by its superior quality, which has earned it a prominent position in both local and global markets(Wickramasinghe *et al.*, 2018). The cultivation of cinnamon in Sri Lanka dates back several centuries, with the Dutch colonial rulers playing a crucial role in establishing systematic cultivation practices in the 18th century. The Dutch Governor Falk was instrumental in promoting cinnamon cultivation, which soon became one of the island's most lucrative exports. By 1841, the demand for cinnamon had surged, leading to the commercial production of cinnamon leaf oil, by product that further expanded the industry's economic footprint (Wijesekera and Chichester, 1978).

Today, cinnamon is cultivated across approximately 14,000 to 16,000 hectares in Sri Lanka, with the Ambalangoda region being a key production area. This region alone accounts for nearly 50% of the country's total cinnamon output, underscoring its importance in the national economy. Ceylon cinnamon's economic value extends beyond its use as a spice. The chemical composition of Ceylon cinnamon, particularly its low levels of coumarin, makes it highly sought after in the global market. Coumarin, a naturally occurring compound found in higher concentrations in other cinnamon varieties like Cassia, can be harmful in large doses, which enhances the appeal of Ceylon cinnamon for health-conscious consumers. Additionally, the extracts from cinnamon leaves and bark are used in the food industry as natural preservatives due to their antimicrobial properties, as well as in the pharmaceutical and cosmetic industries for their therapeutic benefits (Suriyagoda *et al.*, 2021).

Despite its global recognition and economic importance, the cinnamon industry in Sri Lanka faces significant challenges, particularly from pests and diseases that threaten both the yield and quality of the crop. Among the most common

foliar diseases are leaf blight, caused by Colletotrichum gloeosporioides, and algal leaf spot, caused by Cephaleuros virescens. These diseases, along with infestations by insect pests like jumping plant louse/ leaf galls, thrips attack, can lead to severe reductions in cinnamon yield, causing substantial economic losses for farmers (Rajapakse and Kumara, 2007).Traditional disease management strategies, including the use of fungicides and pest control measures, have proven to be only partially effective. These methods are often labor-intensive, environmentally harmful, and unsustainable in the long term, necessitating the exploration of more advanced and targeted approaches (Jayasinghe *et al.*, 2020).

Beyond its challenges in cultivation, cinnamon's importance extends far beyond its role as a spice. Owing to its special properties, cinnamon is a multipurpose ingredient widely used not only in kitchens as a tasty addition to various dishes but also in medicine (Pathirana and Senaratne, 2020). The essential oil derived from cinnamon leaf, which contains a high concentration of trans-cinnamaldehyde, possesses strong antibacterial properties. These properties are effective against infections in plants and animals, as well as bacteria and fungi associated with food spoilage and food poisoning. In addition to its culinary applications, cinnamon offers numerous health advantages, including anti-inflammatory properties, antimicrobial activity, a reduced risk of cardiovascular disease, improved cognitive function, and a decreased chance of colon cancer. The various parts of the cinnamon plant, including the outer bark, inner bark, and leaves, are used for medicinal purposes.

In this context, the advent of Machine Learning (ML) presents a transformative opportunity for the cinnamon industry. ML, a subset of artificial intelligence (AI), involves the use of algorithms and statistical models to analyze large datasets, identify patterns, and predict outcomes with a high degree of accuracy. The application of machine learning (ML) in cinnamon disease management is still in its early stages. Some studies have made strides in related areas, such as using image processing techniques and algorithms like Speeded up Robust Features (SURF) for data extraction from cinnamon (Chandima and Kartheeswaran, 2016; Sunitha *et al.*, 2022). These techniques have been employed to predict the maturity levels of cinnamon trees using classifiers such as Support Vector Machines (SVMs). While these initial findings are promising, there remains a significant gap in research specifically targeting the detection and management of diseases in cinnamon leaves using ML techniques.

In recent years, the application of Machine Learning (ML) has emerged as a transformative opportunity for addressing these challenges. ML, a subset of Artificial Intelligence (AI), allows for the analysis of large datasets, enabling accurate predictions and early detection of diseases through pattern recognition (Gunasekara *et al.*, 2021; Shandilya *et al.*, 2024).Techniques like deep learning and Convolutional Neural Networks (CNNs) have shown significant promise in detecting diseases in cinnamon crops by leveraging image processing technologies. For instance, the potential of CNNs for characterizing cinnamon diseases such as rough bark and stripe canker, providing a model for future applications in this field (Jayasena *et al.*, 2023).Recent reviews have emphasized the growing interest in the application of ML in the cinnamon industry. These studies highlight the potential of deep learning models, particularly Convolutional Neural Networks (CNNs), in improving disease detection and management for cinnamon crops (Giraddi, Desai and Deshpande, 2020; Feltes *et al.*, 2023). Other research has discussed the integration of remote sensing technologies with ML, which offers greater precision in monitoring crop health and managing diseases (T* *et al.*, 2020; Tusher *et al.*, 2022). Additionally, advanced ML techniques such as Transfer Learning have shown potential in addressing key challenges, particularly in disease detection and quality control within the cinnamon industry (Fatima *et al.*, 2021).

This systematic literature review aims to explore the current state of research on cinnamon leaf diseases, their management strategies, and the use of ML in disease detection and prediction. By examining studies conducted up to 2023, the review seeks to evaluate the effectiveness of ML techniques in this domain, assess the impact of these technological advances on the cinnamon industry, and identify areas that require further research. The findings of this review are expected to provide valuable insights for researchers, practitioners, and policymakers interested in improving the sustainability and efficiency of cinnamon production through the integration of

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ML technologies. By bridging the gap between traditional practices and technological advancements, this review aims to contribute to the ongoing efforts to enhance the resilience and productivity of the cinnamon industry in Sri Lanka and beyond.

II. METHODOLOGY

A. Systematic Literature Review

The This study adopts a systematic literature review (SLR) methodology to explore the application of machine learning (ML) in the prediction and management of diseases in cinnamon leaves. The review process was structured into three key phases: planning, conducting, and reporting.

In the planning phase, we identified relevant electronic databases, including IEEE Xplore, Springer, and ACM Digital Library, Google Scholar to source research papers related to our study. Key research questions were defined to guide the review, and specific search strings were developed based on keywords pertinent to the intersection of cinnamon leaf diseases and machine learning. During the conducting phase, we systematically searched the selected databases using the predefined search strings. The search results were carefully reviewed to select studies that addressed our research focus. Additionally, references from these studies were used to perform snowballing, ensuring a comprehensive inclusion of relevant literature. The studies were analyzed to extract essential information such as abstracts, keywords, methodologies, and findings, which were then categorized for further evaluation. In the reporting phase, the selected studies were synthesized and organized into a detailed analysis. The studies were documented with a focus on their contributions to the understanding of ML applications in cinnamon leaf disease prediction. The summarized research was then compiled into structured documents that provide a comprehensive overview of the literature, highlighting key trends, methodologies and future directions in the field. This systematic review process, guided by established SLR protocols, ensures a thorough and objective evaluation of the existing literature, offering valuable insights into the potential of machine learning in enhancing disease management strategies for the cinnamon industry.

B. Research Questions

Research questions are central to guiding a systematic literature review. Table 01 presents the research questions that this study aims to address. By examining these questions, we can identify gaps in the current literature and better understand the state of research in the application of machine learning for disease prediction in cinnamon leaves.

Table 01: Research questions

No	Research Question
RQ1	What are the common cinnamon leaf diseases identified in existing studies?
RQ2	How can various machine learning techniques be effectively utilized to create a predictive model for accurately identify cinnamon diseases?
RQ3	What challenges and limitations have been identified in past studies on machine learning applications for leaf disease prediction?

C. Study Selection

The study selection process involved several key steps:

1) Terms and Search Strings:

The search terms were applied across two main segments: cinnamon leaf disease and machine learning. The search string was applied to three metadata fields: title, abstract, and keywords. Table 02 represents the search strings applied in the databases.

Table 02: Search terms of the mapping study on pioneering disease prediction in cinnamon leaves using machine learning

Area	Search Terms
Cinnamon Disease	"Cinnamon leaf disease", "cinnamon diseases "
Disease Identification	"Leaf disease identification using machine learning", "plant disease detection", "plant disease classification"
Machine Learning	"Machine learning", "ML approaches", "artificial intelligence in agriculture"
Cinnamon disease management	"Cinnamon leaf disease management", "cinnamon leaf disease treatment"
Search String	(“cinnamon leaf disease” OR “cinnamon disease”) AND (“leaf disease identification using machine learning” OR “plant disease detection” OR “plant disease classification”) AND (“machine learning” OR “ML approaches” OR “artificial intelligence in agriculture”) AND ("cinnamon leaf disease management", "cinnamon leaf disease treatment")

3) Sources:

This Systematic Literature Review was performed using the following electronic databases and considered the most relevant studies.

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i. IEEE Xplore <http://ieeexplore.ieee.org>
ii. Springer Link <https://link.springer.com>
iii. Science Direct<https://www.sciencedirect.com>
iv. Google Scholar<https://www.sciencedirect.com>
v. ACM Digital Library<https://dl.acm.org>

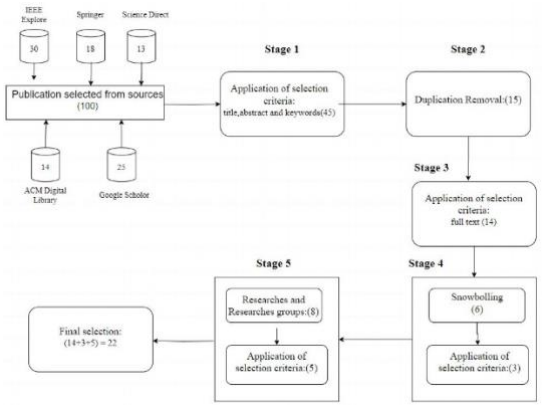

Figure 01: Selection Process Flow

4) Inclusion and exclusion criteria:

The selection process for this study was organized based on two inclusion criterion and five exclusion criteria. Table 03 and Table 04 depict the inclusion and exclusion criteria used in the filtering process respectively.

Table 03: Inclusion criteria of the selection process

No	Inclusion criteria (IC)
IC1	Focuses on common cinnamon leaf diseases.
IC2	Describes the application of machine learning techniques for the prediction of cinnamon plant diseases.

Table 04: Exclusion criteria of the selection process

No	Exclusion criteria (EC)
EC1	The paper does not contain an abstract
EC2	The paper is published only as an abstract
EC3	The paper is not written in English
EC4	The paper is an earlier version of a study that has already been selected
EC5	The paper is not a primary study. It is either editorial or summaries of keynotes and tutorials

5) Data extraction and synthesis:

In this study, a thorough examination of publications to 2023 was conducted to evaluate the application of machine learning techniques in predicting diseases in cinnamon leaves. The initial retrieval process gathered 100 publications from several reputable digital libraries, including IEEE Xplore, Springer, ScienceDirect, ACM Digital Library, and Google Scholar.

The selection process for these studies was organized into five stages. The first stage involved applying predefined selection criteria to the title, abstract, and keywords of each study. In the first stage, 45 of these publications were selected based on their titles, abstracts, and keywords. This filtration aimed to distill the most relevant studies pertinent to research topics. In second stage, Identified and removed 15 duplicate studies from the remaining 45, leaving 30 publications for further scrutiny.

In the third stage, an in-depth review of the full texts of these 30 publications was conducted. Employing stringent inclusion and exclusion criteria ensured the relevance and completeness of the studies, which led to 14 publications proceeding to the next stage of the selection process. The fourth stage expanded search to include studies referenced in the initial set, a method known as snowballing. This yielded 6 additional publications, out of which 3 met rigorous selection criteria and added to study pool.

The final stage focused on significant contributions from key researchers and research groups. Identified 8 additional relevant publications through this method. After applying final selection criteria, 5 of these were deemed highly pertinent to research aims. This comprehensive process resulted in a final selection of 22 publications, which were considered for systematic review, ensuring a broad and thorough coverage of the final synthesis.

III. RESULT AND DISCUSSION

This Cinnamon, particularly Ceylon cinnamon, is a vital economic asset for Sri Lanka, valued not only for its culinary and medicinal applications but also for its significant contribution to the agricultural sector (Suriyagoda *et al.*, 2021).However, the industry faces persistent challenges from diseases and pests that impact both yield and quality.

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Among the most common cinnamon leaf diseases, leaf blight and leaf spot diseases, primarily caused by the fungus Colletotrichum gloeosporioides. This disease manifests as brown or black lesions on leaves, which can spread rapidly, leading to significant foliage loss and a reduction in the plant's photosynthetic ability. Another common issue is algal leaf spot, caused by Cephaleuros virescens, which results in orange or reddish spots on the leaves, eventually causing leaf deterioration (Wickramasinghe *et al.*, 2018; Jayasinghe *et al.*, 2020).In addition to fungal infections, cinnamon plants are also affected by various pests. Jumping plant louse and thrips are frequent insect pests that cause leaf galls and deformation, further impacting the plant's health. These diseases and pests represent major challenges to cinnamon cultivation, addressing these challenges effectively is crucial for maintaining the industry's economic viability (Pathirana and Senaratne, 2020).

Recent advancements in machine learning (ML) have demonstrated great potential for revolutionizing agricultural practices, particularly in disease detection and management. However, research specifically applying these methods to predict diseases in cinnamon leaves remains largely unexplored. Most of the existing literature focuses on general applications of ML in agriculture or on detecting diseases in other parts of the cinnamon plant. One of the key challenges in cinnamon leaf disease prediction using ML techniques is the lack of annotated datasets for training robust models. Image processing techniques have been utilized in related applications, such as recognizing mature cinnamon trees, suggesting the possibility of adapting similar methods for identifying diseases in cinnamon leaves (Chandima and Kartheeswaran, 2016). However, without sufficient data, building an accurate ML model remains a challenge.

Transfer learning has been identified as a promising method to address this data scarcity issue. It has been applied to trace adulteration in spices like cinnamon, which suggests the possibility of applying this technique to cinnamon leaf disease detection (Fatima *et al.*, 2021). By leveraging pre-trained models on other plant datasets, researchers can reduce the need for large, specialized datasets specific to cinnamon.

Convolutional Neural Networks (CNNs) have been a popular choice for image-based disease detection. (Sardogan, Tuncer and Ozen, 2018; Singla, Kalavakonda and Senthil, 2024)Techniques such as CNNs with Learning Vector Quantization (LVQ) have been used in plant disease classification, and similar methodologies that could be adapted for cinnamon disease prediction. The potential of CNNs in identifying specific cinnamon plant diseases has been explored, particularly in deep learning models used to identify conditions like rough bark and stripe canker (Pratondo *et al.*, 2024; Shandilya *et al.*, 2024).

The integration of remote sensing with ML models has also been proposed as a solution for large-scale monitoring of plant diseases. By combining remote sensing data with deep learning, precision agriculture in cinnamon farming could be enhanced, enabling more efficient disease monitoring and management (Lakshan S *et al.*, 2023).This integration could address the environmental variability that impacts disease development in cinnamon plants, ensuring that models generalize well across different regions and climates.

Another emerging technology in cinnamon disease prediction is the use of mobile applications for real-time disease detection (Ekanayaka and Kumara, 2022; Jayasena *et al.*, 2023). Mobile-based tools that utilize image processing have been developed to enhance cinnamon quality and health. This tool demonstrates the feasibility of creating mobile-based solutions for disease detection, providing farmers with immediate insights into the health of their crops.

A significant barrier to the widespread adoption of ML in cinnamon disease prediction is the need for interdisciplinary collaboration. Integrating agricultural knowledge with technological innovations is essential, especially considering the unique characteristics of the cinnamon industry in regions like Sri Lanka (Prof. Koliya Pulasinghe, Dr. Dharshana Kasthurirathna and S.A.A. Ravishan, 2023).Highlight that the unique characteristics of the cinnamon industry in Sri Lanka, including its environmental and climatic factors, must be considered when developing ML-based disease prediction systems. Also, there is significant potential for using ML to predict diseases in cinnamon leaves, the field is still in its early stages.

Future research should focus on developing datasets specific to cinnamon leaf diseases, exploring the use of transfer learning, and integrating ML with remote sensing technologies. Additionally, Interdisciplinary collaboration between agricultural experts and technologists is crucial for ensuring that these models are accurate and applicable in real-world farming scenarios.

Table 05: Feature extraction and system results across studies

Paper ID	Title	System Type	Key Features	Results	Limitations
1	Historical overview of the cinnamon industry.	Historical overview Economic impact	Not applicable	Provides historical context	Does not address current disease management practices or specific disease issues.
2	Ceylon cinnamon': Much more than just a spice	Economic value culinary and medicinal uses	Not applicable	Highlights the multifaceted value of Ceylon cinnamon beyond its culinary uses.	Does not specify common Sri Lankan cinnamon leaf diseases or management techniques.
3	An Introduction to Sri Lanka and Its Cinnamon Industry	Economic impact, industry overview	Not applicable	Provides historical context, cinnamon leaf and economic significance of cinnamon in Sri Lanka	Does not focus on disease management or prediction using ML.
4	Chemical and biological studies of value-added cinnamon products	Cinnamon leaf disease Disease management strategies	Not applicable	Focuses on disease management strategies for cinnamon diseases.	Limited to traditional methods. Lacks advanced machine learning techniques for disease prediction.
5	A Review of Identification and Management Pests and Diseases of Cinnamon (Cinnamomum zeylanicum Blume)	Pests and diseases of cinnamon Environmental factors	Not applicable	Detailed description of pests and diseases in cinnamon	Lacks the application of machine learning for disease prediction.
6	Identification and management of pests and diseases of cinnamon.	Pests and disease identification Cinnamon leaf diseases	Not applicable	Focuses on disease management	Doesn't suggest comprehensive management strategies
7	AgroX: Uplift Ceylon Cinnamon Industry	Technological interventions, Economic development,	Not applicable	Highlights technology's role in advancing the cinnamon industry	No specific mention of disease prediction technologies.
8	Exploring Deep Learning Models for Cinnamon Plant Disease Characterization	Disease types, Image features	Convolutional Neural Networks (CNN)	Achieves high accuracy in identifying specific cinnamon diseases through image analysis	Focuses on specific diseases. Not generalize to all cinnamon diseases and cinnamon leaf diseases.
9	Classification of Cassia Cinnamon and	Visual and chemical	Deep Learning	High accuracy in distinguishing	Focuses on classification, not disease prediction.

	Ceylon Cinnamon using Deep Learning	features of cinnamon	CNN	Cassia and Ceylon cinnamon	
10	Modeling CNN for Detection of Plant Leaf Spot Diseases.	Leaf spot diseases, Image classification	Convolutional Neural Network (CNN)	Classification accuracy of 90.6% for plant leaf diseases.	The model focuses only on leaf spot disease.
11	Recognizing matured cinnamon tree using image processing techniques	Maturity level of cinnamon trees Image processing	Support Vector Machine (SVM)	Identification of maturity level.	Accuracy might decrease in varying environmental conditions or with different cinnamon tree varieties
12	Plant Leaf Disease Detection and Classification Based on CNN with LVQ.	Plant leaf diseases.	CNN with Learning Vector Quantization (LVQ)	Accurate identification of leaf diseases.	LVQ algorithm may not perform well with large and diverse datasets of plant leaf diseases.
13	CinnaSense: Enhancing Cinnamon Quality and Health with Image Processing	Image-based features for cinnamon quality	Image processing	Focuses on improving cinnamon quality through advanced image processing techniques	Limited application to disease prediction and broader health assessments
14	Automatic Recognition of Plant Leaf Diseases Using Deep Learning (Multilayer CNN) and Image Processing	Leaf images Disease features	Multilayer CNN	Accurate leaf disease identification	Limited testing in real-world agricultural settings Results may not fully generalize to outdoor conditions.
15	Differentiating True and False Cinnamon: Exploring Multiple Approaches for Discrimination	Chemical and structural properties of cinnamon	Machine Learning (varied approaches)	Effectively differentiates true vs. false cinnamon	Does not address cinnamon leaf disease detection or prediction.
16	Machine Learning-Based Nutrient Deficiency Detection in Crops	Nutrient deficiencies, Leaf images	Convolutional Neural Network (CNN)	High accuracy in detecting nutrient deficiencies and recommending fertilizers.	System might not account for variations in nutrient deficiency symptoms across different crop types
17	Machine Learning Approach for New Crop Disease Predict and Alert System	Various crop features for disease prediction	Machine Learning, CNN, Random Forest	Efficient in predicting multiple crop diseases	May be too complex for practical deployment in regions with limited technological infrastructure, such as smallholder cinnamon farms.
18	Deep Learning for Agricultural Plant Disease Detection	Leaf images, Disease symptoms	Deep Learning, CNN	High accuracy in disease detection in agriculture	Model's performance may vary across different crop types.
19	Tracing Adulteration in Cumin, Cinnamon, and Coffee using	Chemical composition and adulteration detection	Transfer Learning	High accuracy in detecting adulteration in cinnamon,	Focuses on quality control rather than disease detection

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	Transfer Learning			cumin, and coffee	
20	Detection of plant leaf diseases using deep convolutional neural network models	Leaf texture, color, shape	Deep Convolutional Neural Network	High accuracy in disease detection	Limited dataset size
21	Integrating Remote Sensing and Deep Learning for Precision Agriculture in Cinnamon Farming	Remote sensing data and cinnamon farming characteristics	Deep learning	Effective integration of remote sensing data for precision agriculture in cinnamon farming	Lack of real-world validation for disease-specific applications
22	Expert Prediction System for Spice Plants Grown in Sri Lanka	Environmental parameters Historical data	Various ML algorithms	Improves early detection of disease outbreaks in cinnamon crops, allowing for timely intervention	Relies on comprehensive data input

IV.CONCLUSION

This systematic review has explored the application of machine learning (ML) techniques in the prediction and management of cinnamon leaf diseases, with a focus on advancements in image processing and classification algorithms like Convolutional Neural Networks (CNNs), Support Vector Machines (SVMs), and Random Forests. While significant progress has been made in applying ML for disease detection across various crops, research specifically targeting the most common cinnamon leaf diseases in Sri Lanka remains limited. To date, no research has successfully identified a machine-learning model capable of detecting cinnamon leaf prevalent diseases comprehensively.

This review, therefore, aimed to assess and recommend the most suitable ML techniques that could be adapted for cinnamon disease detection. CNNs, with their ability to analyze image data and detect intricate patterns, have emerged as the most promising approach for this purpose. However, there are challenges to overcome, such as the availability of comprehensive datasets that accurately reflect real-world conditions and the development of models that are scalable and robust across different disease types and environmental variations. The integration of ML offers a transformative approach to disease detection and management, providing a more efficient and precise alternative to traditional methods. Future research should focus on bridging the current gaps by developing more adaptable and scalable ML models, leveraging real-world field data, and addressing environmental variability. These advancements are crucial to enhancing disease management strategies and ensuring the sustainability and productivity of the cinnamon industry in Sri Lanka and beyond.

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Recognition of Sri Lankan Traffic Signs using Machine Learning Techniques

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Abstract

The recognition of traffic signs is a crucial component of driver assistance systems that have been extensively researched worldwide. However, it remains a challenging issue due to the increasing number of vehicles, road signs, and the lack of awareness among drivers and other road users. A Traffic Sign Recognition (TSR) system is an advanced autonomous technology designed to assist drivers by accurately identifying and interpreting traffic signs. This system plays a crucial role in enhancing driver awareness and ensuring appropriate responses to various traffic conditions. The precise recognition of traffic signs is essential for maintaining road safety and improving the overall driving experience. This study focuses on the recognition of Sri Lankan traffic signs and examines the combination of classifiers with a specific feature extractor. A dataset of 300 images of road signs was utilized for this study by capturing the images. The Scale-Invariant Feature Transform (SIFT) was used as a feature descriptor in this process. The classifiers employed were Support Vector Machine (SVM) and k-Nearest Neighbor (k-NN). Different combinations of SVM and k-NN were applied to the dataset, and the study achieved 100% accuracy with various combinations of k-NN. The study found that the combination of SIFT and SVM is the most effective method for the proposed recognition of traffic signs.

Keywords: Sri Lankan Traffic signs, Traffic signs recognition, SIFT, SVM, k-NN, machine learning

I. INTRODUCTION

With the rise in traffic density and the push towards autonomous vehicles, accurately identifying and responding to traffic signs is essential for ensuring road safety and compliance with traffic laws. Human drivers can easily miss or misinterpret signs due to distractions or poor visibility, leading to accidents and traffic violations. Traffic sign recognition systems address these issues by providing real-time, reliable detection and interpretation of road signs, aiding drivers in making safer decisions and enabling autonomous vehicles to navigate more effectively. This technology is vital for reducing accidents, enhancing driver assistance systems, and paving the way for fully autonomous driving solutions.

Traffic sign recognition is a crucial technology in modern transportation systems, playing a vital role in enhancing road safety and enabling autonomous driving. By using advanced image processing and machine learning algorithms, traffic sign recognition systems can accurately identify and interpret various road signs. This technology helps drivers make informed decisions in real-time and assists autonomous vehicles in navigating complex road environments. As the development of intelligent transportation systems continues, traffic sign recognition stands out as a key component in reducing accidents and improving the overall efficiency of road networks. Traffic sign recognition using machine learning involves training algorithms to automatically detect and classify traffic signs from images. Machine learning (ML) is an umbrella term that refers to a broad range of algorithms that perform intelligent predictions based on a dataset (Nichols, et al., 2019). The traffic sign datasets are often large, perhaps consisting of millions of unique data points.

Machine learning models are powerful tools that enable systems to learn from data and make predictions or decisions without being explicitly programmed. These models analyze patterns and relationships within large datasets, allowing them to identify trends, classify information, and make informed predictions. In traffic sign recognition machine learning models are used to process and interpret visual data, identifying and categorizing various traffic signs with high accuracy.

In this study, systematic experiments were conducted to evaluate the performance of classification using SIFT feature representation combined with k-Nearest Neighbor (k-NN) and Support Vector Machines (SVM). The evaluation was performed on a newly created dataset of Sri Lankan traffic signs, focusing on six randomly selected sign types.

The rest of the paper is organized as follows. The literature is reviewed in Section II. The experimental methods are presented in Section III. The results of the experiment and the discussion are presented in Section IV and lastly, the conclusion and future works of the paper are presented in Section V.

II. LITERATURE REVIEW

In this section a summarization of some studies related to road sign recognition is presented.

There are varieties of models and algorithms available for road sign detection. (Nikam & Dhaigude, 2017), proposed a novel system for automatic road sign detection and recognition. The system segments input images in YCbCr color space and detects road signs using shape filtering. Recognition of the road sign symbols is achieved through Principal Component Analysis (PCA). The study also discussed many roads sign detection and recognition techniques. MESR, HSV, SVM, OCR, HIS, and HOG. The system is designed to be both efficient and robust in detecting and recognizing road sign symbols. It is obvious from the study that machine learning and deep learning techniques are used for road sign detection algorithms.

Table 01: Comparability Study with Different Datasets and Models

Study	Model	Dataset	Accuracy
SVM Based Method			
(Mahesh, 2018)	SIFT and SVM	No Details are provided	90%
(Møgelmose, et al., 2012)	SVM, KNN, Random Forest, and Naïve Bayes	Real-time Indonesian Traffic Signs	86%
(Ali, et al., 2023)	SVM and HOG	GTSDB, GTSRB, Linköping University, Real-Time Taiwanese Traffic Signs	94.9%
(Rahmad, et al., 2018)	SVM and KNN	Real-time Indonesian Traffic Signs	82.01%
Other Methods			
(Ardianto, et al., 2017)	CNN	GTSDB, GTSRB	96%
(Sugiharto & Harjoko, 2016)	CNN	Real-Time Russian Traffic Signs	87%
(Chakraborty & Deb, 2015)	SVM, CNN	Own collection of 12 signs of Sri Lankan traffic signs	SVM – 98.33 % CNN – 96.40%
(Roxas, et al., 2018)	CNN	GTSRB	95%
(Wang, 2018)	SVM and SIFT	Sri Lankan Traffic sign Dataset	87%
(Filatov, et al., 2017)	SVM, KNN, MPC, DT, AdaBoost	Sri Lankan Traffic sign Dataset	90%
(Kiridana, et al., 2022)	CNN, SVM	Google Street View	98.5%
Our Method			
*	SVM, KNN, and SIFT	300 images of Sri Lankan traffic signs	**100%**

(Adam & Ioannidis, 2014) presented a comprehensive methodology for road sign detection and recognition, addressing various challenges. It emphasized the effectiveness of using HOG descriptors to represent Regions of Interest (ROIs) and employed HIS color space for thresholding in the detection stage. For recognition, a Histogram of Oriented Gradients (HOG) is used, with Support Vector Machines (SVMs) handling classification. The system also included a successful step for separating overlapping signs and demonstrated high competence, showing robustness to changes in illumination, scale, and partial occlusions. The study shows 94.34% of accuracy the road sign signal.

In (HU, et al., 2010) they proposed a Traffic Sign Recognition (TSR) method that effectively addresses challenges such as weather conditions, shooting angle, and distance variation. Experiments were conducted on training image sets classified by these factors. The method

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utilizes the SIFT technique to extract sign features, forms a codebook using K-means clustering, and classifies the signs with an SVM based on feature distribution. The results demonstrate that our method is robust to variations in weather, distance, and shooting angle, achieving a high accuracy rate of 93% with a low computation time of 0.098 seconds per image.

III. METHODOLOGY

Here, we discuss the compositional parts, and the process engaged with building and fostering our model. The proposed work is based on the Bag of Features approach. The bag of features approach includes the following phases: feature extraction, codebook creation, histogram representation and learning and classification. The main idea is to generate histograms of images for the classification process. MATLAB R2021a and Windows 10 with 8GB RAM were used for all the implementations. Figure 01 illustrates the steps involved in the implementation process.

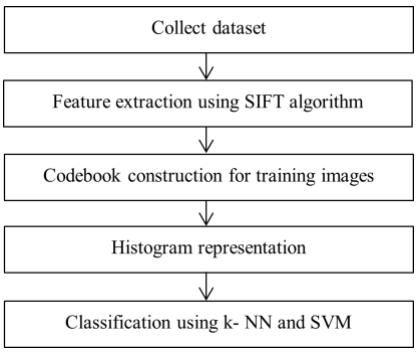

Figure 01: Methodology

Dataset

The dataset for this study comprises 300 images of Sri Lankan traffic signs: two informational signs and four warning signs. The dataset was captured from mobile with a good lighting condition. Initially, the road signs were cropped and normalized to a size of 200×200 pixels from the original image. The Images in each class were divided into two parts 70% for the training dataset and 30% for the testing dataset.

Figure 02: Class images of the dataset

Table 02: Road Sign Dataset

Sign	Train	Test
	35 Images	15 Images
	35 Images	15 Images
	35 Images	15 Images
	35 Images	15 Images
	35 Images	15 Images
	35 Images	15 Images

Feature extraction using the SIFT algorithm

SIFT was employed to extract features from the images. SIFT transforms data images into scale-invariant coordinates relative to local features. This process involves extracting features from the image, representing them as distinct patches, and then converting these patches into a collection of 128-dimensional vectors.

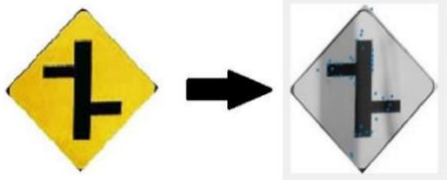

Figure 03: SIFT feature extraction

Codebook construction for training images.

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Codebook construction involves generating visual words or codewords through clustering techniques applied to the original feature space. The K-means algorithm was used for clustering on the training dataset. It is because of the simplicity, efficiency, scalability and speed of the algorithm. Generally, K-means clustering algorithms are straightforward to understand, works very fast, handle large amount of data, therefore this study is utilized k-means cluster as a one of the algorithms over SVM to train the dataset and check the validity. Besides, K-means clustering partitions a set of N features into k clusters, with each feature assigned to the nearest cluster based on the mean of the cluster's members. The centers of these clusters are then used to create codewords, which together form the codebook.

Histogram Representation

The images were represented by histograms using the constructed codebook. Separate histograms were generated for both the training and testing images.

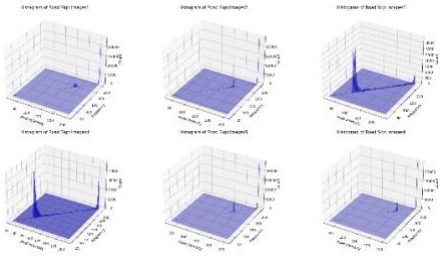

Figure 04: Histogram of road sign images

Classification using k- NN and SVM

The k-Nearest Neighbor (k-NN) approach was used for classification. It calculates pairwise Euclidean distances between key point representations of a test image and all labelled training images in the dataset. The Euclidean norm distance was employed to measure the distance between key points, with k values set to 1, 3, 5, 7, and 9.

Support Vector Machine (SVM) was used as an additional classifier. For multiclass classification, a linear SVM was trained using the one-versus-all (OVA) approach. The OVA rule separates each class from the others and assigns the test image to the class with the highest classifier response. The SVM^{light} package was utilized for the experiments.The accuracy rate for each classification was calculated, and this data was used to analyze the performance of the classifiers.

IV.RESULTS AND DISCUSSION

In this section, the outcomes of the execution of the methods referenced in the above-proposed works will be specified.

Table 03 presents the classification rates for different k values in the k-NN algorithm (k = 1, 3, 5, 7, and 9). All results shown in Table 01 were obtained without dimensionality reduction of the features extracted by the Bag of Features (BoF) method. This approach was chosen to preserve the full feature set and ensure that no potentially important information was lost during the dimensionality reduction process.

Table 03: Classification using different k values

K values	Accuracy
k=1	100.00%
k=3	97.78%
k=5	97.78%
k=7	96.67%
k=9	94.44%

Figure 05 illustrates the changes in classification rates when using the combination of SIFT and SVMs with parameter tuning. The graph depicts the impact of varying C values between 2^{-14} and 2^{10} on classification performance. The C value is the regularization parameter to avoid overfitting values. Normally high C value provides overfitting and low C value provides underfitting, the value between 2^{-14} and 2^{10} provide optimal performance to provide best classification performance without overfitting and underfitting.

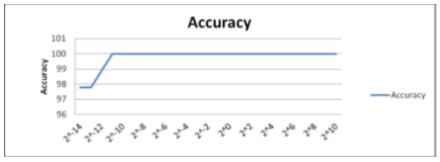

Figure 05: Graph of classification accuracy rates for SIFT + SVM with parameter tuning of C values ranging from 2^{-14} to 2^{10}

According to Table 03, as the number of nearest neighbors k in the k-NN algorithm increases, the accuracy rate decreases. Parameter k determines how many neighboring examples are considered when making a classification. Although considering more neighbors can generally improve classification accuracy, an increase in k may lead to a decline in accuracy if it introduces noise or less

relevant information into the decision-making process.

In Figure 05, which illustrates the combination of SIFT and SVM, the accuracy remains stable until a notable increase is observed when the parameter C is set from 2^{-12} to 2^{-10}. The parameter C in SVM controls the cost of classification errors. A larger C value focuses on minimizing classification errors by finding a more precise margin, while a smaller C emphasizes maximizing the margin, potentially leading to some classification errors. As C increases, the model becomes better at classifying points accurately, leading to higher accuracy rates. At certain points, the accuracy reaches 100% and remains consistent. Therefore, combining SIFT with an SVM classifier, particularly with optimal C values, yields the highest accuracy in our proposed method.

Table 01 above shows the comparative studies of SVM, CNN with different datasets. Different Dataset with different SVM, and other techniques shows different accuracies for relevant countries. For the Sri Lankan dataset k-NN with SIFT feature extraction technique is better suite, and it provides highest accuracy. Besides, In the available road sign dataset of Sri Lanka, this study got more accuracy with k-NN and SIFT.

On the other hand, if the other studies are changing parameters of the model and consider feature engineering techniques it also provides higher accuracy without any suspects.

V. CONCLUSION

Traffic sign recognition is a critical aspect of driver assistance systems and has been extensively studied globally. Intelligent autonomous systems for traffic sign recognition are essential for helping drivers understand and respond accurately to road signs. This study focuses on the recognition of Sri Lankan traffic signs, utilizing machine learning techniques to enhance the system's effectiveness. Specifically, Scale-Invariant Feature Transform (SIFT) is used as the feature descriptor, with Support Vector Machine (SVM) and k-Nearest Neighbor (k-NN) classifiers employed for the recognition process. The results indicated that combining SIFT with SVM is the most effective method for traffic sign recognition, offering significant improvements in classification accuracy and efficiency.

In the future, this study can be enhanced by extending the recognition to include a broader range of Sri Lankan traffic signs and enabling real-time detection, as the current approach is limited to still images. Additionally, expanding the dataset to include more diverse examples would improve the model's robustness. Further research could also involve comparing the proposed model with other existing models to evaluate its relative performance and effectiveness.

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TRACK - FOOD SCIENCE & TECHNOLOGY

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Evaluation of Physicochemical and Sensory Characteristics of Bottled Star Fruit (*Averrhoa carambola)*

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Abstract

Averrhoa carambola, commonly known as star fruit, is a highly valued tropical fruit due to its unique flavor and numerous health benefits. This study examines the effects of several heat treatments on the physicochemical properties, sensory qualities, and oxalic acid concentration of bottled star fruit (Averrhoa carambola). Pasteurized juice at 60 ± 02 0C for 5 min were poured into pre sterilized jars with star fruit pieces. Sensory aspects were evaluated of the product using a nine-point hedonic scale to rate its general acceptability. The oxalic acid content of raw, mature and ripe were 215.4 mg/L, 196.9 mg/L and 174.7 mg/L respectively while ascorbic acid content was reported as 3.21 mg/L, 3.21 mg/L and 6.42 mg/L. After blanching at 1, 2 and 3 min with 80ºC for ascorbic acid content and oxalic acid content results were recorded as 6.42 mg/L, 3.21 mg/L and 3.21 mg/L and 96.1 mg/L, 84 mg/L and 80.5 mg/L respectively. The fresh and bottled star fruit contained characteristics such as pH of 3.87 and 3.93, titratable acidity of 0.40 % and 0.36 %, brix value of 10 and 09 (TSS), Oxalic acid content 567 ± 26.62 mg/L and 341 ± 5.58 mg/L, ascorbic acid content 6.42 mg/L ± 1.28 mg/L and 3.21 ± 1.28 mg/L were recorded respectively. According to the WHO guidelines that oxalic acid content was got the safer level (50 mg/day) and because of that it can be used for susceptible individuals as well.

Keywords: Own juice, Physicochemical, Sensory, Star fruit, Storage

I. INTRODUCTION

The tropical fruit known as star fruit, or *Averrhoa carambola* in scientific parlance, is grown in Sri Lanka. Because of its star-like appearance when cut crosswise, it is also frequently known as "carambola". It is a member of the Oxalidaceae family (Litz *et al.*, 1989). Numerous star fruit cultivars are grown in Sri Lanka. These come in both tart and sweet versions, with different levels of sourness. In Sri Lanka, some of the most well-liked cultivars include "Fanton," "B10," and "Honey Sweet"(*(Star Fruit)*, n.d.) (Department of Agriculture, Sri Lanka, 2024). In Sri Lanka, star fruit trees are usually grown as ornamental trees or in residential gardens or small orchards and can be considered as organic fruit. When star fruit is completely ripe, it is typically harvested. Harvesting should be timed to suit the desired flavor; some people like their fruit slightly acidic and green, while others prefer it entirely golden and sweet (Pereira *et al.*, 2020). Star fruit is usually eaten raw, but it can also be added to salads, juices, chutneys, and desserts, among other cooked dishes. It is frequently used in fruit platters and salads in Sri Lankan cuisine. Antioxidants, fiber, and vitamin C are all present in star fruit (Pereira *et al.*, 2020). It is regarded as a healthy supplement to a diet because it is low in calories(Lakmal *et al.*, 2021). Like many other tropical nations, Sri Lanka values star fruit not only for its flavour but also for its culinary variety and possible health advantages.

The possible anti-diabetic effects of star fruit have been studied. Star fruit may help people with diabetes, while it is not a replacement for medical care or a diabetes management strategy. Compared to foods with a high glycemic index (GI), star fruit has a comparatively low GI, meaning that it affects blood sugar levels more gradually. Low GI foods can lessen the likelihood of sudden blood sugar spikes and crashes. Dietary fiber (Lakmal *et al.*, 2021) which is present in star fruit, may aid to stabilize blood sugar levels by slowing the body's absorption of sugars and carbohydrates. Antioxidants found in star fruit nclude vitamin C and a variety of polyphenols (Narain *et al.*, 2009). Antioxidants can assist in

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lowering inflammation and oxidative stress, both of which are frequently increased in diabetics (Leivas *et al.,* 2016). According to certain research, polyphenolic chemicals found in star fruit may have anti-diabetic effects. These substances could lessen insulin resistance and increase insulin sensitivity. Potassium, a mineral essential to controlling blood pressure, can be found in star fruit. Potassium encourages blood vessel walls to relax and helps offset the effects of sodium on blood pressure. Dietary fiber, found in star fruit, may support heart health. Lower blood pressure and a lower risk of hypertension are linked to a high-fiber diet. It is an essential component of the nation's culinary heritage and gives a distinctive flavour and aesthetic appeal to a variety of foods (Wang *et al.,* 2021). Star fruit can benefit from thermal treatments that improve its texture, flavour, and safety.

Oxalate is a naturally occurring substance found in star fruit that may be hazardous to those who have certain medical disorders, especially kidney impairment (Akhtar *et al.,* 2011). Besides the sensory, nutritional, and medicinal benefits of star fruits, their high oxalic acid content has aroused serious concerns (Hönow and Hesse, 2002; Massey, 2007; Sorensen, 2014; Sá *et al.,* 2019). The consumption of oxalic acid increases the formation of insoluble calcium oxalate salts which get deposited in the small blood vessels or to the units in the kidneys that clean blood (Chen *et al.,* 2001; Wijayaratne *et al.,* 2018). Excessive consumption of star fruit has been associated with the development of oxalate nephropathy in patients with both normal and

As a common fruit in many tropical and subtropical countries, including Southeast Asia, star fruit (*Averrhoa carambola*) is grown in household gardens in Sri Lanka. Although it is a well-liked fruit in the area, Sri Lanka typically does not cultivate it extensively for commercial purposes. During the fruiting season, the majority of starfruits are wasted owing to improper usage and fear of the oxalic acid concentration of starfruit. Value addition of Carambola fruits will improve the consumption by different communities and also reduce the postharvest losses of the unexploited fruit, apart from promoting several health benefits. Various strategies have been used for the reduction of oxalates in foods. An attempt to reduce the oxalates content by different methods such as washing, soaking (with $CaCl_2$, NaCl), and blanching has been reported, (Dahal and Swamylingappa, 2006; Hefter *et al.,* 2018; Rofi'ana *et al.,* 2018; Savage and Dubois, 2006; Thapa *et al.,* 2017). This study evaluated how different heat treatments alter the physicochemical qualities and sensory characteristics of bottled star fruit. (*Averrhoa carambola*) in its own juice offers important information about the product's quality and safety. This study adds significant knowledge to the field of fruit juice processing and advances the creation of consumer-friendly, premium, and safe products.

II. MATERIALS AND METHODS

Perhaps the easiest way to comply with the conference paper formatting requirements is to use this document as a template and simply type your text into it. When using this as a template, you do not need to worry about page layout, fonts, etc. The main body of the paper should be organized into sections, as Introduction, Background/ Literature review, Problem specification, Methodology and Experimental design, Results, Discussion and Conclusion, Acknowledgement and References.

A. Ingredients and Equipment

Fresh star fruit (*Averrhoa carambola*), Water, Sterilized glass bottles or jars with tight-fitting lids, cutting board and knife, Saucepan, mixing spoon, Funnel, Boiling water bath, Retort

B. Sample preparation for analysis - Preparation of starfruit juice

Ripe but firm star fruits were selected for the processing. The fruits were washed thoroughly under potable, running water and sliced. The slices were placed in sterilized glass bottles and juice was extracted from additional star fruit slices. Juice was heated in a water bath to 60°C, and poured over the fruit slices to cover them completely. The bottles were exhausted in a water bath at 80°C for 5 minutes. After securely tightening the lids, the samples were sterilized in a retort at 100°C for 25 minutes under 1 bar of pressure. Bottles were allowed to cool to room temperature before storing in a cool, dark place. All equipment utensils used were properly sanitized to prevent contamination.

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C. Testing of physicochemical properties

1) Oxalic acid level measurement:

Diluted samples were titrated for the oxalic acid content determination purpose. A burette was used and titrated the standard oxalic acid solution and sample with Potassium permanganate solution (Narain *et al.*, 2009).

2) Brix value:

Juice was extracted from the star fruits by crushing and filtering the pulp to obtain a clear liquid sample. Refractometric Method was used for the brix level evaluation purpose (AOAC Official Method 932.12).

3) Ascorbic acid level measurement:

Ascorbic acid content was obtained using titration of the samples with iodine solution. Each samples were diluted and starch solution was added for titration (Iodine titration) (Ruvini *et al.*, 2018).

4) pH Measurement:

Star fruit sample was prepared by extracting juice or creating a homogenized mixture. pH was recorded by using pH meter (AOAC Official Method 981.12).

5) Acidity measurement:

One of the most widely used methods is the titration method using sodium hydroxide (NaOH) as the titrant (AOAC Official Method 942.15 - Titratable Acidity).

6) Sensory evaluation:

Sensory evaluation on star fruit pieces in own juice bottle was conducted with nine-point hedonic scale during the time period. Moderate level of preference (07) was obtained from the trained panelists.

7) Microbial evaluation:

Microbial evaluation was performed using the plate count method (AOAC Official Method 966.23). Samples were diluted, plated onto Standard Plate Count Agar, incubated at 35°C for 48 hours, and colonies were counted to determine CFU/g.

8) Statistical analysis:

The results are the mean ± standard deviation (SD) of triplicate evaluations. Analysis of data was carried by one-way analysis of variance (ANOVA) and the mean comparisons were done by the Tukey-HSD test where necessary. analyses were performed by using SPSS-16 for Windows program.

III. RESULTS AND DISCUSSION

A. Physicochemical properties with different maturity stages

1) Oxalic acid content:

According to the maturity stages, immature star fruits were contained low oxalic acid content than the ripe star fruits. Overall, the chart demonstrates that oxalic acid content decreases as the samples move from the immature stage to the ripe stage.

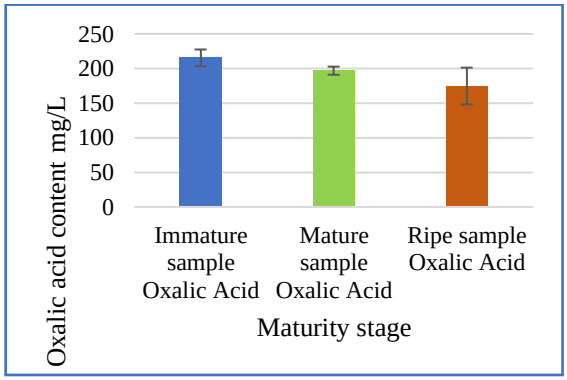

Figure 01. Oxalic acid content on different maturity stages

2) Brix value:

Ripe star fruits were contained high brix value than immature fruits. This bar graph displays the Brix values of samples at different maturity stages: immature, mature, and ripe. Brix is a measure of the sugar content in an aqueous solution, typically used in the context of fruits to gauge their sweetness and ripeness.

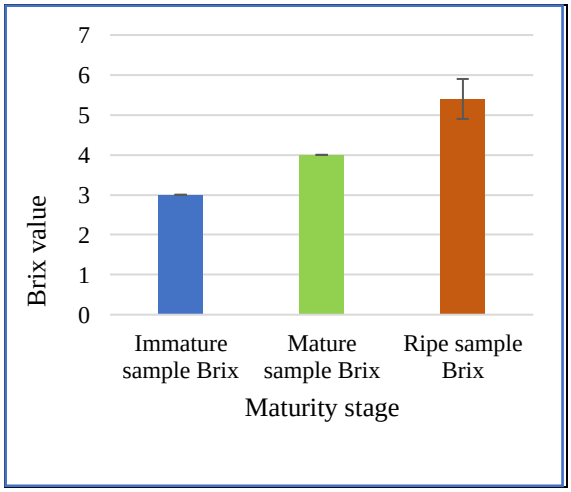

Figure 02. Brix value on different maturity stages

3) Ascorbic acid content:

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This bar chart displays the ascorbic acid (vitamin C) content in mg/L at different maturity stages of a sample. The ascorbic acid content increases from the immature to the ripe sample. Ascorbic acid content was highly contained in ripe star fruits.

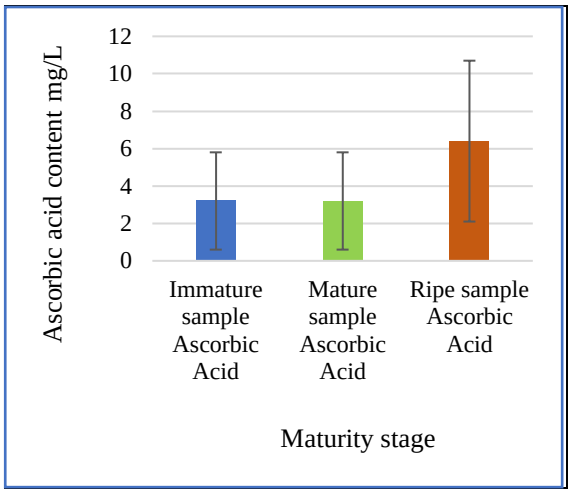

Figure 03. Ascorbic acid content on different maturity stages

4) pH level:

This bar chart depicts the pH levels of samples at different maturity stages: immature, mature, and ripe. The pH level increases as the sample matures from the immature to the mature stage and then stabilizes as it remains constant from the mature to the ripe stage. Acidity level was increased in the ripe star fruits than immature fruits.

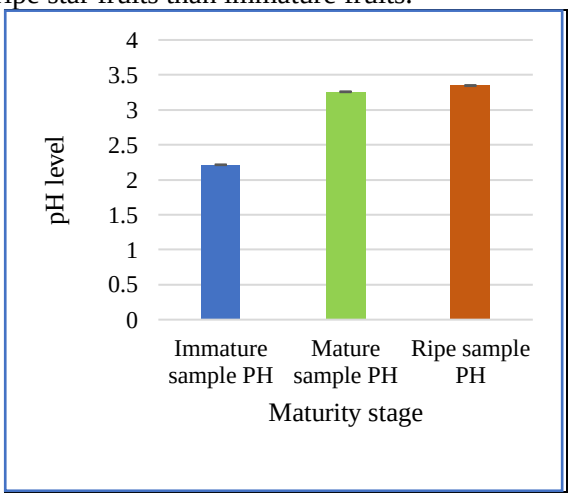

Figure 04. pH level on different maturity stages

A. Physicochemical properties with effect of thermal treatments:

1) Oxalic acid content:

With different blanching times, 03 minutes of blanching time was reduced the oxalic acid content than 01 minutes blanching time.

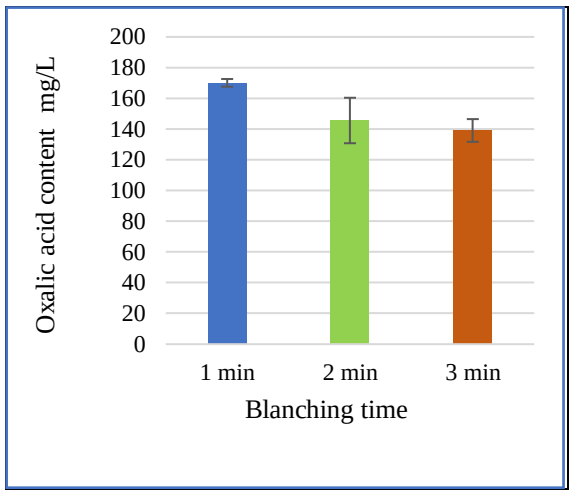

Figure 05. Oxalic acid content on different blanching times

Ascorbic acid content was reduced after the blanching, because that ascorbic acid is water soluble and heat sensitive at the same time. Oxalic acid and ascorbic acid are heating sensitive and available content can be reduced using the heat treatments.

Testing for oxalic acid contents were generated positive results on the evaluation. Final results were obtained after the calculation of final readings. Fresh star fruit juice was resulted 923 mg/l of oxalic acid content according to the process. Water blanched for 01 min sample was obtained 942 mg/l of oxalic acid content. Water blanched for 02 minute and 03minute samples were obtained 749 mg/l, 539 mg/l of oxalic acid contents respectively. Sterilization was done at the final stage of the sample preparation process. Before that, juice pre-heating and exhausting were conducted according to the process. Bottled sample with 03 minutes blanched pieces of star fruits were obtained 317 mg/l of oxalic acid content according to the data.

2) Ascorbic acid content:

Ascorbic acid or vitamin C content is some kind of nutrient included in the fruits or vegetables. In star fruit, it can be available with different values and it depends on the environmental conditions and maturity indices accordingly. In the bottling process, fresh star fruit was obtained 6.42 mg of ascorbic acid value. After processing of star fruit, that ascorbic acid content can be reduce from the materials. Because that ascorbic acid is heat sensitive and water soluble (Narain *et al.*, 2009).

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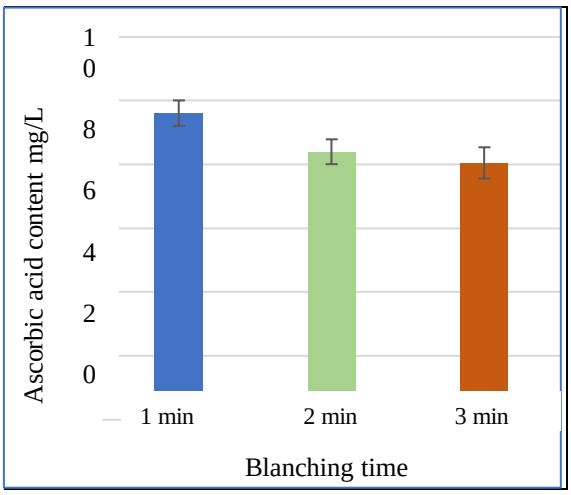

Figure 06. Ascorbic acid content on different blanching times

C. Physicochemical properties result with effect of pre-treatments

1) Oxalic acid content:

Pre-treatments with different acids can significantly alter the physicochemical properties of substances, impacting their stability, solubility, and overall performance in various applications. Comparing the two acids, oxalic acid has a stronger impact on the physicochemical properties of star fruit juice, which could be leveraged in applications requiring significant modification of these properties.

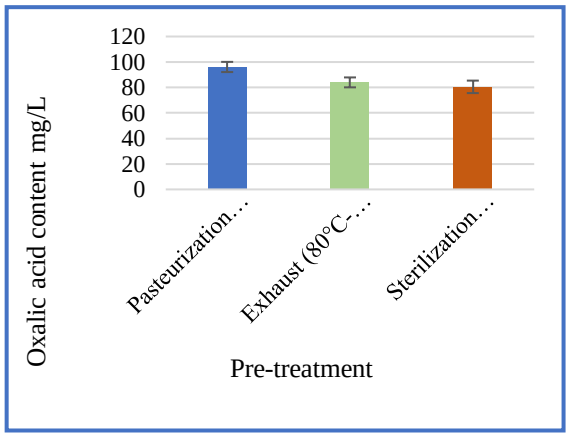

Figure 07. Oxalic acid content on different pre-treatments

2) Ascorbic acid content:

The study demonstrates that oxalic acid and ascorbic acid pre-treatments distinctly influence the physicochemical properties of star fruit. Oxalic acid has a more pronounced effect, which may be beneficial in specific industrial applications.

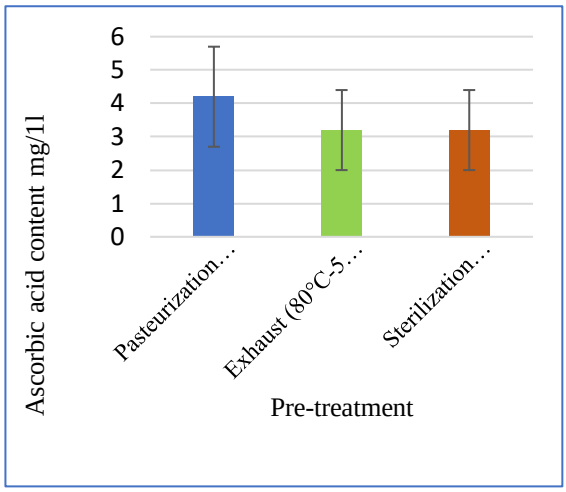

Figure 08. Ascorbic acid content on different pre-treatments

D. Physiochemical properties during storage period

Samples were tested for the ascorbic acid content, pH level, brix value, acidity, microbial count and sensory evaluation with the shelf-life testing. Sample preparation for shelf-life evaluation was conducted using the mature level of star fruits. Fresh star fruit juice was contained 634 mg/l of oxalic acid content at the processing time. Sterilized final product was obtained 341 mg/l of oxalic acid content. During the storage period, samples were resulted reduction of oxalic acid content levels according to the data generated.

Fresh sample was obtained 3.87 pH level and after preparation of the bottles, 3.79 was the pH reading. it can be happening, because that inside bottle was filled with processed and unprocessed materials. Equilibrium level will be process inside bottle during storage period. Level of pH was changed normally after the bottling process.

Brix value of the star fruit was obtained 10 in fresh fruits and after processing, it was gradually decreased with the storage period.

Acidity level was obtained periodically with fresh and bottled samples evaluation.

D. Sensory evaluation results

Sensory evaluation was done during the four-month storage period with 05 trained panelists. Sweet taste increasing idea was concluded finally by the sensory panelists. Additional of value with vitamins, sweeteners like things will commercially valuable in the star fruit-based productions. Moderate level (07) of acceptances were obtained for every month (04) with the positive feedbacks.

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Table 01: Physiochemical properties of Star Fruit juice sample during storage period

Time	Parameter					
	Oxalic Acid content (mg/L)	**Ascorbic Acid content (mg/L)**	**PH**	**Brix (TSS)**	**Acidity (%)**	**Microbial total plate count (TPC)**
Fresh	634	6.42	3.87	10	0.4	Detected
Initial	341	3.21	3.79	9	0.39	Not Detected
Month 01	403	3.21	3.64	8	0.33	Not Detected
Month 02	425	3.21	3.81	7	0.47	Not Detected
Month 03	398	3.21	3.6	7	0.49	Not Detected

E. Sensory evaluation results

Sensory evaluation was done during the four-month storage period with 05 trained panelists. Sweet taste increasing idea was concluded finally by the sensory panelists. Additional of value with vitamins, sweeteners like things will commercially valuable in the star fruit based productions. Moderate level (07) of acceptances were obtained for every month (04) with the positive feedbacks.

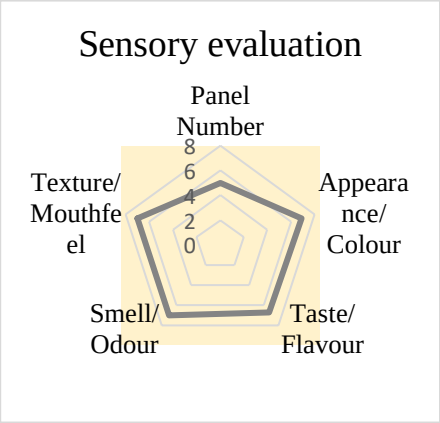

Figure 09. Sensory evaluation data

F. Microbiological results

Microbes were not detected after the bottling process with sterilization.

IV. CONCLUSION

The investigation into how various heat treatments affect the oxalic acid concentration, physicochemical properties, and sensory attributes of bottled star fruit (Averrhoa carambola) offers important information about the product's quality and safety. The star fruit juice was significantly impacted in a number of ways by the heat treatments, such as pasteurization and sterilization. First off, the product's safety and consumption may be enhanced by the reported decrease in oxalic acid content following heat treatments. Excessive concentrations of oxalic acid can be hazardous to human health. Heat treatments have been shown to reduce oxalic acid levels, indicating that these techniques may be useful in reducing the risk. Second, the physicochemical modifications such as variations in pH, colour, and texture are important elements that impact the star fruit juice's overall quality when it is packaged. The study emphasizes how important it is to give these factors considerable thought throughout the heat treatment process in order to preserve desired qualities and create a product that lives up to customer expectations.

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Consumer Purchasing Behaviour on Spicy Products in Matara District, Sri Lanka

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Abstract

Various factors influence the consumption of spicy products, making it essential to identify their significance for satisfactory consumption levels. The purpose of this study is to identify the elements that influence customer purchase decisions in the Matara district, as well as their awareness of available spicy items and future demand trends. A semi-structured questionnaire was administered to a sample of 384 spicy product consumers, collecting data across eight dimensions: price, quality, brand name, convenience, availability, packaging, nutritional value, and recommendations. Descriptive and multiple regression analyses revealed that quality, nutritional value (16.15% for both), and price (15.89%) significantly influence purchasing decisions, while other factors were not statistically significant at 0.05. Preference hierarchy among consumers shows that chilli pieces are the most preferred, followed by curry powder and chilli powder. The study found high consumer awareness of Freelan's spicy products, with 95.05% of participants familiar with the brand. The most commonly used spices include chilli pieces, curry powder, and chilli powder, with awareness rates of 17.71%, 15.89%, and 15.63%, respectively. Consumers primarily learn about Freelan products through Freelan outlets and supermarkets, which capture 23.96% and 23.44% of awareness, respectively. This research provides valuable insights for marketers and producers of spicy products, highlighting the importance of competitive pricing strategies and brand development to meet consumer preferences and enhance market share in the Matara district.

Keywords: Consumer Awareness, Matara District, Purchasing Decisions, Regression Analysis, Spice Consumption, Spices

I. INTRODUCTION

Spices grown on our own soil and its group of food products. It has a very complex composition and varies effects. Spices as products of plant origin, and is the case with seasoning mixes. Spices are commonly used in the kitchen to give spice to food and as a remedy. Asians mostly utilise spices or spice mixtures to make food fragrant, spicy, savoury, and sweet. Spices vary in nutritional content and provide numerous health advantages. Some spices include cinnamon, garlic, cloves, cumin, basil, star anise, galangal, ginger, coriander, turmeric, cilantro, pepper, and ajowain Balasubramanian *et al*., 2015). The several ranges of spicy products are available in the market. For example: - Chilli powder, Chilli pieces, Curry powder, Pepper and Turmeric and etc. Curry is one of the most common spicy foods. Curry powder is a blend of spices (including turmeric, cumin, coriander, paprika, cardamom, and others) and herbs. It contains fat, protein, minerals (such as iron, calcium, and salt), carbs, fibre, and phytochemicals. Spices have a high antioxidant property. Due to this antioxidant property spices are play very special role in the medicine industry. Spices are essential as both medicine and nourishment. The medicinal value of spices is inhibiting the cancer, reduce fever, malaria, stomach offset, nausea, benefit for heart health, immune system and many more. The Ceylon spices are very popular. One of the reasons for it our spices have a taste. Ceylon spices were well-known throughout the world as far back as the 15th century. The spicy industry has a diverse product range. It consists of cinnamon, pepper, cloves, cardamom, nutmeg, mace, and vanilla. In the Sri Lanka the crop production is consist of mix home garden agroforest system. Examples include pepper, cloves, nutmeg, and cardamom. However, 70% of cinnamon is farmed as a pure crop on tiny farms. Sri Lanka is a lower middle-income country with a tiny economy. Consumer purchases are more sophisticated. Consumer purchases are

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influenced by various factors. Some of they are sociological, physiological and psychological factors. People's previous experiences shape their views and attitudes towards specific types of goods, commodity brands, and retail places. According to that, the selection of a good becomes vital for consumers due to the huge variety of consumer goods available on the market (Frewer, and Trijp, 2007). Customers are required to obtain information on the many sources of supply for the items, the brand name, product advantages and disadvantages, the uses and value of their characteristic features, and the services provided. Consumers obtain information from a variety of sources, including markets, advertising media (television, radio, and newspapers), friends, recommendations from others, local retailers, store displays, and product labels. The research area is Matara district in southern province, Sri Lanka. So, this study focusses on what are the factors influence for purchase decision of spicy products in Matara district because there are no more studies done in Matara district related to this area. The study is helpful to the marketers as they can create various marketing programs such as customer promotion programs and that they believe it will be help of interest to the consumers. And also, it can also boost their marketing strategy. The current study tries to analyse the factors influencing consumers' purchase decisions regarding spicy products, focusing on consumer awareness, preferred types of spicy products, the media channels that raise awareness, and the key label considerations that impact purchasing choices.

II. METHODOLOGY

A. Location of this Study

This study was conducted in Matara district, accompanied by Matara Freelan (Pvt) Ltd, Sri Lanka from August, 2023.

B. Description of the Research Area

This investigation was carried out in the Matara district, located in the southern region of Sri Lanka. This district is one of the 25 administrative divisions of Sri Lanka. It has a population of 873,000 people, according to the final result of the Census of Population and Housing (2021).

C. Sampling Technique

The sample size consists of 384 consumers who use spiced products in the Matara district. The sampling approach employed is cluster sampling. It signifies the segmentation of the population into subgroups or clusters based on different areas within the Matara district.

D. Pilot Survey

A pilot survey looks at the validity of each question. In the pilot survey, 10% of the full-scale survey sample size was used. Therefore, 35 spiced consumers were used to conduct the pilot survey.

E. Research Tool

In this research, a semi - structured questionnaire was used. The questionnaire consists five sections. The first section discusses the demographics of the consumers. The second section consist spicy usage also third section include about perceptions of spiced products and fourth section consist of intentions to purchase spiced products and last section consist about Freelan products.

F. Data Collection and Analysis

Data were gathered using in-depth interviews and questionnaires. It included open - ended questions and close-ended questions. Quantitative research collects and analyses data using numbers, and statistics are expressed as numbers and graphs. This was used to test or confirm hypotheses and assumptions. Qualitative research focusses on words and their meanings. These help people understand concepts, thoughts, and experiences. Data analysis is the systematic application of statistical and logical approaches to describe and visualise data. Different tests were performed to analyse the different aspects of the study. Descriptive analysis was carried out for to analyse the demographic factors and sample profile. SPSS 25 (Statistical Package for the Social Sciences) was used to analyse the data. The variables' relationships were determined using multiple linear regression analysis. The present study used regression analysis to determine the association between consumers' purchasing decisions of spicy products (dependent) vs. price, quality, brand name, packaging, previous, availability, convenience, nutritional value, and recommendations from others (independents).

III. RESULTS AND DISCUSSION

The Table 01 is shows to there are 384 individuals in total, with those aged 18-29 being the most represented at 120 individuals (31.3% of the sample). The next largest group is those aged 30-39, comprising 101 individuals (26.3%), followed

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by the 40-49 age group with 59 participants (15.4%). The under 18 category and the 50 and above category are the least represented with 58 (15.1%) and 46 (12.0%) individuals respectively. This table shows that females are the majority, which accounts for approximately 80.99 of the totals. Males represent a smaller fraction, 19.01% of the sample. Out of the 384 respondents, a significant majority, the 85.2%, reported being employed ("yes" to doing a job), while a minority 14.8% reported not being employed ("no" to doing a job). Table 01 shows the distribution of monthly household income among the participants of the study. The majority of respondents fall within the middle-income brackets. The 28.13% respondents earn between 15,000-24,999, and the largest group 29.69%, earn between 25,000-49,999. The next highest category is 50,000-99,999 with 23.70% respondents. The lowest income bracket, under 15,000, is represented by 11.20% respondents, and the highest income bracket, above 100,000, has the fewest number of individuals as a 7.29%. The Table 01 shows that the majority of participants, 334 individuals, identify as Sinhala, making up 87.0% of the sample. The Tamil ethnicity represents a smaller portion with 39 individuals, accounting for 10.2% of the respondents. Those who identify with ethnicities other than Sinhala or Tamil are the least represented, with 11 individuals or 2.9% of the sample.

The Figure 01 is indicating that quality and nutritional value are the most valued factors, each accounting for 16.15% of respondents. Price is the next most considered factor at 15.89%. The factor of packaging concerns 14.58%. Next factor of brand name 13.54%. Convenience is considered by 10.42% showing a moderate level of importance. Availability is important to 7.55%. Which is relatively less compared to other factors. The least considered factor, according to this chart, is recommendation, which influences only 5.73%. Figure 02 displays a pie chart detailing the common use of specific spices in the kitchen by respondents. The most commonly used spice is chili Pieces, with 17.71% reporting its use. Following closely Curry powder, by 15.89% then next Chilli powder 15.63%. Turmeric powder is used by 13.02%, and pepper by 11.96%. Lesser-used spices include Roasted curry powder by 10.94%, Meat curry by 7.03% and Cumin by 4.43%. The least common is Cloves reported by only 0.78%.

The Figure 03 shows that the largest group of respondents, 23.96%, learned about Freelan products through Freelan Outlets. A close second is the 23.44% who became aware via Super markets. Retail shops is the third most common source of awareness, accounting for 19.53% of the responses. Learned about Freelan products via Advertisement 17.45%, Other recommendations, possibly including word of mouth or social media, informed 15.63% of the respondents about Freelan products.

Table 01: Demographic Features of the Respondents

Factors	Description	Frequency	Percent	Valid %	Cumulative%
Age	Under 18	58	15.1	15.1	15.1
	18-29	120	31.3	31.3	46.4
	30-39	101	26.3	26.3	72.7
	40-49	59	15.4	15.4	88.0
	50 above	46	12.0	12.0	100.0
Gender	Male	73	19.0	19.0	19.0
	Female	311	81.0	81.0	100.0
Occupation	Yes	327	85.2	85.2	85.2
	No	57	14.8	14.8	100.0
Income	Under 15000	43	11.2	11.2	11.2
	15000-24999	108	28.1	28.1	39.3
	25000-49999	114	29.7	29.7	69.0
	50000-99999	91	23.7	23.7	92.7
	Above 100000	28	7.3	7.3	100.0
Ethnicity	Sinhala	334	87.0	87.0	87.0
	Tamil	39	10.2	10.2	97.1
	Other	11	2.9	2.9	100.0

(Source; Survey, 2023)

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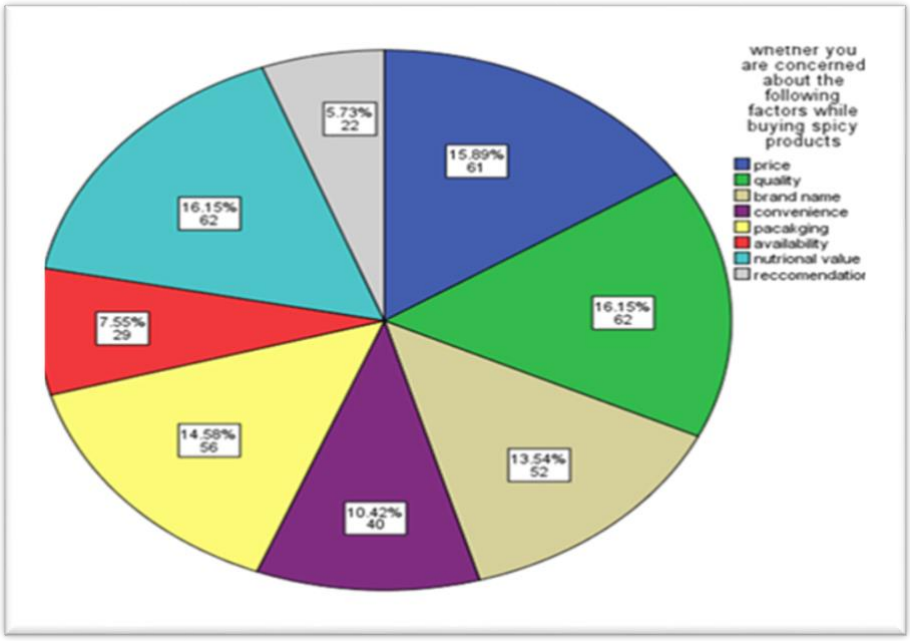

Figure 01: The Factors Affecting the Purchasing Spicy Products

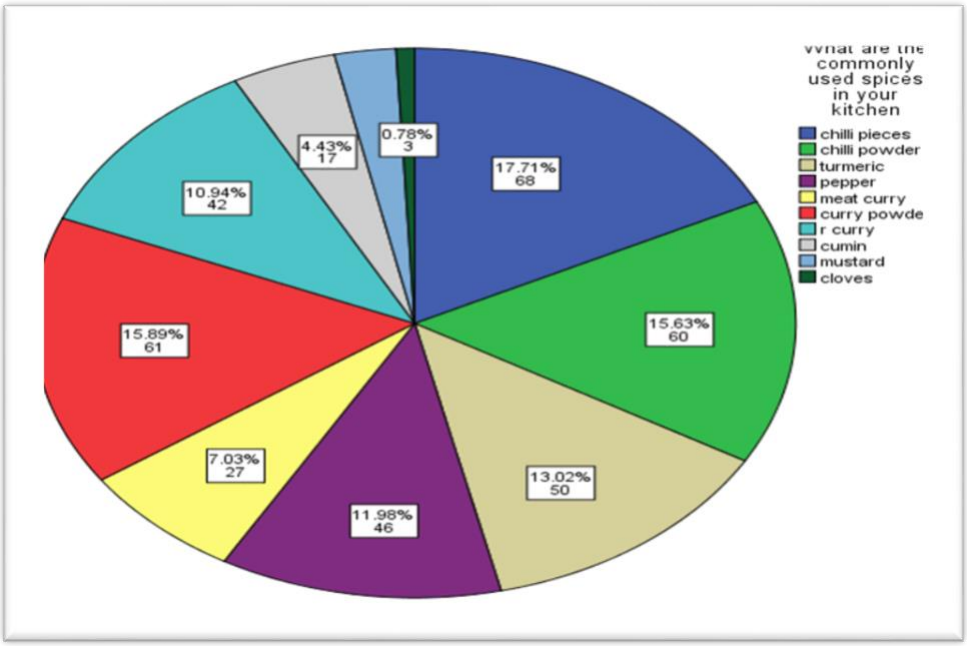

Figure 02: Type of Spicy Products and Consumption

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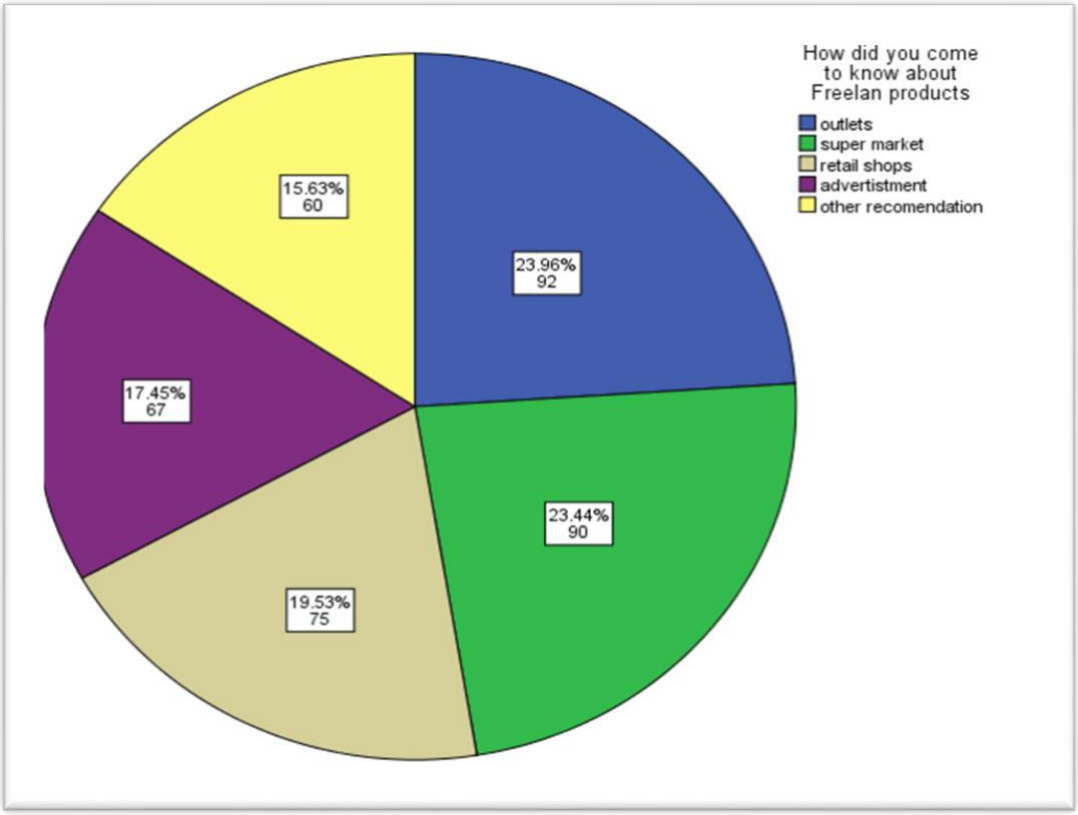

Figure 03: Media and Consumer Awareness

a. Reliability

Table 02: Reliability Analysis

Reliability Statistics	
Cronbach's Alpha	N of Items
.827	27

The Table 02 displays reliability statistics for a scale used in a study. The Cronbach's Alpha value is .827, which indicates a high level of internal consistency among the 27 items in the scale. In research, a Cronbach's Alpha value greater than .7 is generally considered acceptable.

Table 03: Model summary

Model Summary				
Model	**R**	**R Square**	**Adjusted R Square**	**Std. Error of the Estimate**
1	.804[a]	.647	.639	.503

a. Predictors: (Constant), recommendations for others, availability, packaging, nutrional value, brand name, convenience, price, quality

Table 03 shows a model summary for a multiple regression study. The R value, or correlation coefficient, is 0.804, suggesting a high positive correlation between the independent factors and the dependent variable. The R Square value of 0.647 indicates that the model's predictors can explain about 64.7% of the variance in the dependent variable. The Adjusted R Square score is somewhat lower, at 0.639, which takes into account the number of predictors in the model and provides a more accurate estimate of the variance explained when applied to the larger population.

The Table 04 indicates that the regression model has a Sum of Squares of 173.134 with 8 degrees of freedom, resulting in a Mean Square (the average squared deviation from the mean) of 21.642. This model yields an F-statistic of 85.661, which is statistically significant (Sig. value of 0.000, which is less than 0.001, indicating a very strong level of

significance). The Residual (or Error) Sum of Squares is 94.490 with 374 degrees of freedom, giving a Mean Square of 0.253. This suggests that the model is highly significant in explaining the variance in consumer purchase decisions, with the predictors. The F-statistic and its associated p-value indicate that the model is a good fit for the data, and the predictors collectively have a statistically significant effect on consumer purchase decisions.

The regression equation is constructed using the unstandardized coefficients (B) from the regression table. Here's how you can write the regression equation based on the given table:

Consumer Purchase Decisions=1.356+(0.111×price)+(0.123×quality) +(0.272×brand name)-(0.082×convenience)+(0.089×packaging)-(0.048×availability)+(0.097×nutritional value)-(0.037×recommendations for others)

Each variable (price, quality, brand name, etc.) is multiplied by its respective unstandardized coefficient and then added to the constant term, which is 1.356 in this case. The result of this equation would give you the predicted value of the dependent variable, Consumer Purchase Decisions, based on the values of the independent variables

Table 04: ANOVA

ANOVA[a]						
Model		**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
1	**Regression**	173.134	8	21.642	85.661	.000[b]
	Residual	94.490	374	.253		
	Total	267.624	382			

a. Dependent Variable: Consumer Purchase Decisions

b. Predictors: (Constant), recommendations for others, availability, packaging, nutritional value, brand name, convenience, price, quality

IV. CONCLUSION

The statistical analysis carried out in this study provides valuable insights into consumer purchasing behaviour concerning Freelan spicy products. The demographic breakdown revealed that the sample was predominantly female, with a wide distribution across various age groups, mainly concentrated in the 18-39 age range. The majority of participants were employed, with a significant portion falling within the middle-income brackets, suggesting that the economic status of most respondents was relatively stable. Ethnically, the Sinhala community was substantially overrepresented in the sample, which could influence the generalizability of the results to the broader population. As for the perception of Freelan products, most respondents considered the prices to be moderate to high, indicating a perception of reasonable value or premium pricing for these goods. A significant 95.05% of respondents are aware of Freelan products, with spices being the most recognized category. When it comes to consumption preferences, chilli pieces, curry powder and curry powder are the spices most commonly used in the kitchen. Freelan Outlets and Supermarkets emerge as the primary sources of consumer awareness, suggesting that physical stores play a crucial role in influencing purchasing decisions.

In terms of purchasing behaviour, consumers prioritize quality and Nutritional value equally when considering the labels of spicy products, with price, packaging and brand name also being an important factor. The reliability of the survey instrument was high, with a Cronbach's Alpha of .827, suggesting that the survey questions were consistent in measuring the intended constructs across 27 items. This level of reliability strengthens the confidence in the subsequent findings of the regression analysis. Hypothesis testing further supported these findings, confirming significant relationships between price, quality, brand name, packaging, recommendations from others, nutritional value, convenience, and availability with consumer purchase decisions. In conclusion, the study indicates that consumer purchase decisions for Freelan spicy products are primarily driven by brand name, product quality, and packaging. These factors are instrumental in shaping consumer behaviour, and any marketing strategies should focus on enhancing these product

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attributes. Additionally, while price and nutritional value are also important, they are less impactful compared to the brand-related factors. The study suggests that to capitalize on consumer behaviour, Freelan should continue to invest in brand equity and ensure high product quality and appealing packaging while considering the pricing strategy and nutritional aspects of their products

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Impact of Food-related Posts in Social Media on Eating Habits and Dietary Choices among the Undergraduates of Sri Lankan Universities

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Abstract

Compared to past decades, there is a notable rise in social media influencers and content creators who focus on food-related content. Simultaneously, the number of viewers who interact with food-related content also increases. Along with the rise of food-related content in social media, the prevalence of eating disorders and poor dietary choices also increased in young adults. Literature exhibits the gap in assessing the impact of FRPs (food-related posts) based on the Sri Lankan context. This study intends to analyze the frequency of exposure to FRPs and their effects on eating habits, food choices, and food cravings among university undergraduates in Sri Lanka. In this regard, an online survey based on the Google Forms platform was conducted to collect the relevant data. Correlation analysis and the χ^2(5% significance level) were chosen to evaluate the association between variables. Some 396 university undergraduates (female=68.9% & male=31.1%) between the age of 18-42 participated in the study. As per the results, the frequency of exposure to FRPs is notably high where the exposure to FRPs is associated with the number of social media accounts. Results indicate the popular site for watching FRPs is YouTube (63.13%) and the highly preferred contents were reviews on street food places, snacks and desserts, and food preparation videos. The study reports a significant effect due to FRPs on eating habits and food choices than food cravings from the analysis (p value<0.05). The impacts of FRPs might be positive and negative an equal ratio (73.7%) of participants' views.

Keywords: ***Food-related posts, social media, food habits, dietary choices, university undergraduates***

I. INTRODUCTION

By today, social media (SM) platforms have become an integral part of university students' lives and SMs have been imposing a multifaceted impact on students. Information retrieval via social networking sites is specifically linked to the needs of youth consumers for inclusion in the emerging trends of cultural and consumption culture, where technology is an agency to the emotions, cognition, and social patterns of Generation Y (Khalid, Jayasainan and Hassim, 2018). Social media usage in Sri Lanka has been significant over the last decades, representing 34.2% of social media users (from the population) and having the highest range of users aged 18 or above (47.0% of the users) (Kemp, 2024). Furthermore, Facebook has become the most popular social media platform, where YouTube and Instagram follow closely behind. In the above cluster of SM users, the 18-34 years age range corresponds to the largest portion who use SMs for more than 1 hour. Furthermore, 46% of users purchase products or services after seeing reviews or recommendations and 90% check online reviews before making a purchase (Digital Outlook Sri Lanka, 2024). This fact highlights the significant role SMs play in governing user decisions, particularly among young adults. Thus, there may be an influence of food-related posts on decision-making among SM users.

To this end, poor dietary choices and eating habits lead to an unhealthy life at an early age. Also, fast food consumption is a significant factor in obesity and causes non-communicable diseases, with a noticeable association between fast food intake and overweight problems among young adults in Sri Lanka (Nirmal and Padmasiri, 2022). The increasing prevalence of overweight and obesity could be mostly due to various behavioral and lifestyle factors, and that is a burden on the population. Overweight and obesity are recognized as the cause of many health-related complications. Unhealthy dietary practices such as high fat and salt intake lead to excess weight gain (Karthijekan and Angela, 2020). Moreover, food consumption behavior in young adults may be influenced by several factors such as

socioeconomic status, educational attainment, and home food availability (Ludwig-Borycz et al., 2023). Studies show a shift towards fast food consumption due to globalization, busy schedules, and the rise of fast-food outlets in Asian countries, leading to health concerns like obesity and non-communicable diseases (Ludwig-Borycz *et al*., 2023). Not only these, the food choice among the youth is highly influenced by their region, age, and gender (Soam *et* al., 2023). In contrast, the attitude of students toward SMIs (Social Media Influencers) does not affect their daily dietary choices, however, the subjective norms in the students' lives on SMIs make a difference in their eating habits (Ahmad and Bruno, 2021).

In reported studies, the impact of food-related posts on SM on eating habits and dietary choices was surveyed in other Asian countries (Alwafi *et al*., 2022; Tami and Alyousef, 2022; Salleh *et al*., 2021; Scheiber, Diehl, and Karmasin, 2023). In a Sri Lankan context, the published works focus on the impact of social media among Sri Lankan population on different aspects such as academic performance (Mufassirin *et al*., 2023; Chandrasiri and Samarasinghe, 2021, Suganya *et al.,* 2020; Shameera and Sabaretnam, 2019), emotional intelligence (Keara and De Zoysa, 2022), mental health (Weerasundera, 2014) and marketing (Dananjana, Yasara, and Abeysekera 2024). Thus, a notable gap in the literature has been identified regarding the specific impact of food-related posts on social media as well as among the young generation. Given these gaps, this study aims to examine the frequency of exposure to FRPs on SM platforms among Sri Lankan undergraduate students and to survey the influence of FRPs on SM on individuals' eating habits, food choices, and food cravings. This study is significant as the outcomes help reveal the current food practices of undergraduates, who will be the working force of the country very soon. Here, we have limited the scope of the study to undergraduates considering the convenience of conducting the research and analysis.

This article has been organized as follows. Firstly, in the methodology, we discuss the development of a detailed online questionnaire to evaluate the influence of food-related posts in SMs on the eating habits of (university) undergraduates. Next, the outcomes of the study will be presented and discussed, which also reveal possible correlations of variables such as the gender of participants with eating habits, dietary choices, and food cravings as influenced by food-related posts (FRPs). We also discuss the reliability of information shared via FRPs and the impact of FRPs based on the outcomes of the online questionnaire. The concluding remarks of the work are finally presented along with potential future works.

II. METHODOLOGY

A. Study design and sampling

An anonymous online survey was conducted from May to June 2024, using a structured questionnaire to collect data from randomly selected undergraduate students (i.e. level-100, level-200, level-300, and level-400 students). The questionnaire was developed in the Google Forms platform and the respondents were invited via the link shared via social media platforms such as WhatsApp, Instagram, E-mail, and LinkedIn. The next section will outline the different sections included in the questionnaire.

B. Questionnaire

The questionnaire was created based on a previously validated questionnaire (Alwafi et al., 2022) and modified based on the scope of this study. The questionnaire consists of three major parts as listed below:

1. *Part A:* This section collects socio-demographic details of the participants including their age (five age ranges: 18-22, 23-27, 28-32, 33-37, 38-42 and above), gender (male or female), and type of hometown (i.e. city, country) of the participant to enable a detailed analysis.

2. *Part B:* This section comprises social media (SM) posts-related questions including the types and number of SM accounts, frequency of check-in to SM, frequency of exposure to food-related posts on SM, the preferred SM sites to check food-related posts, and the preferred type of food-related contents that participants watch. A Likert scale was used appropriately to gather the responses.

3. *Part C*: This section includes questions related to eating habit changes including food habits, food choices, and food cravings, the reliability of the information given through food-related posts, and the impact of food-

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related posts based on participants' views. A Likert scale was used appropriately to gather responses.

C. *Statistical analysis*

The appropriate data were analyzed using Minitab-20 software. In the analysis, descriptive statistics were used to evaluate the continuous variables, and Chi-square testing was used for categorical variables at a 0.05 significance level.

III. RESULTS AND DISCUSSION

A. *Demographic information of the participants*

Out of 396 participants who responded to the questionnaire, a majority represents the 23-27 age range (i.e 81.1%), the 18-22 age group represents the second highest (i.e. 14.9%), and the 38-42 age group represents the lowest (i.e 0.5%), as depicted in Figure 01. There are 68.9% female participants and the highest number of participants are from the town area (i.e. 45.7%) while the lowest number of participants are from the city area (i.e. 23.5%).

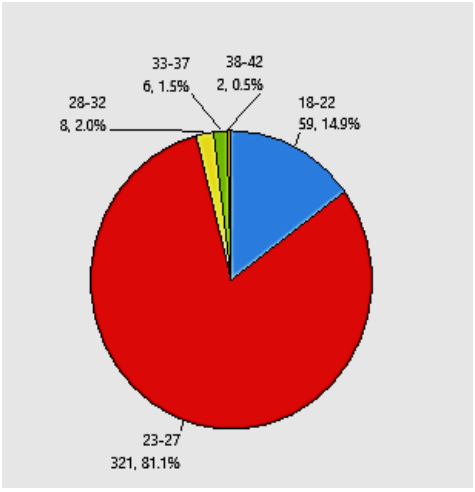

Figure 01: Age distribution of the respondents (18-22), (23-27), (28-32), (33-37), (38-42) represent the age intervals of each segments

B. *Frequency of exposure to social media sites and food-related posts*

According to Figure 02, 93.7% of participants have WhatsApp accounts, and 86.1% have YouTube accounts. Also, 66.7% and 60.4% of the tested population have Instagram and Facebook accounts, respectively. Furthermore, 89.4% of the participants have more than one SM account. Only a very few (< 1%) do not have any SM accounts in the given list.

Figure 03 shows that a majority (i.e. 30.3%) have three SM accounts, which is followed by participants who have four, five, two, and one accounts, respectively. One key reason for this observation could be the free access to these SM accounts. Thus, many undergraduates tend to have different SM accounts for different purposes such as information sharing, marketing their channels, and creating their public image in SM.

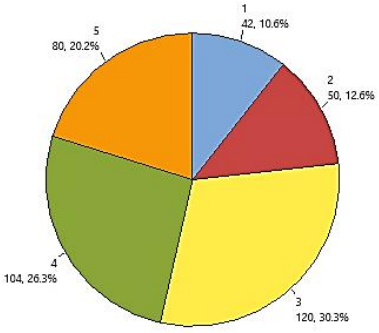

Figure 03: The frequency distribution of social media accounts owned by the participant based on the social media sites including YouTube, Facebook, Instagram, TikTok, and WhatsApp

Next, Figure 04 depicts the frequencies at which respondents use the SM. As per results, 49.0% of participants use SM more than five times per day while 30.8% of the population use SM platforms less than two times per day. To this end, a similar study conducted in Sri Lanka states that most undergraduates use SM for less than 2 hours daily while a notable group uses it for over 8 hours daily (Athukorala, 2021). It is clear that the SM usage has increased over three years (i.e. 2021 to 2024) such that more time is consumed for SM. The elevated use of artificial intelligence in SM platforms could be a reason behind this observation.

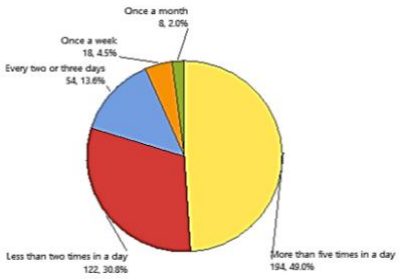

Figure 04: The distribution of frequency of exposure to social media among participants

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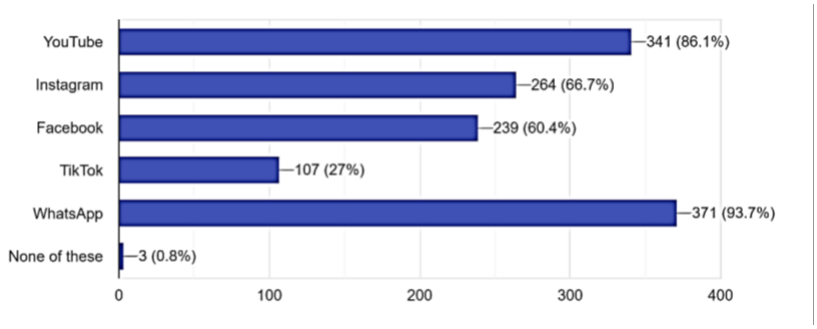

Figure 02: Distribution of the number of social media (SM) accounts participants currently have
Category 1,2,3,4,5 refers to the number of social media accounts participants own.

Figure 05 depicts the frequency of watching food-related posts (FRPs) on SM sites. As per the results, the frequency of watching FRPs on SM often is about 80% (i.e., the sum of percentages of extremely often, very often, and moderately often), and only 8.1% rarely use SM for FRPs. One key reason could be the lack of time that undergraduates have to visit the food shops to check them out due to their busy schedules. By today, most vendors tend to have publicity for their foods on SM, which can also be a reason for undergraduates to use SM to see the related posts.

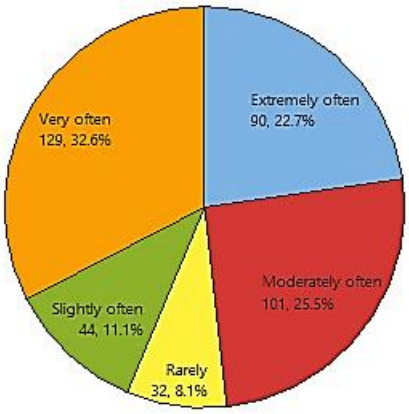

Figure 05: The frequency distribution of watching food-related posts on social media sites

Table 01 shows the relationship between the frequency of watching FRPs on SM and gender and the number of SM. Accordingly, the frequency of watching FRPs is significantly affected (p=0.000) by the number of SM accounts that participants have, while it is not affected by the frequency of engaging in SM (p=0.969). For this observation, one key reason could be the use of different SM platforms to distribute information on FRPs, for example, the same FRPs are shared through TikTok and YouTube shorts, etc.

Table 02 shows the frequency distribution for preferred SMs to watch food-related posts. The results indicate YouTube is largely preferred, while Instagram and Facebook have moderate preferences. On the contrary, a similar study conducted by examining nearly 10 million Instagram posts by 1.7 million users around the world shows that Instagram is highly utilized for food logging and research where the obsession with foods such as desserts, savories as well as healthy eating (Mejova, Abbar, and Haddadi, 2016). A key reason for the observed difference could be that the current study focuses only in Sri Lanka with a limited population. Another reason could be the introduction of YouTube shorts (a short-time video), introduced after 2016 to quickly deliver information.

Figure 06 depicts the likelihood distribution of food-related content participants watch. Results indicate that most of the contents are watched neutrally while contents on snacks and dessert reviews, street food place reviews, and food preparation and cooking videos are watched with great interest. The key reason could be the affordability of purchasing and the majority of participants are female in the study.

Table 01: The relationship between the frequency of watching FRPs on SM and gender, and the number of SM accounts at the significance level=0.05

Variable 01	Variable 02	Chi-square value	p-value	Relationship
Frequency of watching FRPs	Number of SM accounts	654.320	0.000	Dependent
Frequency of watching FRPs	Gender	1.458	0.834	Independent

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FRPs= food-related posts SM= social media

Table 02: The preference distribution for watching Food-related posts (FRPs) on different social media sites

Social media	Moderate to high prefer preference (%)	Neutral preference (%)	Low preference percentage (%)
YouTube	63.13	12.88	23.99
Instagram	43.18	15.91	40.91
Facebook	40.15	22.98	36.87
TikTok	34.34	11.87	53.78
WhatsApp	36.11	11.11	52.78

C. *Influence of FRPs on food habits, food choices, and food cravings.*

Table 03 shows the responses of participants on different statements on FRPs. As per the results, participants agree (i.e. sum of strongly agree and agree) with most of the statements, and the participants are neutral on the statement "The food hacks I have tried have never gone wrong ".

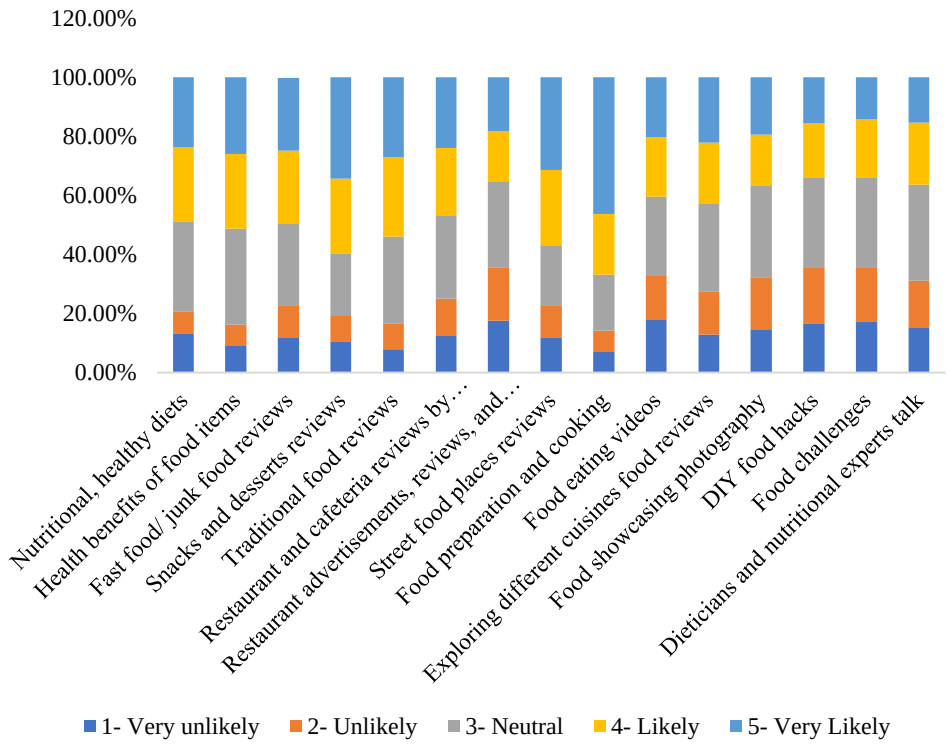

Figure 06: The likelihood percentages of different FRP contents according to the Likert scale 1-5

Table 03: Participants' responses to statements that measure the impact of FRPs on food habits

	Statements on food habits	Strongly Agree	Agree	Neutral	Disagree	Strongly disagree
1.	I have tried a nutritional diet plan promoted by social media	12.37% (47)	25.53% (97)	30.00% (114)	19.47% (74)	12.63% (48)
2.	I have added one or more nutritional foods to my daily diet	14.17% (54)	32.28% (123)	30.71% (117)	15.49% (59)	7.35% (28)
3.	I try novel junk food items on social media that are not in my usual eating habits	12.63% (49)	28.87% (112)	27.32% (106)	22.42% (87)	8.76% (34)
4.	Social media posts increased my fast-food consumption rate.	18.44% (71)	30.39% (117)	22.08% (85)	19.22% (74)	9.87% (38)

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5.	I have tried different cuisines from other countries.	13.51% (52)	25.97% (100)	23.12% (89)	21.56% (83)	15.84% (61)
6.	I have promoted many fast foods/junk foods/places with my friends and family members that I watched on social media.	15.89% (61)	24.47% (95)	22.40% (86)	23.44% (90)	13.54% (52)
7.	Social media posts increase my snacking habit.	20.05% (77)	28.91% (111)	22.66% (87)	18.49% (71)	9.90% (38)
8.	I have started preparing dishes that I watched on social media	28.42% (108)	32.89% (125)	21.32% (81)	11.32% (43)	6.05% (23)
9.	I have started having sugar-containing desserts or beverages as a habit after meals.	13.19% (50)	27.70% (105)	27.44% (104)	20.84% (79)	10.82% (41)
10.	The food hacks I have tried have never gone wrong.	12.06% (45)	19.84% (74)	34.85% (130)	21.45% (80)	11.80% (44)

Next, we present the response analysis of food choices. Table 04 exhibits the distribution of the responses to the statements on food choices. Accordingly, a similar agreeing pattern is observed in all statements except being neutral for the statement Social media posts help me find a nutritionally health FRPs= food-related posts SM= social media diet plan that fits me". This shows a current drawback (in Sri Lankan undergraduates) in choosing a healthy diet plan as proposed by FRPs.

Next, Table 05 shows the distribution of responses to statements on food cravings. As per the results, participants agree (i.e. sum of strongly agree and agree) with all statements.

Table 06 presents the correlation among different focused areas in FRPs with the above statements to further analyze any correlations. Here, statements 1-10, statements 11-17, and, 18-26 correspond to eating habits, dietary choices, and food cravings, respectively. As per results, significant correlations are observed between the frequency of watching FRPs and impacts on food habits (i.e. statements 1-10). In fact, the statements, the participants have started preparing their dishes (p= -0.013), increased their snacking habits (p= 0.013), tend to try different cuisines(p=0.017), and have added nutritional foods to their diet (p=-0.021) show strong associations while their fast-food consumption increased (p=-0.053) and they promoted food item/place (p=0.055) might be associated. In reported studies, SM influences eating habits among undergraduates in Malaysia (Ahmad and Bruno, 2021) and exposure to SM depicting unhealthy products, such as sugar, fast food, and snacks, is directly correlated with high consumption among the Saudi Arabian population (Alwafi *et al*., 2022).

Statements 11-17 also report strong and moderate correlations between the frequency of watching FRPs and the statements. Statements including street food places with affordable food items (p-= 0.002), SM posts help to find good restaurants with authentic dishes (p=0.008), SM helps to find a diet plan (p= -0.006) and the reviews are reliable for making choices (p= -0.033). it shows a significant association while the reviews on eateries and foods when visiting certain locations and before ordering (p= -0,.058) might be associated. To this end, in a recent cross-sectional study conducted in Saudi Arabia, state people are influenced by SM when making food-related decisions (Alwafi *et al*., 2022). Thus, the current study outcomes agree with this finding. However, another study conducted in Malaysia claims that the attitude of students towards SM influencers does not affect their daily dietary choices (Ahmad and Bruno, 2021).

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Table 04: Participants' responses to statements that measure the impact of FRPs on food choices

	Statements on food choices	Strongly Agree	Agree	Neutral	Disagree	Strongly disagree
1.	I searched for social media reviews on restaurants and street food places when I went to certain locations.	22.79% (85)	34.58% (129)	22.52% (84)	10.99% (41)	9.12% (34)
2.	I check social media reviews on food items before ordering them.	24.46% (91)	33.60% (125)	22.31% (83)	10.22% (38)	9.41% (35)
3.	Social media posts help to find good restaurants with luxury/ hospitality/buffet/authentic dishes.	25.40% (95)	42.78% (160)	19.52% (73)	8.02% (30)	4.28% (16)
4.	Social media posts help to try many food items at Street food places at affordable prices	27.88% (104)	37.00% (138)	21.18% (79)	8.85% (33)	5.09% (19)
5.	I search for the health benefits of natural foods before eating or buying them.	20.64% (77)	34.05% (127)	29.49% (110)	9.92% (37)	5.90% (22)
6.	I feel that the reviews are reliable for making choices most of the time	18.40% (69)	35.73% (134)	32.00% (120)	9.33% (35)	4.53% (17)
7.	Social media posts help me find a nutritionally healthy diet plan that fits me	16.89% (63)	27.88% (104)	34.85% (130)	12.60% (47)	7.77% (29)

Table 05: Participants' responses to statements that measure the impact of FRPs on food cravings

	Statements on food cravings	Strongly Agree	Agree	Neutral	Disagree	Strongly disagree
1.	Even though I do not feel hungry, I go to restaurants or street food places to satisfy my food cravings which I watch on social media	16.09% (60)	22.79% (85)	26.27% (98)	16.62% (62)	18.23% (68)
2.	I feel interested in preparing dishes at home from the recipe videos	29.87% (112)	35.73% (134)	20.27% (76)	8.27% (31)	5.87% (22)
3.	I feel a food craving for the foods that they are consuming in their posts.	19.29% (71)	34.24% (126)	29.08% (107)	10.33% (38)	7.07% (26)
4.	My cravings for sugary foods and spicy foods increased after watching social media posts	18.25% (69)	32.80% (124)	25.93% (98)	14.02% (53)	8.99% (34)
5.	I feel hungry after watching food-	24.73% (92)	31.72% (118)	23.92% (89)	11.83% (44)	7.80% (29)

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	consuming videos.					
6.	I forget that I am hungry when I am engaged with food-consuming contents	13.17% (49)	26.34% (98)	26.88% (100)	19.89% (74)	13.71% (51)
7.	I feel pressured to try certain foods or to visit specific eateries because they are popular with social media influencers and celebrities.	13.37% (50)	27.81% (104)	31.28% (117)	15.24% (57)	12.30% (46)
8.	Food-making videos make me feel satisfied like I have truly been involved.	25.60% (96)	32.27% (121)	28.27% (106)	8.00% (30)	5.87% (22)
9.	Food showcasing photographs and advertisements induces my cravings.	18.62% (70)	32.98% (124)	27.66% (104)	12.50% (47)	8.24% (31)

Next, considering statements 18-26, a strong correlation is observed between the frequency of watching FRPs and feeling hungry after watching food-consuming videos (p=0.021) while the association between statements 19,20 and 23 is not strong enough to prove. Past studies show that SM exposure increases anxiety and leads to emotional over-eating (Gao *et al*., 2022) and also the sight of food provokes various brain responses related to the preparation for food and the desire to eat. Also, food marketing may convincingly demonstrate that exposure to SM depicting unhealthy products, such as sugar, fast food, and, snacks, is directly correlated with high consumption among children and adults (Alwafi *et al*., 2022). The results along with the literature suggest that FRPs on SM may impact food cravings among the respondents but they are not strong enough to prove.

Table 06: The correlation analysis between statements and frequency of watching FRPs on social media at a confidence level of 0.05 FRPs= food-related posts (Statements 1-10: Eating habits, Statements 11-17: Dietary choices and Statements 18-26: Food cravings)

Focused area in FRP	**Variable 1: frequency of watching FRPs Variable 02**	**p-value**	**Relationship between variables 01 and 02**
Eating habits	Statement 01	-0.096	Independent
	Statement 02	-0.021	Dependent
	Statement 03	-0.101	Independent
	Statement 04	-0.053	Might be Dependent
	Statement 05	0.017	Dependent
	Statement 06	-0.055	Might be dependent
	Statement 07	0.013	Dependent
	Statement 08	-0.013	Dependent
	Statement 09	-0.089	Independent
	Statement 10	-0.069	Independent
Dietary choices	Statement 11	-0.076	Independent
	Statement 12	-0.058	Might be dependent
	Statement 13	-0.008	Dependent
	Statement 14	0.002	Dependent
	Statement 15	0.078	Independent

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	Statement 16	-0.033	Dependent
	Statement 17	-0.006	Dependent
Food cravings	Statement 18	-0.123	Independent
	Statement 19	-0.058	Might be dependent
	Statement 20	-0.054	Might be dependent
	Statement 21	-0.076	Independent
	Statement 22	0.021	Dependent
	Statement 23	-0.059	Might be dependent
	Statement 24	-0.074	Independent
	Statement 25	-0.081	Independent
	Statement 26	-0.125	Independent

D. ***Impact of food-related posts on social media***

Figure 07 shows the distribution of the frequencies that participants visit the restaurant or taste the food item they watched on SM. As per results, 80% of the population visits the restaurant or tastes the food at least once. Here, only 17% visit just once, and approximately a quarter of the population visits the restaurant more than 10 times. For the former observation, one key reason could be the food was not preferred by the consumers despite the marketing campaign signifying the ignited spark in consumers to visit the restaurant by the SM.

As per the results from Table 07, the participants who visited the restaurant or tasted the food that they checked on SM might have a significant association with gender (χ^2 =7.670 and p=0.053) at 0.05 significance level. However, considering the tested population, no correlation was found between the frequency of tried foods/visits to restaurants and the type of hometown or the frequency of watching FRPs on SM.

One key reason for the above observation could be the countrywide access to SM disregarding the type of hometown. Furthermore, the SM influencers can only make a one-time impact for the first-time visit or first-time tasting of the food as the frequency of tasting the foods is independent of the frequency of watching FRPs on SM. Furthermore, it seems further visits or tasting depend on other factors such as the quality of food, customer service, cleanliness of the place etc.

Next, Figure 08 describes the satisfaction level measure of their own experience they had on visiting the eateries or trying food which they choose from the information via SM posts. Apart from those who have not experienced it (14.4%), the majority of respondents (58.7%) are satisfied. To this end, Qualman (2014) argues "SM users at present trust peer recommendations more than search engines, and this fact is evident from the resonance of SM users with those who review their experiences in product consumption and services on their accounts, particularly on dining out and "cafe-hopping" as a social experience". The study also reveals the information shared about eateries and foods via SM can be mostly reliable.

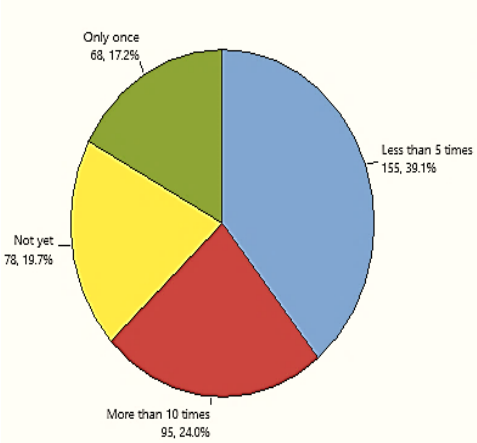

Figure 07: The distribution of frequency of times participants visited the restaurant or tasted the food items.

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Table 07: The relationship between the frequency of trial with food/ restaurants with Gender and type of hometown (i.e. city/village/town) at significance level= 0.05. FRPs= food-related posts SM= social media

Variable 1	Variable 2	Chi-square Value (x^2)	p-value	Conclusion
Frequency of tried foods/visits to restaurants	Gender	7.670	0.053	Might be dependent
	Type of hometown	3.085	0.798	Independent
	Frequency of watching FRPs on SM	6.120	0.910	Independent

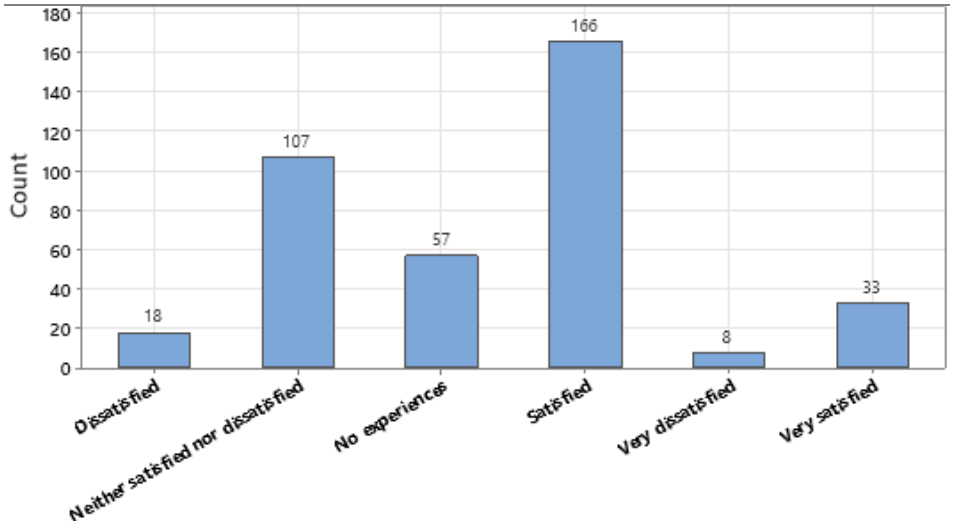

Figure 08. The frequency distribution in measuring the satisfaction level participants had with their own experience of trying foods or visiting eateries that are promoted by social media.

Past studies state that a significant positive correlation was found between the level of obesity rate and the mean percentage of followers of sugary drinks or fast-food brands on Instagram and Twitter (Gu *et al.*, 2021), and engagement with unhealthy food brands on SM is common among adolescents (Fleming-Milici and Harris, 2020). Accordingly, the level of agreement on the statement was assessed using 'Most of the foods promoted via SM platforms lead to an unhealthy lifestyle'.

Following the above agreement, Figure 09 shows the levels of agreement with the above statement. Based on results, 44.9% of respondents agree that they lead to unhealthy lifestyles while 41.7% say they are neutral. These findings agree with a recent study in Australia, which reports that SM engagement impacted negatively in body image and food choices in healthy young (Rounsefell et al., 2020).

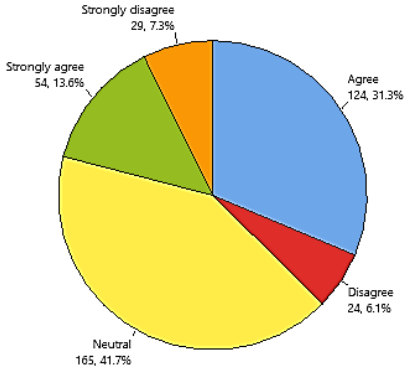

Figure 09: The frequency distribution regarding the level of agreement on the statement "Most of the foods promoted via social media platforms lead to an unhealthy lifestyle'

Figure 10 shows the distribution of responses obtained for overall impact due to food-related posts on SM on the undergraduates. As per results, the majority (i.e. 73.7%) agree that there could be positive impacts as well as negative impacts on an equal ratio from the perspective of the participants. Furthermore, only very few (2 %) are neutral or saying no impact, which implies that the

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undergraduates are well aware that SM has any sort of effect on FRPs.

IV.CONCLUSION

The reported study evaluates the impact of food-related posts on social media on eating habits and dietary choices among university undergraduates in Sri Lanka. The following can be concluded from the study outcomes.

- The time spent on social media in a day shows a rapid increase rate, particularly, the exposure to food-related posts on social media is also notably high among the undergraduates of Sri Lankan universities which strongly correlates with the number of social media accounts individuals have.
- YouTube is the most popular social media site for watching Food-related posts while Instagram and Facebook are moderately popular.
- The participants rather tend to watch food-related content like snack and dessert reviews, street food place reviews, and food preparation and cooking videos.
- The participants' agreement reveals that there are significant impacts on eating habits, food choices, and food cravings due to FRPs. However, correlation analysis results show significant effects due to FRPs on eating habits and food choices rather than food cravings.
- There is a correlation between gender and the frequency of tried foods/visited restaurants watched via FRPs by participants. Most undergraduates are aware that food related posts on social media have both positive and negative impacts on their lives, yet they agree that FRPs possibly lead to an unhealthy lifestyle.

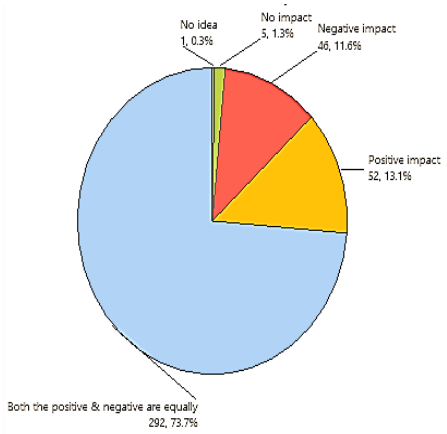

Figure 10: The distribution of the overall impact of FRPs on social media on the young generation

The findings of this study can lead to future research on the association between exposure to food-related posts and the present rise in health complications (i.e. obesity, non-communicable diseases, etc.) among young adults in Sri Lanka.

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Development of a Seaweed-based Vegan Burger Patty Rich in Protein

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Abstract

Seaweed is a versatile plant used globally for food and non-food applications, valued for its nutritional and medicinal benefits. In Sri Lanka, seaweed is abundant yet underutilized due to limited awareness. This study developed a vegetarian burger patty incorporating seaweed to address micronutrient deficiencies. Ulva fasciata (green algae) and Sargassum sp. (brown algae) were selected for their high nutrient value. Fresh seaweed was sorted, soaked in a 4% brine solution, rinsed, washed, blanched, dried, ground, and sieved into powder. Steam blanching was selected to preserve seaweed's nutritional and sensory qualities, enhancing the protein and mineral content of burger patties. The proximate composition (dry basis) of Ulva fasciata includes 24.07%±0.02 protein, 0.81%±0.00 fat, 42.14%±0.01 carbohydrates, 11.59%±0.06 ash, 21.37%± 0.02 fiber, whereas Sargassum sp. contains 13.92%±0.03 protein, 0.79%±0.00 fat, 49.89%±0.01 carbohydrates, 26.97%±0.04 ash, 7.98%±0.00 fiber, highlighting significant nutrient content, with Ulva fasciata showing higher protein, fiber values. Burger patties with varying Ulva fasciata content (50%,55%,60%,65%) were prepared with tomato, onion, garlic, corn flour, and spices. Sensory evaluation by a trained panel using a 7-point hedonic scale assessed color, appearance, odor, texture, taste, aftertaste, mouthfeel, and overall acceptability. Proximate analysis of the seaweed-based burger patty revealed a moisture content of 32.45±0.013%, fat content of 10.86±0.042%, protein content of 11.99±0.17%, carbohydrate content of 30.50±0.14%, ash content of 4.79±0.01%, and fibre content of 8.94±0.03%. Elemental analysis showed reduced heavy metals like Pb and As in burger patties compared to raw Ulva fasciata.

Keywords: Seaweed, Ulva fasciata, Sargassum sp., Burger patty, Blanching, Vegetarian, Proximate composition

I. INTRODUCTION

The global population is projected to reach approximately 9 billion by 2050 and could level off at 10 to 11 billion by the next century (Prager, 2016). This surge necessitates sustainable food alternatives, positioning seaweed-based products as a viable solution due to their nutrient-rich profile and sustainable cultivation, which doesn't require fresh water, chemical fertilizers, or land (Premarathna et al., 2020; Gomez-Zavaglia et al., 2019). Seaweeds, primarily used in Asia, have applications in food, industry, and agriculture (Mahadevan, 2015). In countries like Japan, Korea, and China, seaweed cultivation is a significant industry, whereas in Sri Lanka, it remains underutilized (Wickramasinghe et al., 2020). Seaweeds, classified as algae, are categorized into brown (phaeophyta), red (rhodophyta), green (chlorophyta), and blue-green (cyanophyta) (Emrkb and Rmsm, 2015). They are recognized for their high levels of protein, carbohydrates, minerals, vitamins, and trace elements like iodine (Jayakody et al., 2019). Historically, seaweed has been a part of diets in Japan since the fourth century and in China since the sixth century, used for its nutritional and medicinal properties (Baweja et al., 2016). Currently, China, Japan, and Korea are the largest consumers, but global demand is increasing, prompting the development of cultivation industries that now meet over 90% of market needs (Quitral et al., 2021; Puminat, 2019).

In Sri Lanka, the need for more awareness about seaweed's benefits has hindered its utilization. This study focuses on developing a high-protein, non-meat seaweed burger patty to cater to the growing demand for vegan products, particularly in Western countries and among populations reducing meat consumption (Premarathna et al., 2019). The research examines the nutritional and sensory properties of seaweed-based patties, emphasizing their potential to provide a balanced diet with high protein and fibre content, thus addressing the nutritional deficiencies of conventional burger patties.

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II. LITERATURE REVIEW

2.1 Seaweed as a Nutritional and Functional Food Source

Seaweed, a marine macroalgae, has been utilized for centuries in various cultures for its nutritional and medicinal benefits. Seaweeds are rich in essential nutrients, including proteins, vitamins, minerals, dietary fibres, and bioactive compounds, which confer multiple health benefits. The nutritional profile of seaweeds varies significantly across species, making them a valuable addition to the human diet (Dhargalkar & Pereira, 2005).

2.1.1 Nutritional Benefits

Seaweeds are a potent source of essential micronutrients such as iodine, iron, calcium, magnesium, and vitamins A, B, C, and E. Iodine, in particular, is crucial for thyroid function and is abundant in seaweeds like kelp. The protein content in seaweeds, though varying among species, provides essential amino acids, making it a beneficial supplement for vegetarian and vegan diets (MacArtain et al., 2007). The high fibre content in seaweed aids in digestive health and contributes to a feeling of fullness, which can help in weight management (Jiménez-Escrig & Sánchez-Muniz, 2000).

2.1.2 Medicinal Properties

Seaweeds possess various bioactive compounds, including polysaccharides, polyphenols, and carotenoids, which exhibit antioxidant, anti-inflammatory, antiviral, and anticancer properties. These compounds can help reduce the risk of chronic diseases such as cardiovascular diseases, diabetes, and cancer (Gupta & Abu-Ghannam, 2011). The polysaccharides in seaweed, such as alginate, carrageenan, and agar, have been shown to enhance immune function and promote gut health by acting as prebiotics (Zaporozhets et al., 2014).

2.1.3 Seaweed in Food Products

The incorporation of seaweed into food products has gained traction due to its health benefits and functional properties. Seaweeds are used as gelling, thickening, and stabilizing agents in various food formulations. Their unique umami flavour also enhances the taste profile of many dishes. Recent studies have explored the use of seaweed in bakery products, snacks, beverages, and meat alternatives (Sappati et al., 2019).

2.1.4 Seaweed in Meat Alternatives

The rising demand for plant-based meat alternatives has led to the exploration of seaweed as a key ingredient due to its high nutrient density and functional properties. Seaweed-based meat analogues have been developed to mimic the texture and flavour of conventional meat products while providing added health benefits. The addition of seaweed can enhance the nutritional profile of these products, offering a rich source of vitamins, minerals, and antioxidants (Mouritsen et al., 2019).

2.2 Challenges and Opportunities

Despite its benefits, seaweed still needs to be utilized in many parts of the world due to limited consumer awareness and acceptance. The unique taste and texture of seaweed can be a barrier to its incorporation into mainstream diets. However, with increasing interest in sustainable and health-promoting foods, there is significant potential for the growth of seaweed-based products. Research and development efforts are focused on improving the sensory qualities of seaweed products and educating consumers about their benefits (Fleurence, 2016).

2.3 Seaweed in Sri Lanka

Sri Lanka has a rich diversity of seaweed species, particularly along its coastline. The potential for utilizing these resources to address nutritional deficiencies and promote health is significant. Local seaweed species, such as Ulva fasciata and Sargassum sp., are abundant and can be sustainably harvested year-round. Developing value-added seaweed products, such as the vegan seaweed burger patty, can help promote the consumption of seaweed and improve public health outcomes in Sri Lanka (Mendis & Kim, 2011).

III. MATERIALS AND METHODS

3.1 Sample Collection

Seaweed Ulva fasciata and Sargassum sp. were collected from the southern coast of Sri Lanka, specifically Thalpawatta Thalangama Matara. Samples were washed, rinsed with seawater, and stored in plastic bags. Upon arrival at the laboratory, they were further washed with distilled

water, frozen, and dried at 60°C for 8 hours before being ground and stored at 4°C.

3.2 Processing of Seaweeds

The fresh, undamaged seaweeds were sorted and soaked in a 4% brine solution before being rinsed. Blanching methods, including hot water and steam blanching, were compared through sensory evaluation of appearance, odour, taste, and overall acceptability by a trained panel.

3.3 Chroma meter Values

Measured L*, a*, b* color values using a Lovibond LC 100 chroma meter (n=15).

3.4 Development of Burger Patty with Ulva Fasciata

Ingredients: Seaweeds, corn starch, carrot, tomato, spice mix powder, olive oil, onion, and salt.
Method: Ingredients were mixed, cooked, and deep-fried. The sensory evaluation identified the best formula.

3.5 Proximate Analysis of Fresh Seaweeds

The analyses followed AOAC (2012) and SLS 824 (2018): moisture content was determined using the oven drying method and rapid moisture analyzer; ash content with a muffle furnace; crude fat via a Soxtherm apparatus; crude fibre with a Fibertc hot extractor; protein by the Kjeldahl method using a UDK139 distillation unit; and carbohydrate content calculated by difference (Igbabul et al., 2014).

3.5 Proximate Composition Analysis of Burger Patty

Table 01 : Methods used for Proximate Composition Analysis of Burger Patty

Component	Method
Moisture Content	Oven Drying Method and Rapid Moisture Analyzer
Protein Content	Kjeldahl Method with UDK139 Distillation Unit
Fat Content	AOAC (2012) official method
Fiber Content	AOAC (2012) official method
Ash Content	AOAC (2012) official method
Carbohydrate Content	method described in literature Igbabul B et al., 2014

3.6 Sensory Evaluation

Appearance, colour, odour, texture, and overall acceptability were assessed using a seven-point hedonic scale. The results were analyzed using the Kruskal-Wallis Test in MINITAB.

3.7 Determination of Heavy Metal Content

The analysis was performed using ICP-MS following the protocols outlined in AOAC 2015.01, AOAC 2011.4, and AOAC 99.10.

3.8 Analysis of Shelf Life

Microbiological studies were conducted according to SLS 1463:2013 (ISO 7218:2007). Yeast and mould counts were performed per SLS 516 PART 2/SECTION 1:2013 (ISO 21527-1:2008), and the total plate count was conducted as per SLS 516 PART 1/SECTION 1:2013 (ISO 4833-1:2013).

IV. RESULTS AND DISCUSSION

Figure 02 - Fresh seaweeds (*Ulva fasciata*)

Figure 03 - Fresh seaweeds (*Sargassum* sp.)

Figure 04 - Dried seaweed samples

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4.1 Selecting the best pretreatment method

Steam blanching was selected based on physical conditions and organoleptic properties, over hot water blanching despite taking more time, as it better preserves the texture, color, and nutrients of seaweed. As a pre-treatment, blanching not only enhances shelf life but also helps remove fishy odors, improving overall product quality. A sensory evaluation was conducted by assessing key attributes such as appearance, odor, taste intensity, and overall acceptability using a seven-point hedonic scale, with participation from aseven-member trained industrial panel.

4.2 Proximate Analysis

The proximate composition of *Ulva fasciata* and *Sargassum* sp. was analyzed, revealing significant differences in moisture, protein, fat, carbohydrate, ash, and fibre content.

Table 02 : Results of proximate composition of dry powdered *Ulva fasciata* and *Sargassum* sp.

Composition Dry Basis (%)	*Ulva fasciata*	*Sargassum* sp.
Moisture	85.72±0.00	84.82±0.00
Protein	24.07±0.02	13.92±0.03
Fat	0.81±0.00	0.79±0.00
Carbohydrate	42.14±0.01	49.89±0.01
Ash	11.59±0.06	26.97±0.04
Fibre	21.37±0.02	7.98±0.00

4.3 Proximate Composition Analysis of Seaweed-Based Burger Patty

Table 03: Proximate Composition of Seaweed-Based Burger Patty

Composition /Dry Basis (%)	Percentage ± SD
Moisture	32.45±0.013
Protein	11.99±0.17
Fat	10.86±0.04
Carbohydrate	30.50±0.14
Ash	4.79±0.01
Fibre	8.94±0.03

4.4 Sensory Evaluation of the Burger Patty

The sensory evaluation assessed consumer preference across four burger formulations with varying seaweed content. Kruskal-Wallis Test showed significant differences in attributes like appearance, colour, odour, texture, and overall acceptance. The most preferred sample contained 55% seaweed, 18% corn starch, 15% carrot, 10% tomato, 2% spice mix, 0.5% olive oil, and 0.5% salt.

4.5. Determination of Heavy Metal Content

Heavy metal content in raw materials and the final product was within permissible limits, ensuring safety

Table 04 : Heavy Metal Content in Seaweed and Final Product

Element (ppm)	Powder Product	Final Product	Permissible Value
Pb	0.08	0.08	6.0
Cd	0.092	<0.05	0.2
As	1.21	0.15	1.4
Hg	<0.05	<0.05	0.5

The low levels of heavy metals confirm the relative safety of the macro-algae from the southern coast of Sri Lanka, supporting their use in food products.

V. CONCLUSION

This study successfully demonstrated the nutritional potential of incorporating *Ulva fasciata* and *Sargassum* sp. into vegetarian burger patties. Both seaweed varieties were found to be rich in essential nutrients such as protein, minerals, and carbohydrates, while being low in fat. Notably, the high fiber content in these seaweeds contributes to various health benefits. The results indicated that *Ulva fasciata* is particularly suitable for developing burger patties, offering a high-protein and fiber-rich alternative for vegetarian diets. The processed seaweed patties showed enhanced nutritional profiles, making them a valuable addition to the food industry, especially in addressing nutritional deficiencies. This study found that steam blanching, compared to hot water blanching, is the superior method for preserving the nutritional content and sensory properties of seaweed-based products. Additionally, the reduction in heavy metal content through processing further supports the safety and efficacy of using seaweed as a food ingredient. The findings of this study highlight the potential for seaweed-based products to contribute to sustainable and health-promoting food options, aligning with the growing demand for plant-based alternatives. This study revealed that *Ulva fasciata* (green algae) and *Sargassum* sp. (brown algae) are nutritionally rich in protein, minerals, and carbohydrates, while being low in fat. Both varieties contain high amounts of fiber, which, though indigestible by human enzymes, offers several health benefits. The essential and trace element content, as well as heavy metal levels in seaweed, vary depending on species and location, and are altered by processing steps in product

development. *Ulva fasciata* has been successfully used to develop a fiber-rich vegetarian burger patty, which can be commercialized. Given the increasing global acceptance of seaweed as a vital nutrient source, it may address deficiencies in protein, carbohydrates, and minerals. The findings of this study conclude that seaweeds are a potential health food and can serve as valuable ingredients in the food industry due to their high nutritional and commercial value. Enhancing product quality and expanding the range of seaweed-based products will further boost their appeal.

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Determination of Quality Characteristics of 'Nimba Arishta': A Comparative Analysis of Sri Lankan Brands

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Abstract

Ayurveda is an ancient system of medicine that has been used for thousands of years. It comprises a variety of medicines, including fermented forms such as Arishta (fermented decoctions). The therapeutic use of Arishta is determined by the properties of its ingredients and the method of preparation. Because of the differences in the ingredients used and the manufacturing process applied by different manufacturers, the physicochemical characteristics are susceptible to various changes. In the present study, different brands of Nimba Arishta, mainly made from Azadirachta indica (A, B, C, D, E and F) available in the market were thoroughly evaluated for their physicochemical parameters to establish an accepted procedure for standardisation of these Ayurvedic formulations. The physicochemical parameters such as pH, brix, refractive index, specific gravity, total dissolved solids, total ash content, acid insoluble ash and water soluble ash contents were evaluated. The results of the study were found within these ranges; pH 3.01(D) - 3.64(A), refractive index 1.3725 (A) - 1.4019(C), specific gravity 1.0684(A)- 1.0864(F), brix 25.06(A) - 41.00(C), total dissolved solids (g/mL) 0.1993(A) - 0.4107(C), total ash content (w/w%) 0.0971(D) – 0.1070(A), water soluble ash content (w/w%)(0.004(B) - 0.0899(F), acid insoluble ash content (w/w%) 0.0131(D) - F-0.0571(F). The results showed that the formulation of different brands of Nimba Arishta varies, highlighting the need for standardisation of Arishta.

Keywords: Arishta, Standardization, Nimba arishta, Physicochemical

I. INTRODUCTION

With the known negative impacts of synthetic products, there is a rising shift toward using herbal treatments for disease management. (Luqman et al., 2014). Ayurveda has a rich and ancient tradition of utilizing polyherbal drugs and formulations to address various health conditions. (Nandre et al., 2012). Ayurvedic practitioners have been utilizing fermentation techniques for centuries to enhance the effectiveness of medicines. Arishta are self-fermented ayurvedic medicines prepared by blending a decoction of various parts of different plants with sugar and bee honey. In most Arishta preparations, dried flowers of *Woodfordia fruticosa* L. Kurz (Lythraceae) known as 'malitha mal' in Sinhala are added as the fermentation initiator, in combined with dried plant parts collectively referred to as the 'Kalka'. Differences in preparation methods and ingredients for the same Arishtas result in variations in the quality parameters of the final product. Due to the differing production processes employed by various manufacturers, the organoleptic and physicochemical characteristics can show inconsistencies in quality parameters. Since plant materials are used, the content of the extracted ingredients may be varied depending on the identity, purity, quality and maturity level of the plant materials, their source of origin and on the fermentation process. If commercially available Nimba Arishtas differ considerably with regard to their physical and chemical composition, there's a problem with these products about their quality, safety and efficacy in providing expected outcomes. In Sri Lanka, all commercially available Arishtas are marketed under the traditional names listed in the Ayurvedic Pharmacopoeia. The presence of identical names for preparations from different manufacturing companies might lead to the assumption of uniformity among the products.

To enhance the therapeutic effectiveness of Ayurvedic herbs, it is crucial to ensure they comply with modern standards for identity, purity, safety, drug content, and both physical and biological properties. This can be accomplished through the use of scientific methods to evaluate

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and improve the quality of these herbs. (Patwardhan, 2005; Kulkarni et al., 2012a). In the absence of a well-established system for standardization and monitoring in the country, questions often arise regarding the quality, safety, and efficacy of these medicines.

In Ayurveda pharmacopoeia in Sri Lanka (1976), 32 Arishtas are described. Nimba Arishta is one such Arishta utilized in Sri Lanka to treat rashes and gout, purify the blood, and act as an anthelmintic. To investigate those variations, same type of Arishta, 'Nimba Arishta' produced from different manufacturers in Sri Lanka are analysed and compared by this study.

II. METHODOLOGY

Collection of samples - Sealed bottles of Nimba Arishta were randomly collected from six different manufacturers from the districts of Colombo and Kandy and they were kept at room temperature. Those samples were identified as A, B, C, D, E and F. Following analyses on the physicochemical properties of the samples were performed.

A. Determination of pH

pH was measured using the method described in The Ayurvedic Pharmacopoeia of India -2.4.24. A digital pH meter was calibrated using standard buffer solutions. The Arishta sample was thoroughly mixed to ensure homogeneity, and the pH value was measured with the calibrated pH meter (bench 700 series). The determination was performed at a temperature of 23°C.

B. Determination of Brix

The brix value (total soluble solids) of samples were measured using digital Abbe refractometer (Biobase BK-R2S).

C. Determination of refractive index

The Abbe refractometer (Biobase BK-R2S) was used to measure the refractive index at 23 ◦C according to the method outlined in Indian Pharmacopoeia-2018: 2.4.27.

D. Determination of specific gravity

Specific gravity was measured using the method described in Ayurvedic Pharmacopoeia of India - 2018 : 3.8. A thoroughly cleaned and dried calibrated pycnometer was selected. The temperature of the substance to be examined was adjusted to about 20◦C and the pycnometer was filled with it. The temperature of the filled pycnometer was adjusted to 25◦C. Any excess of the substance was removed and weighed. The tare weight of the pycnometer was subtracted from the filled weight of the pycnometer. The specific gravity was determined by dividing weight of the liquid contained in the pycnometer by the weight of water contained, both determined at 25◦C.

E. Determination of Total Dissolved Solids (TDS)

The method is given in the Indian Pharmacopoeia-2018 : 2.6.5

Method:

Empty weights of cleaned tared dishes were weighed and an accurate quantity of the arishta sample was measured, placed in a tared dish, evaporated at a low temperature as possible until the solvent is removed and heated on a water-bath until the residue is apparently dry. The dishes were transferred to an oven and dried to constant weight at 105°C. Again, the weight after drying (W2) was recorded and the percentage of solid content was calculated based on the following formula:

Total dissolved solids (w/v %) = (W3 – W1) / V x 100%

W1- weight of empty dish, W3- weight of residue, V – volume of the sample

F. Determination of total ash content

Ash contents of the Arishta samples were determined by wet ashing method - gravimetric principal, specified in Ayurvedic Pharmacopoeia of India – 2.2.3.

Method: Arishta sample (10.000 g. n=3) was accurately weighed into a previously cleaned and dried porcelain crucible, then heated over a water bath until all liquid had evaporated. The crucible was subsequently transferred to the muffle furnace set at 450 °C and incinerated until it was free of Black carbon particles, resulting in light grey ash. Afterward, the crucible was taken out of the furnace and allowed to cool in a desiccator. The weight of the crucible was recorded soon after it reached room temperature. The ashing, cooling and weighing processes were repeated until no further weight loss was observed. Ash content of the Arishta sample was calculated using the following equation.

Calculation:

Ash content (%) = $(W_1-W_2) / W_o$ x 100%

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Where, W_1- Weight of the crucible with residue after drying, W_2- Weight of the empty crucible, W_o- Weight of the sample.

G. Determination of Acid-Insoluble Ash

The method described in Ayurvedic Pharmacopoeia of India – 2.2.4 was followed.
The ash obtained was boiled for 5 minutes with 25.00 mL of dilute hydrochloric acid; the insoluble matter was collected on ashless filter paper, washed with hot water and ignited to a constant weight. The crucibles were then cooled in a desiccator and weighed. The percentage of acid insoluble ash was calculated.

H. Determination of Water-Soluble Ash

The method described in Ayurvedic Pharmacopoeia of India – 2.2.5 was followed. The ash obtained in Section 3.4.2.6 was boiled with 25.00 mL of water for 5 minutes. The resulting insoluble matter was filtered using an ashless filter paper, thoroughly washed with hot water, and then ignited for 15 minutes at a temperature not exceeding 450°C. The weight of the insoluble residue was subtracted from the total weight of the ash to determine the water-soluble ash. The percentage of water-soluble ash was then calculated accordingly.

III. RESULTS AND DISCUSSION

A. *Statistical analysis:*

The results are expressed as the mean ± standard deviation (SD) from three independent experiments. Statistical analysis was performed using one-way analysis of variance (ANOVA), followed by Tukey's test, with a significance level of $p < 0.05$. All analyses were conducted using Minitab software. (version- Minitab® 19.2020.1).

B. *Physicochemical properties of Nimba Arishta samples*

Results of all the physicochemical properties were statistically analyzed using one way ANOVA with 95% confidence level (α=0.05).

Two hypotheses were used for each parameter.

H_0 – All means are equal.

H_1 – Not all means are equal.

Decision rule: if p value < α, reject H_0

Data represented as mean values ± S.D. (n=3) Means that do not share a letter are significantly different.
According to the results of one-way ANOVA (Table 01), it can be concluded that there are significant differences among different brands of Nimba Arishta in terms of the pH value except the brands B, C, E and F. The observed pH values are found within the range of 3.01 and 3.64 which are acidic values. The acidic pH can help create an environment conducive to the growth of desired microorganisms and inhibit the growth of undesirable ones, thus helping to extend the shelf life of the Arishta. According to Chinky et al., 2021 this acidic pH range is an indicative of low bacterial count, while neutral or alkaline pH levels may suggest a higher level of contamination in the herbal preparation. The pH of Nimba Arishtas in a previous study ranged from 3.2 to 3.6 (Kroes et al., 1989), which slightly changes to the pH range observed in the present results.
These statistical findings suggest that there are variations in the brix values among the different Arishta brands, indicating differences in their composition or manufacturing processes. Only brands D and F are statistically similar in terms of brix and refractive index, while all the other brands are significantly different from each other. However, one common component of Arishta is sugar, which contributes to sweetness and acts as a source of fermentable carbohydrates for the fermentation process. It's important to note that the specific composition and concentration of soluble solids in Arishta can differ based on the individual recipe and the desired therapeutic effects. The concentration of soluble solids, including sugars, in Arishta can vary depending on factors such as the amount of sweetener added and the duration of fermentation. Those samples with higher brix values were found to contain lesser ethanol content due to the incomplete fermentation.
The refractive index can be influenced by the composition and concentration of solutes present in the sample. Here, the refractive index value is found within a narrow range of 1.37 and 1.40. The Tukey pairwise comparisons further elucidate the specific differences between the brands. Sample C exhibits a significantly higher refractive index compared to all other brands, indicating that it likely contains a different concentration of solutes or unique chemical components affecting its optical properties. In certain cases, the refractive index can be used as an indicator of quality or adulteration in beverages. Deviations from

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expected refractive index values may indicate the presence of contaminants, dilution, or improper manufacturing processes. The refractive index can serve as a quality control parameter for consistency in the production of Arishtas. Establishing a reference range of refractive index values for a specific decoction formulation can help identify any deviations or variations in subsequent batches, indicating potential issues in the fermentation process or ingredient quality.

The analysis of specific gravity among different brands of Nimba Arishta revealed significant differences in the means of specific gravity values. This implies that the specific gravity, which is a measure of the density of the liquid, varies significantly across the different brands.

Higher specific gravity values may indicate a higher concentration of dissolved substances or herbal extracts in the fermented decoction.

Table 01: Results of analyzed tests

Sample	pH	Brix%	Refractive index	Specific gravity	Total Dissolved Solids (g/mL)	Total ash content (w/w%)	Acid insoluble ash content (w/w%)	Water soluble ash content (w/w%)
A	3.64 ± 0.04^{a}	25.06 ± 0.15^{d}	1.3725 ± 0.0005^{e}	1.0684 ± 0.0004^{f}	0.1993 ± 0.0012^{e}	0.1070 ± 0.0014 ^{d}	0.0399 ± 0.0013 ^{a}	0.0580 ± 0.0113 ^{a,b}
B	3.11 ± 0.01^{b}	29.23 ± 0.25^{b}	1.3798 ± 0.0002^{c}	1.0965 ± 0.0005^{c}	0.2522 ± 0.0050^{c}	0.3378 ± 0.0455 ^{c}	0.0135 ± 0.0050 ^{a}	0.0040 ± 0.0028 ^{c}
C	3.10 ± 0.03^{b}	41.00 ± 0.50^{a}	1.4019 ± 0.0001^{a}	1.1632 ± 0.0005^{a}	0.4107 ± 0.0023 ^{a}	0.2709 ± 0.0005 ^{c}	0.0481 ± 0.0099 ^{a}	0.0878 ± 0.0108 ^{a}
D	3.01 ± 0.01^{c}	27.40 ± 0.40^{c}	1.3769 ± 0.0003^{d}	1.0894 ± 0.0004^{d}	0.2534 ± 0.0030 ^{c}	0.0971 ± 0.0045 ^{d}	0.0131 ± 0.0041 ^{a}	0.0444 ± 0.0076 ^{b}
E	3.14 ± 0.04^{b}	30.10 ± 0.10^{b}	1.3814 ± 0.0004^{b}	1.1048 ± 0.0007^{b}	0.2806 ± 0.0013 ^{b}	1.5548 ± 0.0011 ^{a}	0.0406 ± 0.0288 ^{a}	0.0280 ± 0.0113 ^{b,c}
F	3.07 ± 0.03^{b,c}	27.5 ± 0.50^{c}	1.3767 ± 0.0003^{d}	1.0864 ± 0.0004e	0.2387 ± 0.0042 ^{d}	0.9607 ± 0.0010 ^{b}	0.0571 ± 0.0306 ^{a}	0.0899 ± 0.0127 ^{a}

Sample C exhibits a significantly higher specific gravity compared to all other brands. This suggests that the specific gravity of Arishtas is influenced by factors such as the selection and proportions of herbs used, the fermentation process, and the manufacturing techniques employed by different brands.

The variations in TDS content suggest differences in the composition and processing methods among the brands. Additionally, water-soluble components like herbal extracts or secondary metabolites derived from the herbs used in the formulation such as organic acids, amino acids, soluble pectins, etc. may also contribute to the overall dissolved solids content of Arishta. Only brands D and B are statistically similar in terms of TDS, while all the other brands are significantly different from each other. Elevated levels of TDS may suggest the presence of contaminants such as minerals, salts, heavy metals, organic compounds, or other dissolved substances. Controlling and maintaining appropriate TDS levels can help enhance the sensory qualities and consumer acceptance of beverages.

High TDS levels can impact the solubility and precipitation of certain components, leading to sedimentation or changes in appearance over time. Monitoring and controlling TDS levels help

maintain the desired product stability and extend the shelf life of the beverage.

The significance of the total ash (%) parameter in the analysis of Arishta, lies in its ability to provide information about the mineral content of the product. Total ash refers to the inorganic residue left behind after the complete combustion of organic matter. Thus, the ash content serves as a

criterion for assessing the identity and purity of crude drugs.

The brands do not vary in terms of their acid insoluble ash content. The presence of only a little amount of acid insoluble ash in these Arishta samples indicates the absence of impurities resembling silica in the drug. Low acid insoluble ash content in all samples indicates high purity of the drugs with lesser contaminations during the manufacturing process.

The water-soluble ash content of a herbal drug is an indicator of the amount of inorganic substances present in the drug that are soluble in water. It provides information about the level of mineral matter present in the herbal drug. Thus, the water-soluble ash content helps assess the quality of the herbal drug by measuring the amount of these water-soluble inorganic content.

In this study, the determination of the acid value in Nimba Arishta was challenging due to the lack of standardized methods specifically tailored for Arishta formulations. A titrimetric method was described in literature in determining the acid value of sevaral Arishta types, adopted from the Indian and Ayurvedic Pharmacopoeias for crude drugs, which use acetic acid in the calculation to quantify the acid value. However, the applicability of these methods to Nimba Arishta is questionable as the main primary acids present in this Arishta, which could be identified through HPLC analysis may differ from acetic acid.

IV. CONCLUSION

The present investigation evaluated six different brands of ayurvedic commercial preparations of Nimba Arishta. Comparative studies on samples of various brands were done based on their physicochemical parameters.

The investigation showed that organoleptic and various physicochemical parameters such as pH, brix, specific gravity, refractive index, total ash, water soluble ash, total dissolved solid, etc. were found to be different in leading brands of Nimba Arishta. The study revealed that it may be due to the variations in the formulation or in the production process. But from a similar field study, it has been found that the standard method described in the ayurvedic pharmacopoeia for the preparation of Arishta was generally used throughout the country and no alternative method was identified for use. (Menike, 1995).

It can be concluded that the observed variations in the standardization parameters for evaluating commercially available polyherbal formulations may be attributed to several factors, such as the different ingredients used, sources of herbs or plants used, and their quantities. This study was done with the aim to understand the variations of these ayurvedic formulations to standardize them. The data evolved in this study will be highly valuable for routine quality control of Nimba Arishta. By implementing and embracing standardization and quality control mechanisms, the effectiveness and acceptance of these medications can be further enhanced.

Additionally, ensuring the quality and safety measures of these medicines can contribute to their increased efficacy and popularity.

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ABBREVIATIONS

Total Dissolved Solids (TDS)

TRACK - INTERNET OF THINGS

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Design and Fabrication of a Solar-powered Electric Bike

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Abstract

Electric bikes have experienced significant growth due to several factors, including price reductions and increased climate and environmental awareness. This trend presents a promising solution for replacing fossil fuels, with batteries emerging as a new power source. However, limitations such as limited mileage, extended charging times, and the scarcity of charging stations persist. Renewable solar energy also significantly reduces the carbon footprint of urban transportation. The research objective is to enhance the driving range of electric vehicles using solar power. This project aims to design a market-ready solar-powered electric bike using flexible solar panels and a foldable, adjustable solar panel mount for on-the-go charging. This design enables the bike to charge for free when parked in the sun, reducing dependence on traditional charging stations, waiting time reduction and lowering operational costs. Calculations, analyses, and various tests are conducted based on technical specifications, energy consumption requirements, and vehicle movement using the proposed method.

Keywords: Electric bike, Solar-powered mobility, Sustainable transportation, Renewable energy

I. INTRODUCTION

Electric scooters (e-scooters) are becoming increasingly popular as a means of urban mobility, providing a convenient, efficient, and eco-friendly solution for short-distance travel in congested city environments. Their compact size, ease of use, and low operational costs make them an attractive alternative to traditional gasoline-powered vehicles. In a study by Yuvaraj *et al.*, (2024a), the Electric Vehicle Charging Stations Market predicts that the EV market will be worth USD 974 billion by 2027. This growth is driven by a strong annual increase from 2020 to 2027, influenced by global industries and government actions. As urban populations grow and traffic congestion worsens, the demand for e-scooters is expected to continue rising, driven by both consumer preference and supportive government policies aimed at reducing carbon emissions and promoting sustainable transportation options. (Parker *et al.*, 2021) showcase over the past decade, there has been a significant increase in the demand for electric vehicles (EVs) due to their ability to reduce carbon dioxide(CO_2) emissions significantly, and (Zhou *et al.*, 2021) review their lower operating costs compared to traditional internal combustion engine (ICE) vehicles.

Despite their growing popularity, e-scooters face several significant limitations that hinder their widespread adoption. One of the primary challenges is their reliance on charging stations. The limited range of e-scooters often necessitates frequent recharging, which can be inconvenient for users, particularly in areas where charging infrastructure is sparse. Additionally, the time required to charge an e-scooter battery can be substantial, leading to extended waiting periods at charging stations. This not only diminishes the convenience of using e-scooters but also increases the overall cost and time associated with their use.

To address these challenges and enhance the practicality of e-scooters, integrating solar panels into their design offers a promising solution. By equipping e-scooters with flexible, foldable solar panels, it becomes possible to harness solar energy for on-the-go charging. This innovation can significantly reduce the dependence on traditional charging stations, decrease waiting times, and lower the cost of operation. Furthermore, utilizing renewable solar energy aligns with broader environmental goals by reducing the carbon footprint of urban transportation.

Our project aims to develop a solar-powered e-scooter that leverages flexible solar panels for efficient, cost-effective, and eco-friendly urban mobility. By addressing the current limitations of e-scooters and introducing a sustainable charging solution, we hope to contribute to the advancement of green transportation and the realization of a more sustainable urban future.

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II.LITERATURE REVIEW

A. Existing EV Charging Systems

The current electric vehicle (EV) charging systems have several limitations that can hinder the widespread use and convenience of electric scooters (e-scooters). These systems include public charging stations, battery swapping stations, and grid charging at home, each with its own challenges.

B. Public Charging Stations

Public charging stations are commonly used for recharging e-scooters, but their limited availability can be a major inconvenience. In many cities, there aren't enough charging stations to meet the growing demand, leading to long wait times and network congestion. The increasing global use of EVs presents new challenges for distribution system (DS) infrastructure and operators. Potential issues include higher power demands, changes in bus voltages, power loss, stability concerns, harmonic distortion, voltage mismatches, and power efficiency. These factors significantly impact the DS. Experts particularly emphasise the shortage of EV charging infrastructure as a major concern. According to Yuvaraj *et al.*, (2024) the growing popularity of EVs has created a need for more reliable charging stations capable of quickly recharging EV batteries.

Users often have to wait for a charging slot, wasting valuable time and disrupting their schedules. These issues can include unreliable charging stations, delays caused by waiting in line, and concerns about security and management. To address these problems, Erol-Kantarci, Sarker and Mouftah, 2012 showcase it is essential to have proper systems in place to reduce EVRA (Electric Vehicle Range Anxiety) and waiting times at stations. Additionally, the fees at public charging stations can be high, reducing the economic benefits of owning an e-scooter. These factors make public charging stations less efficient and appealing as a reliable charging solution.

C. Battery Swapping Stations (BSS)

Battery swapping stations allow users to exchange their depleted batteries for fully charged ones. Mahoor *et al.*, 2017 the early 19th century backs the history of swapping when interchangeable battery services were first suggested to overcome the limited range of electric cars, trucks etc. The exchange process initially relied on manual labor. According to Better Place y China Southern Grid firman acuerdo estratégico que se concentra en el modelo de intercambio de baterías, 2011. Better Place was the first company to commercially deploy a battery swapping service for electric cars. The main benefit of the swapping model is speed, with the process taking less than five minutes, similar to refueling at a gas station. Additionally, users can stay in their vehicles without handling cords. However, there are complexities and challenges, as shown in Figure 01.

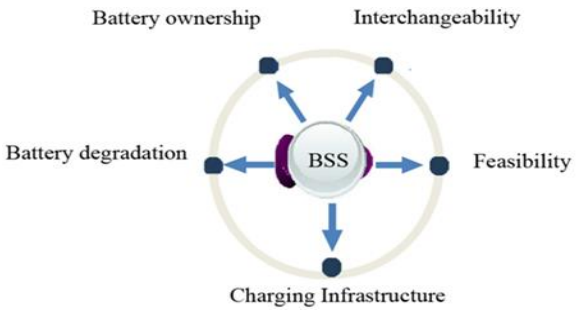

Figure 09: Complexities and challenges of BSS (Ahmad, Alam, *et al.*, 2020)

Challenges of BSS

i. *Interchangeability*

The success of battery swapping depends on the availability of interchangeable battery packs from different manufacturers. This requires manufacturers to agree on standardization, which may limit innovation and product uniqueness. Different power segments could lead to supply and compatibility issues with vehicles.

ii. *Feasibility*

Gao *et al.*, 2017 showcase current battery designs pose significant challenges for battery swapping technology. The batteries need to be robust and easy to remove and reinstall. Yang *et al.*, 2014 review in India, only a few vehicles, like the Hero Maxi, currently offer such designs, allowing easy swapping of discharged batteries with charged ones.

iii. *Infrastructure*

The infrastructure for battery swapping is more complex and expensive than charging stations. Ahmad, Alam and Asaad, 2017 showcase that swapping stations need to keep enough charged battery packs to meet demand, requiring two battery packs per car. The economic feasibility of a nationwide battery swapping system remains uncertain compared to a car charging system

iv. *Battery Degradation*

Sarker, Dvorkin and Ortega-Vazquez, 2016 review battery performance degrades over time, making new battery packs more desirable for customers. This preference for new batteries will reduce the operating cycle of each pack, as older batteries offer less energy storage and lower mileage for EVs.

v. *Battery Ownership*

Cheah and Heywood, showcase if vehicle owners do not own the battery packs, EVs become cheaper as they don't need to buy the batteries. However, they must pay additional lease fees and service charges for swapping stations. This could deter frequent use of swapping stations, especially when charging options are available.

However, this system faces several logistical challenges. Firstly, there are not enough swapping stations, making it hard for users to find convenient locations. Secondly, different e-scooter manufacturers use batteries with various voltages, sizes, and capacities, making standardization difficult. Swapping stations need to keep extra batteries in stock for exchanges, and the returned batteries must be recharged before they can be used again, leading to delays and potential shortages of fully charged batteries. Ahmad *et al.*, 2020 Showcase, despite the rapid development of conductive and wireless (inductive) charging, battery swapping systems have not yet been deployed as a commercially viable option. These issues reduce the efficiency and practicality of battery-swapping stations.

D. Grid Charging at Home

Charging e-scooters at home via the grid is convenient but also has drawbacks. Home charging relies on grid electricity, which may not always come from renewable sources, reducing the environmental benefits. The cost of electricity can be high, especially with tiered tariffs that increase rates as more units are used, making home charging expensive for frequent users. Additionally, home charging can take several hours to fully charge a battery, which can be inconvenient for daily commuters.

Researchers have thoroughly investigated these challenges, focusing on how EVs affect electricity generation capacity, transformer ageing, and power quality within the distribution system (DS). Charging EVs during peak demand could increase peak load requirements, necessitating more power generation. Additionally, the higher demand for EV charging can strain substation and service transformers, reducing their lifespans.Dubey and Santoso, 2015 Showcase integrating EV charging stations (EVCS) may also cause power quality issues such as voltage fluctuations, power distribution imbalances, and disturbances in voltage and current waveforms.

N. Actions Taken to Minimize Challenges in Charging Systems

The limitations of electric vehicles (EVs) have driven various innovations and strategies to improve charging systems. However, despite technological advancements, these solutions often fall short of providing a sustainable, long-term answer to the challenges faced by EV users.

E. Faster Charging Technologies

One approach to addressing the limitations of EVs is the development of faster charging technologies. While these technologies can reduce charging times, they also introduce several technical and operational issues. Fast charging can lead to battery degradation, reducing the overall lifespan of the battery. This occurs because high charging rates generate more heat and stress on the battery cells, accelerating wear and reducing capacity over time.

Additionally, fast charging can cause significant problems for the electrical grid. Issues such as load profile distortion, voltage deviation, frequency imbalance, harmonic injection, and overloading of distribution system components can arise. These problems can lead to excess power loss and grid instability, making the widespread implementation of fast charging infrastructure challenging. Steen and Tuan, 2017 review that the lack of efficient fast-charging stations increases the strain on power demand, affecting the overall stability of the electrical grid. Implementing fast charging ports at home is particularly difficult due to the high power requirements and potential impacts on household electrical systems. Furthermore, the increased fees associated with fast charging at public stations can negate the cost savings of operating a low-cost EV.

F. Increased Battery Capacity

The first EV applications adopted a rechargeable battery invented by Gaston Planté in 1859 which was the lead-acid battery. One of the first was created in 1899 by Waldemar Jungner as the nickel-cadmium battery; they advanced the storage capacity but had the problem of a

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suppressed voltage or memory effect as the battery aged. Research continued throughout the early and latter half of the 20th century, but it wasn't until 1985 that the first lithium-ion (Li-ion) batteries were created. Tarascon and Armand, 2001 created a ragone plot of several of the battery technologies used in EVs.

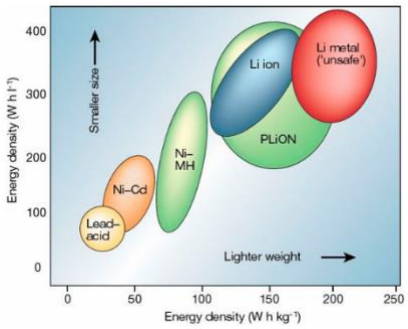

Figure 02: Ragone plot of several of the battery technologies used in EVs(Tarascon and Armand, 2001)

This is a detail of the batteries depicted in Figure 02; each battery has its merits and demerits. Advancements and new technology in Li-ion batteries have placed the battery as the market favourite for small portable electronic gadgets including EVs. Keshan, Thornburg and Ustun, 2016 Showcase that this is mainly due to their specific energy (Wh/kg), long cycle life, and high efficiency. Despite these benefits, they also have downsides, such as high costs and the need for complex safety and monitoring systems.

Another strategy to maximize the range is to increase the number of batteries in EVs to extend their range. However, this solution presents its own set of challenges. Adding more batteries increases the weight of the vehicle, negatively impacting its handling and control. The added weight can make the scooter harder to maneuver and reduce its efficiency.

The cost of additional batteries is another significant issue. Batteries are one of the most expensive components of an EV, and increasing their number significantly raises the overall cost of the vehicle. Moreover, batteries have a limited lifespan and need to be replaced after a few years, leading to high replacement costs. This recurring expense can be a deterrent for potential EV users.

G. Increasing the Number of Charging Stations

Expanding the number of charging stations is another commonly proposed solution. However, this approach also has limitations. The infrastructure cost of building and maintaining a large network of charging stations is substantial. The increasing prevalence of new energy vehicles has consequently generated a heightened demand for accessible electric vehicle charging stations (EVCSs).

Mukherjee and Gupta, 2015 showcase that during the transition to EVs, the general public encounters two major challenges: the relatively high upfront costs of EVs and the inadequate availability of EVCSs . Even if the number of charging stations is increased, the fundamental issue of charging time remains. Unlike refueling a gasoline vehicle, which takes only a few minutes, charging an EV can take hours. If a large number of commuters need to charge their EVs, long wait times at charging stations can become a significant problem. This scenario can be likened to the current situation at gas stations but with much longer waiting periods.

H. Potential Benefits and Impact of Solar-Powered Electric Bikes

Solar-powered electric bikes offer several potential benefits and can address existing gaps in current transportation solutions. Here's how they can make a significant impact:

I. Reduce Waiting Time at Charging Stations

One of the primary advantages of solar-powered electric bikes is their ability to charge on-the-go. By integrating solar panels into the design, bikes can recharge while parked or even while in use, reducing the need to wait at charging stations. This feature not only enhances user convenience but also improves overall efficiency in urban mobility.

J. Lower Charging Costs

Solar-powered charging significantly reduces operational costs compared to traditional methods. Charging from public stations often incurs high fees, while home grid connections can lead to increased costs with higher electricity usage. In contrast, solar energy is renewable and essentially free once the initial investment in solar panels is made. This reduces dependency on expensive charging infrastructure and helps to stabilize long-term operational costs.

K. Environmental Impact

The environmental benefits of solar-powered electric scooters are substantial. The transportation sector contributes significantly to

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carbon emissions, contributing to climate change and air pollution. Adnan *et al.,* 2018 have indicated that by 2030, EVs could potentially contribute to a noteworthy 28% reduction in CO2 emissions. By utilizing solar panels, e-scooters can operate using clean, renewable energy, effectively reducing their carbon footprint. Unlike electricity sourced from fossil fuels, solar energy is a green energy source that minimizes greenhouse gas emissions and environmental degradation associated with traditional power generation methods.

Shrivastava, Alam and Asghar, 2019 showcase that a VIPV (Vehicle-Integrated Photovoltaics) charging system reduces the strain on the electricity grid and decreases CO2 emissions by 0.92 kg per 100 km driven compared to a PV-grid charging station.

L. Overview of Existing Vehicle Integrated Photovoltaic (VIPV) Initiatives

Solar-powered electric vehicles (EVs) represent a niche yet promising area of innovation within the transportation sector. These vehicles integrate solar panels directly into their design to harness solar energy for propulsion or auxiliary functions. Centeno Brito *et al.,* 2021 had the first demonstration of using PV for electric engines in commercial passenger vehicles was made, following earlier models like Audi's solar roofs. In 2010, Toyota introduced the Solar-Prius, a plug-in hybrid with a 180 W PV module on the roof, which is useful for battery charging during long parking periods but not much while driving. Even more recently, many automobile manufacturers have been announcing vehicle concepts where solar contributes to its motion (Tesla (Tesla, 2019), Hyundai (Hyundai, 2019); Lightyear (Lightyear, 2021), Fisker Karma (Fisker, 2020), Hanergy (Hanergy Thin Film Power Group Limited, 2019), Sono Motors (Sono Motors GmbH, 2020), and Stella Lux (Eindhoven University of Technology. “Stella Lux” Solar Team Eindhoven, 2019).

Kutter *et al.,* 2021 showcases the potential of solar yield and range extension VIPV installed only on the roof of the electric vehicle covers a significant part of the energy consumption of commercial vehicles within all investigated scenarios. Considering an optimized system efficiency, the following annual solar ranges can be obtained in Stockholm and Seville. The value in % states the VIPV coverage of the estimated annual energy demand of the vehicle:

i. A - Parcel Delivery Vans: 6637 to 11450 km/year, solar energy coverage 35 to 60%
ii. B – Rural Delivery Trucks: 3084 to 5272 km/year, solar energy coverage 9 to 15%
iii. C – Long Haul Truck 4828 to 8173 km/year, solar energy coverage 5 to 9%
iv. D – Trailer (only harvesting while driving) 763 to 1424 km/year, solar energy coverage 0.9 to 1.6%
v. E – Trailer with battery/grid feed-in 4791 to 8134 km/year, solar energy coverage 5 to 9%

Shrivastava, Alam and Asghar, 2019 showcase the VIPV system is compared with solar carport and rooftop charging stations, showing the VIPV system as a cost-effective solution. Thus, it reduces the burden on the electricity generation system. VIPV charging system reduces the CO2 emission by 0.92 kg to 100 km drive of PEV as compared to PV-grid charging station. Using VIPV charging system the driving range improves to 9 km.

By 2030, Vehicle Integrated Photovoltaics (VIPV) are expected to significantly contribute to the annual mileage of electric vehicles. Projections suggest that VIPV systems could cover up to 9,739 kilometers per year, accounting for approximately 24% of the total distance driven. During optimal conditions, such as in peak sunlight months, VIPV could achieve daily distances of up to 47 kilometers. However, this potential is somewhat diminished by shading losses; with a 30% shading loss, the annual coverage drops to about 3,711 kilometers. The benefits of VIPV are anticipated to increase notably due to technological advancements. From 2022 to 2030, improvements in VIPV technology are expected to enhance efficiency by approximately 34%. These advancements could involve better solar panel materials, improved integration techniques, and more efficient energy conversion systems.

The environmental benefits of VIPV are also significant. Karoui *et al.,* 2023 showcase life cycle assessments indicate that over a 20-year lifespan, VIPV systems could reduce the carbon footprint by up to 28 tons of CO2-equivalent. This reduction is achieved through decreased reliance on conventional energy sources and lower overall vehicle emissions

III.METHODOLOGY

1) Introduction

This section describes the methodological process used in the development of the electric bike's chassis and the integration of its solar power systems. The process starts with concept generation and moves through several stages, such as fabrication, electrical system integration, chassis design, and integration of the solar power system. In order to guarantee the seamless integration of mechanical and electrical components and maximize the overall performance of the bike, the entire methodology is divided into sequential steps. Before hardware implementation, simulation software was used to verify the system's functionality and design.
The process involved in designing and implementing the bike chassis and solar integration is broken down into steps in the flowchart:

2) Concept Generation:

The process begins with generating ideas for the overall bike design, taking into account structural, mechanical, and electrical requirements.

A. Design Chassis Models:

Different chassis models are designed based on the concept generated to ensure that the vehicle meets the structural integrity and weight requirements.

B. Analyze the Chassis:

Once designed, the chassis models are analyzed for mechanical stresses, load distribution, and other critical parameters to ensure safety and efficiency.

C. Fabricate Chassis Models & Design Body Panels:

After analysis, the selected chassis models are fabricated, and the body panels are designed for aesthetic appeal and aerodynamic efficiency.

D. Electrical System Design and Integration:

The electrical systems, including wiring, control units, and power management systems, are designed and integrated into the bike's structure.

E. Assemble Parts:

Once the chassis and electrical systems are ready, the components are assembled to form the basic structure of the vehicle.

F. Calibrating System:

The electrical and mechanical systems are calibrated to ensure smooth operation and safety.

G. Integrating Solar Panels into the Overall Design:

Solar panels are incorporated into structure design for energy harvesting.

H. Integrating Solar Charging System:

The solar charging system, responsible for converting solar energy into electrical power, is integrated with the vehicle's power management system.

I. Performance Testing:

The final vehicle is tested under real-world conditions to evaluate its performance, efficiency, and reliability

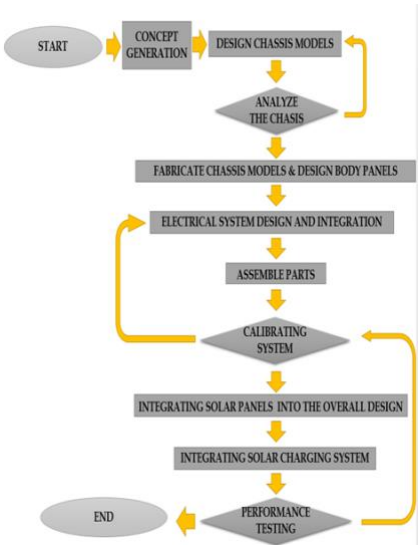

Figure 03: Methodology flowchart

The initial step in vehicle performance modeling is to formulate an equation for the electric force. This force, transmitted to the ground through the drive wheels. When modeling vehicle energy consumption, several resistances must be considered, including rolling, aerodynamic, climbing resistances. These factors are crucial in determining the motor size needed to provide sufficient torque for the vehicle

J. Calculations

Motor selection

Mass of e-bike including riders,
Passenger weight = 70kg * 2
= 140kg
Weight of bike = 60kg
Total Weight (m) = 200 kg;

Maximum velocity bike should reach [when slope is 2.5º (Shivhare *et al.*, 2021)],
v = 30 km/hr
= 8.33 m/s;

Wheel diameter, d = 10 inches
= 254 mm;

Drag coefficient d = 0.50;
(Considering approximate value for two-wheelers(Shivhare *et al.*, 2021))
Frontal area, Af = 0.45 m^2;
(As per the CAD);

Coefficient of rolling resistance,
Crr = 0.004;
(Considering for bike tyres on Asphalt road(Shivhare *et al.*, 2021))

Acceleration due to gravity,
g = 9.81m/s^2

Air density at 30°C,
ρ = 1.1644kg/m^3

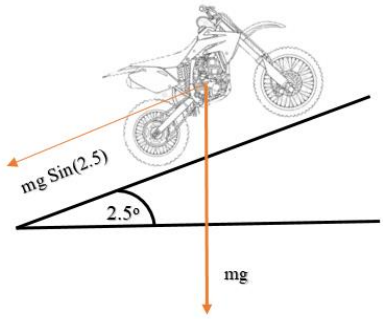

Figure 04: Force diagram

$F_{ROLLING}$ = Crr × mg
= 0.004 × 200kg × 9.81m/s^2
= 7.848 N

$F_{AERODYNAMIC}$ =1/2 × Cd × P ×Af × V_2
= 0.5× 0.5 ×1.1644 × 0.45 × 8.332
= 9.0896 N

$F_{GRADIENT}$ = mg Sin (2.5)
= 200 × 9.81 × Sin (2.5)
= 85.5812 N

F_{TOTAL} = 85.5812 + 9.0896 + 7.848
= 102.519 N

POWER = FTOTAL × V
= 102.519 N × 8.33 m/s
=0.854 Kw

Therefore, after calculation it can be concluded that a 1kW motor would be sufficient for the proposed e-bike. As per the market availability, a motor of 48V, 1kW rating is selected. According to Contò and Bianchi, 2022 its increased power density and dependability, the BLDC motor is smaller in size. Furthermore, brushed DC motors need more frequent maintenance, are heavier, and make more noise.

K. Material selection

Motor

Although many types of motors can be used in the bike, the type recommended and used is called the BLDC, standing for a brushless DC hub motor. BLDC hub motors are always characterized by low noise and as such provide the required power and regulation for a proper ride. How the motor is incorporated in the hub also helps in simplifying the bike structure and cutting down its weight. There are four power transmission systems

Chain drive
Gear hub motors
Crank drive motors
Direct drive motors.

According to Arango, Godoy and Lopez, 2018 the mid-drive develops more power than the hub-drive configuration, this because mid-drive motor operates in the optimal rpm ranges a condition that differs from the hub-drive motor. But for this project hub motor is selected because of its easy fabrication and it will reduce the complexity of the project.

Battery

For the battery, Lithium-ion technology was chosen because of its high energy density, low

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volume and mass, and longer cycle than the other types of batteries. Lithium-ion batteries offer a good power to weight ratio acting as a power source and charge which is vital for the bike's performance and mileage. This decision allows the bike to store and output the needed amount of energy to support extended use.

Batteries currently in use in electric bikes include 12V to 72V. The preferred 48V 50Ah battery was selected because it is readily available, reasonably priced, and requires no thick wires to the motor due to the increased voltage, which causes the motor to draw less current.

Motor controller

The controller plays an important part in controlling the efficiency and performance of the electric bike. Following a review of several controller types, a choice was made based on elements like programmability, responsiveness, and compatibility with the chosen lithium-ion battery and BLDC hub motor. The primary goal of this project is to use solar energy to charge the battery. We can accomplish this by optimizing the battery's performance by adjusting additional parameters. Because of its higher efficiency and smoothness, we employ a sine wave controller. In the end, the selected controller ensures the best possible operation of the electric bike by offering the required balance of performance, dependability, and ease of integration.

Solar panels

Compared to rigid solar panels, flexible solar panels are more design-flexible. Due to their flexibility, they can easily interphase with the form of the bike thus complementing the structural design of the bike. It also assures that for the panels to have a vantage point in attracting sunlight they are made in a way that it can be unfolded whenever needed or folded back when no longer required. Flexible panels commonly have a lower efficiency level compared to the rigid type; however, their adaptability makes up for this. The panels can in fact be placed on various parts of the bike so that it is charging from the rays of the sun all day. This charging capability cuts down the reliance on the normal charging stations, increases the range of the bike and improves the bike's performance. Also, there is enhanced control and efficiency by the use of flexible panels as they are light in weight.

IV.RESULTS

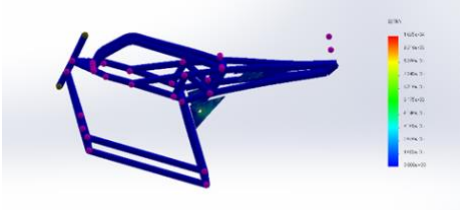
D. Proposed design

The design of the e-bike was created using SolidWorks software. The design prioritizes easy control and stability incorporating a low center of gravity to enhance balance and a smooth ride. And also focuses on ergonomics and aesthetics. This design ensure that the e-bike provides a comfortable and user-friendly ride for commuters. The design is sleek and modern appealing to a wide range of users. It ensures low plastic involvement to the body panels as it is easy to fabricate and minimizes the fabrication cost.

The current design will be further enhanced with the addition of a solar panel mounting system, which will be seamlessly integrated into the e-bike. This integration will allow for on-the-go solar charging, reducing reliance on traditional charging infrastructure and aligning with our sustainability goals.

Figure 05: Final design without body panels and solar structure

Stress, strain analysis, displacement analysis and Factor of safety analysis for loading conditions are performed and incorporated into our project to analyze the strenuous of the bike design. Analyzed the loading conditions and visualized how they affect the components through the application of SolidWorks by applying on the bike 250kg of weight. This evaluation is critical to guarantee that the bike's planned usage comes with no dangerous consequences and to find out the stress factors.



(a)

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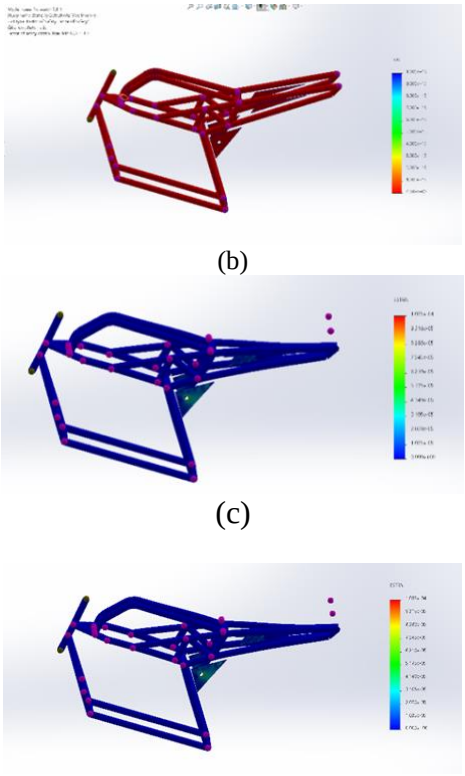

Figure 06: Finite Element Analysis results, (a) Displacement analysis, (b) Factor of Safety analysis, (c) Stress analysis, (d) Strain analysis
(b)

V. CONCLUSION AND FUTURE WORKS

The development of a solar-powered electric bike presents a promising solution to the limitations of traditional e-bikes, such as limited range and dependence on charging stations. By integrating flexible solar panels, the bike can charge on the go, reducing operational costs and environmental impact. Future works include: complete the construction and assembly of the bike, ensuring all components are securely integrated; develop a robust structure to firmly attach the solar panels to the bike, optimizing sunlight capture; and conduct extensive testing under various conditions to ensure reliability and performance. Further, enhance the integration of solar technology to improve energy efficiency.

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TRACK - MULTIMEDIA & GAMING TECHNOLOGIES

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The Study of Gestalt and Cognitive Psychological Theory Influences the Creation of User Interfaces and User Experiences

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Abstract

In the rapidly advancing realm of digital technology, the imperative of creating innovative and user-centric interfaces cannot be overstated. This research undertakes a comprehensive exploration of Human-Computer Interaction (HCI), with a specific focus on harnessing the insights derived from gestalt and cognitive psychological theories to redefine the art of user interface (UI) design and elevate user experiences to new heights. One of the pressing challenges in contemporary digital design lies in the unsettling uniformity that characterizes many UIs. The research methodology comprises four distinct phases. The initial phase involves the meticulous crafting of an ideal UI prototype for an e-commerce platform. The second phase entails an exhaustive review and synthesis of UI design theories grounded in Gestalt and Cognitive psychology. The third phase is marked by the assimilation of these theories into the UI design process. Finally, the fourth phase involves the integration of user feedback, a critical step in validating and comparing the ideal UI prototype against the newly developed UIs infused with psychological principles. In conclusion, this research underscores the vital importance of transcending the ordinary in UI design. By harnessing the potential of Gestalt and Cognitive psychological theories, we aspire to dismantle the shackles of design uniformity, providing users with interfaces that are not just personalized but also harmonized with the intricacies of human cognition. In this pursuit, we anticipate a paradigm shift in HCI, where engagement and user-centricity reign supreme, ultimately elevating user satisfaction, productivity, and the overall quality of the digital experience.

Keywords: Human Factors, Gestalt Psychology, Cognitive Psychology, User Interface, User Experience

I. INTRODUCTION

User interface (UI) design refers to the process of designing the visual and functional components of a digital product or service that enable users to interact with it. The UI design focuses on creating an interface that is intuitive, user-friendly, and aesthetically pleasing. The goal of UI design is to make it easy for users to navigate and interact with the product, ensuring that they have a positive experience. UI design involves the use of various design elements such as typography, color, layout, and imagery to create a visual interface. It is essential to create an interface that is clear, concise, and easy to understand. This means using visual cues that help users navigate the interface and understand what actions they can take. The interface should also be consistent across all pages and screens to provide a cohesive experience.

UI design also involves creating an interface that is responsive and adapts to different devices and screen sizes. This ensures that users can interact with the product regardless of the device they are using. UI designers should also consider accessibility when designing interfaces. This means designing the interface in a way that is accessible to users with disabilities. For example, using color contrast and font sizes that are easy to read.

Human-computer interaction (HCI) has become increasingly complex in the modern world, and the need for effective user interfaces has never been greater. The objective of a designer when creating an interface is to create a system that users of all skill levels can use efficiently and without investing a lot of time in learning how to use it. User interfaces should be created in accordance with human capabilities and limits to achieve this purpose Guidelines and criteria for UI design are not straightforward recipes. Identifying rule applicability and precedence as well as balancing trade-offs when competing rules are necessary for their effective application. Unfortunately, those who create and assess user interfaces sometimes acquire design principles without being aware of their psychological

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foundations (John J. Dudley et al., 2018). To address this issue, it is essential to understand the psychological concepts behind human behavior, including how people make decisions, how they think, and how to apply these theories to real-world scenarios to create user interfaces that provide good user experiences. Gestalt and cognitive psychology have a significant role in human behavior, including how people make decisions, how they think, and beyond that how to apply these theories to real-world scenarios and how to design user interfaces (Vitevitch et al., 2019 and Purcell et al., 2011). With the growing complexity of human-computer interaction (HCI), designers are shifting towards self-personalization in User Interface (UI) design. However, current UI design still lacks effective and efficient user experiences, especially for novices. Designers need to create UI systems that users of all skill levels can use efficiently without investing a lot of time in learning how to use them. To achieve this objective, UI design must be based on human capabilities and limitations. Gestalt and cognitive psychology provide insights into how humans perceive, learn, remember, and solve problems, which can help designers create an interface that users can understand well. Pamudyaningrum et al., (2020) study concluded that the UX process in gamification comprises the tangible user interface, constructive and useful feedback, content and storytelling, and how to appreciate the user.

The main objective of this research is to design a user interface that is efficient UI design for users of all skill levels and the application of Gestalt psychology and cognitive theory enhances the user experience and productivity.

II. RELATED LITERATURE

A. User Interface Design

The article "A Review of User Interface Design for Interactive Machine Learning" by John J Dudley et al., (2018) explores Interactive Machine Learning (IML), aiming to make machine learning more accessible by involving users in the training process. It highlights the importance of effective interface design for IML but notes a lack of consolidated principles. Network science techniques from cognitive psychology can shed light on various aspects of human cognition, as outlined in "Network Science in Cognitive Psychology" edited by Michael S. Vitevitch (2019). Oded Arazy and Ofer López Claudia (2015) emphasize the efficiency of public persona UI design in "Character Architecture at the Human Factor Factors in Computing Systems. Sampada S. Marathe's research (2009) delves into UI modifications and their effects on system function. Alena Stadler's study (2018) explores how psychological components influence user behavior in UX and UI design.

B. Cognitive Psychology Theory for Design Process

The creative cognition approach examines how the human mind generates creative ideas by leveraging basic mental processes. Research within this approach identifies factors like motivation, expertise, and cognitive processes such as divergent thinking. The article on design elements in residential settings for older adults and Alzheimer's patients aims to enhance navigation and well-being using insights from cognitive psychology (Sweller, Ayres and Kalyuga, 2011).

Cognitive load theory, discussed by John Sweller et al., (2019), focuses on how learning tasks affect cognitive processing and instructional design. A study on interface modifications and cognitive load by T. Purcell et al., (2012) investigates the impact of interface changes on user performance. This theory underlines the importance of managing cognitive load for effective learning environments. The use of cognitive psychology in studying deep neural networks is explored in a research paper. It adapts a developmental psychology analysis to DNNs, shedding light on their computational properties.

C. Psychology Theories for Design Process

Purcell et al., (2011) proposed an integration of creativity tools from engineering design and cognitive psychology. This integration can enhance innovation in design processes. Another study explores the role of drawings in design processes, emphasizing the importance of these forms of representation for creativity and innovation. A case study explored the principles of environmental and social psychology in UI/UX design for metaverse social games. This aims to provide a designer with in-depth insights and guidance with metaverse social game interfaces that align with user needs and societal adaptability (Gao B. et al.,2024).

D. *Gestalt Psychology Theory for Design Process*

Sarsam et al., (2020) investigate user happiness with UI and suggest altering interface layouts

based on users' personality traits. Sani et al., (2016) explain the use of Gestalt-based design for websites, emphasizing how it reduces uncertainty and enhances user engagement. Paay et al., (2007) apply Gestalt principles to understand the user experience of location-based services. The article "What should a corporate website look like?" discusses how Gestalt principles and visualizations impact user acceptance and recommendation of websites (Ritter, S. et al., 2017). The use of Gestalt theory in instructional screen design is outlined in another article. Gestalt principles are shown to be valuable for organizing information effectively.

In summary, most research on Gestalt and cognitive theories focuses on static interfaces. However, modern UI/UX designs increasingly involve dynamic, interactive elements (e.g., animations, transitions). More research is needed on how Gestalt and cognitive principles apply to dynamic interfaces and how users perceive and interact with such elements in real-time. Creating effective user interfaces is to understand the psychological concepts behind human behavior and apply these principles to UI design. By focusing on the overall structure of the interface, supporting cognitive processes, and personalizing the interface to the user's preferences, designers can create user interfaces that are both efficient and effective for all users.

III. METHODOLOGY

The primary objective of this research is to design a user interface that is efficient UI design for users of all skill levels and the application of Gestalt psychology and cognitive theory enhances the user experience and productivity. The application of this concept into the software industry, specifically in web development and mobile applications. The research focuses on designing a user interface (UI) and gathering user feedback to refine and evaluate the effectiveness of the UI.

The methodology can be divided into four core parts:

A. First Step - Designing the Initial User Interface:

The initial UI design for the e-commerce website follows conventional standards (Figure 1).

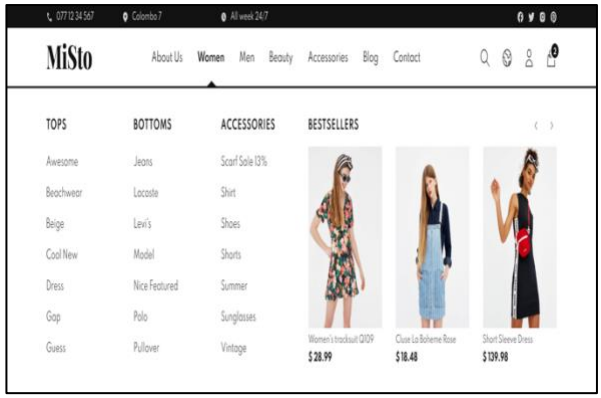

Figure 01: Nav menu User Interface module 1

B. Second Step - Incorporating Design Theories:

Combining concepts of Gestalt and cognitive psychology with marketing psychology and basic psychological principles.

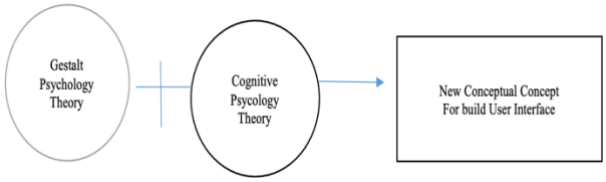

Figure 02: Incorporating design theories

C. Third Step - Refining the Interface:

The research plan involves incorporating design theories from Gestalt and cognitive psychology into the First Step- Designing the initial user interface. The design team will then collaborate with five developers to further refine the interface based on their ideas about user interface design.

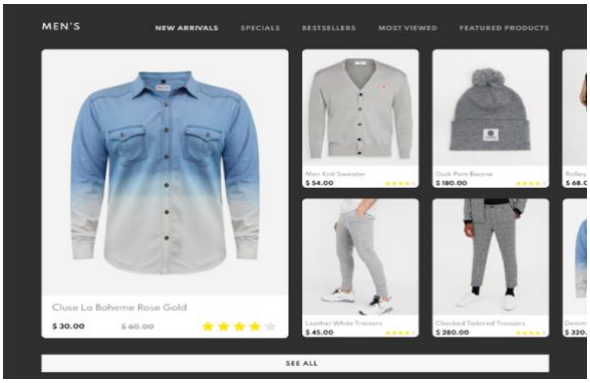

Figure 03: Gestalt theory proximity

D. Fourth Step - Gathering Feedback:

In this stage, we aim to gather feedback from users to determine which interface is more effective and accurate. To achieve this, we have created two types of questionnaires.

- UI/UX Questionnaire with Gestalt Psychology Principles: This questionnaire assesses participants' perceptions of visual design elements and usability based on Gestalt psychology principles, such as proximity, similarity, closure, and figure-ground relationship. Seek feedback on how well the UI design aids users in information organization, task completion, and overall user experience.
- Cognitive Concepts Questionnaire with Face-to-Face Conversation: Face-to-face conversations are conducted to delve deeper into participants' cognitive experiences. Open-ended questions explore attention, memory, and decision-making processes. Provide explanations about cognitive concepts, such as attention span, memory encoding and retrieval, and decision-making heuristics, and ask participants to reflect on how these concepts influenced their experience with the UI. Use questionnaires to gather quantitative data, such as ratings or Likert-scale responses, on participants' perceptions of cognitive aspects, including cognitive load, mental effort, and task comprehension.
- By combining these two questionnaires, we can obtain a comprehensive understanding of participants' experiences and perceptions regarding both the visual design and cognitive aspects of the UI. The face-to-face conversation allows for more in-depth exploration of participants' cognitive processes, while the questionnaires provide quantitative data for analysis. This approach enables you to gain valuable insights into how Gestalt psychology principles and cognitive concepts impact the UI design and user experience.

E. Data analysis method

Google's data analytics program transforms form data. The data was then utilized to create bar charts and pie charts, among other descriptive statistics. The study's objectives were met since the statistical analysis results validated the study's findings, supported its hypotheses, and shed light on its questions.

F. Population and Sampling

The university students in Sri Lanka are considered in this research study as the population. We use random sampling methods.

IV. RESULTS AND DISCUSSION

This section presents the results obtained from user and developer feedback through questionnaires, along with an analysis of the findings in the context of Gestalt and cognitive psychology principles. By incorporating these psychological principles into the user interface (UI) design, the research aims to enhance both user satisfaction and overall usability.

The results from the first questionnaire, which gathered responses from 100 participants, revealed that 65% of users responded positively to the methodology employed in the UI design (Table 01). The approach focused on applying Gestalt psychology principles like proximity, similarity, and closure, which were generally well-received because they made the interface easier to understand and navigate.

A. User Feedback on Color Schemes and Visual Design

One of the most prominent findings from the user questionnaire was the strong preference for light mode over dark mode. As shown in Table 02, 58% of users preferred a light color scheme, while only 26% preferred a dark mode and 16% expressed no preference. This preference emphasizes the importance of high contrast and readability in digital interfaces, particularly in varying lighting conditions.

Moreover, the psychological impact of color schemes became evident, as 66% of users acknowledged that color schemes influenced their purchase decisions (Table 01). This finding indicates that color choices are not only aesthetic but also functional, affecting user engagement, emotional responses, and decision-making processes, especially on e-commerce platforms. The psychological influence of color was further substantiated by 46% of users feeling more confident when interacting with interfaces that aligned with their color preferences, and 38% reporting that color influenced their emotions and mood. These insights suggest the necessity for designers to consider both the aesthetic and emotional effects of color when crafting a user interface

B. Gestalt Principles: Most Favored and Criticized Aspects

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The results also highlighted user feedback on the application of Gestalt principles:

- Proximity and Closure: 70% of users appreciated the use of these principles, as they helped in organizing the interface more logically, enhancing ease of use (Table 01).
- Similarity Principle: However, 25% of users critiqued the overuse of similarity, as it made differentiating between interactive areas difficult.

C. Impact on Emotions and Behavior

Users indicated that UI colors influenced their emotions and behavior. As noted earlier, 46% felt more confident and 38% pointed out that color had a significant effect on their mood (Table 01). 66% of users reported that the color scheme influenced their purchasing decisions. This finding underscores the importance of aesthetic choices in e-commerce platforms.

D. Background Color and Usability

58% of users agreed that background color significantly impacted readability and usability, emphasizing the need for designers to carefully select background colors that enhance content visibility (Figure 04).

Table 01: First Questionnaire Results and Discussion

Question	Results	Discussion
1:Color Scheme Preference	Light Mode – 58% Dark Mode - 26% No Preference – 16%	Substantial portion of users prefer a light color scheme
2: Influence of Color Scheme	Influences their purchase decisions -66%	Significance of color choices in UI design.
3: Influence on Purchasing Behavior	Feel more confident – 46% Influence their emotions and mood – 38%	Psychological impact of color on user behavior
4: Matching Color Scheme with Brand Identity	Agreed – 31% Disagreed – 44% Unsure – 22%	No overwhelming consensus on this aspect, suggesting that further exploration and consideration of the brand's specific context may be necessary
5: Background Color Impact on Readability and Usability	Agreed – 58% Disagreed – 22% Unsure – 20%	Emphasizing the importance of selecting background colors that enhance content visibility and usability
6 – 15: Comparing User Interface Designs	a strong preference among users for certain design options, highlighting the importance of considering user feedback in the UI design process.	

E. Developer Feedback on UI Design

The second questionnaire, which gathered responses from developers, provided insights into satisfaction rates and preferences. 60% of developers found the UI design "average," and 40% were satisfied. The balanced feedback shows that developers had mixed opinions, with some favoring certain UI elements while others suggested improvements (Table 3).

F. Necessity of Sections in UI

A 50-50 split was observed among developers regarding the necessity of certain sections in the UI (Table 03). This suggests a division of opinion on which sections are vital versus unnecessary in user interface design.

Table 02: Question 1 Color Scheme Preference Result

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Light mode	58	58.0	58.0	58.0
	Dark Mode	26	26.0	26.0	84.0
	I have no preference	16	16.0	16.0	16.0
	Total	100	100.0	100.0	100.00

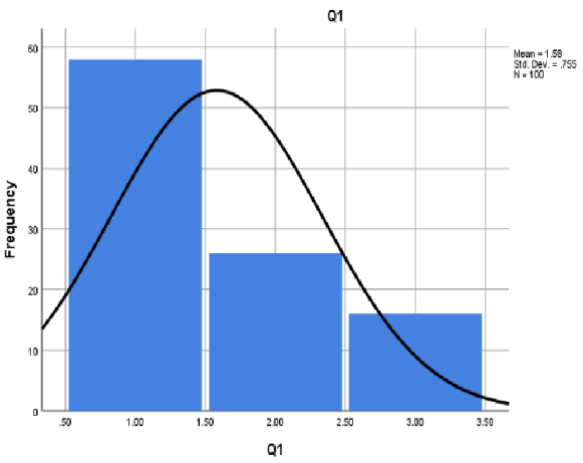

Figure 04: Explains the Table 2 Data in the Bar chart Format

G. Background Color Preference

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80% of developers preferred the green background color, reflecting a preference for environmentally friendly and visually appealing designs (Table 03). This finding aligns with the user's feedback, further emphasizing the importance of background color in both usability and aesthetic appeal.

The overall satisfaction and usability feedback indicated that UI Design 02 was more highly regarded than UI Design 01 in terms of usability. 70% of developers found UI Design 02 to be more usable than UI Design 01, pointing to its superior layout and ease of use. This highlights that developers preferred UI Design 02 due to its intuitive interface, better functionality, and user-friendly design elements. The overall satisfaction rate regarding design elements hovered around 70%, showing that while developers generally favored UI Design 02, there was still a portion who either found it average or believed further refinements were necessary.

Table 03: Developer Feedback on UI Design

Question	Results	Discussion
1: Satisfaction Rate	Satisfy: 40% Average: 60%	60% prefer "Average" in this aspect of UI design.
2:Necessity of Certain Sections	Good to have unnecessary Section - 50% Necessary Section - 50%	A 50-50 split between these two options.
3: Necessity	Yes - 60% No - 40%	60% believe it's necessary, 40% say it's not.
4: Division of Opinion	Yes - 50% No - 50%	An equal division in responses.
5: Background Color Preference	Background green Color - 80% Middle Picture - 20%	80% prefer "Background green color."
6:General Agreement	Yes - 30% No - 70%	70% say "No" and 30% say "Yes."
7:Image Comparison	Image 1 - 70% Image 2 - 30%	70% favor "Image 1" in this comparison.
8:Ui Design Preference 1	UI Design 01 - 20% UI Design 02 - 80%	80% prefer "UI Design 02."
9: UI Design Preference 2	UI Design 01 - 80% UI Design 02 - 20%	80% favor "UI Design 01."
10: UI Design Preference 3	UI Design 01 - 50% UI Design 02 - 50%	An equal split between "UI Design 01" and "UI Design 02."
Overall Satisfaction and Usability		UI Design 02 has 70% better usability than UI Design 01. The overall satisfaction rate with the design elements was around 70%, indicating diverse preferences and sentiments among developers regarding the design elements discussed during face-to-face conversations.

V. CONCLUSION

This research embarked on a comprehensive exploration of Human-Computer Interaction (HCI), with a specific focus on harnessing insights derived from Gestalt and Cognitive psychological theories to redefine the art of user interface (UI) design and elevate user experiences to unprecedented levels. This research has successfully met its main objective, which was to design a user interface that is efficient and user-friendly, catering to users of all skill levels. By leveraging principles from Gestalt and Cognitive psychology, we've managed to enhance the user experience and productivity. Our investigation was driven by a profound commitment to harness the rich resource of Gestalt psychology, which elucidates how the human mind organizes and interprets information. Additionally, we sought to leverage insights from Cognitive psychology, especially in the domains of attention and memory, to engineer UIs that are not just efficient but also aligned with the cognitive processes of users.

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Evaluating the Effectiveness of Homomorphic Encryption in Big Data: A Descriptive and Diagnostic Analysis

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Abstract

The ever-increasing volume of data generated from various sources, including the Internet of Things (IoT) and digital channels, presents a significant challenge for organizations. This rapid growth often necessitates offloading data analysis to the cloud due to limitations on local server capacity. However, security concerns arise when analyzing sensitive data in the cloud environment. Traditional encryption methods, while effective in protecting data at rest, require decryption prior to analysis, potentially exposing sensitive information. On the other hand, Homomorphic Encryption (HE) is gaining popularity as it – offers a solution by enabling computations to be performed directly on encrypted data. This paper investigates the effectiveness of homomorphic encryption on big data through descriptive and diagnostic analyses. Result suggest that this approach is better in terms of execution time and is particularly well-suited for big data analytics due to its inherent scalability.

Keywords: FHE, OpenFHE, BFV, BGV, CKKS

VI. INTRODUCTION

Big data refers to massive datasets that traditional computing methods struggle to handle (Shekhawat,*et al.,* 2019). Fueled by the constant influx of information, big data is characterized by a variety of attributes: volume (immense size), variety (diverse sources and formats), velocity (rapid generation and processing), veracity (accuracy and reliability), variability (continuously changing nature), complexity (intricate relationships), value (potential for insights), vulnerability (susceptibility to breaches), volatility (frequent fluctuations), validity (ensuring data quality), and visualization (effective representation). These characteristics necessitate a multifaceted approach for data governance, management, and analysis (Al-Mekhlal, M. and Khwaja, A.A., 2019). Data from various sources, including Internet of Things (IoT) devices (Kuri, *et al.,* 2017), cyber-physical systems (Gao, *et al.,* 2018), social media, and scientific research, increases the big data growth. To extract valuable insights from this data, advanced analytics techniques like artificial intelligence (AI), machine learning, and deep learning are crucial. As big data has invaded various sectors like business, healthcare, and education, a comprehensive understanding of its characteristics has become an essential. This understanding empowers governments, industries, and academic institutions to leverage big data's potential for a competitive advantage and significant value creation (Al-Mekhlal, M. and Khwaja, A.A., 2019).

The constant integration of new technologies is generating enormous amount of data on both individuals and organizations. This data is paramount for big data analytics, a powerful process that involves meticulous processing and analyzing massive datasets to extract valuable insights (Zaraket, *et al.,* 2022). These insights can be used for a variety of applications, such as precisely targeted advertising campaigns, and personalized healthcare decisions (Hong, *et al.,* 2016). Big data analytics is an essential tool for unlocking the hidden potential within these vast datasets. However, the lack of sophisticated analytical techniques, would leave this data unused. Thus, big data analytics empowers businesses and governments to transform this raw data into actionable intelligence, driving informed decisions across various sectors (Kumarage, *et al.,* 2016).

The ever-growing volume and complexity of big data necessitates a robust infrastructure to handle its storage and processing, resulting in the rise of cloud-based solutions (Al-Mekhlal, M. and Khwaja, A.A., 2019), which offer scalable and cost-effective platforms for big data analytics. Cloud computing provides the flexibility and power needed to process massive datasets,

enabling businesses and organizations to unlock the transformative potential of big data (Biksham, V. and Vasumathi, D., 2017). Despite the many advantages that big data provides, there are also concerns related to the personal data leakages that could collapse many individuals and organizations (Iezzi, M., 2020; Kuri, *et al.*, 2017). Data breaches exposing sensitive details like financial records, medical histories, or social security numbers can lead to identity theft, financial losses, and reputational damage for users. Especially, companies and organizations face serious consequences from data leaks, such as losing customer trust, facing large fines for non-compliance, and disrupting business operations.

The risks associated with data leakages in the domain of big data could be mitigated using encryption. Encryption refers to the method of converting the data into an unreadable format, often known as ciphertext. This ciphertext can only be converted back to its original form with a decryption key. Without this key, unauthorized users cannot understand the data, making it useless to them. By using encryption, organizations can greatly reduce the risk of data breaches and the resulting harm. (Kumarage, *et al.*, 2016).

With vast amounts of confidential data being generated, ensuring its privacy becomes a significant challenge, especially in public cloud environments where data security is inherently more complex (El Makkaoui, K., Ezzati, A. and Hssane, A.B., 2015). Despite the fact that traditional data encryption offers a layer of protection, its limitations should not be overlooked since the data needs to be decrypted before processing, leaving it vulnerable during this window (Alharbi, A., Zamzami, H. and Samkri, E., 2020).

This paper investigates the potential of Homomorphic Encryption (HE) to address this vulnerability (Chauhan, *et al.*, 2015). HE emerges as a revolutionary approach for secure data analytics in the big data era which allows users to perform operations directly on encrypted data, without ever decrypting it (Chauhan, *et al.*, 2015; Waziri, V.O., *et al.*, 2015). This means that the data remains secure and scrambled throughout its entire lifecycle, from storage and transmission to processing and analysis.

HE offers several advantages. It enables secure collaboration between data owners and untrusted data analysts, which is crucial for many industrial applications (Hamza et al., 2022). Data owners can share their encrypted data with analysts, knowing the information remains confidential. HE also reduces the performance overhead of traditional decryption-processing cycles, making data analysis more efficient while preserving privacy (Alabdulatif, Khalil, and Yi, 2020). However, HE is still under development, and different schemes have varying capabilities. Fully Homomorphic Encryption (FHE) allows both addition and multiplication on encrypted data but is computationally expensive (Zaraket et al., 2022; Chauhan et al., 2015). Partially Homomorphic Encryption (PHE) offers a compromise, supporting either addition or multiplication but not both (Chauhan et al., 2015). As research continues, HE libraries like HElib, SEAL, PALISADE, and TFHE are being improved for better efficiency and functionality (Iezzi, 2020).

II. RELATED WORKS

Due to the many advantages that HE offers for big data, different variants of HE has been employed from time to time for secure data transmission and storage. For instance, Kuri, *et al.*, introduce a novel privacy-preserving machine learning model, PP-ELM, designed for secure outsourced machine learning (Kuri, *et al.*, 2017). PP-ELM leverages additively homomorphic encryption, enabling an outsourced server to perform computations on encrypted data without decryption, ensuring data privacy. In addition, Verifiable Fully Homomorphic Encryption (VFHE) emerges as a promising solution for handling noise in encrypted data. VFHE combines homomorphic encryption with verifiability, allowing computations on encrypted data while guaranteeing their correctness (Ahmed, E.Y. and El Kettani, M.D.E.C., 2017). Whereas, Alabdulatif, A., Khalil, I., Reynolds, M., Kumarage, H. and Yi, X. (2017) used a distributed Fully Homomorphic Encryption (FHE) algorithm using MapReduce to address the potential data misuse by Cloud Service Providers (CSPs) or unauthorized access by malicious attackers. This approach facilitates data analysis tasks entirely on the cloud platform, eliminating the need for a Trusted Third Party (TTP). In another work, Alabdulatif, A., Kumarage, H., Khalil, I. and Yi, X. (2017) proposed a novel privacy-preserving anomaly detection model for the cloud

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environment using a lightweight homomorphic encryption approach for distributed data clustering on encrypted data, effectively utilizing cloud resources. To overcome limitations inherent to homomorphic encryption, this model integrated with a trusted private server within the cloud for computations requiring decryption. This collaboration ensured a secure and scalable anomaly detection on encrypted data.

The other variants included a novel homomorphic cryptosystem introduced by Pang and Wang (2020) supporting multiple cloud users with distinct public keys. This innovation caters to customers with limited computing resources who might leverage the cloud for association rule mining tasks (Pang, H. and Wang, B., 2020). Building upon the Paillier cryptosystem Zaraket et al (2022) proposed Vector-based Homomorphic Operations (SAVHO) for secure analytics that demands both security and efficiency.

In addition, research efforts like the distributed privacy-preserving Expectation-Maximization (EM) algorithm for Gaussian mixture modeling underscored the focus on scalability within the cloud context. This approach showed advantages such as scalable distribution settings and accelerated performance of FHE computations while maintaining high analysis accuracy (Alabdulatif, *et al.,* 2020). Moreover, a generic Privacy-Preserving Auction Scheme (PPAS) was proposed, encompassing an untrusted third-party trading platform comprised of two independent entities: the Auctioneer and the Intermediate Platform (Gao, *et al.,* 2018).

III. METHODOLOGY

A. Open-source Software Libraries Implementation FHE Schemes

Several open-source software libraries implementing FHE schemes are available to date. Among them, HElib, PALISADE, SEAL, HEAAN, FullRNS-HEAAN, Concrete, and FHEW are included (See Table 01).

HElib was developed by Shai Halevi and Victor Shoup. It is a sophisticated software library dedicated to the implementation of homomorphic encryption (HE), with a particular emphasis on the Brakerski-Gentry-Vaikuntanathan (BGV) scheme. The Smart-Vercauteren ciphertext packing techniques are leveraged, and the Gentry-Halevi-Smart optimizations are incorporated to enhance efficiency (Halevi, S. and Shoup, V., 2014).

The PALISADE Lattice Cryptography Library offers a comprehensive, layered framework that is designed for homomorphic encryption (HE) and a range of advanced lattice-based protocols. These include identity-based encryption, attribute-based encryption, and program obfuscation, making it a versatile tool for implementing cutting-edge cryptographic solutions (Polyakov, *et al.,* 2017).

Microsoft SEAL provides two distinct homomorphic encryption schemes, each with unique properties. The BFV and BGV schemes enable modular arithmetic on encrypted integers, resulting in precise results. Conversely, the CKKS scheme supports addition and multiplication on encrypted real or complex numbers, though only approximate results are yielded (https://github.com/microsoft/SEAL).

HEAAN (Homomorphic Encryption for Arithmetic of Approximate Numbers) is an open-source, cross-platform software library dedicated to the implementation of the approximate homomorphic encryption scheme introduced by Cheon, Kim, Kim, and Song (CKKS). The CKKS schemes are exclusively executed, with all their inherent properties fully supported (https://github.com/snucrypto/HEAAN).

The FHEW library, licensed under the GNU General Public License, implements a fully homomorphic encryption scheme that enables the homomorphic evaluation of arbitrary Boolean circuits on encrypted data. Efficient performance is achieved by utilizing the FFTW library, and the research ”FHE bootstrapping in less than a second” by Ducas and Micciancio forms the basis (https://github.com/lducas/FHE).

Table 01: Font format for this publication

HE Library	**HE Scheme**					
	BFV	**BGV**	**CKKS**	**FHEW**	**TFHE**	**GSW**
HElib		YES	YES			
PALISADE	YES	YES	YES	YES	YES	
SEAL	YES	YES	YES			
HEAAN			YES			
FHEW					YES	YES

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A new openFHE library (Al Badawi, *et al.,* 2022), designed by some of the authors of the PALISADE, HElib, HEAAN, and FHEW libraries, has been introduced. The design of this new library started with PALISADE and supports all common FHE schemes. Eventually, all supported FHE schemes in this library will include bootstrapping and scheme switching. Additionally, this library can support multiple hardware abstraction layers (HAL).

As shown in Table 02, OpenFHE is an open-source FHE library that includes efficient implementations of all common FHE schemes. In this study, the OpenFHE library will be utilized for the implementation of Big Data analytics using the BFV, BGV, and CKKS schemes, as the scope of this study is limited to arithmetic operations.

Table 02: OpenFHE Schemes (AL Badawi, *et al*., 2022)

Scheme	**Purpose**
BFV (Brakerski/Fan-Vercauteren)	Integer Arithmetic
BGV (Brakerski-Gentry-Vaikuntanathan)	Integer Arithmetic
DM/FHEW (Ducas-Micciancio)	Evaluating Boolean circuits and arbitrary functions over larger plaintext spaces using lookup tables
CGGI/TFHE (Chillotti-Gama-Georgieva-Izabachene)	Evaluating Boolean circuits and arbitrary functions over larger plaintext spaces using lookup tables
LMKCDEY	Evaluating Boolean circuits and arbitrary functions over larger plaintext spaces using lookup tables

B. Implementation of Homomorphic Encryption for Big Data Analytics

The first step involved the identification of suitable homomorphic encryption (HE) Library that can be effectively utilized for big data analytics. Once the appropriate HE Library was identified, the next phase was to implement these libraries within the context of big data analytics arithmetic functions. The implementation of Big Data analytics was carried out in Linux environment. Specifically in the latest version of Ubuntu 24.04. The installation of the OpenFHE library on the Linux environment was guided by the process outlined on the OpenFHE official website. Prerequisites such as g++ and clang were installed as stipulated in the provided documentation.

Subsequent to setting up the environment, the functionalities for descriptive and diagnostic analytics were developed. The implementation was divided into distinct modules corresponding to the CKKS, BFV, and BGV schemes. Each scheme was separately integrated to ensure comprehensive support for the various encryption methodologies. Initially, the dataset was stored in a CSV file. Distinct datasets were employed for testing both types of analytics. Upon uploading the data, it was subjected to a cleaning process to ensure accuracy and consistency.

Separate implementations were developed for each of the three encryption schemes—BFV, BGV, and CKKS. This separation was crucial to measure the time taken for each scheme to complete the analysis accurately. For descriptive analytics, statistical measures such as mean, median, and mode were computed. These metrics provided insights into the central tendencies and distribution of the data. In the case of diagnostic analytics, the focus was on determining the correlation between pairs of variables. This involved assessing the relationships and dependencies between different data points to uncover underlying patterns and trends.

Comparative analysis was conducted based on the time taken for the analytics. Each scheme was executed ten times to obtain an average and more accurate results. This approach ensures a comprehensive evaluation of performance and allows for the identification of any potential variations or inconsistencies in the execution times across the different encryption schemes. By averaging the results from multiple runs, a more reliable measure of each scheme's efficiency could be derived.

IV. RESULT AND DISCUSSION

This study investigated the efficiency of three homomorphic encryption (FHE) schemes (BFV, BGV, CKKS) implemented through the OpenFHE library for secure big data analytics. We focused on three key performance metrics: encryption time, descriptive analytics time, and diagnostic analytics time. Each FHE scheme was

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evaluated on its ability to perform these tasks on encrypted data while maintaining efficiency.

Our analysis revealed a significant difference in execution times between various data analysis tasks. All three FHE schemes exhibited considerably faster processing times for descriptive analytics, which involves basic statistical computations, compared to both encryption and diagnostic analytics. This finding suggests that FHE holds promise for applications requiring encrypted data exploration and basic statistical analysis. Encryption time remained relatively consistent across all three schemes, indicating that the base overhead of encrypting data is comparable for each approach.

Among the FHE schemes evaluated, BFV demonstrated the most efficient performance for descriptive analytics, achieving an average execution time of only 1.6 milliseconds. BGV and CKKS followed closely behind with average times of approximately 3.4 milliseconds. This suggests that BFV might be the preferred choice for use cases prioritizing rapid encrypted data exploration.

Table 03: OpenFHE Schemes

	Avg. time or read and clean(ms)	**Avg. time for encryption (ms)**	**Avg. time for analytics (ms)**
Descriptive Analysis			
BFV	11.3	64047.4	1.6
BGV	13.5	68455.6	3.4
CKKS	16.5	6623.9	3.4
Diagnostic Analytics			
BFV	50.2	327921.1	83.7
BGV	182.4	350033.0	65.1
CKKS	52.2	357448.4	70.4

For diagnostic analytics, which involve more complex computations, all FHE schemes displayed noticeably higher execution times compared to descriptive analytics. However, even with this increase, BFV maintained its lead as the fastest scheme, averaging 83.7 milliseconds. BGV and CKKS showcased comparable performance for diagnostic analytics, with average times hovering around 65-70 milliseconds.

One limitation encountered during the study was a linking error that arose when working with very large numbers. This error suggests a potential constraint within the virtual machine environment used for the analysis. Further investigation is needed to determine if this limitation is inherent to the virtual machine or specific to the configuration employed. Overcoming this limitation would be crucial for enabling the analysis of even larger datasets using FHE.

In conclusion, the OpenFHE library demonstrates significant promise as a platform for implementing data analytics functionalities on encrypted data. While encryption itself remains computationally expensive, the substantial speed advantage observed for descriptive analytics highlights the potential of this approach for secure data exploration and basic statistical analysis. Future research should focus on exploring the application of OpenFHE for predictive modeling, which would broaden its utility in advanced data analysis scenarios. Additionally, investigating methods to address the limitations encountered when working with very large numbers would be highly beneficial for expanding the practical applications of FHE in big data analytics.

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