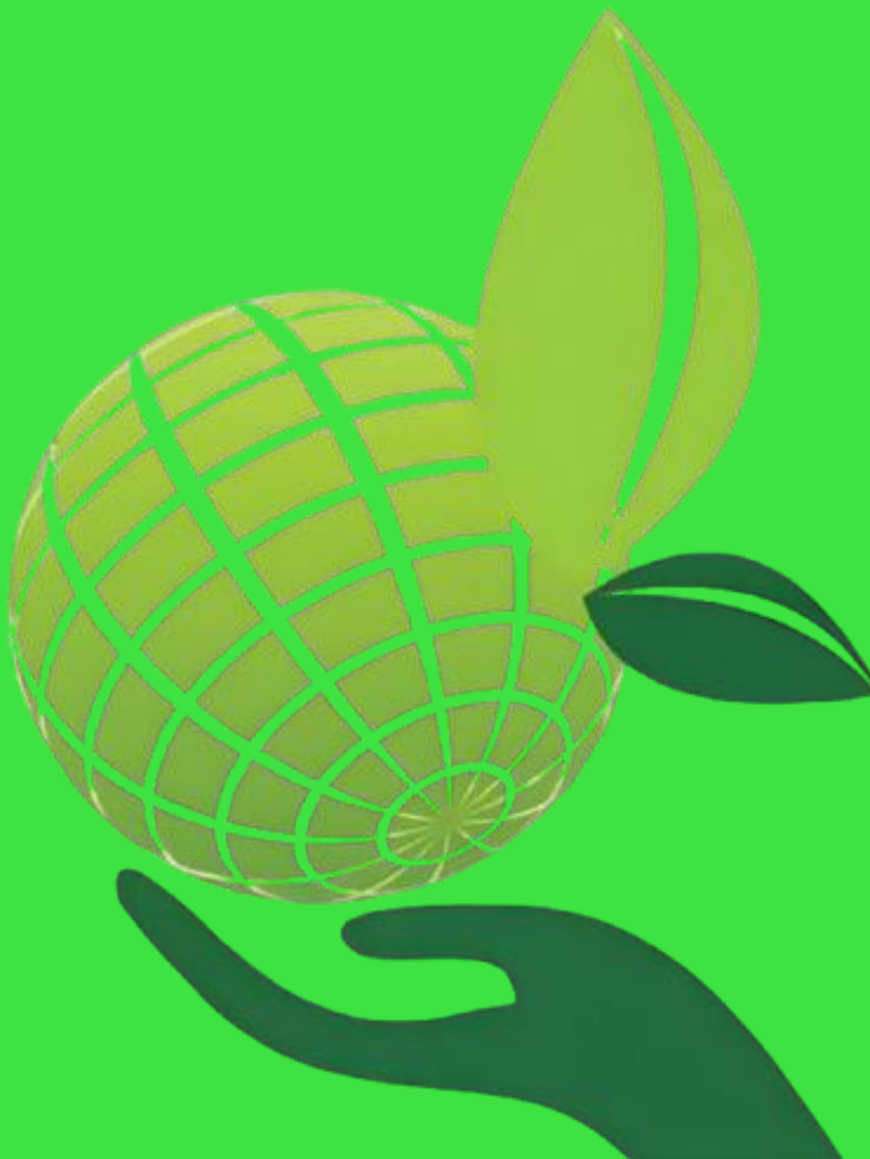
Journal of Tropical Environment

2024
December
Volume 4 Issue I & II



Edited and published by
Department of Environmental Management
Faculty of Social Sciences and Humanities
Rajarata University of Sri Lanka

Journal of Tropical Environment

Department of Environmental Management
Faculty of Social Sciences and Humanities,
Rajarata University of Sri Lanka, Mihintale.

Journal of Tropical Environment

The Refereed Journal of the Department of Environmental Management,
Rajarata University of Sri Lanka.
Volume 4 Issue I and II,2024

ISSN 2950-6808

Published by the Department of Environmental Management,
Faculty of Social Sciences & Humanities
Rajarata University of Sri Lanka

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Journal of Tropical Environment

Department of Environmental Management Faculty of Social Sciences and Humanities, Rajarata University of Sri Lanka, Mihintale

Volume 4, Issue I and II, December 2024

Journal of Tropical Environment
Department of Environmental Management Faculty of Social Sciences and Humanities, Rajarata University of Sri Lanka, Mihintale.
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Panel of Reviewers

Editorial Note - Journal of Tropical Environment

I am pleased to present Volume 4, Issue I and II of the *Journal of Tropical Environment*, a biannual publication dedicated to advancing scholarly discourse on environmental management, particularly within tropical ecosystems. The journal embraces an interdisciplinary approach, drawing from natural sciences, social sciences, management, and philosophy to address the pressing environmental challenges of our time. The main focus remains on research that engages with the complexities of managing tropical environments, encouraging innovative perspectives that span traditional academic boundaries. This issues showcase a diverse range of articles that have undergone a rigorous double-blind peer review process, ensuring the highest standards of scholarly integrity.

I extend my heartfelt gratitude to the authors, reviewers, and editorial board members, whose expertise and commitment have been crucial to the success of this journal. Their contributions have ensured that the *Journal of Tropical Environment* continues to be a valuable resource for researchers and practitioners alike. I hope this issue will inspire meaningful dialogue and inform sustainable development initiatives across both public and private sectors.

Prof. DMSLB Dissanayake - Editor in Chief
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Department of Environmental Management
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Prevalence of Asthma and Allergies among University Students in Sri Lanka

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Abstract

Asthma and allergies are prevalent health issues globally. However, comprehensive data on these conditions among university students in Sri Lankan dormitories have been sparse. This study aimed to evaluate the prevalence of asthma and allergies among university students. The study involved 2,234 students from Rajarata University of Sri Lanka, selected from seven different dormitory buildings using multi-level sampling techniques. Our findings indicate that 'rhinitis ever' was the most commonly reported allergic condition, affecting 36.7% of the participants. Additionally, 26.0% of the students reported 'wheeze ever,' and 25.4% reported 'wheeze current. The incidence of doctor-diagnosed asthma (DDA) was 7.8%, while doctor diagnosed rhinitis (DDR) accounted for 15.4% of the student population. Notable gender disparities were observed, with female students experiencing a significantly higher prevalence of rhinitis symptoms and diagnoses compared to male students. Smoking rates were relatively low, at 7.8%, with significant differences between genders (27.1% in men vs. 0.2% in women). The study also highlighted that a family history of asthma and allergies is a strong predictor of these conditions among students. This study emphasizes the high prevalence of 'rhinitis ever' and the influence of gender and familial health history on asthma and allergies among university students in Sri Lanka.

Given these findings, there is a clear need for further research into environmental and lifestyle factors that contribute to these conditions, aiming to develop effective public health strategies and interventions tailored to the specific needs and risks of this population.

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Keywords: asthma, allergies, wheeze, rhinitis, dormitories

1. Introduction

Asthma and allergies have become more common diseases globally during the last decades (Asher & Weiland, 1998; Ferreira et al., 2017; Lundbäck et al., 2016; Mallol et al., 2013). The prevalence of asthma and allergies, along with the underlying causes of their development, continue to be subjects of ongoing research and debate. (Huang et al., 2016; Ma et al., 2022; Yangzong et al., 2012). However, the prevalence of asthma remarkably varied by geographical region; for example, physician-diagnosed asthma was more than 24% in Chicago, Illinois, and 26 % in Sydney, Australia (Hu et al., 1997; Pearce et al., 1993). The prevalence of lifetime asthma was reported 2.2 % in Shunyi County, Beijing, China for schoolchildren. However, most higher incidence and prevalence of asthma and allergies are recorded in westernized countries (Yangzong et al., 2012; Zhang & Zhang, 2019) Compared with developing regions. However, some Asian countries have a higher prevalence of asthma (Asher et al., 2006; Hou et al., 2021; Asher, 2014; Leung et al., 2021; Ministry of Health SriLanka, 2018; Pearce et al., 2007; Seneviratne & Gunawardena, 2018). And also, there is a variation even within the same genetic group (Mallol et al., 2013; Yangzong et al., 2012).

As an Asian country, Sri Lanka has also experienced a higher prevalence of respiratory health (Gunasekera et al., 2022; Ministry of Health SriLanka, 2018; Ranasinghe et al., 2022; Seneviratne & Gunawardena, 2018). In 2012, respiratory conditions were responsible for a 14.4% death rate among children aged 1 to 5 years in Sri Lanka (Department of Census and Statistics, 2012). Additionally, respiratory diseases were the third leading cause of hospitalization in the country (Hinderaker, 2018). In 2019, asthma was the 7th leading cause of age-standardized Disability-Adjusted Life Years (DALYs) per 100,000 people in Sri Lanka (Institute for Health Metrics and Evaluation, 2023). Furthermore, few studies have addressed the prevalence of asthma and wheezing among children aged 5-14 years and the associated problems (Danansuriya, 2009; K. Karunasekera et al., 2009; Nandasena et al., 2012). In Sri Lanka, there is limited information on asthma and allergies among university students, particularly those residing in dormitories. These dormitories often feature crowded living conditions, with one room of 17.82 m^2 being shared by four undergraduate students, and another room of 29.9 m^2 accommodating ten students. This overcrowding may be linked to an increased prevalence of asthma and allergy symptoms.

Some studies have found a higher prevalence of respiratory health problems in university students in Canada (Lanthier-Veilleux et al., 2016), Greece (Tsantaki et al., 2020), China (Sun et al., 2011), and Malaysia. However, there have been no studies on asthma and allergies among young adults living in university dormitories in Sri Lanka. Given the potential impact of these respiratory conditions on students' academic performance and overall quality of life, it is crucial to conduct a comprehensive investigation into the epidemiology of asthma and allergy disorders in this population. This study aims to address this gap by examining the prevalence of asthma and allergies among students living in university dormitories in Sri Lanka. The findings from this research can improve the living conditions within dormitories, thereby enhancing students' quality of life.

2. Methodology

2.1 Study population

The Sri Lanka Student Health (SLSH) study comprised two phases: Phase I was a cross-sectional study, and Phase II was a case-control study. In a study conducted at Rajarata University of Sri Lanka (RUSL) located in the dry zone of the Anuradhapura district, 2,956 students living in dormitories were surveyed to assess indoor environment quality. The sampling process involved two stages: first, selecting 7 out of 14 dormitory buildings, followed by systematically sampling 502 out of 698 rooms. Ultimately, 2,234 students completed a questionnaire, which was an adaptation of the 'Dampness in Buildings and Health (DBH)' study originally developed in Sweden (Bornehag et al., 2005). This questionnaire has been widely used globally to study indoor environmental quality and its effects on health (Bornehag et al., 2005; Naydenova K, Melikovb A, Markovc D, Stankovc P, Bornehag C.G, 2008; Sun & Sundell, 2011; Sundell et al., 2013). Although the original DBH study focused on preschool children, the decision to adapt this questionnaire for university students was based on its comprehensive coverage of indoor environmental factors and respiratory health. The developed questionnaire is attached. The data from Phase I was utilized in this paper.

To ensure statistical validity, a sample size calculation was performed using a 95% confidence level, a 5% margin of error, and an estimated prevalence rate of indoor environmental issues. This calculation indicated that approximately 2956 participants were needed. The final dataset of 2234 respondents met these requirements and provided a strong basis for analysis.

The dormitories at RUSL vary in design, with buildings ranging from one to four stories, designed for natural ventilation, and built to meet local standards (Urban development authority, 1999). The questionnaire was structured into four sections: demographics, health information, building characteristics, and the environmental conditions of the dormitories, as well as the daily routines of the students. Modifications were made to the questionnaire to accommodate the unique socio-economic, architectural, and tropical climate conditions of Sri Lanka. The dormitory's administrative staff distributed the questionnaires, and students were asked to return them within two days.

2.2 Demographics and medical symptoms

The self-administered questionnaire in the study featured key demographic questions and inquiries about medical symptoms. The demographic aspects covered included gender, current smoking status, age, family income, and family history of allergies.

The questionnaire used in the study included six questions to assess asthma and related respiratory symptoms as well as allergic rhinitis symptoms among the students. For asthma and related symptoms, the questions asked were: “Have you ever had wheezing or whistling in the chest at any time in the past?” and “Have you had wheezing or whistling in the chest in the past 12 months?” with possible answers being “Yes” or “No.” Additionally, students were asked, “Have you been diagnosed with asthma by a doctor?” with the same response options of “Yes” or “No.”

For allergic rhinitis and related symptoms, the questionnaire included the following questions: “Have you ever had a problem with sneezing, or a runny, or a blocked nose when you did not have a cold or flu?” and “In the past 12 months, have you had a problem with sneezing, or a runny, or a blocked nose when you did not have a cold or the flu?” Respondents could answer “Yes” or “No” to these questions. Finally, students were also asked, “Have you been diagnosed with hay fever or allergic rhinitis by a doctor?” with “Yes” or “No” as the response options.

2.3 Statistical analysis

We employed SPSS version 21 for all statistical analyses in this study. Descriptive statistical methods were employed to analyze the data. Differences between the groups were assessed using Chi-square tests to determine statistical significance. The questionnaire and detailed proposal for the SLSH study conducted in the university dormitories were approved (ERC/2019/54) by the Ethical Committee in the Faculty of Medicine and Allied Sciences at Rajarata University of Sri Lanka.

3. Results

In Phase I study, data was gathered from 502 dorm rooms, accommodating a total of 2234 students in May 2020. The response rate was 76%. Table 2 provides a detailed overview of the demographic profiles of the student participants. Our research identified a slight gender imbalance, with 71.4% of participants being female. This proportion is quite similar to the university's overall female population of 68%. A significant proportion of students, around 46.2%, were born in the years spanning from 1994 to 1996. About 11% of students had a family history of allergies. Regarding socio-economic status, a substantial majority, 60.1%, come from families monthly earning more than 14,000 SLR (approximately 47.6 USD). Additionally, our findings showed that 92% of participants were non-smokers. This high percentage was likely influenced by the fact that 71% of the participants were female, consistent with the trend of lower smoking rates among female university students.

Table 1: Demographic characteristics of the students who lived in dormitories

Demographic factors		Frequency (n= 2234)	(%)
Gender	Male	640	28.6
	Female	1594	71.4
Allergy history of the family	Yes	234	10.9
	No	1909	89.1
Age	<1994	147	7.5
	1994-1996	906	46.2
	1996-1998	879	44.8
	>1998	28	1.4
Current smoking	Yes	174	7.9
	No	2042	92.1
Total monthly income (SLR)*	< 7000	441	20.3
	7000-14000	425	19.6
	>14000	1307	60.1

* Sri Lankan SLR.300.7 = 1 USD (2024.05.15).

In Fig. 1, the asthma and rhinitis symptoms reported by the students are depicted. 36.7% of students have reported "rhinitis ever", whereas 29.3% have reported "rhinitis current". Similarly, a considerable percentage of students (26.0%) reported wheeze ever, with 25.4% wheeze current. However, doctor-diagnosed asthma (DDA) incidence was 7.8%. Additionally, diagnosed rhinitis (DDR) accounted for 15.4% of the student population.

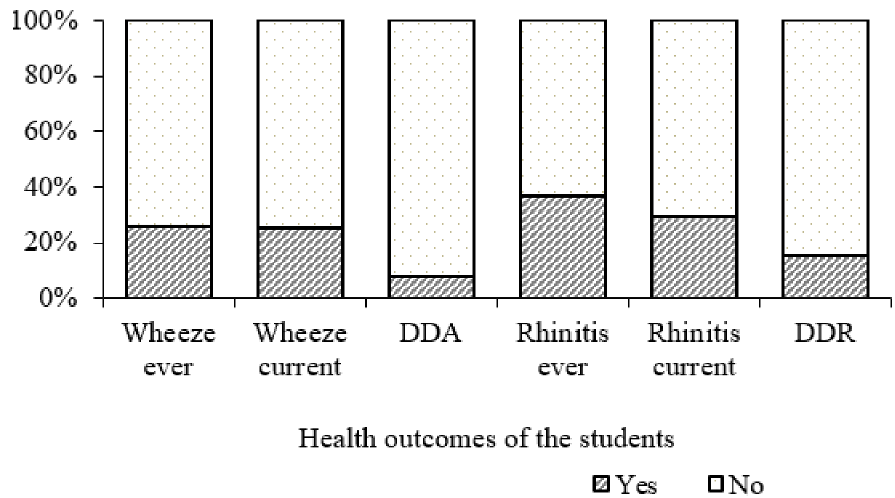

Figure. 1 : Asthma and allergic diseases among university students in Sri Lanka (DDA: Doctor-diagnosed asthma, DDR: doctor-diagnosed rhinitis).

The Chi-square test results on the association between demographic factors and the health outcomes of the students are represented in Table 2. There was a significant difference between asthma and allergy and student age, the income of the family, and family allergy history. The older students (residing in the dormitory for four years) reported a higher prevalence of symptoms. For example, those who have lived in the dormitory for more than four years had a wheeze ever prevalence of 42.5%, rhinitis ever at 46.5%, and current rhinitis at 45.5%, compared to other students. There was a significant association between asthma and allergy symptoms among those with a family allergy history. Students from families with a monthly income exceeding 14,000 SLR (approximately 47.6 USD) reported more symptoms compared to students from other income groups.

Table 2 Chi-square test on the association between socio-demographic factors and health outcomes of Sri Lanka college students

Factor	Wheeze ever n (%)	Wheeze current n (%)	DDA[a] n (%)	Rhinitis ever n (%)	rhinitis current n (%)	DDR[b] n (%)
Age category						
<1994	62 (42.5)	56 (39.2)	15 (10.2)	67 (46.5)	65 (45.5)	32 (22.4)
1994-1996	276 (30.7)	268 (30.5)	70 (7.8)	392 (43.7)	330 (37.5)	164 (18.7)
1996-1998	176 (20.2)	154 (18.4)	62 (7.2)	256 (29.5)	187 (22.2)	106 (12.5)
>1998	6 (22.2)	6 (24.0)	1 (3.6)	8 (28.6)	8 (29.6)	8 (29.6)
p-value	**0.000**	**0.000**	0.500	**0.000**	**0.000**	**0.000**
Gender						

Male	159 (24.9)	153 (25.1)	48 (7.6)	202 (31.9)	169 (27.3)	69 (11.1)
Female	417 (26.4)	394 (25.6)	123 (7.8)	609 (38.7)	465 (30.1)	263 (17.0)
p-value	0.465	0.822	0.827	**0.003**	0.194	**0.001**
Family income SLR(Monthly)						
<7000	87 (20.0)	88 (20.9)	28 (6.5)	143 (32.7)	101 (23.4)	62 (14.4)
7000-14000	100 (23.7)	90 (22.0)	37 (8.9)	145 (34.3)	99 (24.1)	53 (12.9)
>14000	369 (28.4)	351 (27.8)	101 (7.8)	501 (38.8)	417 (32.9)	207 (16.4)
p-value	**0.001**	**0.004**	0.419	**0.037**	**0.000**	0.203
Student smoking						
Yes	47 (27.0)	40 (24.0)	20 (11.6)	63 (36.4)	52 (30.6)	22 (12.9)
No	525 (25.9)	505 (25.7)	150 (7.4)	736 (36.5)	573 (29.0)	307 (15.5)
p-value	0.757	0.627	0.053	0.985	0.658	0.367
Allergy history of the family						
Yes	101(43.7)	100 (44.6)	63 (27.3)	120 (52.4)	111(49.1)	54 (23.9)
No	437(23.0)	409(22.2)	96 (5.1)	650 (34.4)	501 (27.1)	263 (14.2)
P-value	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**

[a]DDA: doctor-diagnosed asthma,
[b]DDR: doctor-diagnosed rhinitis,
Bold represents *p*-value <0.05,

4. Discussion

We conducted the research in university dormitories in Sri Lanka to find the prevalence of asthma and allergies. The prevalence of 'rhinitis ever' was the most frequently reported health outcomes among the students. There was a significant gender difference for rhinitis and doctor diagnosed rhinitis.

Table 3: Studies of the prevalence of asthma and allergy in Sri Lanka

Study	Location (n)	Age group	Wheeze ever %	Wheeze current [a]	DDA[b] %	Rhinitis ever %	Rhinitis Current [a]	DDR[c] %
Current study 2020	Anuradhapura	21-27	26.0	25.4	7.8	36.7	29.3	15.4
(Ranasinghe et al., 2022) 2022	Kandy (1696) Anuradhapura (2986)	13-14	21.9 19.9	15.3 14.9	-	-	30.5 22.5	-
(Gunasekera et al., 2022)2022	7 provinces study (1872)	>18	-	23.9	11.1	-	-	-
(Rajapakse et al., 2022) 2022	Anuradhapura (3324)	15-48	-	-	6.6	-	-	-
(Nitharna et al., 2018) 2019-2000	Kelaniya (360)	21-26	-	-	47.0	-	-	-
(Danansuriya et al., 2015) 2015	Gampaha (1483)	12-14	19.4	16.7	10.7	-	-	-
(Gunasekera et al., 2018) 2013	9 Province study in Sri Lanka (3381)	13-14	-	17.5	-	-	79.1	-
(Samarasinghe, 2007) 2007	Colombo CMC (1380)	5-11	22.7	12.8	-	-	-	-
(Amarasekera et al., 2010) 2006	Western Province (640)	10 years	22.4	-	-	-	42.4	-
(Karunasekera et al., 2003) 1998	Gampaha (2195)	5-11	-	23.0	-	-	10.0	-

[a] Within 12 months,
[b] Doctor-diagnosed asthma,
[c] Doctor-diagnosed rhinitis,
[d] Not data available.

In the study, the prevalence of Doctor-Diagnosed Asthma (DDA) was 7.8%. However, several other studies conducted in different districts of Sri Lanka reported a higher prevalence of DDA (Table 4). For example, a study conducted across seven provinces reported a DDA prevalence of 11.1% (Gunasekera et al., 2022). Another study from the University of Kelaniya found that 47% of the students had DDA (Nitharna et al., 2018). Similarly, a study completed in Gampaha District focusing on school children aged 12-14 reported a DDA prevalence of 10.7% (Danansuriya et al., 2015). Conversely, a study conducted in Anuradhapura District among pregnant women aged 15-48 found a lower percentage than our study (6.6%) (Rajapakse et al., 2022). In our study, the prevalence of 'wheeze ever' and 'wheeze current' were 26.0% and 25.4% respectively, which were higher compared to other studies (Amarasekera et al., 2010; Danansuriya et al., 2015; Ranasinghe et al., 2022; Samarasinghe, 2007). The prevalence of 'rhinitis ever' in our study was 36.7%. However, other Sri Lankan studies reported a lower percentage for 'rhinitis ever' (Amarasekera et al., 2010; Fernando et al., 2004). This discrepancy may arise from differences in the study population; their studies primarily included individuals below 14 years of age, while our study focused on those aged 21 to 27 years. These findings underscore the need for targeted public health interventions that consider age-specific respiratory health risks within the population.

Previous research from various countries has documented the occurrence of asthma and allergies among university students, including in China (Sun et al., 2009), Canada (Lanthier-Veilleux et al., 2016), and Thailand (Uthaisangsook, 2007). Specifically, a study from Tianjin University in China reported lower rates of physician-diagnosed asthma and rhinitis compared to our findings (Sun et al., 2009). In contrast, studies conducted in Canada, Sweden, and Thailand showed a higher prevalence of diagnosed asthma relative to our results (Kim, 2006; Lanthier-Veilleux et al., 2016; Uthaisangsook, 2007). Moreover, the studies by Lanthier-Veilleux et al. and Uthaisangsook indicated a greater prevalence of rhinitis, at 32.6%, than observed in our study (Lanthier-Veilleux et al., 2016; Uthaisangsook, 2007).

The results of this study indicate that older students who have lived in dormitories for four or more years report a higher prevalence of symptoms such as wheeze and rhinitis. While the initial interpretation attributes these findings to age, an alternative explanation may be prolonged exposure to environmental factors within the dormitories, such as poor air quality, allergens, or overcrowding. This prolonged exposure could be a key contributor to the increased symptoms, suggesting a cumulative effect rather than age alone. Future research should explore these environmental factors to better understand their impact for improving dormitory conditions to enhance student health. In addition, our findings suggest a possible link between higher income levels and an increased prevalence of asthma and allergies, aligning with previous research conducted in Tianjin, China (Ellie et al., 2021).

Female students reported significantly higher rates of rhinitis symptoms and physician-diagnosed rhinitis compared to male students. However, a study at Shanxi University in China found no significant gender differences in asthma symptoms among students living in dormitories (Fu et al., 2021). The reason for this remains unclear, and since this is the first study of its kind in Sri Lanka, further research is necessary to understand gender differences in asthma and allergies among university students in dorm settings.

The overall smoking rate was 7.8%. However, the rates differed significantly by gender: 27.1% for men and only 0.2% for women. Smoking is relatively uncommon, particularly among women, possibly because public smoking is banned in Sri Lanka (Marasinghe et al., 2024). Additionally, cultural factors also play a role, as women rarely smoke in Sri Lanka. Despite this, our findings indicate that smoking was not associated with asthma and allergies among the students. Moreover, students from families with a history of allergies had a strong correlation with all reported asthma and allergy. Recent review studies have shown that a family history of asthma consistently predicts the likelihood of asthma in both children and adults (Jose et al., 2017; Sears, 2008). A study from Sweden also indicated that adults with a family history of asthma or rhinitis are three to four times more likely to develop asthma and two to six times more likely to develop rhinitis than those without such a family history (Lundbäck, 1998).

Limitations and Strengths

This study may have underreported doctor-diagnosed asthma, leading to a lower observed prevalence. The use of questionnaires relying on students' recall introduces potential recall bias, and the cross-sectional design makes it difficult to establish cause-and-effect relationships. Additionally, the study had a high response rate of 76%. The large sample size reduced the risk of selection bias, strengthening the reliability of the findings.

5. Conclusion

This study conducted in university dormitories in Sri Lanka revealed that 'rhinitis ever' was the most commonly reported allergic condition among students, with noticeable gender differences in prevalence. Female students exhibited higher rates of rhinitis. Additionally, the finding that older students had a higher prevalence of allergic conditions could indicate increased exposure to environmental factors over time. Given these insights, we recommend that future research should thoroughly investigate environmental and lifestyle factors, including dormitory ventilation, hygiene practices, and exposure to indoor allergens. Furthermore, a longitudinal study across different geographical and climate zones within Sri Lanka would help in generalizing the findings and providing broader public health recommendations.

6. References

1. Amarasekera, N. D., Gunawardena, N. K., de Silva, N. R., & Weerasinghe, A. (2010). Prevalence of childhood atopic diseases in the Western Province of Sri Lanka. The Ceylon Medical Journal, 55(1), 5–8. https://doi.org/10.4038/cmj.v55i1.1700

2. Asher, M. I., & Weiland, S. K. (1998). The International Study of Asthma and Allergies in Childhood (ISAAC). Clinical and Experimental Allergy, Supplement, 28(5), 52–66. https://doi.org/10.1046/j.1365-2222.1998.028s5052.x

3. Asher, M., Montefort, S., Bjorksten, B., Lai, C., Strachan, D., Weiland, S., Williams, H., & Phase, I. I. (2006). Worldwide time trends in the prevalence of symptoms of asthma, allergic rhinoconjunctivitis, and eczema in childhood. Lancet, 368(9537), 733–743.

4. Beasley, R., Keil, U., Von Mutius, E., & Pearce, N. (1998). Worldwide variation in prevalence of symptoms of asthma, allergic rhinoconjunctivitis, and atopic eczema: ISAAC. Lancet, 351(9111), 1225–1232. https://doi.org/10.1016/S0140-6736(97)07302-9

5. Bornehag, C. G., Sundell, J., Hagerhed-Engman, L., Sigsggard, T., Janson, S., & Aberg, N. (2005). Dampness at home and its association with airway, nose, and skinsymptoms among 10,851 preschool children in Sweden: a cross-sectional study. In Indoor Air, Supplement (Vol. 15, Issue 10, pp. 48–55). https://doi.org/10.1111/j.1600-0668.2005.00306.x

6. Danansuriya, M. N.,(2009). Prevalence and correlates of asthma among 12-14 year old school children in a district and their quality life. Master Thesis. https://doi.org/10.1038/132817a0

7. Danansuriya, M. N., Rajapaksa, L. C., & Weerasinghe, A. (2015). Genetic, familial and environmental correlates of asthma among early adolescents in Sri Lanka: A case-control study. World Allergy Organization Journal, 8(1), 1–7. https://doi.org/10.1186/s40413-015-0068-x

8. Department of Census and Statistics. (2012). Census of Population and Housing 2012 - Final Report, Population by ethnicity and district according to Divisional Secretary's Division, 2012. Census of Population and Housing, 52.

9. Ellie, A. S., Sun, Y., Hou, J., Wang, P., Zhang, Q., & Sundell, J. (2021). Prevalence of childhood asthma and allergies and their associations with perinatal exposure to home

environmental factors: A cross-sectional study in tianjin, china. International Journal of Environmental Research and Public Health, 18, 1–11. https://doi.org/10.3390/ijerph18084131

10. Fernando, M. A. M., Senathilake, P. H. R. S., & Perera, B. J. C. (2004). Body mass index, allergic rhinitis and asthma in children. Sri Lanka Journal of Child Health, 33, 102–105. https://doi.org/10.4038/sljch.v33i4.619

11. Ferreira, G., Oliveira, R., Santos, H., & Castro, C. F. (2017). Asthma in Children and Indoor Air Pollutants : Associations in Residential and School Environments. June, 1145–1148.

12. Fu, X., Li, Y., Meng, Y., Yuan, Q., Zhang, Z., Wen, H., Deng, Y., Norbäck, D., Hu, Q., Zhang, X., & Sun, Y. (2021). Derived habitats of indoor microbes are associated with asthma symptoms in Chinese university dormitories. Environmental Research, 194(November 2020). https://doi.org/10.1016/j.envres.2020.110501

13. Gunasekera, K. D., Amarasiri, D. L., Fernando, A., & Wickramasinghe, R. (2018). The prevalence of asthma and related atopic diseases in Sri Lankan children from 2001 to 2013 utilizing the International Study of Asthma and Allergies in Childhood (ISAAC) questionnaire. European Respiratory Journal, 52(62), 1–8. https://doi.org/10.1183/13993003.congress-2018.pa4609

14. Gunasekera, K. D., Amarasiri, W. A. D. L., Undugodage, U. C. M., Silva, H. K. M. S., Sadikeen, A., Gunasinghe, W., Fernando, A., Perera, B. P. R., & Wickremasinghe, A. R. (2022). Prevalence of asthma and its symptoms in Sri Lankan adults. BMC Public Health, 22(1), 1–8. https://doi.org/10.1186/s12889-022-14793-3

15. Hinderaker, I. (2018). Department of Health. Administrative Districts and Field Offices of the Minnesota State Government, 10505, 53–61. https://doi.org/10.5749/j.cttts72q.17

16. Hou, J., Sun, Y., Wang, P., Zhang, Q., Kong, X., & Sundell, J. (2021). Associations between ventilation and children's asthma and allergy in naturally ventilated Chinese homes. Indoor Air, 31(2), 383–391. https://doi.org/10.1111/ina.12742

17. Hu, F. B., Persky, V., Flay, B. R., Zelli, A., Cooksey, J., & Richardson, J. (1997). Prevalence of asthma and wheezing in public schoolchildren: Association with maternal smoking during pregnancy. Annals of Allergy, Asthma and Immunology, 79(1), 80–84. https://doi.org/10.1016/S1081-1206(10)63090-6

18. Huang, C., Wang, X., Liu, W., Cai, J., Shen, L., Zou, Z., Lu, R., Chang, J., Wei, X., Sun, C., Zhao, Z., Sun, Y., & Sundell, J. (2016). Household indoor air quality and its associations with childhood asthma in Shanghai, China : On-site inspected methods and preliminary results. Environmental Research, 151, 154–167. https://doi.org/10.1016/j.envres.2016.07.036

19. Asher, N. P. (2014). Global burden of asthma among children. Health Technology Assessment, 23(29), 1–11. https://doi.org/10.3310/hta23290

20. Institute for Health Metrics and Evaluation. (2023). How do causes of death and disability compare to those in other locations ? Sri Lanka.

21. Jose A. Castro-Rodriguez; Erick Forno; Carlos E. Rodriguez- Martinez;Juan C. Celedón. (2017). Risk and protective factors for childhood asthma: what is the evidence? Allergy Clinical Immunol Practiceical Immunol Practice, 4(6), 1–24. https://doi.org/10.1016/j.jaip.2016.05.003.Risk

22. Karunasekera, K. A. W., Perera, K. P. J., Perera, M. T. P. R., & Abeynarayana, J. (2003). Prevalence of asthma and atopic symptoms in children aged 5-11years. Sri Lanka Journal of Child Health, 32, 11–14. https://doi.org/10.4038/sljch.v32i1.737

23. Karunasekera, K., Perera, K., Perera, M., & Abeynarayana, J. (2009). Genetic and environmental risk for asthma in children aged 5-11 years. Sri Lanka Journal of Child Health, 34(3), 79. https://doi.org/10.4038/sljch.v34i3.398

24. Kim, J.L., (2006). Environmental Factors in Relation to Asthma and Respiratory Symptoms among Schoolchildren in Sweden and Korea [Acta Universities Upsaliensis, Uppsala]. http://www.diva-portal.org/smash/get/diva2:169428/Fulltext 01.pdf

25. Lanthier-Veilleux, M., Baron, G., & Généreux, M. (2016). Respiratory diseases in university students associated with exposure to residential dampness or mold. International Journal of Environmental Research and Public Health, 13, 1–12. https://doi.org/10.3390/ijerph13111154

26. Leung, A. S. Y., Tham, E. H., Li, J., Pacharn, P., Takizawa, T., Lee, E., Xing, Y., Leung, T. F., Hong, S. J., & Wong, G. W. K. (2021). The role of the environment in shaping the trends of childhood asthma – An Asian perspective. Pediatric Allergy and Immunology, 32(6), 1152–1164. https://doi.org/10.1111/pai.13508

27. Lundbäck, B., (1998). Epidemiology of rhinitis and asthma. Clinical and Experimental Allergy, 28(2), 3–10.

28. Lundbäck, B., Backman, H., Lötvall, J., & Rönmark, E. (2016). Is asthma prevalence still increasing? Expert Review of Respiratory Medicine, 10(1), 39–51. https://doi.org/10.1586/17476348.2016.1114417

29. M. R. Sears. (2008). Evolution of asthma through childhood. Clinical and Experimental Allergy, 28(5), 82–89. http://repositorio.unan.edu.ni/2986/1/5624.pdf

30. Ma, Y., Tang, J., Wen, Y., Hu, Y., Liang, J., Jiang, L., Xing, Y., & Song, Y. (2022). Associations of sleep problems with asthma and allergic rhinitis among Chinese preschoolers. Scientific Reports, 12(1), 1–9. https://doi.org/10.1038/s41598-022-12207-3

31. Mallol, J., Crane, J., von Mutius, E., Odhiambo, J., Keil, U., & Stewart, A. (2013). The International Study of Asthma and Allergies in Childhood (ISAAC) Phase Three: A global synthesis. Allergologia Immunopathologia, 41(2), 73–85. https://doi.org/10.1016/j.aller.2012.03.001

32. Marasinghe, S. A., Sun, Y., Norbäck, D., Adikari, A. M. P., & Mlambo, J. (2024). Indoor environment in Sri Lankan university dormitories: Associations with ocular, nasal, throat and dermal symptoms, headache, and fatigue among students. Building and Environment, 251(January). https://doi.org/10.1016/j.buildenv.2024.111194

33. Ministry of Health SriLanka. (2018). Weekly pidemiological report. In Weekly Epidemiological report (Vol. 40, Issue December r).

34. Nandasena, S., Wickremasinghe, A. R., & Sathiakumar, N. (2012). Respiratory health status of children from two different air pollution exposure settings of Sri Lanka: A cross-sectional study. American Journal of Industrial Medicine, 55(12), 1137–1145. https://doi.org/10.1002/ajim.22020

35. Naydenova K, Melikovb A, Markovc D, Stankovc P, Bornehag C-G, S. J. (2008). A comparison between occupants ' and inspectors ' reports on home dampness and their association with the health of children : The ALLHOME study. Building and Environment, 43(11), 1840–1849.

36. Nitharna, S., Nusfa, M. N. F., Palagama, S. P., Panagoda, P. A. S. U., & Pathirana, P. P. C. P. (2018). Prevalence of asthma and related symptoms amongst medical students of Faculty of Medicine , University of Kelaniya Faculty of Medicine , University of Kelaniya. University of Kelaniya. https://medicine.kln.ac.lk/depts/publichealth/images/PosterPresentations/Posters/B27_C.1.3_Poster.pdf .

37. Pearce, N., Aït-Khaled, N., Beasley, R., Mallol, J., Keil, U., Mitchell, E. A., Robertson, C., Anderson, H. R., Asher, M. I., Björkstén, B., Brunekreef, B., Cookson, W., Crane, J., Ellwood, P., Foliaki, S., Lai, C. K. W., Robertson, C. F., Montefort, S., Odhiambo, J., … Williams, H. (2007). Worldwide trends in the prevalence of asthma symptoms: Phase III of the International Study of Asthma and Allergies in Childhood (ISAAC). Thorax, 62(9), 757–765. https://doi.org/10.1136/thx.2006.070169

38. Pearce, N., Weiland, S., Keil, U., Langridge, P., Anderson, H. R., Strachan, D., Bauman, A., Young, L., Gluyas, P., Ruffin, D., Crane, J., & Beasley, R. (1993). Self-reported prevalence of asthma symptoms in children in Australia, England, Germany and New Zealand: An international comparison using the ISAAC protocol. European Respiratory Journal, 6(10), 1455–1461.

39. Rajapakse, S., Wickramasinghe, N., Warnasekara, J., Abeyrathna, P., Amarasinghe, G., Hettiarachchi, A. U., Jayasinghe, I. U., Koralegedara, I., Agampodi, T. C., & Agampodi, S. B. (2022). Asthma in a prospective cohort of rural pregnant women from Sri Lanka: Need for better care during the pre-conceptional and antenatal period. PLoS ONE, 17(7 July), 1–12. https://doi.org/10.1371/journal.pone.0269888

40. Ranasinghe, J. C., Karunarathne, R. R., Munasinghe, T. S., Vidanapathirana, G. U., & Kudagammna, S. T. (2022). Childhood allergic diseases across geographical regions of Kandy and Anuradhapura districts of Sri Lanka; where do the rates stand among other regions: experience from Global asthma network Phase 1 study. Allergy, Asthma and Clinical Immunology, 18(1), 1–9. https://doi.org/10.1186/s13223-022-00720-z

41. Samarasinghe, A. I. (2007). Prevalence of childhood asthma amoung 5-11 years old children in an urban setting and its impact on the child and the family. 70130.

42. Seneviratne, R., & Gunawardena, N. S. (2018). Prevalence and associated factors of wheezing illnesses of children aged three to five years living in under-served settlements of the Colombo Municipal Council in Sri Lanka: A cross-sectional study. BMC Public Health, 18(1). https://doi.org/10.1186/s12889-018-5043-3

43. Strachan D, Sibbald B, Weiland S, Ait-Khaled N, Anabwani G, A. H. (1997). Worldwide variation in prevalence of symptoms of allergic rhinocon- junctivitis in children: the International Study of Asthma and Allergies in Childhood (ISAAC). Pediatr Allergy Immunol 1997;8:161-76.

44. Sun, Y., & Sundell, J. (2011). Life style and home environment are associated with racial disparities of asthma and allergy in Northeast Texas children. Science of the Total Environment, 409, 4229–4234. https://doi.org/10.1016/j.scitotenv.2011.07.011

45. Sun, Y., Wang, Z., Zhang, Y., & Sundell, J. (2011). In China, students in crowded dormitories with a low ventilation rate have more common colds: Evidence for airborne transmission. PLoS ONE, 6(11). https://doi.org/10.1371/journal.pone.0027140

46. Sun, Y., Zhang, Y., Sundell, J., Fan, Z., & Bao, L. (2009). Dampness at dorm and its associations with allergy and airways infection among college students in China: A cross-sectional study. Indoor Air, 19, 174–182. https://doi.org/10.1111/j.1600-0668.2008.00577.x

47. Sundell, J., Li, B. Z., & Zhang, Y. P. (2013). China, Children, Homes, Health (CCHH). Chinese Science Bulletin, 58(34), 4179–4181. https://doi.org/10.1007/s11434-013-9897-6

48. Tsantaki, E., Smyrnakis, E., Constantinidis, T. C., & Benos, A. (2020). Indoor air quality and sick building syndrome in a university setting: a case study in Greece. International Journal of Environmental Health Research, 32(3), 595–615. https://doi.org/10.1080/09603123.2020.1789567

49. Urban development authority. (1999). City of Colombo Development Plan 1999. Colombo.

50. Uthaisangsook, S. (2007). Prevalence of asthma, rhinitis, and eczema in the University population of Phitsanulok, Thailand. Asian Pacific Journal of Allergy and Immunology, 25(2–3), 127–132.

51. Yangzong, Y., Shi, Z., Nafstad, P., Håheim, L. L., Luobu, O., & Bjertness, E. (2012). The prevalence of childhood asthma in China: A systematic review. BMC Public Health, 12(1). https://doi.org/10.1186/1471-2458-12-860

52. Zhang, L., & Zhang, Y. (2019). Increasing prevalence of allergic rhinitis in China. Allergy, Asthma and Immunology Research, 11(2), 156–169. https://doi.org/10.4168/aair.2019.11.2.156

JOURNAL OF TROPICAL ENVIRONMENT
Vol. 4, Issue I and II, (December) 2024

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Policy Frameworks and Incentives for Sustainable Practices in Developing Regions to Combat Climate Change

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Abstract

Climate change poses significant challenges for developing regions, exacerbating existing vulnerabilities and inequalities. This paper explores the role of policy frameworks and incentives in promoting sustainable practices and technologies in these areas to ensure inclusive and equitable climate action. By examining the current state of climate impacts and evaluating various policy approaches, the research highlights the necessity of tailored strategies for developing regions. Key mitigation policies, such as energy efficiency measures, renewable energy incentives, carbon markets, and sustainable agriculture, are discussed alongside adaptive strategies like resilient infrastructure, early warning systems, and disaster risk management. The findings underscore the importance of integrating economic, social, and environmental dimensions of sustainable development, leveraging partnerships, and fostering international cooperation. A holistic approach, combining both mitigation and adaptation policies, is essential for developing regions to effectively combat climate change and contribute to a more sustainable and equitable global response.

Keywords: Climate change, Sustainable development, Policy frameworks, Mitigation and adaptation

1. Introduction

The intensifying global climate change crisis presents a significant and disproportionate challenge to developing countries, which are broadly characterised by high socio-economic vulnerability, inadequate infrastructure, and limited capacity to cope with adverse climate effects (Le, 2020). These regions frequently encounter heightened vulnerabilities due to significant dependence on climate-sensitive economic sectors, necessitating urgent and tailored policy intervention (Descheemaeker et al., 2016).

Developing regions face a significant impact from climate change, amplifying vulnerabilities, and inequalities worldwide. While developed nations bear substantial responsibility for greenhouse gas emissions (GHG) and climate change, developing countries also contribute significantly, with China standing out as the largest global carbon emitter in 2021 (Glemarec, 2023; Qin et al., 2023). In 2021, China's emissions of 10.5 billion tons(annual) surpassed the U.S.'s 4.7 billion tons(annual), accounting for approximately one-third of the world's total carbon emissions(Qin et al., 2023). Furthermore, emissions from Asia's emerging markets and developing economies, excluding China, surged by 4.2% or 206 Mt CO_2 in 2022, primarily due to a substantial increase in coal-fired power generation (International Energy Agency, 2022). Notably, among the top ten methane emitters in 2021, most were developing economies, with only the USA and Russia representing developed nations (International Energy Agency, 2022).

Effective climate action fundamentally relies on two essential strategic pillars: mitigation and adaptation. Mitigation policies are interventions designed to decrease the sources of greenhouse gas emissions or to improve the sinks that accumulate greenhouse gases (Ghosh et al., 2020). In contrast, adaptation policies constitute modifications in ecological, social, or economic systems in reaction to actual or expected climatic stimuli and their impacts, primarily aimed at mitigating harm or capitalising on advantageous chances (Button & Harvey, 2015; Le, 2020).

To address this challenge effectively, this research underscores the pivotal role of policy frameworks and incentives in promoting sustainable practices and technologies in developing regions. The key argument of this paper posits that a holistic approach, integrating policy frameworks and strategic incentives, is essential for inclusive climate action in developing regions. This approach encompasses economic, social, and environmental dimensions of sustainable development.

The subsequent exploration within this paper seeks to substantiate this argument by critically examining various dimensions of sustainable development policy frameworks and incentives.

By delving into the intricacies of net-zero policies, renewable energy strategies, and a wide array of incentives, it is aimed to uncover the pathways that can lead to sustainable practices and technologies in developing regions. Importantly, these pathways will be scrutinized for their potential to ensure inclusive and equitable participation.

As the following sections will reveal, the journey towards inclusive climate action involves not only understanding the unique challenges faced by developing regions but also harnessing the power of partnerships.

2. Material and Methods

2.1. Research Design

This paper utilises a systematic review methodology, relying solely on secondary data obtained from published academic and institutional literature. The study employs a qualitative and analytical design, concentrating on synthesising available evidence to critically assess policy frameworks and incentives pertaining to climate change mitigation and adaptation in developing regions. The main objective was to locate, categorise, and analyse consensus and discrepancies within the academic discourse to formulate a coherent argument.

2.2. Data Collection and Sources

The data collection performed during the author's postgraduate studies at The University of Queensland (UQ), Australia, employing the university's institutional access and library resources.

2.2.1 Search Platforms

The principal source for all resources was the digital collections of the UQ eLibrary. This granted access to a wide array of prominent academic databases and publication platforms, including Scopus, Web of Science, ScienceDirect, JSTOR, Oxford Academic, Taylor & Francis Online, Elsevier, and Springer (the latter on behalf of the Royal Swedish Academy of Sciences). Particular emphasis was made on high-impact journals, including the Asia Pacific Journal of Environmental Law and the Journal of Renewable Energy and Sustainable Development (RESD). Preliminary exploratory searches and cross-referencing were performed using Google Scholar.

2.2.2 Search Strategy

A focused search approach was executed utilising Boolean operators to integrate essential topic domains. The primary search strings encompassed versions of (“climate change” AND “developing regions” AND “policy”), (“renewable energy” OR “carbon markets” AND “incentives”), (“adaptation” AND “resilience” AND “developing nations”), and (“sustainable agriculture” AND “mitigation” AND “developing regions”).

2.2.3 Inclusion and Exclusion Criteria

The study focused on peer-reviewed journal articles, official reports from international organisations (including the Intergovernmental Panel on Climate Change (IPCC), UNDRR, IEA, and World Bank), and credible book chapters. The preliminary search was confined to publications from 2003 to 2023 to maintain topical relevance, thereafter, extended by essential highly referenced foundational works as required. Non-scholarly sources (e.g., news articles, blogs, general websites) were excluded.

2.3. Data Analysis

The collected materials underwent a multi-phase analysis procedure:

2.3.1 Categorization: Each selected document was initially classified according to its principal emphasis: Mitigation Policies (e.g., carbon pricing, renewable energy), Adaptation Policies (e.g., early warning systems, resilient infrastructure), and Impacts/Vulnerability.

2.3.2 Thematic Synthesis (Inductive Approach): An inductive approach was employed to synthesise findings within each category. The author analysed the abstracts and relevant sections of the chosen literature to identify repeat themes, essential policy instruments, and common challenges or success factors specific to developing regions.

2.3.4 The synthesized information was critically assessed to ascertain scholarly consensus, identify contradicting results, and underscore significant policy deficiencies. This process enabled the author to organize the Literature Review into distinct sub-sections and to directly inform the arguments articulated in the Findings & Discussion section (Chapter 4). The analysis established the basis for asserting that a "holistic approach, incorporating policy frameworks and strategic incentives, is crucial for inclusive climate action in developing regions."

3. Literature Review

3.1. The Current State of Climate Change in Developing Regions

Climate change, a global phenomenon, imposes particularly severe impacts on developing regions, as emphasized by numerous studies(Mertz et al., 2009). It is argued that, despite bearing the least responsibility for climate change, these nations are disproportionately vulnerable, affecting their resources, economies, and societies(Thomas et al., 2008). These challenges are the increased frequency of extreme weather events, impacts on agriculture and livelihoods, coastal vulnerabilities and climate-induced migration, displacement, and loss of biodiversity(Glemarec, 2023; Krishnan et al., 2019; Li & Huang, 2023; Thomas et al., 2008)). The region experiences heightened frequency of extreme weather events, such as hurricanes, droughts, floods, and heatwaves, especially in rural areas(Bisht et al., 2016; Mertz et al., 2009). Future projections indicate that developing regions will experience even more of these events, with significant implications(Adger et al., 2003), notably for Central America, the Caribbean(Mertz et al., 2009), and Southeast Asia due to rapid urbanization and industrialization(Glemarec, 2023).

In many developing economies, agriculture serves as a cornerstone(Adger et al., 2003), but it faces a perilous two-way relationship with climate change(Ibrahim & Johansson, 2022; Lybbert & Sumner, 2012). On one hand, climate change-induced alterations in weather patterns, particularly in rural areas, can have devastating consequences(Bisht et al., 2016). These changes lead to crop failures, reduced agricultural productivity, and decreased water availability due to shifting rainfall patterns, posing serious threats to food security and rural livelihoods (IPCC, 2007). Limited access to technology and resources for adaptation makes the situation severe(Lybbert & Sumner, 2012). Consequently, climate change-induced challenges, vividly demonstrated by smallholder farmers in India in the work of Bish et al. (2016), underscore the pressing need for adaptive measures.

Coastal regions in numerous developing countries also are grappling with distinctive climate change challenges, as documented in the literature, characterized by rising sea levels and intensified storm surges that imperil low-income livelihoods(Krishnan et al., 2019; Le, 2020). The vulnerability of coastal rice farming communities in Bangladesh, highlighted in a study by Islam et al. (2021), exemplifies the dire situation. These communities not only face livelihood threats due to problems like salinity intrusion, sea level rise, and frequent cyclones and storm surges but are also pushed into food insecurity(Islam et al., 2021). This underscores the critical importance of robust adaptation strategies in the face of climate change, as the literature consistently reveals(Krishnan et al., 2019; Le, 2020; Salik et al., 2015).

3.2. Policy frameworks and Incentives which promote sustainable practices and technologies.

Numerous studies have examined the extensive range of policy frameworks and incentives aimed at promoting sustainable practices and technologies to combat climate change, with a focus on mitigation and adaptation.

3.2.1. Mitigation policies and incentives

Energy efficiency policies have garnered substantial attention in this context(Bibas et al., 2015). Research by Geller et al. (2006) highlights the pivotal role of energy efficiency policies in addressing climate change, a perspective that policymakers in many developed countries have acted upon by implementing various energy efficiency measures. Industrialized nations, including Japan, the USA, and Western Europe, have intensified their efforts to improve energy efficiency, employing policies such as Minimum efficiency standards, labels, Building energy codes (BECs), industrial voluntary agreements, and pricing initiatives for appliances, industries, and the private sector (Geller et al., 2006). BECs are regarded as instrumental in building energy policies and have the potential to achieve a 50% reduction in energy consumption worldwide(Nejat et al., 2015). Mandatory energy requirements in buildings, as seen in Europe and parts of the United States, as well as light-vehicle standards in Europe, Japan, and the US, have significantly contributed to reducing fossil fuel consumption and greenhouse gas emissions(Bibas et al., 2015; Wills & La Rovere, 2010). While there is limited literature on similar practices in developing countries, a study by Wills & La Rovere (2010) demonstrates how an energy efficiency program for light vehicles can substantially reduce CO2 emissions in Brazil. Some energy efficiency policies, like Japan's Top Runner Program, aimed at setting efficiency standards for major home appliances, have shown mixed results(Inoue & Matsumoto, 2019). Moreover, developed countries have initiated or expanded energy efficiency incentive schemes, such as low-interest loans for building retrofit projects and tax incentives to promote the purchase of highly efficient new cars (Geller et al., 2006).

Renewable energy policies also play a vital role in the global transition to sustainable, low-carbon energy systems. Developed nations like Germany, Denmark, and the United States have implemented various policies and fiscal incentives to encourage investment in clean energy infrastructure(Gullberg et al., 2014; Jacobsson & Lauber, 2006; Meyer, 2004; Muhammed & Tekbiyik-Ersoy, 2020). These policies include feed-in tariffs, tax incentives, renewable portfolio standards, and quotas(Ghosh et al., 2020; Tanaka, 2021; Zhang et al., 2020). As a result, these countries have seen significant growth in renewable energy capacity, reduced greenhouse gas emissions, and improved energy security, economics, and health(Shahbaz et al., 2020; Q. Wang et al., 2020; Q. Wang & Wang, 2020). However, the effectiveness of such policies varies depending on specific contexts, including policy design, regulatory frameworks, and socio-economic conditions(Ozcan & Ozturk, 2019; Papas, 2017). Affordability, accessibility, and energy equity are the main areas that developing regions are focused on as they adapt these policies to their local settings (Ozcan & Ozturk, 2019). As renewable energy technologies become more cost-competitive, supportive policy frameworks remain crucial for achieving a sustainable energy transition(Gullberg et al., 2014; Meyer, 2004; Ozcan & Ozturk, 2019; Shahbaz et al., 2020).

Carbon markets and carbon taxes also have become significant policy instruments in the transition to a low-carbon economy(Hua & Dong, 2019; Tanaka, 2021). Carbon markets, such as cap-and-trade systems like the European Union Emissions Trading System and the Regional Greenhouse Gas Initiative in the United States, facilitate the trading of emission allowances among regulated entities, promoting cost-effective emissions reductions(Ghosh et al., 2020; Tanaka, 2021; Zhang et al., 2020). Meanwhile, carbon taxes impose a price on carbon emissions, providing a clear economic incentive to reduce emissions (Ghosh et al., 2020; Zhang et al., 2020). Countries like Finland, Sweden, and Canada have introduced national carbon taxes to incorporate carbon costs into market prices(Andersson, 2019; Best et al., 2020). Carbon pricing, including both carbon markets and carbon taxes, is often seen as a less intrusive policy approach, allowing the market to determine how emissions reductions are achieved (Mankiw, 2009 as quoted in Best et al. (2020).

Sustainable agriculture policies are also integral to global efforts addressing climate change, ensuring food security, and promoting environmental stewardship. These policies encompass diverse measures, from agroecological farming practices to land-use planning and conservation incentives(Ibrahim & Johansson, 2022; Lybbert & Sumner, 2012). Research demonstrates how such policies improve soil health, reduce chemical inputs, enhance biodiversity, and mitigate greenhouse gas emissions (Bisht et al., 2016; Lybbert & Sumner, 2012). Examples include the European Union's Common Agricultural Policy, which integrates sustainability principles into subsidy allocation, and the Sustainable Agriculture Initiative's framework, adopted by global food companies to support sustainable supply chains(Daugbjerg & Swinbank, 2016). The literature also discusses implementation difficulties, highlighting the significance of stakeholder involvement, information sharing, and financing(Amjath-Babu et al., 2019; Giles et al., 2021). Amid climate uncertainty and resource limitations, sustainable agriculture policies remain critical for enhancing food system resilience while minimizing environmental impacts.

Reforestation, a critical nature-based strategy for climate mitigation, has received substantial academic attention. It involves activities like planting trees and allowing forests to naturally regenerate to restore ecosystems and capture carbon dioxide. Reforestation offers a range of advantages, including the preservation of biodiversity, provision of ecosystem services, and enhanced resilience (H. D. Le et al., 2012; Van Kooten & Johnston, 2016). Notably, reforestation effectively reduces carbon emissions by storing carbon in both trees and soil (Van Kooten & Johnston, 2016). Nevertheless, it faces challenges, such as issues related to landownership and the influence of climate on the types of tree species that thrive (H. D. Le et al., 2012). With the global focus on nature-based climate solutions growing, reforestation continues to be a central topic in discussions about sustainable land use (Van Kooten & Johnston, 2016).

3.2.2. Adaptation policies and incentives.

Strengthening early warning systems is a vital strategy for adaptation of climate change, aiming to minimize the risks associated with extreme weather events and natural disasters. Research consistently emphasizes the crucial role of timely, precise, and cost-effective information in mitigating the impacts of climate-related hazards(Bai et al., 2014). This approach involves meteorological and hydrological forecasts, as well as alerts for events like floods, hurricanes, and droughts, which facilitate preparedness and response measures(Bai et al., 2014; Coughlan De Perez et al., 2022). It highlights the need for ongoing investment in early warning infrastructure and technology, as well as community engagement and inclusive practices (IPCC, 2018).

Building climate-resilient infrastructure is another proactive adaptation policy that spans various sectors, including transportation, energy, and housing. The literature emphasizes that resilient infrastructure is pivotal in reducing community vulnerability to climate-related risks(Giordano, 2012). Researchers explored strategies for enhancing infrastructure resilience, such as engineering solutions, improved construction methods, and the integration of climate risk considerations into planning and design (IPCC, 2014). It stresses the importance of tailoring climate-resilient infrastructure to local conditions (Cacho et al., 2020).

Another complete adaptation strategy that includes measures for readiness, response, recovery, and risk reduction is to improve disaster risk management (UNDRR, 2019). The literature highlights the significance of holistic disaster risk management frameworks that incorporate climate change considerations (UNDRR, 2019). Scholars have examined the significance of early warning systems, community disaster risk reduction programmes, and governance frameworks in minimizing vulnerability(Linnerooth-Bayer & Mechler, 2006). Coordination between many stakeholders is necessary for effective disaster risk management(Kunreuther, 2020). Challenges include resource limitations, coordination issues, and the need for long-term risk reduction strategies to address the developing impacts of climate change (UNDRR, 2019; Linnerooth-Bayer & Mechler, 2006).

4. Findings and Discussion

The climate change impacts in developing regions are distinctly more severe compared to developed regions. These localized climate change effects underscore the need for tailored policy frameworks and incentives for developing regions. In fact, developing countries may have already achieved emissions savings exceeding those of industrialized nations. As a result, several mitigation strategies, including solar energy, wind energy, urban green infrastructure, energy efficiency, better management of forests and crops, and less food waste and loss, are potential solutions and are becoming more affordable (IPCC, 2023). Hence, these options can be easily deployed in the developing countries most.

4.1. Mitigation Strategies and Financial Instruments

Carbon markets hold substantial promise for addressing global climate change(Hua & Dong, 2019), and offers a compelling solution for developing countries as a cost effective method(Boyce, 2018). These mechanisms, including carbon markets and taxes, effectively incentivize emissions reduction in these nations (Global Climate Policy, 2020). They provide financial motivation for households, businesses, and governments to adopt sustainable practices (Boyce, 2018). For example, China's carbon emission trading system, implemented in 2013, has significantly reduced industrial CO_2 emissions by 24.2% (Zhang et al., 2020) while generating revenue for climate efforts (Best et al., 2020). Similar incentives, such as tradeable carbon credits or carbon payments, can be used by developing nations, especially in industries like agriculture (Amjath-Babu et al., 2019). To compensate for emissions reductions, particularly in agriculture, novel policy solutions are required due to difficulties in monitoring and enforcing carbon pricing, particularly in low-income countries(Amjath-Babu et al., 2019).

Renewable energy policies globally encompass economic instruments, strategic planning, and regulatory measures, with feed-in tariffs (FITs), renewable portfolio standards (RPS), and quotas being widely utilized, especially in developing nations (Muhammed & Tekbiyik-Ersoy, 2020). China's Wind Power Concession Program showcases the success of such policies, reducing costs and attracting private investment (Muhammed & Tekbiyik-Ersoy, 2020). Feed-in tariffs have also driven renewable energy adoption, particularly in emerging economies like Brazil, China, and India (Best et al., 2020). Long-term incentives such as FITs, auctions, and net metering have been effective in Brazil, while various government initiatives, including tax credits and renewable energy certificate markets, play crucial roles in nurturing the renewable energy sector (Muhammed & Tekbiyik-Ersoy, 2020; Ozcan & Ozturk, 2019) and these can be further adopted.

Energy efficiency policies are crucial across various sectors, including household appliances, industry, and automobiles. Developed countries like Japan and the USA have successfully implemented policies such as minimum efficiency standards, voluntary agreements, and financial incentives (Geller et al., 2006). For instance, Japan's Top Runner Programme aims to elevate product efficiency levels (Wills & La Rovere, 2010), and developing countries can adopt similar standards with consideration for technical and economic feasibility. Voluntary agreements, as seen in European countries (Geller et al., 2006), offer collaborative approaches suitable for developing nations. Financial incentives, such as Germany's low-interest loans for energy efficiency, can be emulated to encourage adoption of energy-efficient technologies in buildings and vehicles. Fuel efficiency programs have reduced fossil fuel consumption and emissions in countries like the USA, Germany, and Japan, offering a model for developing nations with growing automotive fleets (Geller et al., 2006; Wills & La Rovere, 2010). Combining targeted demand-pull policies (e.g., standards, feed-in tariffs, taxes), which create incentives and market opportunities, with dedicated technology-push policies and investments (e.g., for scientific training, R&D, demonstration), can strengthen the development of low-emission technologies (IPCC, 2023). These not only contribute to environmental sustainability but also drives the automotive industry towards producing more efficient vehicles and reducing fossil fuel reliance in developing countries.

To promote sustainable agriculture in developing regions, governments can take a multifaceted approach. This includes educating farmers about agricultural production risks, leveraging their loss aversion tendencies to encourage carbon-reduction methods, and providing subsidies for technology adoption (Li & Huang, 2023). Improving the agricultural risk management system, enhancing insurance services, and emphasizing technological innovation are essential steps (Li & Huang, 2023). Additionally, promoting the use of climate-resistant seeds and offering concessions to farmers can boost agricultural resilience

(Cacho et al., 2020). Adopting renewable energy on farms can reduce energy costs and environmental impacts, making sustainable agriculture more viable(J. Wang et al., 2023). Switching to renewable energy technology for irrigation can further reduce carbon emissions and improve energy efficiency (J. Wang et al., 2023). Developing countries can implement policies to facilitate these initiatives effectively.

Green finance initiatives such as blockchain markets can be introduced however, requires higher upfront capital and face greater sensitivity to policy changes and technology risks compared to conventional investments(Glemarec, 2023; Zhang et al., 2020). Nonetheless, developing countries can introduce investment incentives, such as tax incentives and concessions, to attract sustainable investments.

4.2. Adaptive Measures and Resilient Development

Developing countries must enhance their adaptive capacity to cope with the impacts of climate change, as they are disproportionately affected (Adger et al., 2003). Without adaptation measures, South Asia, for example, could face significant economic losses, with potential GDP reductions of 1.8% by 2050 and 8.8% by 2100(Aryal et al., 2020). To achieve this, policies related to building climate-resilient infrastructure, strengthening early warning systems, and improving disaster risk management need to be prioritized. When considering building climate-resilient infrastructure, per-capita emissions in developing countries are expected to rise due to new infrastructure and urban development (IPCC, 2022). While some Indian cities have made strides in building resilient infrastructure for sustainable development, African countries face challenges in providing and maintaining adequate infrastructure due to issues like corruption and political stress(Chirisa et al., 2016). Latin America has made progress in constructing resilient infrastructure facilities, but further actions can include publishing guidelines on climate-resilient infrastructure, facilitating public-private partnerships, and offering tax incentives and concessions to attract private investments, particularly in the ASEAN region. Additionally, adopting "green infrastructure" practices, aimed at increasing ecosystem resilience and reducing biodiversity loss and resource waste, as seen in the EU region, can be considered(Chirisa et al., 2016).

Developing regions must also invest in early warning systems (EWS) to reduce disaster impacts. To maximize their effectiveness and enable strategic adaptation, EWS must be enhanced to include improved methodology and systems for long-term (seasonal) climate forecasting(Coughlan De Perez et al., 2022), which is crucial for sectors like agriculture and water management. This involves infrastructure development, equipment maintenance, capacity building, data sharing agreements, integration of indigenous knowledge, and community-based systems. These comprehensive policies and incentives enhance the effectiveness of EWS, making them more actionable and relevant to local needs (IPCC, 2022). Additionally, effective disaster risk management necessitates collaboration between governments, NGOs, local communities and global partnerships in developing countries to combat climate change.

4.3. Towards a Holistic Approach: Integrating Mitigation and Adaptation

The prior discussion clearly emphasises that effective climate action in developing regions requires more than the singular commitment to legislative initiatives. Success depends on a holistic approach that systematically blends mitigation and adaptation initiatives across economic, social, and environmental spheres, in accordance with the fundamental principles of sustainable development. This integration is not just a political necessity but also a practical imperative, as numerous initiatives produce reciprocal advantages. Policies that promote sustainable agriculture, a crucial mitigation strategy, immediately strengthen agricultural resilience by increasing the utilisation of climate-resistant seeds and enhancing risk management, thus fulfilling the adaptation objective of safeguarding vulnerable livelihoods. The transition to renewable energy technology for key services such as irrigation (mitigation) simultaneously addresses a significant adaptive capacity problem by ensuring affordable energy access and lowering operational expenses for farmers (adaptation). Ultimately, although targeted policies like carbon markets and resilient infrastructure are crucial individually, their integrated and coordinated execution strengthened by international collaboration and multi-stakeholder partnerships is essential to guarantee that climate action is both effective and equitable for developing regions.

5. Conclusion

Addressing climate change in developing regions necessitates a multifaceted approach that combines mitigation and adaptation policies and incentives. The severe, disproportionate impacts of climate change on these regions necessitate tailored strategies that address their unique vulnerabilities and opportunities.

The findings confirm that robust Mitigation Strategies and Financial Instruments such as effective carbon markets, renewable energy incentives, and energy efficiency measures are essential for reducing global greenhouse gas emissions and transitioning economies towards sustainable practices. Equally vital are Adaptive Measures and Resilient Development, which include building climate-resilient infrastructure and strengthening long-term forecasting within early warning systems to build resilience and protect vulnerable communities.

It is essential to adopt a holistic approach that guarantees the integration of these two policy streams. Holism necessitates that policy formulation transcends sectoral boundaries and integrates the economic, social, and environmental facets of sustainable development. Integration is achieved by actively pursuing synergies between mitigation and adaptation; for instance, fostering sustainable agriculture reduces emissions while concurrently strengthening resilience through technology such as climate-resistant crops.

To guarantee inclusivity and equitable participation, these policies must be formulated with regard to the local context, cost, and accessibility, while also promoting international cooperation and partnerships. This comprehensive framework is essential for promoting sustainable practices and technologies in developing regions, facilitating a more equitable and sustainable global response to climate change.

6. References

1. Adger, W. N., Huq, S., Brown, K., Conway, D., & Hulme, M. (2003). Adaptation to climate change in the developing world. Progress in Development Studies, 3(3), 179–195. https://doi.org/10.1191/1464993403ps060oa

2. Amjath-Babu, T. S., Aggarwal, P. K., & Vermeulen, S. (2019). Climate action for food security in South Asia? Analyzing the role of agriculture in nationally determined contributions to the Paris agreement. Climate Policy, 19(3), 283–298. https://doi.org/10.1080/14693062.2018.1501329

3. Andersson, J. J. (2019). Carbon Taxes and CO2 Emissions: Sweden as a Case Study. American Economic Journal: Economic Policy, 11(4), 1–30. https://doi.org/10.1257/pol.20170144

4. Aryal, J. P., Sapkota, T. B., Khurana, R., Khatri-Chhetri, A., Rahut, D. B., & Jat, M. L. (2020). Climate change and agriculture in South Asia: Adaptation options in smallholder production systems. Environment, Development and Sustainability, 22(6), 5045–5075. https://doi.org/10.1007/s10668-019-00414-4

5. Bai, Y., Kaneko, I., Kobayashi, H., Kurihara, K., Takayabu, I., Sasaki, H., & Murata, A. (2014). A Geographic Information System (GIS)-based approach to adaptation to regional climate change: A case study of Okutama-machi, Tokyo, Japan. Mitigation and Adaptation Strategies for Global Change, 19(5), 589–614. https://doi.org/10.1007/s11027-013-9450-6

6. Best, R., Burke, P. J., & Jotzo, F. (2020). Carbon Pricing Efficacy: Cross-Country Evidence. Environmental and Resource Economics, 77(1), 69–94. https://doi.org/10.1007/s10640-020-00436-x

7. Bibas, R., Méjean, A., & Hamdi-Cherif, M. (2015). Energy efficiency policies and the timing of action: An assessment of climate mitigation costs. Technological Forecasting and Social Change, 90, 137–152. https://doi.org/10.1016/j.techfore.2014.05.003

8. Bisht, J. K., Meena, V. S., Mishra, P. K., & Pattanayak, A. (Eds.). (2016). Conservation Agriculture. Springer Singapore. https://doi.org/10.1007/978-981-10-2558-7

9. Boyce, J. K. (2018). Carbon Pricing: Effectiveness and Equity. Ecological Economics, 150, 52–61. https://doi.org/10.1016/j.ecolecon.2018.03.030

10. Cacho, O. J., Moss, J., Thornton, P. K., Herrero, M., Henderson, B., Bodirsky, B. L., Humpenöder, F., Popp, A., & Lipper, L. (2020). The value of climate-resilient seeds for smallholder adaptation in sub-Saharan Africa. Climatic Change, 162(3), 1213–1229. https://doi.org/10.1007/s10584-020-02817-z

11. Chirisa, I., Bandauko, E., Mazhindu, E., Kwangwama, N. A., & Chikowore, G. (2016). Building resilient infrastructure in the face of climate change in African cities: Scope, potentiality and challenges. Development Southern Africa, 33(1), 113–127. https://doi.org/10.1080/0376835X.2015.1113122

12. Coughlan De Perez, E., Harrison, L., Berse, K., Easton-Calabria, E., Marunye, J., Marake, M., Murshed, S. B., Shampa, & Zauisomue, E.-H. (2022). Adapting to climate change through anticipatory action: The potential use of weather-based early warnings. Weather and Climate Extremes, 38, 100508. https://doi.org/10.1016/j.wace.2022.100508

13. Daugbjerg, C., & Swinbank, A. (2016). Three Decades of Policy Layering and Politically Sustainable Reform in the European Union's Agricultural Policy: Policy Layering and Politically Sustainable Reform. Governance, 29(2), 265–280. https://doi.org/10.1111/gove.12171

14. Geller, H., Harrington, P., Rosenfeld, A. H., Tanishima, S., & Unander, F. (2006). Polices for increasing energy efficiency: Thirty years of experience in OECD countries. Energy Policy, 34(5), 556–573. https://doi.org/10.1016/j.enpol.2005.11.010

15. Ghosh, P., Jha, A., & Sharma, R. (2020). Managing carbon footprint for a sustainable supply chain: A systematic literature review. Modern Supply Chain Research and Applications, 2(3), 123–141. https://doi.org/10.1108/MSCRA-06-2020-0016

16. Giles, J., Grosjean, G., Le Coq, J.-F., Huber, B., Bui, V. L., & Läderach, P. (2021). Barriers to Implementing Climate Policies in Agriculture: A Case Study From Viet Nam. Frontiers in Sustainable Food Systems, 5, 439881. https://doi.org/10.3389/fsufs.2021.439881

17. Giordano, T. (2012). Adaptive planning for climate resilient long-lived infrastructures. Utilities Policy, 23, 80–89. https://doi.org/10.1016/j.jup.2012.07.001

18. Glemarec, Y. (2023). Financing green and climate resilient infrastructure in ASEAN countries. Environmental Progress & Sustainable Energy, 42(4), e14097. https://doi.org/10.1002/ep.14097

19. Gullberg, A. T., Ohlhorst, D., & Schreurs, M. (2014). Towards a low carbon energy future – Renewable energy cooperation between Germany and Norway. Renewable Energy, 68, 216–222. https://doi.org/10.1016/j.renene.2014.02.001

20. Hua, Y., & Dong, F. (2019). China's Carbon Market Development and Carbon Market Connection: A Literature Review. Energies, 12(9), 1663. https://doi.org/10.3390/en12091663

21. Ibrahim, M. A., & Johansson, M. (2022). Combating climate change – What, where and how to implement adaptive measures in the agriculture sector of Öland, Sweden, keeping in view the constraints of carrying capacities and risk of maladaptation. Land Use Policy, 122, 106358. https://doi.org/10.1016/j.landusepol.2022.106358

22. Inoue, N., & Matsumoto, S. (2019). An examination of losses in energy savings after the Japanese Top Runner Program? Energy Policy, 124, 312–319. https://doi.org/10.1016/j.enpol.2018.09.040

23. International Energy Agency. (2022). CO2 Emissions in 2022. https://iea.blob.core.windows.net/assets/3c8fa115-35c4-4474-b237-1b00424c8844/CO2Emissionsin2022.pdf

24. The Intergovernmental Panel on Climate Change. (2007). AR4 Climate Change 2007: Synthesis Report. https://www.ipcc.ch/site/assets/uploads/2018/02/ar4_syr_full_report.pdf

25. The Intergovernmental Panel on Climate Change. (2014). AR5 Synthesis Report: Climate Change 2014. https://www.ipcc.ch/report/ar5/syr/

26. The Intergovernmental Panel on Climate Change. (2018). Global warming of 1.5°C. https://www.ipcc.ch/site/assets/uploads/sites/2/2019/06/SR15_Full_Report_High_Res.pdf

27. Intergovernmental Panel on Climate Change (IPCC). (2022). Summary for Policymakers. In Climate Change 2022 - Mitigation of Climate Change: Working Group III Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (pp. 3–48). frontmatter, Cambridge: Cambridge University Press.

28. The Intergovernmental Panel on Climate Change. (2023). Climate Change 2023 Synthesis Report. https://www.ipcc.ch/report/ar6/syr/downloads/report/IPCC_AR6_SYR_LongerReport.pdf

29. Islam, F., Alam, G. M. M., Begum, R., Sarker, M. N. I., & Bhandari, H. (2021). Vulnerability, Food Security and Adaptation to Climate Change of Coastal Rice Farmers in Bangladesh. In G. M. M. Alam, M. O. Erdiaw-Kwasie, G. J. Nagy, & W. Leal Filho (Eds.), Climate Vulnerability and Resilience in the Global South (pp. 187–197). Springer International Publishing. https://doi.org/10.1007/978-3-030-77259-8_9

30. Jacobsson, S., & Lauber, V. (2006). The politics and policy of energy system transformation—Explaining the German diffusion of renewable energy technology. Energy Policy, 34(3), 256–276. https://doi.org/10.1016/j.enpol.2004.08.029

31. Krishnan, P., Ananthan, P. S., Purvaja, R., Joyson Joe Jeevamani, J., Amali Infantina, J., Srinivasa Rao, C., Anand, A., Mahendra, R. S., Sekar, I., Kareemulla, K., Biswas, A., Kalpana Sastry, R., & Ramesh, R. (2019). Framework for mapping the drivers of coastal

vulnerability and spatial decision making for climate-change adaptation: A case study from Maharashtra, India. Ambio, 48(2), 192–212. https://doi.org/10.1007/s13280-018-1061-8

32. Kunreuther, H. (2020). Risk Management Solutions for Climate Change–Induced Disasters. Risk Analysis, 40(S1), 2263–2271. https://doi.org/10.1111/risa.13616
33. Le, T. D. N. (2020). Climate change adaptation in coastal cities of developing countries: Characterizing types of vulnerability and adaptation options. Mitigation and Adaptation Strategies for Global Change, 25(5), 739–761. https://doi.org/10.1007/s11027-019-09888-z
34. Li, L., & Huang, Y. (2023). Sustainable Agriculture in the Face of Climate Change: Exploring Farmers' Risk Perception, Low-Carbon Technology Adoption, and Productivity in the Guanzhong Plain of China. Water, 15(12), 2228. https://doi.org/10.3390/w15122228
35. Linnerooth-Bayer, J., & Mechler, R. (2006). Insurance for assisting adaptation to climate change in developing countries: A proposed strategy. Climate Policy, 6(6), 621–636. https://doi.org/10.1080/14693062.2006.9685628
36. Lybbert, T. J., & Sumner, D. A. (2012). Agricultural technologies for climate change in developing countries: Policy options for innovation and technology diffusion. Food Policy, 37(1), 114–123. https://doi.org/10.1016/j.foodpol.2011.11.001
37. Mertz, O., Halsnæs, K., Olesen, J. E., & Rasmussen, K. (2009). Adaptation to Climate Change in Developing Countries. Environmental Management, 43(5), 743–752. https://doi.org/10.1007/s00267-008-9259-3
38. Meyer, N. I. (2004). Renewable energy policy in Denmark. Energy for Sustainable Development, 8(1), 25–35. https://doi.org/10.1016/S0973-0826(08)60388-9
39. Muhammed, G., & Tekbiyik-Ersoy, N. (2020). Development of Renewable Energy in China, USA, and Brazil: A Comparative Study on Renewable Energy Policies. Sustainability, 12(21), 9136. https://doi.org/10.3390/su12219136
40. Nejat, P., Jomehzadeh, F., Taheri, M. M., Gohari, M., & Abd. Majid, M. Z. (2015). A global review of energy consumption, CO 2 emissions and policy in the residential sector (with an overview of the top ten CO 2 emitting countries). Renewable and Sustainable Energy Reviews, 43, 843–862. https://doi.org/10.1016/j.rser.2014.11.066
41. Ozcan, B., & Ozturk, I. (2019). Renewable energy consumption-economic growth nexus in emerging countries: A bootstrap panel causality test. Renewable and Sustainable Energy Reviews, 104, 30–37. https://doi.org/10.1016/j.rser.2019.01.020
42. Papas, M. (2017). The 2030 Sustainable Development Agenda and the Paris Climate Agreement — taking urgent action to combat climate change: How is Australia likely to

fare? Asia Pacific Journal of Environmental Law, 20(1), 94–114. https://doi.org/10.4337/apjel.2017.01.04

43. Qin, M., Zhang, X., Li, Y., & Badarcea, R. M. (2023). Blockchain market and green finance: The enablers of carbon neutrality in China. Energy Economics, 118, 106501. https://doi.org/10.1016/j.eneco.2022.106501

44. Salik, K. M., Jahangir, S., Zahdi, W. U. Z., & Hasson, S. U. (2015). Climate change vulnerability and adaptation options for the coastal communities of Pakistan. Ocean & Coastal Management, 112, 61–73. https://doi.org/10.1016/j.ocecoaman.2015.05.006

45. Shahbaz, M., Raghutla, C., Chittedi, K. R., Jiao, Z., & Vo, X. V. (2020). The effect of renewable energy consumption on economic growth: Evidence from the renewable energy country attractive index. Energy, 207, 118162. https://doi.org/10.1016/j.energy.2020.118162

46. Tanaka, N. (2021). Comment on " ENERGY-RELATED Environmental Policy and Its Impacts on Energy Use in Asia." Asian Economic Policy Review, 16(1), 62–64. https://doi.org/10.1111/aepr.12326

47. Thomas, C. D., Ohlemüller, R., Anderson, B., Hickler, T., Miller, P. A., Sykes, M. T., & Williams, J. W. (2008). Exporting the ecological effects of climate change: Developed and developing countries will suffer the consequences of climate change, but differ in both their responsibility and how badly it will affect their ecosystems. EMBO Reports, 9(S1). https://doi.org/10.1038/embor.2008.42

48. United Nations Office for Disaster Risk Reduction. (2019). UNDRR Annual Report 2019. https://www.undrr.org/media/47153/download?startDownload

49. Wang, J., Li, W., Haq, S. U., & Shahbaz, P. (2023). Adoption of Renewable Energy Technology on Farms for Sustainable and Efficient Production: Exploring the Role of Entrepreneurial Orientation, Farmer Perception and Government Policies. Sustainability, 15(7), 5611. https://doi.org/10.3390/su15075611

50. Wang, Q., Li, S., & Pisarenko, Z. (2020). Heterogeneous effects of energy efficiency, oil price, environmental pressure, R&D investment, and policy on renewable energy Evidence from the G20 countries. Energy, 209, 118322. https://doi.org/10.1016/j.energy.2020.118322

51. Wang, Q., & Wang, L. (2020). Renewable energy consumption and economic growth in OECD countries: A nonlinear panel data analysis. Energy, 207, 118200. https://doi.org/10.1016/j.energy.2020.118200

52. Wills, W., & La Rovere, E. L. (2010). Light vehicle energy efficiency programs and their impact on Brazilian CO2 emissions. Energy Policy, 38(11), 6453–6462. https://doi.org/10.1016/j.enpol.2009.06.057

53. Zhang, W., Li, J., Li, G., & Guo, S. (2020). Emission reduction effect and carbon market efficiency of carbon emissions trading policy in China. Energy, 196, 117117. https://doi.org/10.1016/j.energy.2020.117117.

JOURNAL OF TROPICAL ENVIRONMENT
Vol. 4, Issue I and II, (December) 2024

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Utilization of Herbarium Data in Phenological Research: Addressing Climate Change Implications and Research Gaps in Sri Lanka

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Abstract

In recent years, the profound impact of climate change on biodiversity has become increasingly evident, with significant consequences for critical life events within the biotic environment. These phenological shifts serve as vital indicators of climatic changes. This study investigates the contribution of herbarium data for bridging the gap in plant phenological observations for investigations on climatic change. This review critically analyzes comprehensive studies from the past two decades and focuses on the utility of herbarium specimens as phenological tools. Long-term observation of phenological data by various observational networks has paved the way for advanced environmental analysis in climatic change studies. However, despite the importance of phenological data from field observation, its collection and long-term monitoring present challenges emphasizing the need for spatiotemporal depth. A noticeable gap in field data collection has hindered various studies reliant on plant phenological data. In response to these challenges, herbaria serve as repositories of plant specimens, showcasing rich historical records and providing deep spatiotemporal and taxonomic insight. Research findings indicate the fidelity of herbarium records to fill the gap in field observations. Overcoming the challenges associated with extensive herbarium datasets, digitalization of herbarium data has emerged as an effective strategy, granting researchers easy access to these data. Moreover, it is evident that in Sri Lanka, there is a research gap in utilizing herbarium data for phenological studies in climate change observation and the implementation of online accessibility for herbarium data, highlighting the need to address this gap in future research endeavors.

Keywords: *Climate change; Herbarium data; Biodiversity; Phenological data; Digitalization*

1. Introduction

In biotic environments, flora exhibit various seasonal life history events related to vegetative growth and reproductive growth, such as flowering, leaf outing, bud bursting, emerging inflorescences, changing of the color of leaves, and ripening of fruits, which is called phenology. Phenology, the scientific investigation of the temporal patterns of these recurring seasonal biological phenomena, has been a longstanding field of inquiry spanning centuries. The majority of research pertaining to phenological shifts has been conducted over past epochs and relies on agriculture investigations, meteorology studies, ecology, and evolutionary-related studies.

The shift of these phenological events in temperate and tropical ecosystems closely correlates with climatic change, and climatic fluctuations can affect the growth and productivity of the plants at their individual level as well as their community level (Primack et al., 2004; Ahas & Aasa, 2006; Calinger et al., 2013; Schröder et al., 2014; Davis et al., 2015; Singh et al., 2023). As supported by various studies, these phenological patterns of the plants are crucial indicators of climatic change, especially for temperature changes like spring advancement and autumn postponement (Park & Schwartz, 2014; Willis et al., 2017; Singh et al., 2023). The correlation between phenological shifts and climatic relations has been thoroughly addressed in past research studies and long-term observation of phenological data. Field observations lead to sophisticated studies on environmental analysis. Further, there are different global networks of phenological observations, such as phenology network observations of wild plants, agricultural observation systems, measurement of pollen concentration using pollen traps, etc., that pertain the studies to a broad spectrum (Ahas & Aasa, 2006; Koch, 2009; Schröder et al., 2014; (Brenskelle et al., 2019; Ramirez-Parada et al., 2022).

As indicated by recent researches, while the observations of the global phenology network encompass a wide spatial breadth, the temporal coverage extends only to the last century. Along this line, understanding phenological variation has emerged as a difficult process due to the problems in collecting the long-term observation of phenological data which emphasizes a spatiotemporal depth. (Primack et al., 2004; Davis et al.,2015; Wills et al.,2017; Lang et al.,2018; Brenskelle et al., 2019; Lima et al., 2021; Ramirez-Parada et al., 2022). In particular concern, the gap in the field data due to the lack of long-term field observation has become a challenge for the application of plant phenological data for the different array of studies. According to the studies that delve into the climatic change related to plant phenological data, natural history collections in various institutions, including museums, botanical gardens, zoos, and research institutions have emerged as a powerful tool that addresses this gap. This study critically reviews the contribution of herbarium specimens as repositories for phenological data to document climatic changes, using recent research studies done in the past two decades. Further, it is noteworthy to address the research gap in Sri Lanka on the utilization of herbarium data for the investigation of climatic change implications.

Utilization of Herbarium Data for the Phenological Application

Botanical collecting over 450 years has amassed 396 million specimens in 3567 index herbaria worldwide, forming a vital record of biodiversity (Index Herbariorum: The New York Botanical Garden, 2024). Herbaria play a pivotal role as repositories for an extensive collection of herbarium specimens, housing data on a multitude of species over centuries. Herbarium specimens consist of dried and pressed plant samples mounted on sheets, supported by detailed label information indicating the time, details of the collector, and location of the collection. Typically, plant collection for the herbarium collection is done in the flowering season to preserve their optimal state for subsequent investigations into plant taxonomy and morphology. This practice ensures that herbarium collections provide a valuable resource for researchers examining various aspects of plant biology based on well-documented and preserved plant samples. With a repository exceeding a million specimens, these herbaria provide a valuable resource for addressing gaps within the phenological data networks, presenting an extensive dataset encompassing reproductive, flowering, and population-related information, as well as taxonomic differences over time (Besnard et al., 2018; James et al., 2018).

The first attempt at applying herbarium data in a phenological study conducted by Rivera et al. (2001) utilized both field observations and herbarium collections to identify flowering periods that were highly synchronized (Jones & Daehler, 2018). However, it's important to note that the study done by Rivera et al. (2001), did not specifically focus on investigations related to climate change.

Utilization of Herbarium Data for Phenological Application in Climatic Change Investigations

Primack et al. (2004) assessed the impact of climate change on the flowering times of plant species by comparing field observations of the year 2003 with 229 living plants and with historical herbarium records from museums dating back to 1985–2002 of 372 plants. The study utilized herbarium specimens, extracting the collection dates, and converting them into Julian dates to compare these herbarium data from the past century with current flowering dates from the field observations. The purpose of this application was to evaluate long-term shifts in flowering times and species responses to springtime temperature

changes (Figure 1). This study was based on the hypothesis that plants would demonstrate earlier flowering in response to a warmer climate. In this research, multiple regression analysis has been used to examine the relationship between flowering times, temperature changes, and years (Figures 2, 3). The number of days that plants flowered earlier or later in the past than they did in 2003 was calculated as the Julian date from the herbarium specimens, subtracted from the peak flowering date in 2003.

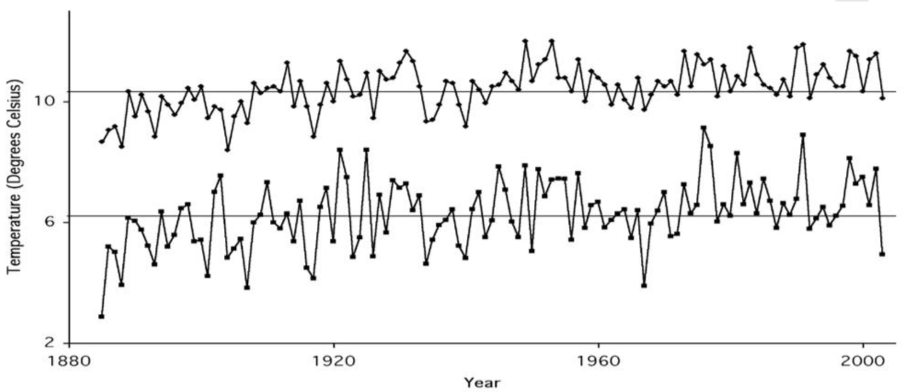

Figure 1: The location of the study of Primack et al*.,* 2004 was under-taken, Boston temperatures from 1885 to 2003. The top series (diamonds) represents mean annual temperatures. The bottom series (squares) represents mean temperatures in February, March, April, and May. The two horizontal lines represent the long-term mean temperatures for each series. (Primack et al., 2004)

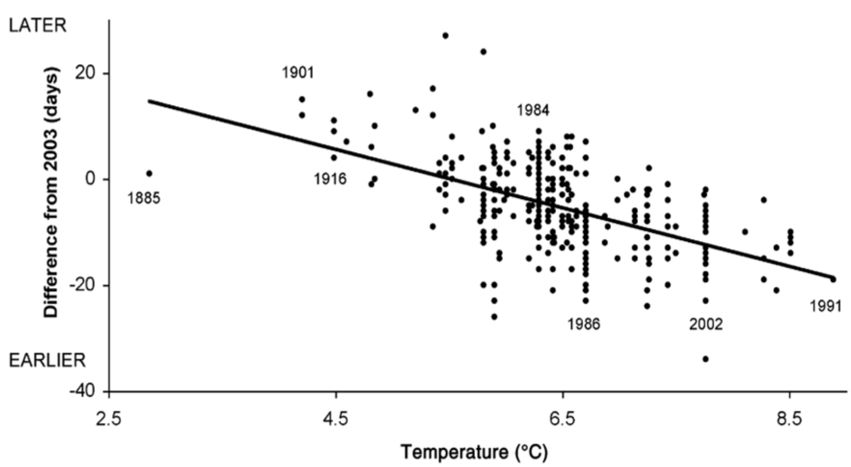

Figure 2 : Changes in flowering times of plants as temperatures increase: number of days plants flowered earlier or later in the past than they did in 2003 in relation to the average temperatures in the February, March, April and May preceding flowering. (1885- 2002- flowering times from herbarium data / 2003- field observations)Years are indicated for certain years with many specimens and years with extreme temperatures. The line is the best-fit line for the series. (Primack et al*.,* 2004)

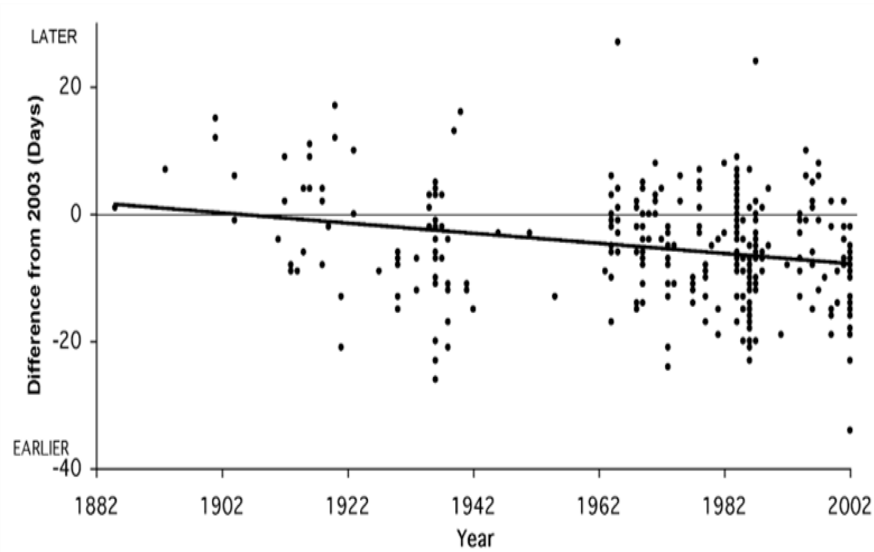

Figure 3: Changes in flowering times over time: number of d

The findings have revealed a significant trend toward earlier flowering times, with an 8-day shift towards earlier flowering from 1980 to 2002 compared to 1900 to 1920 due to the increase in mean annual temperature.

Further, this study, acknowledged by Jones et al. (2018), marks the pioneering climate change investigation using herbarium data.

When considering the studies following the research of Primack et al. *(*2004) in studies utilizing herbarium specimens, researchers commonly follow the procedure outlined by Primack et al. (2004) that was summarized above.

Table 1 : Recent studies that have used herbarium data to examine the implications of climate change.

Authors	Year	Geographic Region	Period	No of Specimens / No of Species	Phenophase/ Phenophases
Primack *et al*	2004	North America	1885-2002	372 of 37 sps.	Flowering
Lavoie and Lachange	2006	Southern Quebec, Canada	1971-2000	216 of 39 sps.	Flowering
Miller_Rushing *et al*	2006	North America	1881-2004	142 of 3 sps.	Flowering
Panchen *et al*	2012	North America	1840- 2010	2539 of 28 sps.	Flowering
Calinger *et al*	2013	North America	1895-2015	5053 of 36 sps.	Flowering
Harta *et al*	2014	China	1884- 2009	10295 of 36 sps.	Flowering
Everill *et al*	2014	New England	1834-2008	1599	Leaf Outing
Davis *et al*	2015	North America	1853-2012	1108 of 20 sps.	Flowering
Willis *et al*	2017b	New England	1823-2012	820 (Digitized data)	Leaf outing, buds, Flowering , Fruits,
Park *et al*	2018	United States	Over 120 years	>7000 of 30 sps. (Digitized Data)	Fruiting , Flowering
Williams *et al*	2021	Europe and North America	1901-2009	6200 of 29 sps.	Flowering
Park *et al*	2022	Brazil	1988-2003	4638 of 23 sps. (Digitized Data)	Flowering , Fruiting
Khan *et al*	2023	Himalayan Region	1878-2008	41 of 1 sps.	Flowering

Pearson *et al*	2021	North America	1901-2001	993	Flowering (Digitized data)

The study conducted by Lavoie and Lochance (2006) focused on the adjustment of flowering dates for plant species based on the date of snow cover disappearance in the collection region. The researchers used a reference point, specifically the earliest snowmelt date, and utilized a herbarium-based method for reconstructing the flowering dates of plant species. This method involves the use of preserved plant specimens of Coltsfoot (*Tussilago farfara* L.) to gather information about flowering dates. The information supported in this study highlights that herbarium-based phenological studies on climatic change are more reliable for the spring flowering plant than the summer or fall flowering species (Lavoie & Lachance, 2006).

Although the studies of Panchen et al. (2012) and Miller-Rushing et al. (2006) followed the basic methodology of Primak *et al*. (2004), the study utilizes a multidimensional approach, incorporating meteorological data, herbarium specimens, field observations, and photographic records to understand the impact of temperature on the flowering times of woody plants over an extensive historical period. These studies have concluded that the combined data with a multidimensional approach is an effective method to detect the climatic change.

When considering the majority of the existing studies (Table 01), they have predominantly focused on single phenological events, with flowering, mean, or peak flowering dates being the most commonly studied phenophase concerning climate change. Few investigations have attempted to quantify various events within a phenophase, highlighting the untapped potential for expanded applications of comparable techniques (Everill et al., 2014; Panchen et al., 2014; Miller-Rushing et al., 2006; Lang et al., 2018). The research done by Everill et al. (2014) evidenced the application of phenophase in leaf outings despite flowering (Figure 4). This study highlights the potential of using herbarium specimens to gather information on historical leaf-out times in temperate forests and examines the influence of climatic variations on these timings. This research also employs a comprehensive approach combining satellite-based remote sensing, modeling, weather records, and field observations. Long-term trends in leaf-out timing illuminated through herbarium records can be aligned with the observations of large-scale patterns of earlier leaf-out evident in satellite data (Lang et al., 2018). Geographically varying mean leaf-out dates, closely aligned with satellite data, underscore the value of herbarium specimens as a valuable resource for studying past leaf-out times of deciduous trees.

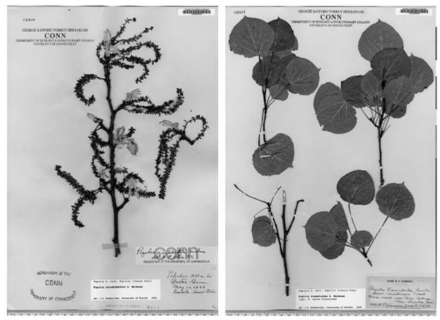

Figure 4 : Two specimens of *Populus grandidentata* accessed online that were used for the study of EnVille et al., 2014. (Young leaves and flowers are visible on the left specimen - collected 10 May 1936), but only mature leaves on the right specimen (collected 8 June 1932) (EnVille et al., 2014)

The opportunity exists to assess multiple phenological characteristics at different developmental stages using specimens, allowing for a nuanced understanding of the sensitivity of various points within a given phenophase and exploring relationships between different phenophases. However, most of the studies have used a single phenophase for their studies. Park et al. (2022) mentioned that estimates of flowering phenology were generally more consistent between specimens and field observations than the other phenophases like leaf buds, leaf outing, or fruiting.

The Sri Lanka National Herbarium in Peradeniya serves as the primary institution responsible for the authentication of plants, acting as the national repository for plant specimens in Sri Lanka. Additionally, the Herbarium of the Department of National Museums also houses a collection of herbarium data, providing resources for research studies.

However, despite the existence of these herbarium resources, their application in studying the implications of climate change in Sri Lanka appears to be limited. There is a lack of literature evidence regarding the utilization of herbarium data for such purposes within the country.

Application of Digitized Herbarium Data for the Climatic Change Investigations

Recent analyses have brought to the forefront the use of digitized herbarium data for their investigations, facilitated through crowdsourcing platforms (Table 1). As the study reveals by Park et al. (2018), phenological responses of angiosperm species using digitized specimens have been applied for the study. These global online portals collectively contain over six million digitized herbarium records, including specimen images. Crowdsourcing was employed to collect phenological data, focusing on two phenophases: flowering and fruiting states, scored based on the presence and quantity of relevant structures.

In the studies of Park et al. (2018), Willis et al. (2017), Pearson et al. (2021), and Park et al. (2022) (Table 1), they have applied the digitalized herbarium data to investigate the climatic changes. Park et al. (2022) demonstrated that assessments of tropical plant reproductive phenology using herbarium records align well with field observations. This suggests the effective utility of herbarium specimens for evaluating patterns and mechanisms of plant phenological responses in tropical regions. However, in comparison to temperate floras, there is a scarcity of phenological observational datasets for tropical plants. These studies have applied the digital specimen images and associated metadata using online databases, and crowd workers assessed peak flowering time by counting buds, flowers, and fruits. These studies compare reproductive phenology inferred from field observations with that derived from digitized herbarium specimens at various scales. They have used crowd-sourcing platforms to estimate the phenological sensitivity to temperature for both species across multiple phenophases.

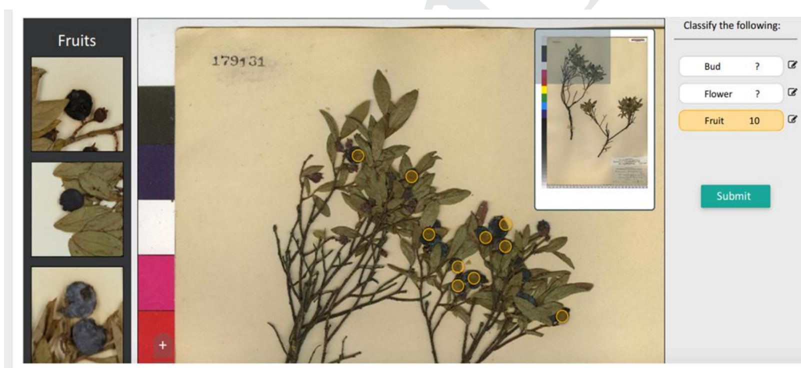

Figure 5: Herbarium Specimen of *Vaccinium angustifolium* Aiton (Lowbush Blueberry). The specimen is presented through the interface of CrowdCurio, a web-based platform for the annotation of phenological information on digitized herbarium specimens. Here, the phenological information being collected includes counts of flower buds, flowers, and fruits. Citizen scientists count each phenological trait by clicking on the presence of corresponding objects on the image (orange dots). As a reference, examples of each phenological trait are provided on the left (Willis et al., 2017b).

Limitations of Using Herbarium Data for Phenological Research

In contemporary climatic change studies, the utilization of herbarium data for phenological research has become increasingly prevalent. Despite the extensive application of such data across a diverse range of studies, it is imperative to acknowledge and address the challenges and limitations associated with its application.

When considering the collection of plants for herbarium specimens, botanists collect the plant specimens from their natural habitats, and they are subjected to a multitude of

environmental influences, encompassing not only climatic variations but also fluctuations in nutrient availability, competitive interactions, and herbivory. Consequently, specimens cultivated under controlled conditions exhibit diminished variability in nutrient availability, competition, and herbivory, variables that can substantially influence a species' responsiveness to climate change. Hence, botanical specimens sourced from controlled environments, such as botanical gardens, may offer a more discerning insight into the impacts of diverse climatic variables on phenological patterns, while concurrently mitigating the confounding effects of other ecological factors (Primack et al., 2004).

It is noticed that most of the studies have utilized the flowering phenology; however, a limited number of studies are involved with the fruiting and leaf outing phenologies (Table 1). Nevertheless, the study by Park et al. (2022) indicated that estimates of flowering phenology were generally consistent between specimens and field observations. In contrast, estimates of fruiting phenology showed weaker congruence.

The reasons for this discrepancy are: fewer herbarium specimens capture plants in fruit, creating greater uncertainty; tropical fruits may persist on the plant for extended periods, complicating age determination from digitized specimens; and smaller fruits may be confused with leaf or flower buds during scoring, reducing the accuracy of fruiting phenology estimates (Park et al., 2022).

The utilization of herbarium data in studies may introduce sampling errors attributable to variations in both collection dates and locations. By addressing these errors, Primack et al. (2004) emphasize that using the large size of herbarium data collection for the study and using the mean flowering times could yield valid interferences. As well as even if specimens were not collected at the time of peak flowering, which helps mitigate potential errors stemming from variations in collection dates relative to peak flowering times. Additionally, the specimens are sourced from a geographically consistent location; a homogenous location can effectively reduce sampling errors, enhancing the study's ability to discern and assess the impacts of climate change on plant phenology.

Although the herbarium specimens represent a non-random, non-comprehensive sampling of phenological events, the collection and expansion of the number of specimens in herbaria are mainly aimed at sampling the specimens of species from specific geographical distributions, at the same time every year. However, it is not for the purpose of phenological records, and it does not emphasize inter-annual climatic variations. Hence, the collection of phenological data from herbaria may be subjected to bias and reflect the gaps related to the first flowering date; leaf-outing dates may have little regard for the climatic changes

(Davis et al., 2015; Willis et al., 2017a; Willis et al., 2017b; Primack et al., 2022; Pearson et al., 2021).

When considering the collection of botanical specimens for the herbarium collections, there are challenges in accurate species identification and discrimination of phenological events and phases. Despite efforts by experienced botanists, misidentifications or labels based on outdated taxonomies may occur. The advantage lies in the potential to revisit and confirm species and phenophase identifications for herbarium data, a flexibility not readily available in observational datasets. Herbarium data are susceptible to unique biases due to their opportunistic nature, influenced by botanists' interests, schedules, and locations, rather than specifically capturing plant phenological status. Furthermore, biases related to plant habit, morphology, and nativity may occur. For example, preferences for larger, showier plants result in potential limitations in the representation of smaller species, plants with specific inflorescence colors, or introduced species in herbarium datasets (Willis et al., 2017[b]). Another collection bias highlighted in the literature is the common practice of amassing a substantial number of specimens during a single collecting trip. This tendency often leads to oversampling, contributing to the production of duplicate specimens distributed to various institutions. These duplicates, mistakenly treated as independent samples, pose a significant challenge. Recognizing the prevalence of this issue, ongoing initiatives are dedicated to enhancing the reconciliation of duplicate records within databases and data portals.

Extraction of the phenological data from a huge herbarium collection dated back over 50 or 100 years is a time-consuming and labor-intensive task, and this limits the utilization of herbarium data (Brenskelle et al*.,* 2019). Recent studies have addressed this limitation by suggesting and applying crowdsourcing platforms and effective automated applications to extract the herbarium data.

When considering the studies done in the past two decades, more studies have been conducted for temperate regions than tropical biomes. The studies have shown that understanding phenological patterns in tropical biomes from herbarium specimens is difficult because tropical species often have irregular reproductive cycles, with some producing flowers or fruits multiple times a year, unlike species in temperate biomes.The challenge becomes evident when considering species in the Amazon Rainforest that may only flower four times in 25 years. In such cases, the timing of flowering peaks can vary widely throughout the year, especially for less studied species and different stages of their life cycle.

This variability makes it difficult to accurately determine phenological patterns from herbarium specimens alone, resulting in greater discrepancies in estimating fruiting times, as noted by Primack et al. (2022). Furthermore, herbarium specimens often represent only a portion of a plant and may not accurately reflect the overall phenological stage of an individual. This concern is particularly relevant in tropical ecosystems with abundant tree species, where priority is given to the collection of reproductive materials.

Several studies have highlighted that herbarium specimens frequently capture only a partial representation of an entire plant, particularly woody perennials. It is crucial to carefully assess the extent to which specimens accurately depict the phenology of the complete plant or the local population from which they are extracted. This recognition underscores the limitations of utilizing herbarium data comprehensively (Primack et al., 2022).

Sometimes inferring phenophases from digital images poses challenges for certain plant taxa, such as *Miconia, leandra* (Melastomataceae), and many Chrysobalanaceae species, due to tiny, clumped, or overlapping buds and flowers. Recognizing fruits can be especially challenging, leading to difficulties in quantifying reproductive organs and assessing phenological stages without physical specimens. However, expert botanists can manually discern and quantify reproductive organs from high-resolution digital images. Recent advancements in machine learning applications and technological development offer promise for automated data extraction with accuracy comparable to or better than that of non-expert humans, even in distinguishing between flowering and fruiting stages. (Primack et al., 2004; Park et al., 2022)

In the study of phenology, the likelihood of plants being collected diminishes at the outset or conclusion of a reproductive season, particularly if a species proves challenging to identify during these phases or remains inconspicuous. A study by Davis et al. (2015) reveals that estimates for the first flowering date derived from specimens tended to be, on average, 3 days later than those obtained from field observations. To aid in identification, botanists have the discretion to collect only those individuals displaying a specific phenological stage, such as mature flowers or fruits. Nevertheless, it is worth noting that botanists might intentionally gather plants that are flowering or fruiting out of season, rendering them unrepresentative of the species' typical phenology. However, such atypical records may still hold ecological significance, as they can offer insights into shifts in phenological patterns potentially driven by environmental triggers such as climate change. The digitization of herbarium data introduces potential biases in data quality, which may occur during collection, label transcription, or digitization processes. Errors in location or collection date transcription can arise due to ambiguous handwriting or descriptions. The task of transcribing phenophases from digital images is more challenging compared to physical specimens. Resolving errors relies on contextual clues, necessitating careful assessment and management of each aspect of data quality in phenology studies. Challenges also arise from variations in recording methods across countries and individuals, impacting data aggregation. Ongoing efforts are directed towards standardizing and integrating this data. Despite potential biases, herbarium records offer strengths when species and phenological phases are carefully selected, observers are well-trained, imaging is of high quality, and statistical methods are developed (Willis et al., 2017[b]).

Herbarium Data for Phenological Studies Future Direction

With the leveraging of digital advancement and spatiotemporal depth, the studies are looking forward to enhancing the advancement of the digital infrastructure. As addressed by the researchers, future directions of the digitalization facilities should be directed to capture phenological data from digitized specimens, focusing on species with not only flowering seasons and responses to climatic change but also leaf-out, transitions from bud to flower, peak flowering time, transition to fruiting, seed dispersal timing. The overall implication is that herbarium specimens offer valuable insights into various ecological responses to climate change beyond flowering.

While digitization efforts are underway, only a fraction of the global herbarium specimens have been digitized. Large-scale digitization is emphasized to enhance research and support projects, but the true power of herbaria lies in their continuity through time. Challenges include declining collection efforts and insufficient support for herbaria worldwide, leading to reduced data for modeling, especially in tropical regions.

Continued and consistent global collection efforts are deemed essential to maintain herbaria as valuable repositories of genetic variation and diversity, crucial for climate change research and understanding adaptation and evolution. Despite growing recognition, herbaria remain underused in this context, emphasizing the need for guidelines, protocols, and quality standards to promote high-quality sequencing data and DNA preservation-informed efforts in the future.

According to the current literature evidence, the utilization of herbarium data in Sri Lanka for assessing the implications of climatic change has been documented as considerably limited. This underscores the significant underutilization of available data resources in the area of research studies. Herbarium collections, serving as invaluable repositories of botanical specimens, offer a wealth of historical and contemporary plant biodiversity data. However, despite their potential, the incorporation of herbarium data into climate change research in Sri Lanka remains notably deficient.

In light of the pressing challenges posed by climate change, particularly in a region as biodiverse as Sri Lanka, harnessing the full potential of herbarium data becomes imperative. These collections provide valuable insights into changes in species distributions, phenology, and ecological interactions over time, offering a crucial foundation for understanding the ecological impacts of climate change. Moreover, the longitudinal nature of herbarium records enables the reconstruction of historical climate patterns, facilitating assessments of long-term climatic trends and variability.

Efforts to enhance the utilization of herbarium data in climate change research should encompass several key strategies. Firstly, fostering collaborations between botanists, climatologists, and other relevant stakeholders is essential for promoting interdisciplinary research initiatives that capitalize on the complementary expertise and resources across disciplines. Additionally, investing in digitization initiatives to digitize herbarium specimens and associated metadata can facilitate broader accessibility and utilization of these valuable data resources.

In conclusion, the underutilization of herbarium data in assessing the implications of climatic change in Sri Lanka represents a significant gap in current research endeavors. Addressing this gap requires concerted efforts to promote interdisciplinary collaborations, invest in digitization initiatives, and build research capacity within the scientific community. By harnessing the full potential of herbarium data, we can enhance our understanding of the ecological impacts of climate change and inform evidence-based conservation and management strategies in Sri Lanka and beyond.

2. References

1. Ahas, R., & Aasa, A. (2006). The effects of climate change on the phenology of selected Estonian plant, bird and fish populations. *International Journal of Biometeorology*, *51*(1), 17–26. https://doi.org/10.1007/s00484-006-0041-z

2. Besnard, G., Gaudeul, M., Lavergne, S., Muller, S., Rouhan, G., Sukhorukov, A. P.,... Jabbour, F. (2018). Herbarium-based science in the twenty-first century. *Botany Letters*, *165*(3–4), 323–327. https://doi.org/10.1080/23818107.2018.1482783

3. Brenskelle, L., Stucky, B. J., Deck, J., Walls, R., & Guralnick, R. P. (2019). Integrating herbarium specimen observations into global phenology data systems. *Applications in Plant Sciences*, *7*(3). https://doi.org/10.1002/aps3.1231

4. Calinger, K. M., Queenborough, S., & Curtis, P. S. (2013). Herbarium specimens reveal the footprint of climate change on flowering trends across north-central North America. *Ecology Letters*, *16*(8), 1037–1044. https://doi.org/10.1111/ele.12135

5. Daru, B. H., van der Bank, M., & Davies, T. J. (2017). Unraveling the evolutionary origins of biogeographic assemblages. *Diversity and Distributions*, *24*(3), 313–324. https://doi.org/10.1111/ddi.12679

6. Davis, C. C., Willis, C. G., Connolly, B., Kelly, C., & Ellison, A. M. (2015). Herbarium records are reliable sources of phenological change driven by climate and provide novel

insights into species' phenological cueing mechanisms. *American Journal of Botany*, *102*(10), 1599–1609. https://doi.org/10.3732/ajb.1500237

7. Everill, P. H., Primack, R. B., Ellwood, E. R., & Melaas, E. K. (2014). Determining past leaf-out times of New England's deciduous forests from herbarium specimens. *American Journal of Botany*, *101*(8), 1293–1300. https://doi.org/10.3732/ajb.1400045

8. Hart, R., Salick, J., Ranjitkar, S., & Xu, J. (2014). Herbarium specimens show contrasting phenological responses to Himalayan climate. *Proceedings of the National Academy of Sciences*, *111*(29), 10615–10619. https://doi.org/10.1073/pnas.1403376111

9. Hatfield, J. L., Antle, J., Garrett, K. A., Izaurralde, R. C., Mader, T., Marshall, E., and Ziska, L. (2018). Indicators of climate change in agricultural systems. *Climatic Change*, *163*(4), 1719–1732. https://doi.org/10.1007/s10584-018-2222-2

10. Heberling, J. M., Prather, L. A., & Tonsor, S. J. (2019). The Changing Uses of Herbarium Data in an Era of Global Change: An Overview Using Automated Content Analysis. *BioScience*, *69*(10), 812–822. https://doi.org/10.1093/biosci/biz094

11. Index Herbariorum: The William & Lynda Steere Herbarium. https://sweetgum.nybg.org/science/ih/. Accessed 29 January 2024.

12. James, S. A., Soltis, P. S., Belbin, L., Chapman, A. D., Nelson, G., Paul, D. L., & Collins, M. (2018). Herbarium data: global biodiversity and societal botanical needs for novel research. *Applications in Plant Sciences*, *6*(2). https://doi.org/10.1002/aps3.1024

13. Jones, C. A., & Daehler, C. C. (2018). Herbarium specimens can reveal impacts of climate change on plant phenology; a review of methods and applications. *PeerJ*, *6*, e4576. https://doi.org/10.7717/peerj.4576

14. Khan, S., Gaira, K. S., Asgher, M., Verma, S., Pant, S., Agrawala, D. K., and Kesawat, M. S. (2023). Temperature Induced Flowering Phenology of Olea ferruginea Royle: A Climate Change Effect. *Sustainability*, *15*(8), 6936. https://doi.org/10.3390/su15086936

15. Lang, P. L. M., Willems, F. M., Scheepens, J. F., Burbano, H. A., & Bossdorf, O. (2018). Using herbaria to study global environmental change. *New Phytologist*, *221*(1), 110–122. https://doi.org/10.1111/nph.15401

16. Lavoie, C., & Lachance, D. (2006). A new herbarium-based method for reconstructing the phenology of plant species across large areas. *American Journal of Botany*, *93*(4), 512-516. https://doi.org/10.3732/ajb.93.4.512

17. Lima, D. F., Mello, J. H. F., Lopes, I. T., Forzza, R. C., Goldenberg, R., & Freitas, L. (2021). Phenological responses to climate change based on a hundred years of herbarium collections of tropical Melastomataceae. *Plos One*, *16*(5), e0251360. https://doi.org/10.1371/journal.pone.0251360

18. MacLean, H. J., Nielsen, M. E., Kingsolver, J. G., & Buckley, L. B. (2018). Using museum specimens to track morphological shifts through climate change. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *374 (1763*), 20170404. https://doi.org/10.1098/rstb.2017.0404

19. Miller-Rushing, A. J., Primack, R. B., Primack, D., & Mukunda, S. (2006). Photographs and herbarium specimens as tools to document phenological changes in response to global warming. *American Journal of Botany*, *93*(11), 1667–1674. https://doi.org/10.3732/ajb.93.11.1667

20. Panchen, Z. A., Primack, R. B., Aniśko, T., & Lyons, R. E. (2012). Herbarium specimens, photographs, and field observations show Philadelphia area plants are responding to climate change. *American Journal of Botany*, *99*(4), 751–756. https://doi.org/10.3732/ajb.1100198

21. Park, D. S., Breckheimer, I., Williams, A. C., Law, E., Ellison, A. M., & Davis, C. C. (2018). Herbarium specimens reveal substantial and unexpected variation in phenological sensitivity across the eastern United States. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *374 (1763*), 20170394. https://doi.org/10.1098/rstb.2017.0394

22. Park, D. S., Lyra, G. M., Ellison, A. M., Maruyama, R. K. B., dos Reis Torquato, D., Asprino, R. C., and Davis, C. C. (2022). Herbarium records provide reliable phenology estimates in the understudied tropics. *Journal of Ecology*, *111*(2), 327–337. https://doi.org/10.1111/1365-2745.14047

23. Park, I. W., & Schwartz, M. D. (2014). Long-term herbarium records reveal temperature-dependent changes in flowering phenology in the southeastern USA. *International Journal of Biometeorology*, *59*(3), 347–355. https://doi.org/10.1007/s00484-014-0846-0

24. Pearson, K. D., Love, N. L. R., Ramirez-Parada, T., Mazer, S. J., & Yost, J. M. (2021).

25. Phenological trends in the california poppy (*Eschscholzia californica*): Digitized herbarium specimens reveal intraspecific variation in the sensitivity of flowering date to climate change. Madroño, 68(4). https://doi.org/10.3120/0024-9637-68.4.343

26. Primack, D., Imbres, C., Primack, R. B., Miller-Rushing, A. J., & Del Tredici, P. (2004). Herbarium specimens demonstrate earlier flowering times in response to warming in

Boston. *American Journal of Botany*, *91*(8), 1260–1264. https://doi.org/10.3732/ajb.91.8.1260

27. Ramirez-Parada, T. H., Park, I. W., & Mazer, S. J. (2022). Herbarium specimens provide reliable estimates of phenological responses to climate at unparalleled taxonomic and spatiotemporal scales. *Ecography*, *2022*(10). https://doi.org/10.1111/ecog.06173

28. Schröder, W., Schmidt, G., & Schönrock, S. (2014). Modeling and mapping of plant phenological stages as bio-meteorological indicators for climate change. *Environmental Sciences Europe*, *26*(1). https://doi.org/10.1186/2190-4715-26-5

29. Singh, R., Rawat, M., Chand, T., Tripathi, S., & Pandey, R. (2023). Phenological variations in relation to climatic variables of moist temperate forest tree species in western Himalaya, India. *Heliyon*, *9*(6), e16563. https://doi.org/10.1016/j.heliyon.2023.e16563

30. Williams, T. M., Schlichting, C. D., & Holsinger, K. E. (2021). Herbarium records demonstrate changes in flowering phenology associated with climate change over the past century within the Cape Floristic Region, South Africa. *Climate Change Ecology*, *1*, 100006. https://doi.org/10.1016/j.ecochg.2021.100006

31. Willis, C. G., Ellwood, E. R., Primack, R. B., Davis, C. C., Pearson, K. D., Gallinat, A. S., and Soltis, P. S. (2017a). Old Plants, New Tricks: Phenological Research Using Herbarium Specimens. *Trends in Ecology & Evolution*, *32*(7), 531–546. https://doi.org/10.1016/j.tree.2017.03.015

32. Willis, C. G., Law, E., Williams, A. C., Franzone, B. F., Bernardos, R., Bruno, L., Davis, C. C. (2017b). CrowdCurio: an online crowdsourcing platform to facilitate climate change studies using herbarium specimens. *New Phytologist*, *215*(1), 479–488. https://doi.org/10.1111/nph.14535

JOURNAL OF TROPICAL ENVIRONMENT

Vol. 4, Issue I and II, (December) 2024

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Archeological and Environmental Perspective of the Coconut (*Cocos nucifera*): Earliest Evidence in the World

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Abstract

The existing literature provides different interpretations about the origin of the Coconut (Cocos nucifera). According to the botanical and agricultural sciences analysis, different varieties of coconut have different characteristics. Sri Lanka is one of the major countries in coconut production and the fourth largest coconut exporter globally. Coconut serves various purposes such as food, medicinal, as raw material for cosmetic production, architectural material, agricultural, household, ornamental products, and many more. The problem is, When and where coconut originated? In this case it's expect to search origin, evolution, domestication and expansion of coconut, base on historical and qualitative case study systems. The origin of the coconut, fossils of primitive coconut found in the Eocene and Miocene eras date back to the prehistoric period. Subsequently, coconut was domesticated and evolved. Coconut fossil analysis reveals that coconut originated in northern Australia, Indonesia, Malaysia, and India (Sri Lanka and India were in the same land in the ancient Pangea continent). According to the views of the scholars, the first documented evidence about coconut was found in the book called ‘ Topographia Christiana’ written by the Cosmas in 545 A.D. Thereafter, Sinbad, the sailor's story of “One Thousand and One Night’’ and various documentary evidence and travelers’ reports were produced since 1510 A.D.

However, it is important to note that comprehensive details on coconut were found in the book written by the Italian author Antonio Pigafetta in early 16th century.

However, according to the present study findings, the historical documentary evidence produced on coconut was rejected based on the historical and Buddhist commentaries and archeological evidences in Sri Lanka. Though the origin of the coconut palm is still the subject of debate, it is generally accepted that the palm originated in the India- Indonesia region and float-distributed itself worldwide by rigging ocean currents. Based on the findings of this paper, it can be concluded that the oldest history of coconut can be found in Sri Lanka but not in other parts of the world as mentioned in previous literatures.

Keywords: *Archeology, Coconuts, history, origin, fossils, inscriptions*

1. Introduction

The term 'Coconut' (Nucifera) can refer to the entire coconut palm, the seed, or the fruit, which botanically is a drupe, not a nut. The specific name nucifera is Latin for "nut-bearing." Cocos nucifera, the coconut tree, is a member of the Arecaceae palm family and the only species of the genus Cocos (RBGW; 43). The name of cocoanut is an archaic form of the word (COD 1999; 130). The term is derived from the 16th century A.D. Portuguese and Spanish word, 'Coco' meaning head or skull, from the three indentations on the coconut shell that resemble facial features (Gla). Evidently, the name 'coco' and 'coconut' derived from the encounters of Pacific Islanders (1521), and not from the other regions where it was found, as no name is similar in any of the languages of India where the Portuguese discovered the fruit. Barosa and Garcia, in mentioning the Tamil or Malayalam name 'tenga' and 'canarese naira' expressly say, "We call these fruits quoquos, our people have given it the name of coco, and that which we call coco and the Malabars temga other facts to explain the origin of the word have come to light." The OED states, Portuguese and Spanish authors of the 16 century agreeing to identify the word with Portuguese and Spanish coco "grinning face," "grin grimace," and also "bugbear," "Scarecrow" cognate with cocar to grin make a grimace the name being said to refer to the face – like appearance of the base of the shell, with its three holes. According to Losada, the name came from Portuguese explores, the sailors of Vasco da Gama in India, who first brought them to Europe. The Coconut shell reminded them of a ghost or witch and Portuguese folklore called coco and caca (Losada & Fernando Dies, 2004. 481; Figueiredo & Candido, 1940: 203).

1.2. Classification

The coconuts are generally classified into two major types as tall (var. typica) and dwarf (var. nana). On fertile soil, a tall coconut tree can yield up to 75 fruits per year, and given proper care and growing conditions, the tree produces its first fruits in six to ten years, taking 15 - 20 years to reach peak production (Grim Wood BE, Ashman, F, 1975: 1,2; Pradeep Kumar, etal 2008). Botanically, the coconut fruit is a drupe, not a true nut. Like other fruits, it has three layers: exocarp, mesocarp, and endocarp. The exocarp and mesocarp make up the husk of the coconut. The mesocarp is composed of a fiber, called coir, which has many traditional and commercial uses. A full-sized coconut weights about 1.44 kg (3.21 b). It takes around 6000 full-grown coconuts to produce a ton of copra (Bourke, Michael, & Tracy Harwood, 2009: 327).

The coconut tree (Cocos nucifera) is a palm found in most tropical regions, growing on coasts and producing the coconut (Annandale, 130:10). The structure of the coconut tree, except on rare occasions, is an unbranched cylindrical column, which sometimes reaches a height of 80 to 100 feet with a diameter of three feet or even less at the base. It is, therefore, very clear that the stem needs great strength and elasticity to enable it to bear the weight of the crown of leaves and bunches of nuts it carries at the apex and stand the force of strong winds common on the seashore where the palm is usually found. A cross-section of the coconut stem shows the distribution of a fibro-vascular bundle throughout the ground tissue made up of cells, the whole enclosed in a strong fibrous cortex or false bark. Hence, from its structure, the stem can withstand the great strain and bend to the force of the wind without breaking. At the same time, the root system, with its innumerable spreading branches, gives the tree such a firm grip on the soil that it is only under exceptional circumstances that it gets blown flat. Through the vessels in the bundles, distributed throughout the system in association with fibers, water with mineral plant food in a solution taken up by the roots travels up to the leaves and is converted into organic matter. The tree, like all monocotyledons, has no taproot. The system's base entering the ground is usually conical and embedded to a depth of 2 or 3 feet (CPM, 1923: 12). The number of roots produced depends on the tree's age and the environment, possibly more than 3600 roots on a 60 to 70-year-old tree.

1.3. Production and Array of Benefits

Coconuts are known for their great versatility, evidenced by many edible, economic, industrial, cultural, traditional, and religious uses ranging from food to cosmetics. They form a regular part of the diets of many nations in tropical and subtropical countries. They are distinct from other fruits for their large quantity of ‘water’ of tender – nuts or jelly –

nuts and can be harvested for their potable sweet water. When mature, they still contain some water and may be used as seed nuts or processed to derive oil from the kernel,

charcoal from the hard shell, and coir from the fibrous husks. The endosperm is initially in its nuclear phase suspended within the coconut water. The cellular layers of endosperm deposit along the walls of the coconut, becoming the edible 'flesh' and milk derived from the fresh flesh.

When dried, the coconut flesh produces 'copra.' The oil derived from copra is commonly used in cooking and frying and in soaps and cosmetics. The timbers, husks, and leaves are used as raw materials to make roofs and various products for furnishing and decorating. Further, every part of the coconuts has traditional, cultural, indigenous medicinal, and religious significance in some societies, especially in India and Sri Lanka, which practices Hinduism (Partil & Vimala, 2016: 18) and Buddhism.

1.4. Origin and Varieties

The modern coconuts have two different species, essentially a Pacific version and an Atlantic species. However, all modern coconuts appear to be domesticated plants than the more primitive forms found in fossils in North Australia and Indonesia. The conventional scientific opinion supports an Indo – Pacific origin, either around Melanesia and Malesia or the Indian Ocean (Jackson, 2006: 16).

According to modern scientific research and experiments, the oldest fossils known of the modern coconut dating from the Eocene period from around 37 to 55 million years ago were found in Australia and India. Still, older palm fossils such as some of the nipa fruits were found in the Americas. A species with strawberry-sized nuts (Cocos zeylanica) lived in New Zealand in the Miocene era. Since 1978, tracing the probable origin and dispersal of Cocos nucifera has only recently been augmented by a publication on the germination rate of the coconut seed nut and another on the importance of the coral atoll ecosystem. Briefly, the coconut originated in the coral atoll ecosystem – without human intervention - and required a thick husk and slow germination to survive and disperse (Harries, HC 1978: 265 – 309; 2013: 565 – 570; Harries, H. 2012: 45).

1.5. History and Evolution

Historically, one of the earliest mentions of the coconuts is "One Thousand and One Nights" story of Sinbad, the Sailor; he is known to have bought and sold coconut during his fifth voyage (TFVSS, 2009: 1). Thenga is its Malayalam and Tamil name, used in the detailed description of coconut found in itineraries by Ludovico di Varthema published in 1510 and also in the later Hortus Indicus Malabavicus. Even earlier, it was called nux indicia, a name used by Marco Polo in 1280, while in Sumatra, taken from the Arabs who called it jawz hindi. Both names translate to Indian nut: In the earliest description of the coconut palm known, given by Cosmos of Alexandria in his Topography Christiana written

about 545 A.D., there is a reference to the Argell tree and its drupe (Elzebroek, ATG & Kop Wind, 2008: 186 - 192 and Rosengrten, Frederic, JR 2004: 65 - 93).

In 1521, Antonio Pigafetta presented a detailed description of the coconut by writing in Italian and using the words "Cocho" and "Cochi" as recorded in his journal after the first European crossing of the Pacific Ocean during the Magellan circumnavigation and meeting the inhabitants of what would become known as 'Guam' and the Philippines. He explained how in Guam "they eat coconuts" (Mangiano cochi), and the natives there "anoint the body and the hair with coconut and bean seed oil." The journal then details how Magellan's expedition landed at Suluan, east of Leyte Gulf in the Philippines, on the following week. There the natives gave them gifts, which included two coconuts (dui cochi), indicating that the name "coconuts" would be brought later. Pigafetta then provided many details on how the Philippines' natives use and process coconuts (Rosengarten, Frederic, JR, 2004: 65 – 93; Antonio Pigafetta, 1906).

Although the origin of the coconut palm is still the subject of debate, it is generally accepted that the coconut originated in the Indian – Indonesia region and float – distributed itself worldwide by riding ocean currents. Most of these claims one vigorously disputed. O. F. Cook was one of the earliest modern researchers to conclude the location of origin of Cocos nucifera based on its current-day worldwide distribution. He hypothesized that the coconut originated in the Americas, believing that American coconut populations predated European contact. He considered pan-tropical distribution by ocean currents improbable. Thor Heyerdahl later used this as one part of his hypothesis to support his theory that the Pacific Islanders originated as two migration steams from the Canadian Pacific coast (themselves recent migrants from Asia) to Hawaii and on to Tahiti and New Zealand in a series of hops, and another migration from South America via sailing balsa – wood rafts (Heyerdahi, Thor, 1950: 260; Cook, OF, 1901: 37).

It is said that coconut can travel by sea for 110 days, or 4800 km, and still germinate. (Edmondson, C.H. 1941: 293 – 304) This figure has been questioned based on the extremely small sample size that forms the basis of the paper that makes this claim. On the other hand, coconuts could not reach inland locations without human intervention, and early germination on the palm (vivipary) was necessary (Harries, H. 2012: 45) rather than increasing the number or size of the edible parts of a fruit that was already large enough. Anyhow, coconuts are grown in approximately 90 countries globally, with a total production of 62 million tons per year. Most of the world's production is in tropical Asia, with Indonesia, the Philippines, India, Brazil, and Sri Lanka collectively accounting for 73% of the world total, the highest coconut production in 2013.

Indonesia	18.3% (millions of tons)
The Philippines	15.3%
India	11.9%
Brazil	2.9%
Sri Lanka	2.5% (FAO STAT, 2013; 36)

1.6. Cultivation

Coconuts need high humidity (70 – 80% +) for optimum growth; hence they are rare in low humidity areas. However, they can be found in humid areas with low annual precipitation, such as in Karachi, Pakistan, which receives only about 250 mm (9.8 in) of annual rainfall but is consistently warm and humid. If they had evolved in India, then it can expect that the extensive trading that existed between the Mediterranean cultures and India and Pakistan – Indus and Ganges Valley civilizations would have ensured that the plant was well known to the Egyptians, Romans, and Greeks from a very early stage. However, this was not to be so until the possible time of Alexander the Great.

Kerala, Tamil Nadu, Karnataka, Pondiceherry, Andhra Pradesh, Goa, Maharashtra, Odisha, and West Bengal, Islands of Lakshadweep, Andaman, and Nicobar are the traditional coconut cultivation states in India. Four southern states combined account for almost 90% of the total coconut production in the country: Tamil Nadu (33.84%), Karnataka (25.15%), Kerala (23.96%), and Andhra Pradesh (7.16%). The balance of 10% is from Goa, Maharashtra, Odisha, West Bengal, Tripura, and Assam (NE) states. While Tamil Nadu leads among all states, Coimbatore and Tirupur regions are two places of coconut production (CDBGI, 2015: 8; The Guardian, 2016: 20).

1.7. Sri Lankan Context

In this context, in Sri Lanka, a tropical country, coconut cultivation was originally confined to the coast and sea level under the impression that proximity to the sea was a sine qua non. Still, this theory having been explored, and you now find the cultivations around Kandy, Peradeniya, Gampola, the Dumbara Valley, Matale, and up to Badulla, 100 miles from and 2000 feet above the sea level. At higher elevations, the nuts tend to become small. Though the palm will grow even at 4000 feet elevation, it does not fruit at such high altitudes. In modern times, the prominent coconut growing districts are Colombo, Henaratgoda, Veyangoda, Negambo, Chilaw, Puttalam, Kurunegala, Galle, Matara, Batticaloa, and Jaffna. Along the western and southern coastline, the trees are primarily used to produce toddy to be supplied to arrack distilleries (Ferguson, 1885; 9).

The varieties and forms of coconuts grown in Sri Lanka are classified into 15 different forms as per three varieties:

Variety & form	**Common name**
Typica Typica	Sri Lanka Tall
Typica Gon Thembili	Gon Thembili
Typica Nawasi	Nawasi
Typica / Pora pol	Pora pol
Typica / Ran Thembili	Ran Thembili
Typica / Kamandala	Kamandala
Typica / Bodiri	Bodiri
Typica / Dikiri	Dikiri
Aurantiaca / Nawasi Thembili	Nawasi Thembili
Aurantiaca / Rathran Thembili	Rathran Thembili
Nana / Green Dwarf or Pumila	Green Dwarf
Nana / Yellow dwarf or Eburnea	Yellow Dwarf
Nana / Red Dwarf or Regia	Red Dwarf
Nana / Brown Dwarf or Draune	Brown Dwarf

The three varieties, namely, Typica, Nana, and Aurantiaca, are cultivated in Sri Lanka, most introduced by the National Coconut Research Institute. They identified these varieties during a coconut germplasm exploration mission in the Southern Province of Sri Lanka. The visual morphological features of several new coconut morphotypes were characterized to include them in the taxonomic classification of coconuts in the country (Ekanayake, etal 2010: 10). According to some botanists, botanical evidence reveals that coconut is a native of Tropical America and was carried westward across the Pacific.

From Polynesia, it is presumed that it reached New Guinea and Malaya and found its way to Sri Lanka. However, de Candolle, a botanist, believed that its original habitat was the Eastern Archipelago, close to Sumatra and Java. The nuts floated East and West (Ferguson, J. 1923: 7 - 11) and reached Sri Lanka. Finally, the latest Scientific conclusion supports an Indo–Pacific origin around Melanesia and Malaysia, and the Indian Ocean. Accordingly, coconuts possibly may have arrived in India and Sri Lanka when they were the same land at the time of the Pangea Sub–Continent. Anyhow, coconut palm is not found in the Sri Lankan forests.

One Sanskrit name for the coconut is Mahaphala, which means ‘large nut’ (maha=large phala=nut). Coconut palm bears its nut all around the year, hence the Sanskrit synonym, Sadaphala, signifying ‘everyday nuts’ (Sada = every day or ever. Pahala = nuts). Furthermore, Deergha Vruksha signifying ‘long tree’ (Deergha = long Vruksha = tree), is used in Sanskrit for this palm as it has a long trunk or its long lifetime, and also Trunaraja signifying ‘the king of grass.’ (Truna = grass Raja = King). Another Sanskrit name for the coconut is Narikel. (Gunawardana, Gabriel, GW 1917: 176-177; SME 1947: 66). The Pali (Magadhi) name for the Coconut is Nalikera<while Narikela<Nariyal in Hindi, Tenkai in Tamil, and Tenkey chettu in Telugu languages.

1.8. Earliest Evidence

The modern Sinhalese name for the coconut is *pol*, while the ancient names were Pulup, Neralu, and Maruk. Accordingly, the word ‘pol’ may have derived from the Sanskrit name Mahaphala (pol<pulup<mahaphala), and Neralu from Pali word ‘Narikela’ through the Prakrit language (old Sinhalese Neralu<nadia<Narikela). Because the word Nadira was used for coconut in the ancient inscriptions in Sri Lanka (Paranavitana, S., 1983: 31-34), not only a Sinhala word but also Bengali (Narikela) and Hindi (Nariyal) words may have originated from the Pali word *narikela*. A close relationship exists between the four terms mentioned above.
For the first time in Sri Lankan history, the palm tree is mentioned in the Pandukabhaya legend of the Mahavamsa, the great chronicle. When king Pandukabhaya established the city of Anuradhapura, he also dedicated a palmyra tree as an abode for Vyadadeva (Vyadadevassa talakam), probably the God of Veddas tribe close to the royal precincts in the fourth century B.C. (MV. 10-89). Megasthenes has mentioned palm trees in Sri Lanka in the third century B.C. (AIDMA, 1960: 45). The earliest reference of the coconut palm is found in the Mahavamsa during the second century B.C. It is in connection with the story of ten paladins or warriors of the king Dutthagamini (161–137 B.C.). As described in the chronicle, the warrior Theraputtabhaya could pluck out palmyra and coconut trees and put them into the ground by catching their trunk with hands (Talanam nalikeranam khandhe abhachcha) (MV, 23-59). At the same time, the warrior Gothaymbara is said to have used a coconut tree and the warrior Mahasona a Palmyra tree as weapons to slaughter the enemies (Nalikera tarum gotha – MV. 25 – 45, and Talarukkham Mahasona – MV 25 – 46). According to this, it is possible that early writers, i.e., Megasthenes and Aelian, referred to talipot, palmyra, and coconut in the 3rd and 2nd centuries B.C.

The earliest archaeological evidence of coconut in Sri Lanka has been revealed at Mihintale, the first and foremost Theravada Buddhist monastery in the third century B.C. One of them is the Mihintale rock inscription of the king Mahadathika Mahanaga (7-19 A.D.). This inscription is engraved on the rock, forming the hillside to the right as one ascends the main flight of steps at Mihintale, about twenty feet below the point at which it lands on the plateau of the Sela – Cetiya, the small stupa with two circles of stone pillars around it at the upper terrace (Uda – maluva). (Paranavitana, 1983: 31 -34; Muller, AC & Bell, 1911 – 12). The inscription covers an area of 27 ft. by 15ft and consists of nineteen writing lines. The individual letters vary in height from 2 ¾ in. to 11 in. This inscription is one of the largest and the most carefully executed among the rock epigraphs of the Anuradhapura period. The king and the engraver were responsible for it and had carefully secured its endurance for a long time.
The epigraph had given an enumeration of the meritorious acts and the donation to the monks

(Sangha) at Cetiyagiri (Mihintale) of the king Bhatika Abhaya (22 B.C. – 7 A.D.) and his younger brother king Mahadathika Mahanaga (7-19 A.D.). The record is thus, in reality, one of the kings, Mahadathika Mahanaga. The inscription contains a list of tanks (weva) villages and lands given to Cetiyagiri. In this case, facts and several place names on the coconut are included in the lines of sentences from 8 – 11 out of the 19 lines of the epigraph.

1.9. Text – Transcription

8. (about 32 letters missing) gama ca Atarahamudahi mase-masa.
9. (about 32 letters missing) n a pakiliya nadira arabe eke punaka.
10. (Several letters missing) (ara)be Karabadara (Several letters missing) (a) rabe eke Magana – (nakarikahi) (several letters missing) (du)ve Aganagamahi nadira ara(be) eke.
11. (Several letters missing) (Cetagiriya sagah – ataya (puvu)ta yame yame va jeta (letters missing) ti gamana(a) ya (letters missing) ma (Cetagiriya).

1.10. Translation

"……………… and the village …………. month by month ……….in ……………. Antarasamudda …………. One grove of coconuts in ………………. Napakili …………. puna ……………. one grove of coconuts ………………. Karabadara …………. one grove of coconuts …………………. in Aganagama ……………… Whatever that has continued to exist for the benefit of the Sangha in Cetiyagiri ………….. The revenue of the villages ………….. of Cetiyagiri …………………. for the purpose of …………………" (Paranavitana, 1982).

Evidently, several place names in which coconut groves were present, and a few names of coconut groves are missing in the inscription. The placenames of Antarasamuddda, Napakili, Puna, Karabadara, Magana – nakarika, and Anganagama still remain, and those areas where coconut groves had. The coconut is referred to as Nadira, Narikela/Narikera<Nadira<Neralu/pol (in modern Sinhalese), while grove/plantation or garden is referred to as Arabe (Ashrama). (San,) Arama (Pali) Arab<Arabe< Aramba/Watta in modern Sinhalese), i.e., Pol Aramba (coconut grove), Tala Aramba (palmyra grove), and Puwak Aramba (areca nut grove) in the inscriptions.

Coconuts are common in the Sri Lankan diet as the primary source of dietary fat. It is also prominent in cultural, religious, social, medicinal, and possibly in the economic purpose in the ancient period. In this connection, large tree crops, such as coconut, kitul (Caryota urens C.), arecanut, talipot, palmyra, tamarind, mango, jak, orange, mee (Madhuka longifolia), banana, and lime were grown in the home gardens in addition to vegetables, yams, spices, and herbs.

The home gardens were called 'Gevatu' and 'Arub' in ancient records, and coconut palm was cultivated in large ground areas on a large scale called ‘Nadira arambe’ and later ‘Neralu arambe’ separately. Those were the coconut gardens or estates referred to in the inscription above. Coconut palm is not found in forestry areas (wild) in Sri Lanka but is cultivated throughout the low country, especially along the seacoast.

This palm, initially grown in home gardens of the coastal belt, was later cultivated on a large scale in the area, including uplands and mountainous areas where climatic and soil conditions were favorable (Siriweera, WI, 2002: 187-188).

On this ground, Paranavitana interpretation of the place names in this inscription is accurate and acceptable. “Atarahamuda, which occurs, probably as the name of a district in which a coconut grove was granted to Cetiyagiri, is Antarasamudda in Pali. In the Samatapasadika, there is the story of a monk who had a water vessel made of a coconut shell and decorated it by turning it in the lathe. He left the vessel at Antarasamudda and came to Mihintale. Another monk took away the vessel with the intention of stealing and also came to Mihintale. The first monk saw the vessel in the hand of the other and, having questioned as to how he obtained it, made a complaint to the Sangha against him. The second monk was about to be convicted of theft when the question of the value of the stolen object was raised. It was pleaded on behalf of the accused that coconut was very plentiful in Antarasamudda, and coconut shells were thrown away after eating the kernel. The labor cost involved in making the vessel was a masaka (an ancient coin with a low value used in Sri Lanka) or even less. Therefore, at the place where the vessel was stolen by the second monk, it had a value definitely less than a pada (an ancient coin in Sri Lanka) ¼ of a Kahapana. For committing the offense of theft, the object stolen must be a pada or more in value, so the monk was acquitted” (SP, 1924; 27).

This story establishes that there were extensive coconut plantations in the Antarasamudda District. The name means “between the seas.” It must, therefore, have been a Peninsula with saltwater on either side. An area corresponding to the geographical characteristics and soil suitable for coconut is the Kalpiti Peninsula, which has the Kalpiti lagoon on its east and the Arabian sea on its west. Ptolemy’s map has a cape called ‘Anarisimoundou’ to the South of Jagana, which is to the south Marjana. Simoundu in this name represents Samudda (old Sinhalese Samuda), and Anari represents probably Antara (old Sin. Atara), the form found at present in Ptolomy‘s map being due to a clerical error. It is accepted by the scholars that there are errors and effusiveness (hyperboles) in Ptolomy’s map (Brohier, RL & Pauluze, JHO, 1951: 72; TNE, 1987: 84). The position of Anarisimondou in Ptolomy’s map would correspond to modern Kalpiti.

Another area (village) with a coconut grove is Magananakarika. Magananakarika is probably the same as Ptolomy’s Margana, placed south of Moduttou, probably Mahatittha (Manthei – Mannar). The name takes the form of Mangana in Pali. In the Sihalavatthuppakarana, it is said to have been five yojanas from Anuradhapura (SVP, 1959: 168). The name is also found in

King Vasaba's inscription of Sinna – Andiyagala. Nicholas thinks that the remains at Mullikulam at the mouth of Modaragam Aru are these of Magana (Paranavitana, 1983:31- 34).

In addition to these two locations, coconut groves were present at Napakiliya, Punaka, Karabadara, and Aganagama, as named in the inscription. This allows us to decide that Sri Lanka had separate coconut groves at the beginning of the first century AD. The story in the Samantapasadika also mentioned that coconut was very plentiful in Antarasamudda, and coconut would have been introduced to Sri Lanka a long time ago, before the first century AD. Another physical archaeological evidence at Mihintale proves coconut had been used for religious and other purposes before the first century A.D., i.e., stone bas – relief sculpture of the eastern frontispiece of the Kantaka Cetiya stupa. Neither the builder nor the date of the building of stupa is known definitely. The Mahavamsa mentions that King Devanampiyatissa (250 – 210 B.C.) prepared sixty-eight caves as dwellings for monks in the place of Kantaka Cetiya and its periphery (MV, 16, 12) while King Lanjitissa (119 – 109 B.C.) enlarged the stupa by a stone cover (Kanncuka-blouse) (MV, 33, 25). Accordingly, the stupa would have been built in between the reign of these two kings. The powerful and devoted kings in the period were Devanampiyatissa (250 – 210 B.C.), Uttiya (210 – 200 B.C.), Dutthagamini (161 – 137 B.C.), Saddhatissa (137 – 119 B.C.), and Lanjitissa (119-109 B.C.). King Lanjitissa succeeded King Saddhatissa. If Saddhatissa built the stupa, there was no need to repair or enlarge it immediately after it was built. All religious activities done by Dutthagamini were ascribed in detail in the Mahavamsa without mentioning this stupa which implicitly reflects that the stupa may not built by the same king. Two brothers of kings, i.e., Devanampiyatissa and Uttiya, kept a closer relation with Mihintale than any other ruler, and they have built several buildings, including stupas, according to the chronicles and archaeological evidence. The above factors allow to conclude that the kings, either Devanampiyatissa or his successor Uththiya, built Kantaka Cetiya and four frontispieces in the third century B.C. Otherwise, the frontispieces would have been built by King Lanjitissa, who enlarged the stupa in the second century B.C. The above-mentioned frieze of the stone bas relief is sculptured at the upper part of the eastern frontispiece of the Kantaka Chethiya which was also belongs to the same period of the king.

There is a seated figure of God Ganesha (lyar-lyyanayaka), i.e., God of the wisdom of the Hindu pantheon of gods, in the center of the frieze. This is the oldest figure of God Ganesha in Sri Lanka, and it is the only Buddhist monument ever found with the figure of Ganesha (Lagamuwa, 2009: 104-106). Either side of him has two queues of male devotees coming towards the Ganesha with meritorious goods in their hands. Those are a stick of sugar cane (*Saccharum officinarum),* a fruit of mango (*Mangifera indica*), a bunch of plantain (*Musa sapientum*), a pot of water, and a fruit of the coconut, which he likes to eat and drink. He prefers coconut over other edibles. Coconut is also closely related to the cult of God Ganesha. Therefore, nothing is offered to him without coconut, even with no other meritorious goods.

These are the earliest stone carvings in Sri Lanka found to date (Paranavitana 1963: 48), the references in the Pandukabhaya legend, Megastenes, and Aelian in the fourth and third centuries B.C, the war of Dutthagamini in the second century B.C. is connected with the factors that came to light from the stone carving. Therefore, it can decide that the growing and use of coconut was introduced to Sri Lanka, at least before the third century B.C.

Since then, coconut groves and coconut consumption is mentioned in the inscriptions and literary sources periodically. Another two inscriptions of them are at Mihintale too One is the pillar inscription of King Sena II (853 – 887 A.D.) at the ancient indigenous ayurvedic hospital dedicated to the Buddhist monks of the monastery at Mihintale. It says in the lines from 7 – 12, "Girigal" uda pulupan, mivan silimbalan mokapanu isa" (Lagamuwa, 2009; 181 – 187).
It is prohibited to cut down the trees, i.e., Palmyra (*Borassus flabellifer*), Coconut (*Cocos nucifera*), Meepup (*Madduca longifoia*), and Tamarind (*Tamarindus indicus*) in the sacred mountain of Mihintale. The word "pulapan" in the inscription was used for coconut, which may have derived from the Sanskrit word "mahapala," meaning "coconuts." According to these regulations of the ruler, it is evident that the said trees were considered very important at the time, especially coconut palms, grown in the monastery and the hospital premises.
The other epigraph is the slab inscription of King Mahinda IV (959-972 AD), called "Slab inscription at Mihintale." As indicated in this inscription, the public should not consume the paddy fields, and the coconut groves belonging to the inner monastery and reserve them for the monks of Segiri or Mihintale.

"Et Vehera badtuwa tanhi Kumbur Arub eyi kavara pariyayen noveleniyaytuwa" (lines. 18 and 46) (Lagamuwa, Ariya, 2009: 104 – 106). It says there were coconut groves belongs to both monasteries of Mihinthale and the inner monastery (Et Vehera) at Mihintale, donated by the kings and nobles. This allows us to conclude that coconut groves were present in the various areas belonging to at least major monasteries of the country in the middle of the Anuradhapura period. If so, plenty of coconut groves must have been grown on the island to make similar offers to the monasteries.

In addition to this archaeological evidence, several incidences of coconuts are mentioned in the Mahavamsa during the 6 – 7 centuries. It refers to three yojanas: a large coconut grove was laid out by King Agrabodhi I (571 – 604 A.D.) at a place close to Mannar and donated to the Kurunada Monastery in the sixth century (MV. 41 – 15). This has been recognized as modern "Kurundumale" at Magachole reservation of Thannimuruppu D.N. Division of Muhundubada Paththa D.S. Division in Mullative District (25 km from the Mullative town area Kokilai – Kumudumale road – now under excavation).

Though this is the first record of the formation of a proper coconut grove by a ruler in the country, there were many coconut plantations in the country from the third century B.C. to the sixth century, as mentioned above. Siriweera also believes that palms in Sri Lanka are mentioned by Megathenesin the 3^{rd} century B.C. and Aelian in the 2^{nd} century as palmyra in the north and coconut in the south (Siriweera, WI, 2002; 187). On the other hand, it is difficult to believe forming such a large size plantation as recorded hyperbolically, and one yojana is a measure of distance equal to 16 miles or four Gauwas. Accordingly, the Coconut grove should be 43 x 44 miles^2 in size.

In ancient times Mannar was named as Manteyi or Mahathittha and Mathota. Paranavit ana pointed out the place name Magana-nakarika, in the Mihintale rock inscription of King Mahadathika (7-19 AD), where there was a coconut plantation is probably the same as Ptolemy's Margana, the place to the south of Modottou, possibly Mahatitta. The name takes the form of Mangana in pali. In the Sihalavatthuppakarana (SV. PTS), it is said to have been five yojanas from Anuradhapura to Magana. The name is also found in King Vasabha's inscription at Sinna-Andiyagala. Nicholas thinks that the remains at Mullikulam at the mouth of Modaragam Aru are those of Magana (Paranavitana, 1983). It is clear now that the Kurunda monastery was situated in the area of Magana nagarika, or Mahatitta, i.e., Manteyi, Matota, or Mannar. It is mentioned that when writing the Buddhist Sinhalese commentaries (Sihalatthakatha) around the early historical period, one volume was written at a monastery Kurundi Vihara, a monastery named as Kurundi atthkatha, i.e., Kurundi commentary. Possibly the monastery is indicated in the sources (Guruge, Ananda, WP, 1992: 206).

The Mahavamsa refers that the King Kashyapa II (650 – 659 AD) laid out flower gardens and coconut groves during his reign in the seventh century (MV 42 – 147). According to this information, coconut plantations were grown throughout the island.

The chronicle records another incident that happened during King Manavamma (684-718 A.D.). When the king was riding on the royal elephant, he became thirsty and drank the water of an immature coconut (Kasapen in old sin.), known as tender – nut or jelly – nut (Kurumba in sin) (MV. 45 – 10). This signifies that drinking coconut water was a common habit in the country, not only among the general public but also of royalties, during that period. It is also understood that coconut plantations and groves were present at home gardens everywhere in Sri Lanka in the seventh century.

According to local legendary tradition, the earliest known coconut palms of the Rohana were on the southern coast near Weligama, where the medicinal value of coconut oil was discovered by King Kustha–Raja, whose figure is carved on a rock at Kustavajagala near Weligama. He is believed to be a leper.

Another story says that the figure was of a local physician, carved on the rock by the king to honor him. However, neither a king nor a physician represents this statue, according to folklore. It is the figure of Sinhanada Avalokitesvara Bodhisattva (embryo Buddha or a person preparing for Buddhahood of the Pantheon of the Mahayana Buddhism). He is said to be the divine guardian of navigators and seafarers and a deity physician of cure of diseases (leprosy patients) (Lagamuwa, Ariya, 1999: 172 – 173). The creator of this statue is not known. It can believe that the statue was carved by King Agrabodhi III (629 – 639 A.D.) because, as mentioned in the Mahavamsa, he died in Ruhuna by disease after living there for twelve years (MV. 42,143,144). The statue also belongs to the seventh century.

These factors emphasize that coconuts were first established along the South–West coast of the island, a fact that would support de Candolle's theory on the origin of the palm. But it may be that its propagation was fostered by the more enterprising inhabitants of the populous western side of the island when there was scarcely any settled population on the East coast.
Many Sinhala, Pali, and Sanskrit classical literary sources composed in the periods of Polonnaruwa, Dambadeniya, Kurunegala, Kotte, and Mahanuvara (Kandy) have mentioned coconuts and coconut plantations all over the island, e.g., Jataka Atuva Getapadaya (78 – 8), Butsarana (280 – 18), Saddharma Ratnavaliya (55 – 23, 128 – 24). Kankavitarani (88 – 21, 110 – 12), Kudusika Purana Sannaya (75-31), Dalada Sirita (1 – 19, 47 -1, 49 -8, 8-90), Saraswati Nighanduva (260 – 2), Purana Namavaliya, (136) Parevi Sandeshaya (84 – 112), Kovul Sandeshaya (104 -200), Kavyashekaraya (5-4, 644), Selalihini Sandeshaya (43), Guttilakavya (10), Gira Sandeshaya (73), Hansa Sandeshaya (154,160), Kunstantinu Hatana (115), Sandkinduru Dakava (30), Asadrusha Jataka Kavya 9207, 414, 474), Saddharma Ratnakaraya (7-66). It is understood that using of coconuts in Sri Lanka was higher level in these historical periods.

At the same time, the scholars' opinion can also be accepted on the development and expansion of coconuts in the later historical period of the country. As per Siriweera, the cultivation of coconut expanded after the thirteenth century. This coincides with the expansion and development of the settlements in the South–West and the beginning of the decline and abandonment of the Rajarata Kingdom.

Once the Rajarata areas were neglected and the settlements in the South–Western and the Southern coastal areas expanded, the compulsion arose to engage in types of cultivation that suited the climatic and soil conditions of the later regions. Sesame, from which oil was primarily extracted for food preparation in the Dry-Zone, was not found in sufficient quantity here. Therefore, using coconut in dietary habits extended. The chronicles, literary texts, and epigraphy vouch for the existence of extensive coconut plantations along the seacoast, especially in areas such as Kalutara, Bentota, Totagamawa, and Kapkandura in Rohana. The Sandesha poems refer to those at Moratuwa, Kamburugamuwa, and from Kelaniya to Keragala (Siriweera, 2002; 188).

The Portuguese were interested in coconut planting, but palm cultivation was stimulated with the arrival of the Dutch. At the beginning of the 17th century, the Western and Southern coasts of Sri Lanka presented, with certain intervals, a fairly contiguous grove of coconut palms, but it did not extend far inland. Bertolacci pointed out the large field for an extension of planting on the North – West coast around Chilaw and Puttalam. He mentions that the Kalpitiya peninsula was, in his own time within 18 years, changed from a barren, unproductive area to an expanse of the finest plantations of this palm so that cultivation extended from Colombo via Negombo nearly to Chilaw (Ferguson J, I, 1885: 7).

The coconut cultivations by Colonists in Sri Lanka were first commended in the Jaffna and Batticaloa districts in 1841. In 1853, A.O. Brodie, Agent at Puttalam, reported that the cultivation was rapidly extending in the Chilaw – Puttalam district. From 1840 to 1850 was the era of planting by Europeans, then came a blank ten years. Then the Sri Lankans began to embark upon the cultivation, and especially in the Western and North–Western provinces, they brought many thousands of acres of the jungle under cultivation, more especially along the valley of the Mahaoya between Negombo and Polgahawela, since 1866, and later in the Chilaw – Puttalam district and the Eastern province. This movement resulted from the growing prosperity of the people through the money circulated by the coffee enterprise from 1850 onwards and of the Government, unlocking their low–country reserves of grown land. Since then, further extension took place in all parts of the island and districts where a low rainfall makes dry farming compulsory areas being exploited. Initially, massive coconut cultivations in the premodern period were confined to the coastal area. Later it expanded from Kandy up to Badulla in the upcountry.

2. Conclusion

Fossils of primitive coconut or such other remains were not discovered so far in archeological excavations of Sri Lanka owing to various reasons: e.g., organic materials may destroy within a short period, no excavation has so far aimed to explore the historical perspective of a coconut tree, and it was not able to find suitable land for such excavations. However, there is a possibility to find out such evidence through archeological excavations in the future.

However, according to the inscriptions, carvings and sculptures, chronicles, Buddhist commentaries, Sinhala and Pali literature, and travelers' reports, the use of coconut was found around the 3rd century B.C. or indeed in the 2nd century B.C. in Sri Lanka. Furthermore, as coconut fossils are found in India, it is possible to assume that the coconut fossils can be found through archeological excavations because both countries were placed in the same land in the ancient period. This is further confirmed by the fact that use of coconut happened since the 3rd century B.C. to date.

Therefore, it can be concluded that only Sri Lanka produces the information on the use of coconut, coconut plantations, and the oldest historical and archeological evidences. Accordingly, it was evident that coconut may have originated in Sri Lanka and been used for many purposes from the early historical period.

3. References

1. McCrindle, J. W. (Ed.). (1960). Ancient India as described by Megasthenes and Aelian (AIDMA). Reprint. Calcutta.

2. Annadale, C. (1960). The Concise English Dictionary. Library Scientific and Technical, Blackie and Son Ltd., London.

3. Pigafetta, A. (1906). Magellan's Voyage Around the World (Vol. I). Translated by J. A. Robertson. Arthur H. Clark Co.

4. Bourke, R. M., & Haarwood, J. (2009). Food and Agriculture in Papua New Guinea. Australian National University.

5. Coconut Development Board (CDBGI). (2015). Coconut cultivation No. 8. Government of India.

6. Coconut Planters Manual. (1923). Colombo: Driebery Ceylon Observer Press.

7. Pearsall, J. (Ed.). (1999). Concise Oxford Dictionary (10th ed.). Clarendon Press, Oxford.

8. Cook, O. F. (1901). The Origin and Distribution of the Coca Palm. Washington Government Printing Office.

9. Edmondson, C. H. (1941). Viability of Coconut Seeds after Floating in Sea. Bemis Bishop Museum Occasional Paper, No. 66.

10. Ekananyake, G. K., Perera, S. A. C. N., Dissanayake, P. N., & Everard, J. M. D. T. (2010). Varietal Classification of New Coconut (Cocos nucifera) Forms Identified (PDF). Coconut Research Institute of Sri Lanka.

11. FAOSTAT. (2013). Food and Agricultural Organization of United Nations Statistical Division, Coconut Production/Crops. New York.

12. Ferguson, J. (1885). All about the Coconut Palm (Cocos nucifera).

13. Figueireao, C. (1940). Pequeno Dicinario de Lingua Portuguesa. Livraria Bertrand, Lisboa, Lisbon.

14. Dalgado, S. (Ed.). (Year). Clossario Isuo – Asiatico.

15. Grimwood, B. E., & Ashman, F. (1975). Coconut Palm Products, Their Processing in Developing Countries. USA Food and Agricultural Organization, No. I, New York.

16. Gunawardana, G. W. (1917). Medicinal Plants of Ceylon and Sinhalese Medicines in English. Colombo.

17. Guruge, A. W. P. (1992). 2300 Years of Mihindu Culture. Ministry of Buddhist Affairs, Colombo.

18. Haries, H. C. (1978). The Evolution, Dissemination, and Classification of Cocos nucifera L. The Botanical Review, 12(44).

19. Haries, H. C. (2012). Germination Rate as a Significant Characteristic Determining Coconut Palm Diversity. Annals of Botany, Plants.

20. Haries, H. C. (2013). Long-Distance Dispersal of Coconut Palm by Migration Within the Coral Atoll – Ecosystem. Annals of Botany, 113.

21. Heyerdahl, T. (1950). Kon-Tiki: Across the Pacific by Raft. Mattituck: American House.

22. Jackson, E. (2006). From Whence Come Coconuts. The Panama News, 12(16).

23. Gnanobhashatissa, M. (Ed.). (1954). Kudusika Purana Sanna (KPS). Maradana.

24. Lagamuwa, A. (2009). Carvings, Sculptures, and Paintings at Mihintale. Amila Publishers, Aturugiriya.

25. Lagamuwa, A. (2009). Inscriptions of Mihintale. Neat Graphic, Matara.

26. Lagamuwa, A. (1999). The Buddhist Iconography of Sri Lanka. Central Cultural Fund, Colombo.

27. Diez, F. L. (2004). La Tribuna Del Idioma. Editional Technologica de CR, Spanish.

28. Geiger, W. (Ed. & Trans.). (1908). Mahavamsa. PTS, London.

29. Ilangasingha, M. (Ed.). (2006). Mahavamsa. S. Godage and Brothers, Colombo.

30. Paranavitana, S. (1979). Inscriptions of Ceylon, Vol. I, pt. I. Dept. of Archaeology,

Colombo.

31. Paranavitana, S. (1983). Inscriptions of Ceylon, Vol. I, pt. II. Dept. of Archaeology, Colombo.

32. Patil, V. (2016). Coconut – Fruit of Lustre in Indian Culture. Samskriti, India.

33. Perera, L. S., Perera, C. A. N., Champaka, K., Basnayaka, K., & Harries, H. C. (2009). Coconut Oil Crops. Chapter 12, In J. Vollmann & S. Rajcan (Eds.), Springer.

34. Kumara, B. P., Sumajyothibhaskar, & Satheesan, K. N. (2008). Management of Horticultural Crops. Horticultural Sciences Series, Vol. II, pt. II. New India Publishing, India.

35. Rosengarten, F. J. R. (2004). The Book of Edible Nuts. Dover Publications.

36. Royal Botanic Gardens – Kew (RBGW). Cocos – Work Check List of Selected Plant Families.

37. Samarasinghe, D. H. (Ed.). (1959). Samanthapasadika (Cha-7). Colombo.

38. Buddhadatta, P. (Ed.). (1947). Saraswathi Nighandu (SN). Colombo.

39. Samarasinghe, D. H. (Ed.). (1959). Saraswathi Nighandu (SN). Cha-7. Colombo.

40. Siriweera, W. I. (2002). History of Sri Lanka. Dayawansa Jayakody and Company, Colombo.

41. Burton, R. (Trans.). (2009). The Fifth Voyage of Sindbad the Seeman. The One Thousand One Nights. Classicist About Company.

42. The Guardian. (2006). Indian State Decides Coconut Trees Are No Longer Trees but Palms. Vol. 20.

43. Elzebroek, A. T. G. (2008). Guide to Cultivated Plants. CABI.

The Role of Shade Management in Enhancing Tea Cultivation Resilience to Climate Change: A Review of Global and Sri Lankan Practices

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Abstract

Tea is a preferable shade plant, and it is more vulnerable to climate change. This review article explores the shade management practices and its resilience of tea cultivation focusing on global and Sri Lankan practices. Through implementing shade trees to the tea lands as sustainable strategy, increasing threats of tea productivity has minimized. This strategy has capability of enhancing soil fertility of the tea lands, reducing evapotranspiration, and improving water retention during periods of drought. It creates a preferable micro climatic condition around the tea plantation against high temperature, abundant rainfall pattern and wind. Moreover, it helps to maintain natural pest control mechanisms. Natural enemies of pests are abundant in shaded areas, and it can effectively reduce pest populations without the need for chemical interventions. Tea cultivation faces unpredictable weather conditions, and it badly affects tea growth and yield. Therefore, all the tea farming strategies should be updated strongly. There are limited existing studies about long-term effects of shade management on tea plant health, yield stability, and soil quality. Researchers can introduce new suggestions to shade management practices by integrating with other climate resilience strategy practices such as soil conservation and water management techniques. And there is an opportunity to introduce innovative technologies by combining shade management in the tea industry such as remote sensing and (Internet of Thing. Further, to maintain sustainable shade management of tea plantation, a policy framework should be needed to the local tea community. This review recognizes the importance of resilience ability of shade trees to of tea plantation as a viable strategy and it contributes to achieve broader environment sustainability goals.

Keywords: Climate Change Resilience, Shade Management, Tea Cultivation

1. Introduction

Climate change is emerging as a major menace to tea production, especially in countries like Sri Lanka, as indicated by frequent fluctuation of weather patterns, rising temperatures and changes in precipitation. It adversely affects the growth, yield, and quality of tea which is a vital economic crop for local communities. Therefore, tea plantations' resilience should be improved against the climate challenges to maintain better tea productivity. In response to challenges, shade management has developed as a key strategy that could help tea plantations counter climate variability (Mohotti & Mohotti, 2020). It is a sustainable and climate - smart practice designed to adapt to climate change and improve the tea yields. Further Sri Lankan Tea Research Institute mentions that shade management is a key adaptation strategy to combat issue like rising temperature badly affecting to tea productivity (TRI Circular number 03/03, 2003). This review article focuses on global and local shade management strategy practices and its contribution role to enhance the tea plant resilience.

Shade management includes planting of trees (Tea plantations use various types of species as shade plants) and maintaining them in a proper manner to provide shade to the tea plants. Shade trees basically help tea plants to withstand the effects of climate change (Chettri & Ghosh, 2023). Different shade plants are grown in tea lands according to their purpose. Silver oar is most preferred tree worldwide and they are quick growth, deep roots and light canopy. Mainly they contribute to shade and timber, organic matter producer and attract beneficial insects. Acacia species is used for medium shade and soil enrichment. Other species include Cajanus cajan, Tephrosia candida, Calliandra calothrysus, Melia azedarach, Dalbergia species are grown as temporary shading purpose and rotate every few years (Agriculture Institute, 2023).

Tea is a shade-loving plant and shade plants also have many other beneficial effects on photosynthesis and other physiological processes, to growth and yield of tea (Mohotti *et al.,* 2020). Studies show that if there are many trees around tea plants, they may influence the micro weather in a way that is favorable to tea plants such that temperatures are reduced, wind speed is minimized, and humidity rises (Chettri & Ghosh, 2023). Furthermore, by offering organic matter to soil through the shed leaf litter, soil fertility and structure will improve (Mohotti *et al.,* 2020). Shade plants are not only an environmental sustainability supporter. It provides economic benefits and multiple purposes such as retention water in soil, reducing soil erosion, enhance biodiversity by providing habitats for various species, and can be harvested for timber or fuelwood (Chettri & Ghosh, 2023).

The importance of shade-providing plants in mitigating climate change effects and high temperatures in tea cultivation is significant and multi-faceted. Shade reduces the exposure of tea plants to direct sunlight, which can cause heat stress that damages leaf quality and plant growth. Specifically, shade trees help moderate temperature by lowering leaf temperatures, which can otherwise be 10-15°C higher than ambient temperatures under direct sunlight, causing stomatal closure and reduced photosynthesis in tea plants. This temperature regulation through strategic shading keeps the microclimate stable, reduces temperature fluctuations, and maintains suitable growing conditions for tea, roughly between 20-30°C (68-86°F). The microclimate under shade also retains moisture longer with less evaporation, benefiting tea plants' water status and quality (Ge *et al.,* 2024).

Shading canopy decreases radiant heat and UV exposure, which lowers heat stress on crops and mitigates urban heat island effects in landscapes. They improve surrounding air quality by filtering pollutants and conserve soil water by reducing evaporation and stabilizing soil moisture. This improves the resilience of tea plantations against climate challenges like increased temperatures and drought conditions caused by global warming (Ge *et al.,* 2024).
In India shade management has a long-standing tradition in particular regions like, Assam and Darjeeling. As a historical practice, *Albizia chinensis* is used as shade tree and it helps to maintain tea plant resilience and enrich the soil with nitrogen through its leaf litter. Shade trees are value to build favorable temperature condition for tea plants and especially important to regions where temperatures frequently exceed 30°C (Shade and Shade Management in Tea in India: Tea World, 2018). To provide providing necessary shade, various types of shade species are utilized in Indian tea gardens (Chettri & Ghosh, 2023).

In Kenya Tea cultivation, shade management is a significant kay strategy, and it aims to optimize tea growth conditions, enhance yield, and ensure sustainability. They commonly use Grevillea robusta, Eucalyptus, and Albizia species to get sufficient shade and these plants have passed to minimize competition for nutrients and water with the tea plants. Kenya's tea industry utilizes a combination of traditional practices and modern sustainable agriculture techniques to manage the shade (Tea Cultivation Manual for Good Agricultural Practices - Tea Board of Kenya, 2024).

Shade management is a critical strategic practice in the Sri Lankan tea industry due to its multiple benefits for sustaining tea growth, improving tea quality, and mitigating environmental climate stresses. Sri Lankan tea plants, naturally adapted to grow under forest canopies, require filtered sunlight rather than direct harsh sunlight. Proper shade management recreates this ideal microclimate, enhancing healthy tea plant functions to sustain yield, quality, and vigour of plantation. In Sri Lanka, strategy of shade management involves planting and managing shade trees like Silver Oak (Grevillea robusta), Albizzia species, and Erythrina lithosperma, which provide medium to high shade levels tailored to local micro-climatic conditions (Agriculture Institute, 2023).

2. Methodology

A comprehensive literature search was conducted to identify the role of global and Sri Lankan shade management strategies and their practical applications in tea cultivation. Scientific articles were found through Google Scholar, Scopus, Web of Science and Sri Lankan government websites. Study used the key search terms included *"shade management in tea cultivation", "climate change in tea", "Sustainable development of tea with shade"* and *"agronomic benefits of shading in tea lands"*. Total of 35 studies were chosen for the review based on their relevance to the research objectives, alignment with the search keywords, and availability of full-text content. Considering broad geographic relevance and global perspective, 15 international studies were selected. 10 studies of them were used for the study by giving priority to key areas of shading, tea productivity and climate resilience of tea. 20 local articles were shortlisted by focusing Sri Lankan climate impact on tea cultivation and improving shading practices on it. Most of them were not recent articles. Therefore 13 studies were excluded.

Finally, 17 selected articles which were focusing on special shading, agronomic, and economic benefits were included in the study. Studies provided detailed insights into how different shading systems influence tea plant functions, soil microclimate, yield stability, and long-term climate resilience. In addition, several articles offered evidence on the economic advantages of adopting shade management, improved leaf quality, and enhanced resource usage efficiency. Together, carefully selected studies formed the core evidence base for evaluating the effectiveness of shade management as a climate-resilient strategy in tea cultivation.

3. Results

Shade Management for Climate Resilience in Tea Cultivation: Global and Sri Lankan Insights

Shade management is one of the elements of sustainable tea growing to moderate heat impact, conserve soil moisture, controlling pests, and creating favorable microclimates in response to climate change objectives.

1.1 Global perspective of Shade management

Shade management is a recommended practice to improve the microclimate in tea growing regions and thus a useful approach for sustaining tea production affected by climate change around the world. According to past studies, a few main shade management practices could be identified. Agroforestry is the common shading practice in tropical regions. It is an integration of trees and shrubs which are introduced to the tea land. Further it improves biodiversity and soil fertility as well as provide additional income from the timber or fruit production (Shade management to mitigate Climate change on tea smallholding sector, 2023). Second main practice is most common in China. It was ecological shading. For this, roadside trees are used to provide intermittent shade for tea plantations. This practice reduces heat stress by intercepting solar radiation (Figure 1). Maintaining regulating light intensity and temperature, ecological shading helps to protect optimal growth conditions for tea and improve tea quality (Zou *et al.,* 2022).

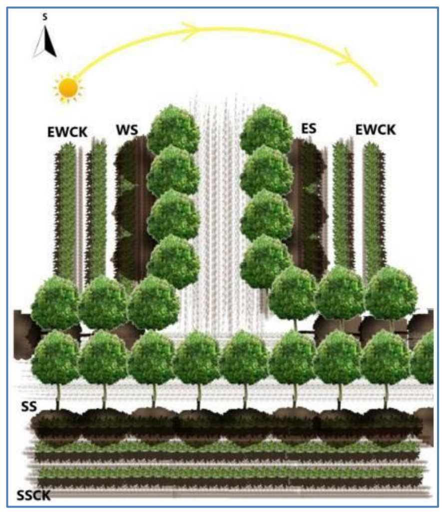

Figure 1: Experimental plot layout of roadside tree ecological shading (i.e., camphor trees) in the tea plantation (Note: ES - east shading; WS - west shading; EWCK - control of the shading treatments of WS and ES; SS - south shading; SSCK - control of the shading treatment of SS.)

Source: Zou *et al.,* (2022)

Another key strategy is species selection. Appropriate shade tree species help to continue effective shade management. *Gliricidia sepium, Erythrina indica,* and *Albizia chinensis* are the most common species in many tea producing countries because they provide sufficient shade without competing heavily for nutrients (Mohotti et al., 2020). *Gliricidia sepium* is a small to medium size deciduous plant with a short trunk and long slender branches. Its' bark is soft and grey, flowers are mauve pinkish color and to 30 cm long. Morphological and leaf characteristics of *Gliricidia sepium* are as below (Figure 2). *Albizia chinensis* is an evergreen plant. Bark consists of dark brown or greenish grey and flowers are stalked heads with yellow panicles. Morphological and leaf characteristics of plants are as figure 3 (Rahman et *al.,* 2020).

Figure 2: Morphological and leaf characteristics of *Gliricidia sepium* plant

Figure 3: Morphological and leaf characteristics of *Gliricidia sepium* plant

Source: Rahman *et al.,* (2020)

Pruning and thinning is an important strategy as it helps to control the amount of shade provided. It ensures that tea crops receive sufficient sunlight to enhance photosynthesis to lead to better yields and quality as productive canopy. As a regular shade managements practice, Monitoring and Assessment strategy evaluates light levels, soil moisture, and plant health of the tea cultivation. Next key strategy is promoting collaboration among tea farmers, industry associations and government organizations. Workshops and field demonstrations are used to improve farmer engagement with effective shade management techniques (Shade management to mitigate Climate change on tea smallholding sector, 2023).

1.2 Shade Management in Sri Lankan Tea Cultivation

Sri Lankan tea industry is currently facing climate change challenges like floods, soil erosions by occurring extensive rainfall, and droughts recording with high temperature. Therefore, Sri Lankan tea producers adhere to the Sustainable Agriculture Network and practice the standards that have been set for sustainability and protection of the environment. The government of the country has introduced several strategies that seek to address climate change problems in tea production (Sri Lanka Tea Board, 2024). Among them, shade management is playing a valuable role because it is more practicable one and suitable for more than 30 ^{0}C temperature conditions (Shade and Shade Management in Tea in India: Tea World, 2018). Shade pant establishment should be done early during tea planting or after pruning the tea. Once the trees are established, prune them periodically to control the canopy size and shape, ensuring that the shade is optimal for the tea plants.

Both medium and high shade plant types have been introduced to tea cultivation according to the elevation (TRI Circular number 03/03, 2003). In Sri Lanka, there are three main shade management practices can be seen such as Pruning and Thinning, Strategic Planting and Monitoring and Adaptation**.** Especially strategic planting and monitoring consider the shade plant arrangement and their density. Trees are often planted at specific intervals to maintain stratified canopy (Mohotti *et al.,* 2020). The ring-barking method is used to remove old shade plants and replace shade trees during the rainy season to ensure better survival and establishment (TRI Circular number 03/03, 2003).

1.3 Effectiveness of Shade Management in Enhancing Climate Resilience

As a key strategy, effective shade management can mitigate adverse effects of climate change small holder tea farmers are highly vulnerable to protecting tea with high temperature and soil erosion. The shade trees enhance the soil structure, water retention and nutrient availability of the soil (Wartenberg *et al.,* 2020). Shade plants pass to diverse soil microbes to enhance nutrient cycling process. Studies provide evidence about higher levels of soil carbon and nitrogen are more under the shaded areas than unshaded areas (Sauvadet *et al.,* 2022). Fallen shade leaves enrich the soil by providing organic matter and it promotes strong healthier tea root systems. This is more helpful to tea plants' productivity to face changing rainfall patterns (Chettri & Ghosh, 2023). Research articles indicate that leaf litter decomposition of certain shades can release essential nutrients to the soil such as nitrogen and phosphorus, which are vital for plant growth (Wartenberg *et al.,* 2020).

Shade trees create cooler microclimate for tea plantation by decreasing temperature both soil and air above the tea plants. Temperature reduction helps build lower rates of soil moisture evaporation, and it ensures more moisture remains to uptake plants. Shades act as a wind breaker and it minimizes the drying effects of both soil and plants (Koutouleas *et al.,* 2022). In addition, shade trees have hydraulic lift ability, it means thar trees can redistribute water from deeper soil layers into upper horizons. This process helps to enhance drought resilience (Wartenberg *et al.,* 2020). Greater biodiversity can be seen around the shading areas and these areas provide habitats for various organisms, including beneficial insects, birds, and other wildlife. This helps to maintain ecological balance and enhance pest control mechanisms. For instance, according to the studies natural enemies of pests are abundant in shaded areas and it helps to effectively reduce pest populations without the need for chemical interventions (Shade and Shade Management in Tea in India: Tea World, 2018).

Shades contribute carbon sequestration through photosynthesis in their leaves, branches, stems and roots by absorbing carbon dioxide (CO_2) from the atmosphere. Half of dry weight of a tree's biomass is carbon. Therefore, it is an effective carbon sink process. Research has shown that well-managed shade crops have the ability to remove between 200 to 520 tons of CO2 equivalent per hectare over time depending on its growth conditions and management practices. Moreover, studies indicate that the total carbon stock in plantations with shades was higher than in unshaded plantations (Johnson & Coburn, 2010).

1.4 Gaps in Research and Future Directions

Most current research considers the short-term outcomes of tea plantations. But there is a need for long-term effects of shade management on tea plant health, yield stability, and soil quality. A few shade tree species like **Gliricidia** and **Erythrina** are commonly recommended for research activities. But there are some species that can ability to enhance tea growth across diverse climatic and soil environments. Therefore, there is a need for more research to analyze their comparisons (NCBI, 2022). Researchers can introduce new upgrades for shade management practices by integrating with other climate resilience strategy practices such as soil conservation and water management techniques. And there is an opportunity to introduce new technologies by combining shade management in the tea fields such as remote sensing and IoT. To maintain sustainable shade management, a new policy framework can be introduced to the tea community (Shade management to mitigate Climate change on tea smallholding sector, 2023).

4. Conclusion

Shade plants play a major role in increasing the resilience of tea cultivation to successfully face climate change challenges in maintaining microclimates, enhance soil moisture retention, reduce temperature and improve soil fertility through organic matter, benefiting both tea plants and the surrounding ecosystem. The ecological features of shade plants affect creating favorable microenvironment for maintaining healthy tea plantation. Tea plants with shades more contribute to carbon sink process than without shades. It moderately helps to reduce the carbon footprint of the tea industry. In globally, shade management is followed with new technologies and newly innovative practices. Sri Lankan tea industry needs to improve shade management practices with current unpredictable weather events. Therefore, as a main strategy, shade management should be evaluated to update its practices. If researchers understand the major strengths, weaknesses, opportunities and threats of shade management, it will be helpful to identify preferable areas to change.

5. References

1. Bracken, P., Burgess, P. J., & Girkin, N. T. (2023). Opportunities for enhancing the climate resilience of coffee production through improved crop, soil, and water management. Agroecology and Sustainable Food Systems, 47(9), 1125-1157. https://doi.org/10.1080/21683565.2023.2225438

2. Chettri, V., & Ghosh, C. (2023). Tea gardens: A potential carbon-sink for climate change mitigation. Current Agriculture Research Journal, 11(3). https://doi.org/10.12944/CARJ.11.3.01

3. Chettri, V., & Ghosh, C. (2023). Tea gardens: A potential carbon-sink for climate change

mitigation. Current Agriculture Research Journal, 11(3), 1-10. https://doi.org/10.12944/CARJ.11.3.01

4. Johnson, I., & Coburn, R. (2010). Trees for carbon sequestration. Primefact, 981. Climate in Primary Industries, Forest Science Centre.

5. Koutouleas, A., Sarzynski, T., Bordeaux, M., Bosselmann, A. S., Campa, C., Étienne, H., Turreira-García, N., Rigal, C., Vaast, P., Cochicho Ramalho, J., Marraccini, P., & Ræbild, A. (2022). Shaded-coffee: A nature-based strategy for coffee production under climate change? A review. Frontiers in Sustainable Food Systems, 6, 877476. https://doi.org/10.3389/fsufs.2022.877476

6. Mohotti, A. J., & Mohotti, K. M. (2020). Tea industry of Sri Lanka: Are we ready for the climate change impacts? In ResearchGate. https://www.researchgate.net/publication/349762199

7. Mohotti, A. J., Pushpakumara, D. K. N. G., & Singh, V. P. (2020). Shade in tea plantations: A new dimension with an agroforestry approach for a climate-smart agricultural landscape system. In M. R. M. K. N. Bandara & P. S. S. R. Bandara (Eds.), Agricultural research for sustainable food systems in Sri Lanka, Volume 2: A pursuit for advancements (pp. 67-87). Springer. https://doi.org/10.1007/978-981-15-3673-1_4

8. NCBI (2022). Impacts of Ecological Shading by Roadside Trees on Tea Foliar Health

9. Rahman, M. A., Moni, Z. R., Rahman, M. A., & Nasreen, S. (2020). Investigation of shade tree species used in tea garden in Bangladesh. SAARC Journal of Agriculture, 18(1), 219-237. https://doi.org/10.3329/sja.v18i1.48395

10. Sauvadet, M., Van den Meersche, K., Allinne, C., Gay, F., Virginio Filho, E. de M., Chauvat, M., Becquer, T., Tixier, P., & Harmand, J.-M. (2022). Shade trees have a higher impact on soil nutrient availability and food web in organic than conventional coffee agroforestry. Science of the Total Environment, 833, 155109. https://doi.org/10.1016/j.scitotenv.2022.155109

11. Shade management to mitigate Climate change on tea smallholding sector. (2023). Daily News. https://archives1.dailynews.lk/2023/07/05/business/306987/shade-management-mitigate-climate-change-tea-smallholding-sector

12. Shade-and-Shade-Management-in-Tea-in-N.E.-India : Tea World - An Initiative of KKHSOU. (2018). Kkhsou.ac.in. https://teaworld.kkhsou.ac.in/page-details.php?name=Shade-and-Shade-Management-in-Tea-in-N.E.-India&page=bec89d5988c458c73922b51c4

13. Tea Cultivation Manual for Good Agricultural Practices - Tea Board of Kenya (2024). Teaboard.or.ke. https://teaboard.or.ke/resources/manuals-and-handbooks/tea-cultivation-manual-for-good-agricultural-practices

14. Wartenberg, A. C., Blaser, W. J., Roshetko, J. M., Van Noordwijk, M., & Six, J. (2020). Soil fertility and Theobroma cacao growth and productivity under commonly intercropped shade-tree species in Sulawesi, Indonesia. Plant and Soil, 453(1), 87–104. https://doi.org/10.1007/s11104-019-04341-y

15. Zou, Y., Zhong, Y., Yu, H., Pokharel, S. S., Fang, W., & Chen, F. (2022). Impacts of Ecological Shading by Roadside Trees on Tea Foliar Nutritional and Bioactive Components, Community Diversity of Insects and Soil Microbes in Tea Plantation. Biology, 11(12). https://doi.org/10.3390/biology11121800

16. Agriculture Institute. (2023, November 18). The role of shade in tea cultivation. https://agriculture.institute/crop-production-technology/role-of-shade-in-tea-cultivation/

17. Ge, S., Wang, Y., Shen, K., Wang, Q., Ahammed, G. J., Han, W., Jin, Z., Li, X., & Shi, Y. (2024). Effects of Differential Shading on Summer Tea Quality and Tea Garden Microenvironment. Plants (Basel, Switzerland), 13(2), 202. https://doi.org/10.3390/plants13020202

Vol. 4, Issue I and II, (December) 2024

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Waste Assessment and Mitigation Strategies in Pineapple Supply Chain: A Case Study in Gampaha District

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Abstract

The study examines wastage along the Pineapple Supply Chain (PSC), focusing on physical and quality waste at different stages. This study aims to assess the magnitude of wastage along the PSC, to identify the causes of wastage along the PSC, to examine economic implications of wastages at each node, to identify critical points of wastage in PSC and propose wastage reduction strategies. Six farmers, five wholesalers ten retailers, and thirty-two consumers were selected by convenient, snow ball sampling techniques and randomly. The data were collected by individual interviews with pre-designed guidelines and semi structured questionnaire. Data were analyzed descriptively and using Wilcoxon signed ranked test. Findings revealed that physical and quality waste occurs at every stage of the PSC. Farmers experience 11.47% physical waste and 7.94% quality reduction per month. For wholesalers' physical waste and quality reduction are 0.82% and not measured per month and for retailers 5.43% and 10.48% per month. Consumers indicate the highest physical waste and quality reduction which are 30% and 28% respectively. Highest economic implication for physical waste is for wholesaler and quality reduction is for farmers. Increasing efficiency and effectiveness of the supply chain by organizing training and awareness programs, implementing method for immediate purchase from suppliers and providing quality inputs to the actors' waste can be reduced. Findings would contribute to improving the overall efficiency and sustainability of the pineapple industry in *Gampaha* District. The findings of this study will be valuable to supply chain actors and other relevant officials from both the

government and private sectors, including research officers and extension officers. Supply chain actors can utilize the insights to identify critical points of inefficiency where significant wastage occurs and implement corrective measures, thereby enhancing profitability. Furthermore, responsible government officials can pinpoint areas requiring intervention to bolster the industry's contribution to Sri Lanka's GDP, particularly in the context of the current economic crisis.

Keywords: Gampaha District, Lean management, Pineapple supply chain, Waste, Waste mitigation

1. Introduction

Pineapple (*Ananas comosus*) belongs to family Bromeliaceae. The origin is from tropical South America. Baruwa (2014) states that it is among the world's most significant commercial fruit crops. The United States of America and the European Union continued to be the top destinations for Costa Rican pineapple imports, with a supposedly stable market for these products (FAO, 2023).

The supply chain is a network of operational and decision-making processes linked by cross-organizational material and information flows (Lommen et al., 2014). There are many types of supply chain. For one product there may be more than one different supply chains as complex and long and simple and short. Since business is conducted between individuals, it is critical to comprehend how the relationships between chain participants currently stand and how they are influencing the flow of funds and information along the chain (Dent & Collins, 2021).

There is a need for robust impact assessments of interventions to reduce waste for consumers and actors and this study assess the extent of loss affecting supply chain actors differently. According to FAO estimates, 1.3 billion tons of edible food for human use are lost or wasted annually, or one-third of the world's total food production (Luo et al., 2021). Same study reported that The United Nations has set the goal of "reducing food loss and waste along the production and supply chains and halving the per capita global food waste by 2030 at the retail and consumer levels."

Food "waste" is the reduction in food quantity or quality as a result of retail, food service, and customer decisions and activities. There are four types of wastes. They are Physical, Quality, Nutritional and Market waste. Physical waste is loss in weight or monetary value and happens when fish are completely removed from the value chain as a result of spoilage or animal or bug ingestion. Quality reduction is decrease in the quality of the product. It is estimated by the difference between value of the high- quality product and product after degradation and expressed in monetary terms. These wastes occur due to poor planning resulting overproduction and low production, unsuitable packaging, inefficient storage, transport delays (Kruijssen et al., 2020). A large amount of waste was produced as a result of the vast production of pineapples and related byproducts (Roda & Lambri, 2020).

According to this half of the weight of the pineapple is a byproduct and a potential source of useful compounds. Total extent of area of pineapple cultivation in 2020/2021 is about 4,663 ha in Sri Lanka. Average production of pineapple is about 39,285 Mt in 2020/2021 (Department of Census and statistics, 2022). Pineapple extent of cultivation in *Gampaha* district was 1,739 ha and production was 14,920 fruits in 2009 (Hathurusinghe et al., 2012). In *Gampaha* District *Balummahara* is the famous pineapple market. Many collectors, whole sellers and retailors are there. Kew and Mauritius are the main commercial varieties grown in Sri Lanka (Kahandage et al., 2021). Mauritius is the most widely grown cultivar in Sri Lanka, accounting for over 95% of the cultivating extent, compared to only 5% for Kew.
Mainly fresh pineapples are sold. Apart from fresh pineapple there are many values added pineapple products as dried pineapple, canned pineapple, pineapple jam and juices. These products are mainly for supermarkets and export markets. Processors buy fresh fruits from collectors or farmers directly for their value-added production. During pineapple preparation, transportation, and storage, around 80% of pineapple pieces such as the crown, peels, leaves, core, and stems are discarded (Das et al., 2022). The annual loss of fruits during postharvest operation represent about 210,000 metric tons of fruits, which is about 30%– 40% of the harvest, representing approximately US$ 90 million losses in financial terms in Sri Lanka (Rajapaksha et al., 2021).

The high wastage rate negatively impacts economic, environmental, and social aspects of pineapple production and distribution. Therefore, this study aims to identifying the root causes and finding effective solutions to reduce wastage will contribute to improving the overall efficiency and sustainability of the pineapple industry in *Gampaha* District.

This research fills a critical gap by exploring the pineapple supply chain and quantifying the waste occur along the supply chain. While in Sri Lanka, most of the researches relevant to pineapple supply and value chains focused on evaluating the pineapple industry's prospects, obstacles, and entrance points in relation to the *Gampaha* district and investigate the challenges that pineapple growers face in terms of production and marketing, calculate the average cost of production per kilogram of pineapple, pinpoint fresh pineapple marketing channels in the *Gampaha* district, and assess net market margins, this study innovatively examines the quantity of physical waste, the reduction in value resulting from quality degradation, and the economic implications of these forms of wastage. Furthermore, this study makes a novel contribution by identifying the critical points of wastage for each actor and their corresponding economic implications.

Asthma and allergies have become more common diseases globally during the last decades

(Asher & Weiland, 1998; Ferreira et al., 2017; Lundbäck et al., 2016; Mallol et al., 2013). The prevalence of asthma and allergies, along with the underlying causes of their development, continue to be subjects of ongoing research and debate. (Huang et al., 2016; Ma et al., 2022; Yangzong et al., 2012). However, the prevalence of asthma remarkably varied by geographical region; for example, physician-diagnosed asthma was more than 24% in Chicago, Illinois, and 26 % in Sydney, Australia (Hu et al., 1997; Pearce et al., 1993). The prevalence of lifetime asthma was reported 2.2 % in Shunyi County, Beijing, China for schoolchildren. However, most higher incidence and prevalence of asthma and allergies are recorded in westernized countries (Yangzong et al., 2012; Zhang & Zhang, 2019) Compared with developing regions. However, some Asian countries have a higher prevalence of asthma (Asher et al., 2006; Hou et al., 2021; Asher, 2014; Leung et al., 2021; Ministry of Health SriLanka, 2018; Pearce et al., 2007; Seneviratne & Gunawardena, 2018). And also, there is a variation even within the same genetic group (Mallol et al., 2013; Yangzong et al., 2012).

As an Asian country, Sri Lanka has also experienced a higher prevalence of respiratory health (Gunasekera et al., 2022; Ministry of Health SriLanka, 2018; Ranasinghe et al., 2022; Seneviratne & Gunawardena, 2018). In 2012, respiratory conditions were responsible for a 14.4% death rate among children aged 1 to 5 years in Sri Lanka (Department of Census and Statistics, 2012). Additionally, respiratory diseases were the third leading cause of hospitalization in the country (Hinderaker, 2018). In 2019, asthma was the 7th leading cause of age-standardized Disability-Adjusted Life Years (DALYs) per 100,000 people in Sri Lanka (Institute for Health Metrics and Evaluation, 2023). Furthermore, few studies have addressed the prevalence of asthma and wheezing among children aged 5-14 years and the associated problems (Danansuriya, 2009; K. Karunasekera et al., 2009; Nandasena et al., 2012). In Sri Lanka, there is limited information on asthma and allergies among university students, particularly those residing in dormitories. These dormitories often feature crowded living conditions, with one room of 17.82 m^2 being shared by four undergraduate students, and another room of 29.9 m^2 accommodating ten students. This overcrowding may be linked to an increased prevalence of asthma and allergy symptoms.

Some studies have found a higher prevalence of respiratory health problems in university students in Canada (Lanthier-Veilleux et al., 2016), Greece (Tsantaki et al., 2020), China (Sun et al., 2011), and Malaysia. However, there have been no studies on asthma and allergies among young adults living in university dormitories in Sri Lanka. Given the potential impact of these respiratory conditions on students' academic performance and overall quality of life, it is crucial to conduct a comprehensive investigation into the epidemiology of asthma and allergy disorders in this population. This study aims to address this gap by examining the prevalence of asthma and allergies among students living in university dormitories in Sri Lanka. The findings from this research can improve the living conditions within dormitories, thereby enhancing students' quality of life.

2. Methodology

a. Study Area

Study area is *Gampaha* district. It was purposely selected. Because *Gampaha* is the district which is the famous district for pineapple cultivation in Sri Lanka. District has the suitable climate for the production. In 2014 total extent of cultivation of pineapple in *Gampaha* district is 5,183 ha (Department of Census and Statistics, 2014).

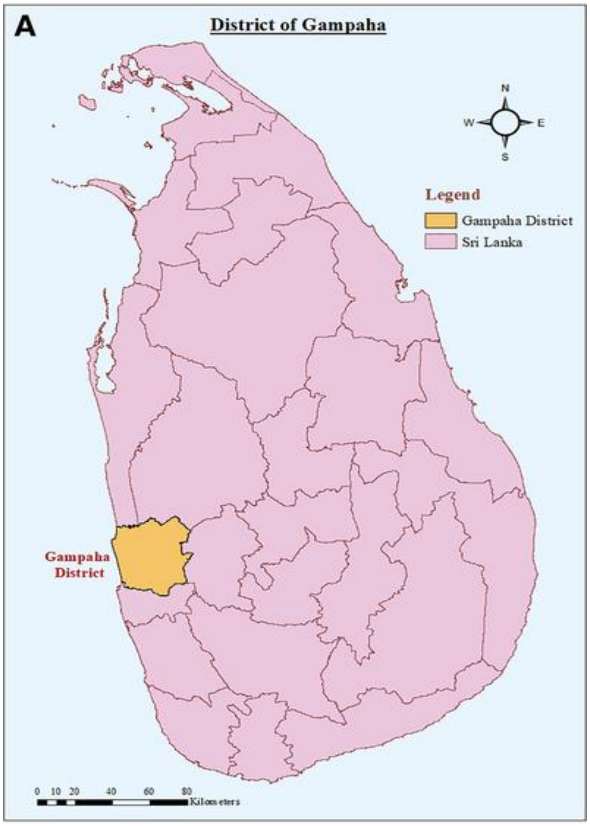

Figure 1: *Gampaha* District

Source: Tissera et al., (2023)

2.2 Target group

Fresh pineapples and value-added products have different paths. Local consumers receive fresh pineapples though farmers, wholesalers and retailers. Therefore, actors of selected pineapple supply chain who are farmer, wholesaler and retailer including local customers were selected as target groups.

2.3 Sampling Method

Convenient sampling technique used for selecting farmers, wholesalers and retailers. Convenient sampling was used because farmers, wholesalers and retailers were spread in wide area in *Gampaha* district. It was difficult to reach most of them. By using above technique actors with easy access were selected. List of farmers were obtained from Department of Agriculture in *Gampaha*. Snow ball sampling was used to found farmers and wholesalers also. Because most of the farmers in the list from Department of Agriculture in *Gampaha* were left the industry due to various reasons including financial crisis. Using snow ball sampling it was easy to access farmers and wholesalers in the area who are active in the industry. Using above sampling methods six farmers, five wholesalers and ten retailers were selected. Thirty-two consumers were selected using simple random sampling during 10 am–15 pm time slot. Simple random sampling was used because it was easy to find consumers than other mentioned actors and it provided fair chance to all the consumers. Total sample size was 53.

2.4 Sources of Data Collection

Both primary and secondary data sources were used for the study. For farmers, wholesalers and retailers' individual interviews with pre-designed guidelines were held. The guidelines for farmers include questions about cultivation, buyers, harvesting and other activities performed, types of waste, economic status and implications, quality attributes, present situation of the industry and their suggestions. Guidelines for wholesalers and retailers have consisted with questions about the business, buyers and suppliers, activities performed, amount of pineapple, types of waste, causes of waste, waste management, quality attributes, economic status and implications, present situation and their suggestions. For collecting information from consumers semi-structured questionnaire was used. Questionnaire collected demographic information of consumers, consumer purchasing behavior, pineapple attributes, types of waste, amount of waste, causes for waste, waste management and suggestions to reduce waste. The amount of physical waste, quantified by weight in kilograms, and quality waste, evaluated in monetary terms expressed in rupees. Research articles and annual reports were used as secondary data sources. Through them both qualitative and quantitative data were collected. Sources of data were obtained from journals, books and Department of Census and Statics of Sri Lanka.

2.5 Data Analysis Method

Data analysis methods were carefully selected to achieving all the objectives successfully. Mainly descriptive analytical methods such as graphs and tables were used to analyses both qualitative and quantitative data. Other data analysis methods were non-parametric as most of the data were qualitative. Wilcoxon signed rank test was used to analyses Likert scale data. SPSS and MS Excel software were used to analyzed the data.

3. Results and discussion

3.1 Demographic Information

Average expected final amount of harvest per acre per farmer is around 5666.67 kg. This can be varying according to the weather conditions, soil condition and knowledge and experience of farmer. Vidanapathirana et al. (2020) reported yield was 7,200 kg per acre. This is not a good trend in pineapple industry because average yield per ha have been reduced. Average amount of pineapple a wholesaler received per month is 85200 kg. Least amount wholesaler receive is 2000kg per month and maximum amount is 300000kg per month. most of the retailers in the sample receive 100kg-200kg of pineapple per month. Average received pineapple of the retailer is 500kg per month. Many retailers receive less than 1000kg per month. Many consumers prefer to pay less than Rs. 500 to buy pineapple which is 62.50% and most of the consumers buy pineapple monthly. It was about 78.13%. This is not good for pineapple industry because people are not willing to spend money more on purchasing pineapple and people are not buying pineapple weekly. Because of that retailers may not able get a good profit as well as other actors. According to the results consumers in *Gampaha* district do not consume pineapple frequently and demand is at lower level. It has negative impact on retailers as well.

Table 1: Different stages of PSC and attributes concern at stages

Stage of the SC	Attributes
Farmer	Mature eyes Good stem Green color
Wholesaler	Half ripened with yellowish green color Completed eyes and proper distance between eyes Good appearance without bruises
Retailer	Yellowish green color Undamaged tail and crown Freshness

Source: Authors' own survey data, (2023)

Most of the attributes concerned by the wholesalers are same as the retailers. Attributes are differing from stage to stage because they purchase pineapple at different time periods and storage duration is different.

Table 2 : Different attributes of pineapple and concern level of consumers

Variable	Mean	Significant level	Decision
Consumers concern about quantity of pineapple	2	0.73	Consumers concern about quantity of pineapple while purchasing
Consumers concern about appearance of pineapple	2	0.256	Consumers concern about quantity of pineapple while purchasing
Consumers concern about nutrition of pineapple	2	0.88	Consumers concern about quantity of pineapple while purchasing
Consumers concern about quality of pineapple	2	0.303	Consumers concern about quantity of pineapple while purchasing

The significance level is 0.05

Source: Authors' own survey data, (2023)

According to the findings, consumers evaluate pineapple products based on attributes such as quantity, quality, appearance, and nutritional value. The results indicate that all these factors are regarded with equal importance by consumers.

3.2 Magnitude of Waste and causes of waste along Pineapple Supply Chain

3.2.1 Physical waste of pineapple and causes for waste

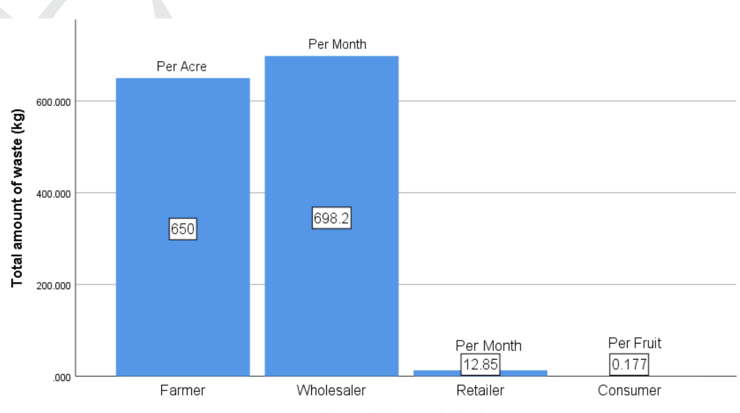

Figure 2: Amount of physical waste at different stages of PSC

Source: Authors' own survey data, (2023)

Attacks of pests like rats, squirrels, wild boar, monkeys, porcupine and civets is a main problem. Another one of the main causes is drought. Water is very essential factor. Therefore, long term no rain cause reduction in final pineapple harvest. If the cultivated land is sloppy when fruits transport inside the land waste occur.

Wholesalers need to transport fruits from farmers. Average waste during transport from farmer to wholesaler is around 6098.2 kg per wholesaler per month out of average received pineapple per month per wholesaler which is 85200 kg. According to the survey results wholesalers in the sample state that during sorting, grading and cutting stem there is no physical damage occur. Rain, improper transport and over ripen fruits are causes for physical waste.

Causes for physical waste at retailer level are improper transport, storage. Therefore, total physical waste is around 27.15 kg per month per retailer. Physical waste occurs mainly due to attacks of such as rats and crows. When fruits are exposed to water blemishes appear on the peel and it start to spoil.

Reasons for occurring physical waste are date confusion, lack of freezing, overbuying, poor planning, large portions, over preparing and improper storage. Majority of the consumers state that improper storage is the main reason to waste. It is around 27.84%. Both poor planning and large portions have equal percentages and they are the least affecting factors for waste according to the sample.

3.2.2 Value reduction caused by quality reduction at different stages of PSC

Table 3 : Value reduction due to quality reduction at different stages of PSC

Stage of the supply chain	Total value of waste (Rs.)
Farmer	202,000 per acre
Wholesaler	Not measured
Retailer	36667 per month
Consumer	182.14 per fruit

Source: Authors' own survey data, (2023)

Total quality waste is around 450kg per acre per farmer as an amount. Main factor affecting quality is water. If not enough rain or water received, quality will be decreased. Another cause is not adding fertilizer at right time in right amount. If fertilizer is not added as recommended pineapple stem will be burst. Then nutrient will supply to only one side of the fruit and that side will develop while other side distorted. It reduces the quality of the pineapple. If the cultivated land is sloppy when fruits transport inside the land waste occur.

At wholesaler stage during sorting, grading and cutting stem quality waste may occur. But it is not measurable. Rain, improper transport and overripen fruits are causes for quality waste at wholesaler level. Apart from that improper handling by labor also cause some damages. Not having immediate buyers reduce the quality with the time. After harvesting, mature pineapple fruits should not be stored for longer than four to five days (Baruwa, 2014).

At retailer level it was difficult to calculate quality waste during transportation as results such as bruises are appeared with the time. During sorting and grading no quality waste occur. But during storage quality waste may occur. Average quality waste during storage is around Rs. 36667 per month per retailer. Quality of the pineapple reduce with the time. Within a week time its quality become very low. Damages occur during transport will appear with the time as bruises. Rain is also a main issue. If fruit is expose to rain or water it begins to spoil. When fruit is expose to heat and sunlight it will dry the fruit and reduce the quality of the fruit. If pineapple fruit in a place with direct sunlight the fruit will be dried. It will loss it's freshness and become withered. When people buy the pineapple, they touch the fruit and add pressure to the fruit to check the fruit and sometimes they don't purchase that same fruit. Then it will cause a damage on the fruit. Average value reduction due to decreasing quality is around 182.1429kg per fruit per consumer. Date confusion, improper storage, lack of freezing, over preparing and poor planning are reasons for quality waste. According to the respondent's improper storage is the most affecting factor while poor planning became least affecting factor.

3.3 Economic Implication of pineapple waste along supply chain

Table 4: Economic implication of waste along the PSC

Stage of the value chain	**Average value of physical waste**	**Average value of quality waste**	**Average cost for waste disposal**
Farmer	Rs. 302,250 per acre	Rs.202,500 per acre	No cost
Wholesaler	Rs. 384,000 per month	Not measured	Rs.2000 per month
Retailer	Rs. 14,978 per month	Rs.36667 per month	Rs. 950 per month

Consumer	Rs. 221.78 Per purchase	Rs.182.14 Per purchase	Rs. 50 per month

Source: Authors' own survey data, (2023)

Highest economic impact due to physical waste is on wholesalers. Because they purchase large amount of pineapple and distribute them. During that physical waste can occur. Highest economic impact due to quality reduction is on farmers. Due to problems of fertilizer, weather and pest attack quality may reduce highly at farmer level. At retailers' level highest price reduction is occurred due to bargaining because they are directly involved with consumers and last sellers in the SC. Wholesalers bear the highest waste disposal cost. Farmers bear no cost for waste disposal because they dispose their pineapple waste in the same area of cultivation. It wold help farmers to reduce animal attacks to good fruits also.

3.4 Critical Waste Points

Table 5 : Physical waste, value reduction due to decreased quality and market waste

Type of waste / Stage	Physical %	Value reduction due to decreased quality %
Farmer	11.47	7.94
Wholesaler	0.82	Not measured
Retailer	5.43	10.48
Consumer	29.54	27.77

Source: Authors' own survey data, (2023)

According to the results highest physical waste and value reduction due to decreased quality are occurred at consumer level. Because they are last stage of the SC. All the damages occurred along the supply chain has final impact on consumers.

3.5 Strategies to Obtain Good Quality Fruits

At farmer level, to obtain good quality fruit they use quality fertilizer and suckers. Fertilizer should use in recommended amount and time. Using liquid fertilizer should be avoided. Because it will increase water concentration in the fruit and reduce taste. At wholesaler level for maintain good quality proper transport is important. When storing fruit in the vehicle need to be careful. By proper handling quality can be maintained. Proper containers can use to transport. When handling fruits should not hit with each other. Reducing using chemicals is also valuable to good quality. Fruits should be covered to protect them against rain.

Most of the retailers' state that to maintain fruit in good condition proper storing is very important. Fruit should be place upside down within 15^0 angle. They should not have direct sunlight. If the weather is rainy covers like polythene should be used to cover the fruits. By dusting the fruits daily waste can be reduced also.

3.6 Suggestions to Improve PSC reducing waste

Farmers should use quality fertilizer. Farmers should be given good knowledge about cultivation. New technology and quality fertilizer should be introduced. To selling the pineapple for reasonable price ceiling price for fertilizer should be applied. Another suggestion is to introducing method for farmers to obtain quality inputs such as suckers and fertilizer. By introducing program to buy fruits from farmers as soon as harvest waste can be reduced. Another method is to left the damage fruits on the plant. Then when pests attack again, they damaged to previous damaged fruit without damaging new fruit.

Wholesalers suggest that farmers need to be supplied with quality inputs and reduce using chemicals to the fruit. Another suggestion is reducing fertilizer price. Another suggestion is reducing chemicals by farmers. Framers use some chemicals to increase the size of the fruit. But it increases water concentration in the fruit. Therefore, when transporting they easily get damaged. Labors should be trained well. Retailers imply that proper transport is very important to maintain good quality. Because the damages during transport appear lately and then it will be loss for them. Another suggestion is reducing chemical usage for the fruit. Farmers add some chemical to increase the size of the fruit. It will increase the fruit size by increasing water concentration of the fruit. Because of that fruit will be subject to bruises.

Another suggestion is to reduce fertilizer price. Because due to high price demand has decrease.

Suggestions to reduce wastage provided by consumers are select fruits wisely, store properly, buy only amount you need, buy fruits, when necessary, do not over prepare, handle properly, when consuming cut the exact quantity you want, freeze extras, knowing the expiring time, learn to preserve.

But the implementation of the proposed strategy has several challenges. One significant obstacle is the high cost associated with procuring suitable containers, which often leads to reluctance among stakeholders to adopt their use. Additionally, the procurement of quality inputs remains a persistent issue, further complicating the effective implementation of the strategies. Another critical challenge is the lack of a comprehensive and reliable database.

This causes interruption in timely dissemination of essential information, preventing it from reaching relevant actors when needed. Consequently, the absence of accurate and timely data reduces the efficient functioning of the system.

Waste reduction would contribute positively to both environmental and social outcomes, enhancing sustainability and fostering broader societal benefits. Kodagoda & Marapana (2017) reports that accumulation of pineapple waste has emerged as a significant global environmental concern due to its high acidity and the substantial quantities of biodegradable organic matter it contains. It also reports that pineapple processing residues range from 45 to 65%, indicating significant organic-side stream disposal issues that, if not properly handled, pollute the environment. This issue could be mitigated by reducing the amount of pineapple waste generated.

As discussed above under economic Implication of pineapple waste along supply chain, actors in the industry are required to bear the costs associated with waste disposal, in addition to the losses incurred due to wastage. These financial burdens make it challenging for actors to achieve significant profits within the industry. Moreover, these economic constraints have broader social implications, affecting the social status of the actors involved. However, by reducing waste, actors can enhance their profitability, which, in turn, could improve their living standards and contribute to greater social well-being.

4. Conclusion

During each and every stage considered in the supply chain when activities are performed physical waste and value reduction due to quality reduction wastes can occur. Highest physical waste and value reduction due to decreased quality are for consumers. Main causes for wastage in the farmer level are attacks of pests and diseases and drought. Improper transport, rain and over ripen fruits are the main causes for wastage at wholesale level. Rain and attacks of pests are the main causes for wastage at retailer level.

The primary causes of waste at the consumer level include improper storage practices, inadequate freezing, excessive preparation, and confusion over expiration dates. The most significant economic impact of physical waste occurs at the wholesale level, while quality degradation primarily affects farmers.

To reduce waste at the farmer, retailer, and wholesaler levels, education on effective cultivation, handling, and waste reduction practices is crucial because as observed many actors lack awareness of waste quantity and financial impacts. Introducing emerging agricultural technologies and offering training on utilizing pineapple waste, such as making wine from peels, can further reduce waste. Consumer awareness and government policies are also important for promoting waste reduction, given the sector's significant contribution to the national economy.

The pineapple industry in Sri Lanka is a highly lucrative sector due to its substantial market demand.

5. Recommendations

The recommendations focus on improving the pineapple supply chain through various strategies. Ensuring farmers have access to high-quality inputs is emphasized, as this directly impacts the quantity and quality of the fruit. Organizing awareness and training programs is suggested to reduce waste at the farmer, wholesaler, and retailer levels. Mechanized harvesting and labor training are recommended to minimize physical damage during handling.

To address price instability, implementing a ceiling price for fertilizer is proposed. Additionally, developing systems to identify immediate buyers can help mitigate quality degradation as the fruit ripens. To reduce the wastage, occur when transporting, suitable containers can be introduced. Finally, introducing recycling and reuse methods for pineapple waste, such as producing pineapple peel tea and extracting phenolic compounds, is recommended to enhance sustainability.

Another recommendation is to develop proper database for the industry including details about available actors in the industry, details about available suppliers, information required to perform day to day activities and novel information relevant to the industry.

6. Acknowledgement

First of all, I am sincerely grateful to my internal supervisor, Dr. (Mrs.) K.N.N. Silva, Senior Lecturer, Faculty of Agriculture, University of Ruhuna, for her unwavering support, guidance, and expertise throughout this research journey. I extend my appreciation to the participants and interviewees in *Gampaha* district who generously shared their time and insights, contributing essential data to this research, my family and friends. First of all, I am sincerely grateful to my internal supervisor, Dr. (Mrs.) K.N.N. Silva, Senior Lecturer, Faculty of Agriculture, University of Ruhuna, for her unwavering support, guidance, and expertise throughout this research journey. I extend my appreciation to the participants and interviewees in *Gampaha* district who generously shared their time and insights, contributing essential data to this research, my family and friends.

7. References

1. Baruwa, O. I. (2014). Profitability and constraints of pineapple production in Osun State, Nigeria. Journal of Horticultural Research, 21(2), 59–64. https://doi.org/10.2478/johr-2013-0022

2. Das, A., Islam, A., Dey, H., Dutta, S., & Mazumder, S. (2022). Pineapple waste and its utilization. International Journal for Modern Trends in Science and Technology, 8(05), 272–278.

3. Dent, B., & Collins, R. (2021). A manual for agribusiness value chain analysis (R. Stubbs, E. McCann, & J. Bishop, Eds.). https://doi.org/10.1079/9781789249361.0000

4. Department of Census and Statistics. (2022). Economic statistics of Sri Lanka.

5. Department of Census and Statistics. (2014). General report economic census 2013/14 agricultural activities Sri Lanka. http://www.statistics.gov.lk/Economic/Final_Report_Agri.pdf

6. FAO. (2023). Major tropical fruits market review: Preliminary results 2022. Statistical Compendium, FAO, 23.

7. Hathurusinghe, C. P., Vidanapathirana, R., Rambukwella, R., Somaratne, T. G., & Research. (2012). A study on value chain of pineapple and banana in Sri Lanka (Issue March).

8. Kahandage, P. D., Hettiarachchi, S. W., Weerasooriya, G. V. T. V., Kosgollegedara, E. J., & Piyathissa, S. D. S. (2021). Design, development, and performance evaluation of a mechanical device for harvesting pineapple. International Journal of Trend in Scientific Research and Development (IJTSRD), 5(4), 1109–1116.

9. Kodagoda, G. K., & Marapana, R. (2017). Development of non-alcoholic wines from the wastes of Mauritius pineapple variety and its physicochemical properties. Journal of Pharmacognosy and Phytochemistry, April.

10. Kruijssen, F., Tedesco, I., Ward, A., Pincus, L., Love, D., & Thorne-Lyman, A. L. (2020). Loss and waste in fish value chains: A review of the evidence from low and middle-income countries. Global Food Security, 26, 100434. https://doi.org/10.1016/j.gfs.2020.100434

11. Lommen, W. J. M., Hotegni, V. N. F., DerVorst, J. G. A. J. van, Agbossou, E. K., & Struik, P. C. (2014). Bottlenecks and opportunities for quality improvement in fresh pineapple supply chains in Benin. International Food and Agribusiness Management Review, 17(3).

12. Luo, N., Olsen, T. L., & Liu, Y. (2021). A conceptual framework to analyze food loss and waste within food supply chains: An operations management perspective.

13. Rajapaksha, L., Gunathilake, D. M. C. C., Pathirana, S. M., & Fernando, T. N. (2021). Reducing post-harvest losses in fruits and vegetables for ensuring food security – Case of Sri Lanka, 9(1). https://doi.org/10.15406/mojfpt.2021.09.00255

14. Roda, A., & Lambri, M. (2020). Review food uses of pineapple waste and by-products: A review. International Journal of Food Science and Technology, 1–9. https://doi.org/10.1111/ijfs.14128

15. Tissera, H., Dheerasinghe, D. S. A. F., Malavige, N., de Silva, H. A., Morrison, A. C., Scott, T. W., Reiner, R. C., Grieco, J. P., & Achee, N. L. (2023). A cluster-randomized, placebo-controlled trial to evaluate the efficacy of a spatial repellent (Mosquito Shield™) against Aedes-borne virus infection among children ≥ 4–16 years of age in the Gampaha District, Sri Lanka: Study protocol (the AEGIS program). Trials, 24(1). BioMed Central. https://doi.org/10.1186/s13063-022-06998-z

16. Vidanapathirana, R., Wijesooriya, W. A. N., Rambukwella, R. N. K., & Priyadharshana, W. H. D. (2020). Value chain analysis of pineapple: Evidence from Gampaha district of Sri Lanka. Applied Economics and Business, 4(2).

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ISSN 2950-6808

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