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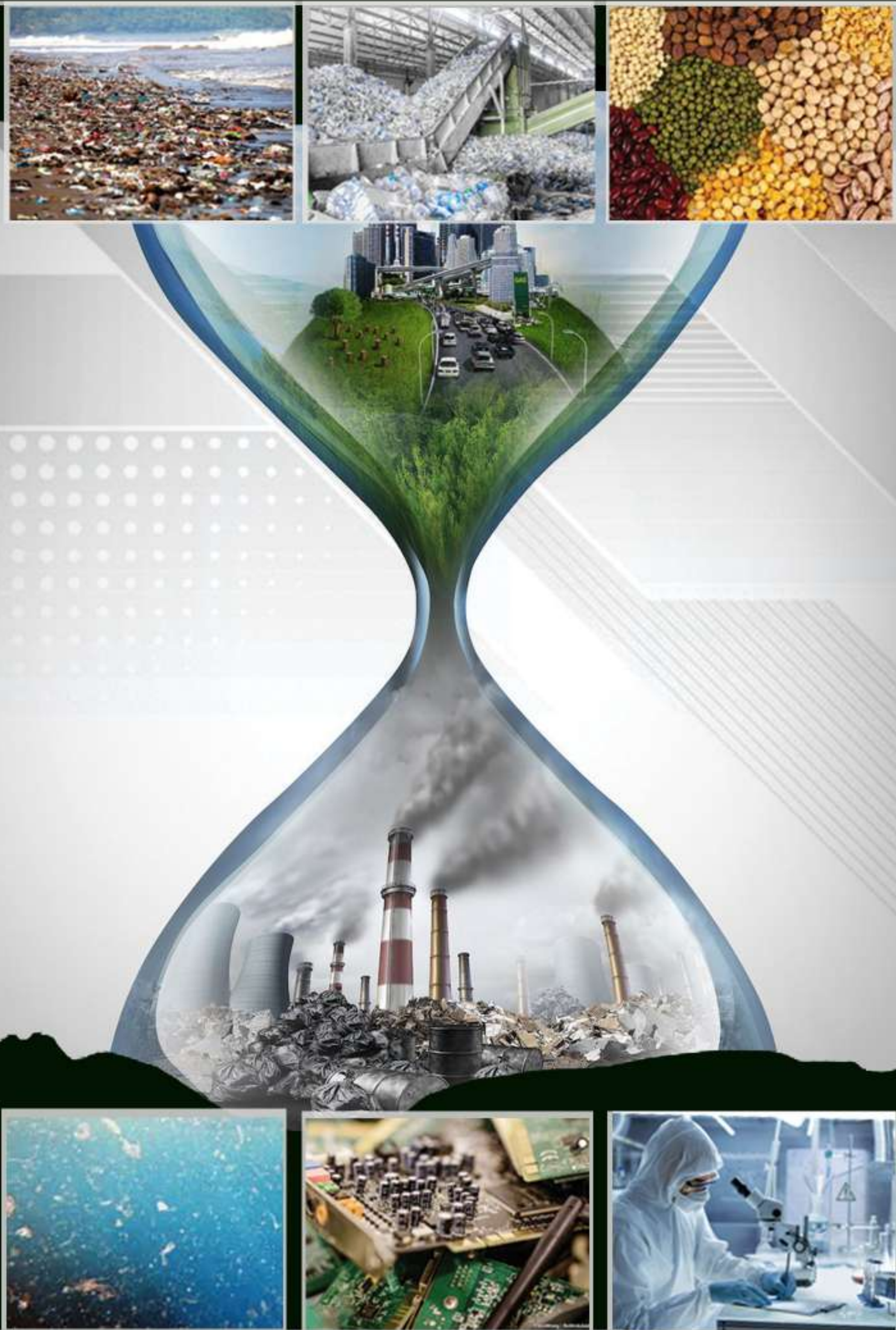
YOUNG SCIENTISTS FORUM



ENVIRONMENT SUSTENANCE AND FOOD SAFETY: NEED FOR MORE VIBRANT POLICY INITIATIVES FOR SRI LANKA

Environment Sustenance and Food Safety: Need for More Vibrant Policy Initiatives for Sri Lanka

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Environment Sustenance and Food Safety: Need for More Vibrant Policy Initiatives for Sri Lanka

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PREFACE

The National Science and Technology Commission (NASTEC) was established by the Science and Technology Development Act No. 11 of 1994 and came into operation in August 1998. It was formally inaugurated on 06 December 1998 and became a functional commission in January 1999. The Young Scientists Forum (YSF) of Sri Lanka has been hosted by NASTEC since 2000, to provide an opportunity for young scientists in Sri Lanka to voice their opinions on science and technology related issues. YSF currently consists of more than 400 members representing different disciplines.

The Steering Committee (SC) of YSF, that consist of 13 members, came up with a novel idea of publishing a chapter E-book identifying gaps/deficiencies related to existing policies, areas to be improved, and further strengthened in relation to Science, Technology, and Innovation (STI) in Sri Lanka. Given that the mandate of NASTEC is to advise the government in making policies on science and technology related aspects, SC firmly believed that this would be a golden opportunity for young scientists to raise their opinions and perspectives in a more critical, different and comprehensive manner.

Within this context, the theme of the chapter E-book was selected as "Environment sustenance and food safety: need for more vibrant policy initiatives for Sri Lanka". It has selected very timely and important topics, including: promotion of organic agriculture/ organic fertilizer; efficient utilization of biofertilizer; food safety and security-strategic to look for; improving biosafety; electronic waste management; and further strengthening of post-harvest technology and value addition etc.

Given the rapid change in the socio-economic environment along with a potential financial crisis in the near future, we see a real need to look at things from a different perspective with a broader future vision to address the above-mentioned issues despite their persistence for years without generating tangible solutions.

We hope that this chapter E-book will provide a useful resource for understanding the existing policy gaps and measures to overcome the existing barriers related to environment sustenance and food safety issues in Sri Lanka.

Prof. L.K. Weerasinghe
Editor-In- Chief
18th March, 2022

MESSAGE FROM THE ACTING DIRECTOR/NASTEC

It brings me great pleasure to deliver this message to the first ever E-book published by the National Science and Technology Commission's (NASTEC) Young Scientists Forum. This e-book provides a thorough examination of the existing material and information in the area of environmental sustainability and food safety. The E-book emphasizes the necessity for a vibrant policy intervention, as the issues do. As a result, NASTEC, as the government's policy advisory body for science and technology affairs, will use the review findings to identify gaps and recommend policy initiatives to address them. This e-book will also provide a wealth of information for readers who wish to conduct further research on specific topics.

This E-book consists of 11 chapters, each with a different topic linked to the main title. The YSF's Steering Committee thoroughly evaluated these chapters to ensure that the main title's major components were covered. Food safety and nutritional security, organic farming management systems, e-waste management, and all other chapters are highly debated problems within the current context that deserve priority in policy interventions. Therefore, I am confident that each and every chapter of this E-book will be of great service not only for research and development but also for instilling scientific thinking in the general public.

I am pleased that NASTEC was able to publish this first E-book despite numerous obstacles, and I would like to express my gratitude to the Chairman and all members of the YSF Steering Committee, as well as Ms. Thilini Munagamage, NASTEC Scientist, for their hard efforts in making this E-book a reality. I also express my gratitude and congratulate all of the young scientists who contributed papers to this E-book.

Ms. Nazeema Ahamed
Actg. Director/CEO
18th March, 2022

MESSAGE FROM THE CHAIRPERSON/YSF

As global citizens, we face a lot of precedent and unprecedented challenges every day. Have you ever wanted to make a positive difference but did not know where to begin or questioned whether one person could truly make that much of a difference? For the dreamers striving to contribute towards a positive impact, the Young Scientists Forum (YSF) of NASTEC has created an overview of a few global issues which are more relevant for overcoming the policy gaps in Sri Lanka and what has been done about them on a scientific note and compiled an e-book to address them. As the Chairperson of the Steering Committee of the YSF, I am honored to make a note on a valuable compilation presented as a result of the tremendous efforts put forward by the Editorial Committee of the book and the YSF Steering Committee.

This e-book attempts to address global problems that demand scientific solutions. This e-book has devoted particular attention to address 11 major topics and find answers for them in science, in line with the growing acceptance and importance attributed to this type of initiative all over the world, set itself the goal of sharing results, ideas, conclusions, and developments achieved along its course with interested colleagues/ scientists. Furthermore, the e-book offers an overview of all the scientific thoughts presented in the form of book chapters, aiming to be the seed of future developments, in particular, the solutions to the timely issues and policies. This e-book combines multiple perspectives and ways of addressing and relating technology, creativity, and affect, with promising development directions in current research on the above strands of topics, issues, and solutions.

I wish to take this opportunity to compliment all the authors for presenting their relevant perspectives on the thematic topics that required thorough addressing, and I am in debt to all the reviewers who kindly and thoroughly collaborated in revising and improving the chapters, under a process of strong reviewing. All this contributed to the high quality of the final published chapters in the e-book. One last note of recognition to the Editorial Committee of the e-book and the YSF steering committee for compiling and promoting this e-book and extending their invaluable support to find solutions for a better tomorrow.

Prof. S. Samarakoon
Chairperson YSF- 2021

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- We are grateful to Ms. Senuri Eriagama, Eye Pixels, Pilimatalawa for designing this chapter e-book in a very attractive manner.
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CONTENTS

Contents **Page No.**

CHAPTER 01

TOWARDS EFFECTIVE MANAGEMENT OF ELECTRONIC WASTE IN SRI LANKA: CHALLENGES AND WAY FORWARD

Towards Effective Management of Electronic Waste in Sri Lanka: Challenges and Way Forward

H.M.A.J. Herath*, L. Udayanga and U.S. Liyanaarachchi

Abstract Advancement in technology has induced human civilizations to largely depend on electrical and electronic products in their day-to-day activities. This has led to the generation of Electronic Wate (E-waste) in enormous quantities, which has been estimated to increase by 5–10% per year. Further, improper disposal of E-waste has been recognized to result in serious detrimental impacts on ecological and human health at different scales. Therefore, effective management of E-waste has become a challenge to many counties, including Sri Lanka. At present, the import and reselling of used electrical and electronic items have led to enormous accumulation rates of E-waste in Sri Lanka. Limitations in public awareness, poor knowledge, and practices related to E-Waste handling among residents and scrap dealers, gaps in existing policies and regulations, limitations in technical expertise, and inadequate budgetary allocations for E-waste management have further aggravated this issue. To face aforesaid Challenges, the government of Sri Lanka has to strengthen the existing policies and legislations on E-waste management. Further, the consumers and scrap dealers must be educated regarding the harmfulness of E-waste and safe procedures to handle household E-waste. Establishing a well-organized E-waste management mechanism that includes the door-to-door collection of E-waste, recycling, reusing, and appropriate disposal methods is also essential. In addition, continuous monitoring of the E-waste management practices of the relevant scrap dealers and agencies, restricting the inflow of used electronic equipment to Sri Lanka through taxing mechanisms, and establishment of proper E-waste treatment and disposal facilities are also important strategies to ensure proper E-waste management in Sri Lanka.

Keywords: E-waste, E-waste management, Trends and challenges, Sri Lanka, Emerging crisis

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An Overview of Electronic Waste (E-waste)

We are on the verge of a technology revolution that will change the way we live, work, and interact with one another. Electrical and Electronic Equipment (EEE) has become an indispensable and integrated part of human life, since the introduction of electric power and mass production facilities during the second industrial revolution, which enhanced the overall living standards of humans. Now a Fourth Industrial Revolution is emerging in the world, which is a digital revolution that has been taking place since the middle of the last century. As a result, the use of EEE is rapidly increasing in the world and the usable lifespan of EEE is now becoming shorter and shorter, due to the booming growth of technology. This has driven the global market towards the ever-increasing production of EEE, while generating megatons of electronic waste (E-waste) all over the world. The United Nations Environmental Programme has made known the huge growth of E-waste as a "Tsunami of E-waste rolling out over the world" [1].

Electronic waste, which is commonly known as E-waste, "E-scrap" and "End-of-life electronics", refers to all kinds of electronic and electrical devices that are disposed of after their short lifespan have been exhausted. Often, E-waste is discarded, donated, or given to a recycler when the desired life span is nearing the end. Different definitions and classifications are being used for E-waste by different institutions and countries [2].

According to the Environmental Protection Agency (EPA) in the United States, E-waste has been classified under ten categories:

1. Large household appliances (refrigerators, washing machines, microwaves, etc.)
2. Small household appliances (toasters and blenders etc.)
3. IT and telecommunications equipment (laptops, printers, mobile phones, routers, etc.)
4. Consumer electronics (radios, televisions, cameras, etc.)
5. Lamps and luminaires
6. Electronic toys
7. Different tools (drills, sewing machines, grinders, etc.)
8. Medical devices
9. Monitoring and control instruments (smoke detectors and moisture sensors etc.)
10. Automatic dispensers

Trends in E-Waste Generation in the Global Context

Electronic waste remains the fastest growing waste stream in the world [3], where the billions worth of valuable heavy metals such as gold, silver, and copper are being dumped or burned in every year with discarded EEEs. As highlighted by the United Nations Institute for Training and Research, only a few countries are collecting internationally comparable E-waste statistics, while many countries lack the capacity to collect E-waste data [4]. E-waste is increasing drastically, with a growth rate of 20-25% annually [5]. A recent study conducted in 2019 has evidenced that the Asia Pacific region accounts for the highest amount of E-waste generation (25 MT), in comparison to America (13.1 Mt), Europe (12.1 Mt), Africa (2.9 Mt), and Oceania (0.7 Mt) [6]. Further, the volume of E-waste generated in 2014 has increased from 44.4 Mt up to 53.6 Mt. in 2019. It is predicted that the total volume of E-waste will increase up to 74.7 Mt by 2030. The economic consequences due to the COVID-19 pandemic have not been considered for this future projection. The lack of a proper data collection and documentation mechanism on the global E-waste flow has been recognized as a major constraint in enhancing the efficiency of E-Waste management [7].

Even though, as of 2019, E-waste legislation, policies, and regulations were in place in 78 countries throughout the world, proper recycling facilities have not yet been established in most of the countries. Therefore, the majority of the counties rely upon fundamental approaches to recover valuable components in EEEs, while hazardous components are disposed of, through engineered landfills [4]. China, which uses the highest amount of technological equipment, accounts for the highest E-waste generation rate in Asia. A recent study conducted in Singapore, which remains the second-largest E-waste producer in Asia, revealed that more than 60% of Singapore's population are unaware of proper E-waste management strategies. This lack of awareness has become a challenging issue in most of the developing and least developed countries [8].

According to the United Nations, millions of tons of old and unserviceable EEE have been shipped out from Europe, mostly to the developing nations of West Africa and Asia. The heavy cost of recycling E-waste leads to dumping them in countries that lack adequate environmental standards or have poor legislation frameworks. In the past decade, most of the developing countries have launched multiscale projects to strengthen their IT infrastructure in order to achieve a digital future without proper procedures to manage the increased generation of E-waste. As a result of that, a global surge of electronic waste is expected in the near future [9].

Previous studies have identified five main driving factors that influence people to discard EEE. Those are social effects (recommendations from friends, neighbours, and advertisements), purchasing power, additional features in new products, expiry or poor capacity of the old equipment, and damages/poor-functioning nature. Often, the additional features in the new EEE remain the most influencing fact, which encourages people to dispose used EEE items and purchase new items, while the exponential development of technology plays a critical role. In addition, the growth of the economy and purchasing power of the community also contribute to higher generation rates of EEE [7, 10]. Therefore, adopting effective strategies for E-waste management has been recognized as a requirement to ensure sustainable development.

Environmental and Health Concerns Related to E-Waste

A person may become exposed to E-Waste mainly due to informal recycling and formal recycling. Certain primitive recycling techniques, such as acid leaching and cable burning, to recover precious metals such as gold, silver, copper, etc., could lead workers in informal E-waste recycling centers to become directly exposed to contaminants as they dismantle the discarded devices. Further, a variety of hazardous substances such as polyaromatic hydrocarbons and dioxins, are often released into the environment, due to such informal recycling practices [11].

In the case of the formal E-waste recycling centers, especially designed equipment and methods are used to extract valuable components in EEE. Even though health and safety procedures are also followed, ceratin hazardous compounds could be released into the environment accidentally or unintentionally. Further, the construction and maintenance of such advanced centers are highly expensive and therefore these are rare in less developed countries. Owing to the relatively higher levels of environmental, food, and water contaminants in E-waste, people who are living within a specific distance from an E-waste recycling or dumping areas, are also at the risk of being exposed to hazardous elements [11-12].

A variety of hazardous elements such as lead, Cadmium, Chromium, Mercury, Copper, Manganese, Nickel, Arsenic, Zinc, Iron, and Aluminum, could be found in E-waste as shown in Table 1. In addition, certain Persistent Organic Pollutants (POPs), namely Brominated flame retardants (polybrominated diphenyl ethers), polybrominated biphenyls, dibrominated diphenyl ethers, polychlorinated biphenyls, polychlorinated or polybrominated dioxins, and dibenzofurans dioxins, hexabromocyclododecan, could also be released into the atmosphere due to E-waste processing [12]. Therefore, people residing in nearby areas or working in such E-waste processing sites can be exposed to

these pollutants through contaminated air, water, soil, dust, and food sources, including meat and fish.

Table 1: Chemical classification of e-waste components, along with their sources and routes of exposure

Hazardous chemical element	Component of electrical and electronic equipment	Ecological source of exposure
Lead	Printed circuit boards, cathode ray tubes, light bulbs, televisions, and batteries	Air, dust, water, and soil
Chromium or hexavalent Chromium	Anticorrosion coatings, data tapes, and floppy disks	Air, dust, water, and soil
Cadmium	Switches, springs, connectors, printed circuit boards, batteries, infrared detectors, semi-conductor chips, ink or toner photocopying machines, cathode ray tubes, and mobile phones	Air, dust, soil, water, and food (especially rice and vegetables)
Mercury	Thermostats, sensors, monitors, cells, printed circuit boards, and cold cathode fluorescent lamps	Air, vapour, water, soil, and food (bioaccumulative in fish)
Zinc	Cathode ray tubes, and metal coatings	Air, water, and soil
Nickel	Batteries	Air, soil, water, and food (plants)
Lithium	Batteries	Air, soil, water, and food (plants)
Barium	Cathode ray tubes, and fluorescent lamps	Air, water, soil, and food
Beryllium	Power supply boxes, computers, x-ray machines, ceramic components of electronics	Air, water, and food

(Source: Lancet Global Health Summit, 2009)

Based on the reports of the International Agency for Research on Cancer (IARC), certain chemical pollutants found in E-waste such as Cadmium, hexavalent Chromium, and Beryllium have been recognized as carcinogens [10]. In addition, some polychlorinated biphenyls, polycyclic aromatic hydrocarbons, polybrominated diphenyl ethers, metallic nickel, and polycyclic aromatic hydrocarbons have been classified as possible carcinogens [11]. Meanwhile, certain polybrominated diphenyl ethers, polycyclic aromatic hydrocarbons, chromium, nickel, and aluminum have been identified as genotoxins, which can result in DNA or chromosomal damage [12].

Many studies have evidenced that heavy metals such as Copper, Iron, and Aluminum could result in cell injuries, acting as cytotoxins. Exposure to certain dioxins (polychlorinated biphenyls, perfluroalkyls, lead, and Cadmium), released due to E-waste processing could result in chronic diseases later in life, including obesity, type 2 diabetes, hypertension, and cardiovascular diseases [12]. Apart from the above, polycyclic aromatic hydrocarbons, hexavalent chromium, Cadmium, Nickel, Arsenic, and Lithium that are commonly found in E-waste could cause lung cancers and lung damage, while hindering lung functions [11-12]. In addition, exposure to certain compounds in E-waste has been linked with strong neuro-developmental and neuro-behavioural effects, which may lead to decreased intelligence, impaired cognitive functioning, behavioral disturbances, and attention deficiencies [13].

Often, harmful toxins tend to seep down to the soil and groundwater table near poorly designed E-waste dumping areas, leading to alterations in pH levels and composition of soil and groundwater. This, may lead to serious ecological concerns. The microorganism communities in soil and water will be directly influenced along with another biot [14]. The rivers, ponds, and lakes can become more acidic and poisonous, causing harm to populations even miles away from the landfill, while leading to bioaccumulation of heavy metals. The higher acid levels of water can damage marine life, thus harmfully influencing the ecosystem. Further, exposure to POPs through food chains may influence the entire wildlife.

The manufacturing and treatment of EEEs may release different Greenhouse Gases (GHGs), that contribute to human-induced global warming. These GHGs such as PerFluoroCarbons (PFC), Sulfur hexafluoride (SF_6), and Nitrogen tri Fluoride (NF_3) are characterized with relatively higher Global Warming Potentials (GWP) and atmospheric lifetimes [13]. Therefore, both manufacturing and treatment of EEE could result in undeniable impacts on global warming and climate change. If necessary actions and policy-level decisions are not taken immediately, E-waste can cause permanent damages to the environment and humankind, recovery of which may be difficult or even impossible. In the case

of sustainability, improper management of E-waste directly contribute to a significant loss of scarce and valuable raw materials [3].

E-Waste Generation in Sri Lanka

Most of the developing and less developed counties are at a disconsolate level in E-waste management. They are importing a large number of discarded mobile phones, laptops, tablets, toys, digital cameras, and other EEE under the label of “reusable or refurbished items”. Therefore, tons of E-waste are illegally shipped into poor countries by developed nations with the support of corrupted or inactive government authorities of those countries [4]. Due to the lack of policies and legislative framework on E-waste management, gaps in E-waste recycling technologies, the unbearable capital and maintenance costs required for E-waste management, and unawareness of people on E-waste handling, these countries have become dumping grounds of E-waste, causing significant environmental issues and health risks. The favourable attitudes among the community to consume “used goods” have further aggravated this issue. These equipments are often diverted to the black market and sold as refurbished products to avoid the costs associated with legitimate recycling. As being a country in the same category, Sri Lanka is also facing a huge challenge in managing E-waste in the country.

Annually, Sri Lanka produces around 70 Mt – 75 Mt of E-waste, where Cathode Ray Tubes (CRT), mobile phones, CFL bulbs, batteries, computers remain prominent types. Based on a recent study, around 27.4 million mobile connections are being used in Sri Lanka, which is being increased steadily. The usage of mobile devices has also been increased from 126% in 2017 to 131% in 2018, reporting the highest mobile usage in the South Asian Region [14]. Furthermore, computer-owned households have also increased from 22.5% in 2016 to 23.5% in 2017. Due to the technological advancement of the world, the demand for mobile phones and computers is rapidly increasing in Sri Lanka. The majority of this demand is catered by refurnished devised imported from different countries. As a result, the unbearable load of E-waste is also being generated within the country [17]. End-of-life CRT Televisions (TV) and monitors in Sri Lanka provide an ideal example for the above issue, where only 10% of the available CRT monitors and TVs in the country (around 7.6 million) are properly disposed. The remaining 90%, which are disposed via informal approaches, contain around 8840 t of Lead and 110 t of Arsenic, which may induce undeniable environmental and health impacts [15].

The limited purchasing power of the country is elevating the secondhand market of EEE. According to a recent study conducted by the Central Environmental Authority (CEA), approximately 30% of the imported computers in Sri Lanka are in used conditions, where the average life span is relatively shorter and most of them are not in a working condition. Therefore, these devices are destined to end up as E-waste within a very short period. Currently, Sri Lanka tends to denote a per capita E-waste generation rate of 4.2 kg/year [14].

E-Waste Management Strategies

Most of the developing countries have already taken steps to manage E-waste properly to minimize the harmful long-lasting negative consequences on the environment and human health. The main focus of E-waste management strategies is to enhance the sustainability and environment-friendly nature of electronic products, to extend the life of used electronics through refurbishing/ reusing, and by other means, and to develop cost-effective strategies to ensure effective E-waste management [6]. Most of the reviews published recently have emphasized that effective E-waste management programmes are associated with higher capital and maintenance costs.

The most commonly proposed solution to manage E-waste is to decrease the amount of EEE production and usage. Further, the importance of improving the design of EEE to facilitate repair and reuse, also known as "Eco-Design" has also been highlighted. Under this concept, the main focus is laid on the use of easily recoverable, recyclable, and less toxic materials, which can be used for disassembly, refurbishment, reuse, and remanufacturing [6]. In addition, strategies such as eco-labeling could also be promoted via government policies to promote eco-designed EEE. Further, appropriate use of taxing and economic incentive tools is also an important strategy that could be utilized to control the entry of EEE into the Municipal waste stream of a developing country. A comprehensive E-waste management system should be comprised with standard E-waste collection procedures, material recovery techniques, and segregation and safe disposal of hazardous waste to ensure sustainability [4]. Under this context, all the EEE manufacturers, consumers, governments, policy makers, and Non-Government Organizations (NGOs) have to account for the responsibility of effective E-waste management. Conducting proper awareness programmes for the general public (consumers) on the impacts of improper E-waste disposal and educating them regarding proper practices of E-waste handling is critical. In addition, training of the scrap dealers in E-waste handling and management, registering of such dealers, and periodical monitoring of the standard of their operations are also important to enhance the efficacy of E-waste management [18].

Based on the available literature only 66 countries of the world had implemented E-waste related legislations, policies, and regulations by 2017, which increased up to 78 in 2019 [18]. Figure 1 depicts a proposed policy framework for E-waste

management considered during 2017 [16]. Different countries have adapted their E-waste management programmes with different models, frameworks, and legislations. By being the first country that implemented a proper E-waste management programme in 1991, Switzerland is capable of recycling or incinerating around 98% of all E-waste properly to produce energy. This approach, which is also known as "The Swiss Model" is widely known as "the Wheel of Life" [17].

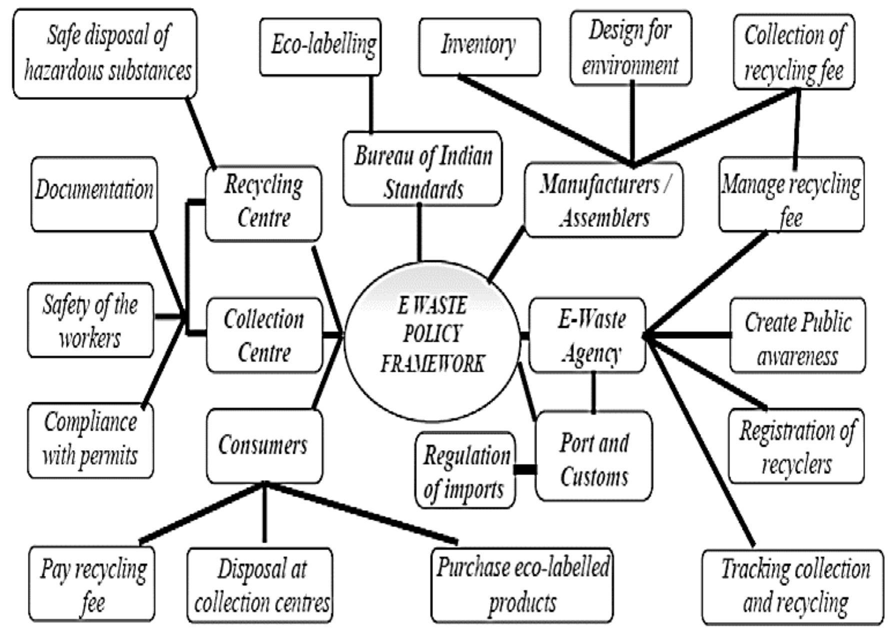

Figure 1. A policy framework for E-waste management (Source: www.oaijse.com)

Global E-waste Management Approaches

The Swiss Model

The "Swiss Model for E-waste Management" was introduced in 2003 by the State Secretariat for Economic Affairs (SECO) under a global E-waste management programme known as the "Knowledge Partnerships in E-waste Recycling". This model mainly aimed to avoid entering E-waste into the Municipal waste stream and illegal dumping, while enhancing the recovery of all possible valuables from the E-waste stream and minimizing the disposable fractions that are incinerated or dumped into sanitary landfills [18]. The proposed Swiss "Wheel of Life" model consists of five steps: 1) Purchase of new EEE; 2) Returning old items; 3) Detoxing E-waste (removing all hazardous components in E-waste to avoid contaminations); 4) Shredding/mechanical processing of E-waste, and

5) Refining resources (extracting raw materials with minimal environmental impacts) [19]. Regardless of the strategic nature of this model, the economical, environmental, social, and technical feasibility of the proposed strategies at different stages of this model have to be carefully evaluated in adopting this model for E-waste management in a developing country.

UNIDO E-Waste Management Concept

United Nations Industrial Development Organization (UNIDO) has proposed a framework for E-waste management with the active involvement of government, community, and private sectors (Figure 2). This model attempts to encourage industry to “design for recycling”, while promoting sustainable solutions to transform the E-waste recycling process into opportunities and resources for sustainable production.

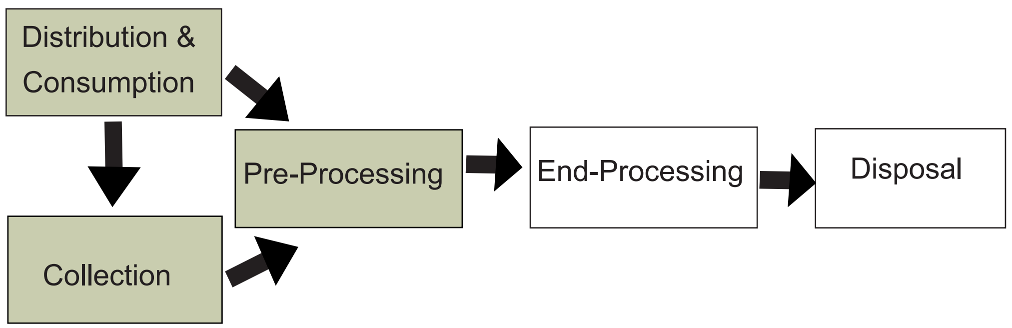

Figure 2. E-waste management model of UNIDO

Conventions and Policies

Extended producer’s Responsibility (EPR) is a key agreement in the majority of E-waste management programmes. Under this concept, the producer of EEE has to bear the responsibility of handling EEE even after its “End of Life”. In addition, the Basel Convention on the Control of Transboundary Movement of Hazardous Waste and their Disposal, proposed in 1989, also aims to minimize the generation of harmful waste, restrict the transboundary movements of hazardous waste, and promote environment-friendly management [17]. The Rotterdam Convention in 2004, also aims to induce a shared responsibility between E-waste exporting and importing countries, facilitating E-waste importing countries to obtain more reliable information to support the making of sound decisions, whether to purchase E-waste from the exporting countries.

The Waste Electrical and Electronic Directive of the European Union, which was

enacted in 2012, aims to prevent or reduce the adverse impacts of improper E-waste management via regulations on product design (Eco-design) and Life Cycle Assessment (LCA) of EEE. Through this directive, reuse, recycling, and recovery of E-waste are encouraged as the best E-waste management options, while reducing the disposal of E-waste. Restriction of Hazardous Substances (RoHS) Directive was launched in 2011, aiming to restrict the use of hazardous substances (Lead, Mercury, Cadmium, hexavalent Chromium and polybrominated biphenyl) as raw materials in the production process of EEE, while promoting the use of Eco-design concepts for environmental-friendly recovery and disposal [20].

Key Stakeholders and Their Roles and Responsibilities for Effective E-Waste Management

The success of any E-waste management system is directly influenced by the active participation and roles played by different stakeholders relevant to the E-waste management stream. Promotion of the integrated approaches for E-waste management with the active participation of various key stakeholders, particularly governments, regulators, producers, and recyclers, is a key factor to establish successful E-waste management systems. Almost all E-waste management systems have identified the following stakeholders as the leading contributors.

- Government: A properly functioning regulatory and policy framework for E-waste management has to be developed at the national and regional levels. The existing mechanisms for E-waste management have to be further strengthened and supported.
- Municipalities and Urban Councils: A comprehensive and efficient E-waste collection system has to be implemented with adequate treatment options under the guidance of national policies and with the support of other relevant stakeholders.
- Producers/Manufacturers and Retailers: More eco-friendly EEE have to be produced and sold under standard guidelines and regulations (international and national), with attention on the concepts of Eco-design and Life Cycle Assessment of impacts.
- Producer Responsibility Organisations: Should monitor and operate E-waste collection mechanisms on behalf of producers, transport them to appropriate treatment centres, and ensure they are properly treated.
- Waste Collectors and Aggregators: Should support the collection and temporary storage of E-waste, based on standard operational guidelines until directed for further treatment.
- Consumers: Have to purchase the better EEE, considering the environmental feasibility, Eco-labels, and Eco-designs of the products.

Further, consumers should be aware of best practices, and procedures on proper disposal of E-waste, and have to attempt to reduce the unnecessary purchase of EEE.

- E-waste Processors: Recycling or disposal, material recovery, and operation of second-hand markets have to be governed by the E-waste processes adhering to best practices on E-waste management. In addition, management of scrap dealers, dismantlers, processors, recyclers, and downstream partners should also be done by them.
- Non-Governmental Organizations (NGO): Monitoring the performance, strengths, and limitations of existing E-waste management systems and Knowledge transfer, stakeholder interaction, and provision of funds remain as the main roles and responsibilities of NGOs.

Barriers and Challenges Against E-Waste Management in Sri Lanka

The Central Environmental Authority (CEA), which was established under the National Environmental Act, No. 47 of 1980 acts as the main government entity responsible for the management of Electronic Waste in Sri Lanka. Subsequently, a policy on E-waste management was drafted in 2008 to address the E-waste crisis in Sri Lanka, while adhering to the provisions of the Basel Convention and other related Conventions [21]. This National Electrical and Electronic Waste management policy aims to facilitate the following objectives.

- To prevent or minimize the negative impacts arising due to haphazard use of EEE and improper disposal of E-waste on the environment and health of the people.
- To promote integrated E-waste management at all phases of the life cycle of EEE using the most effective strategies to prevent disposal of E-waste in geographically scattered locations and to enhance maximum resource recovery.
- To promote social responsibility towards sustainable production and consumption of EEE.
- To ensure the environmental feasibility of E-waste treatment and disposal operations in Sri Lanka.

The implementation and successful operation of E-waste management in Sri Lanka faces a number of challenges as the discussion below.

Lack of Policy-based Legislations for Managing E-waste

According to the Performance and Environment Audit Division, the policy framework for managing E-waste in Sri Lanka has not been properly empowered. Therefore, all the E-waste management operations are been conducted without

a proper policy framework. Further, the developed policy has only focused on the management of discarded computers, computer accessories, and mobile phones, while other management of E-waste generated from other EEE has not been considered. Even though, Extended producer's Responsibility (EPR) is included in the policy, only a limited number of institutions had obtained the licenses for that purpose [22].

Inadequacy of Awareness about Proper E-waste Handling

Importers, manufacturers, and consumers must be educated about the harmful impacts of E-waste and methods that must be followed for the proper disposal of E-waste. The country must have an explicitly defined mechanism for E-waste collection, treatment, and disposal. Then the respective parties must be made aware of the mechanism. Few studies conducted in Sri Lanka have evidenced knowledge gaps on different categories of E-waste, their impacts on ecosystems and human health, and the role and responsibilities of different stakeholders in E-waste management [16, 22-23]. Further, the use of mass media for increasing awareness among the general public on the methods of E-waste management and disposal, while inculcating the importance of reducing the E-waste generation.

Absence of Databases on E-waste Generation and Treatments

Unavailability of data regarding E-waste generation and treatments is a global issue and only very few countries including the US, Switzerland, Japan, etc. maintain frequently updated databases on E-waste. At present, around 82.6% of the global E-waste flow is not well monitored and documented [4]. In the Sri Lankan context, a properly functioning database for E-waste generation and treatment is not being maintained. Therefore, policymakers and other stakeholders are facing difficulties in evaluating the efficacy of E-waste management procedures and implementing best policy practices [21].

Lack of Coordination Among the Relevant Institutions

The coordination among government authorities, E-waste collectors, private institutions in the field, and EEE consumers is very important for an effective and well-functional E-waste management system. In Sri Lanka, the CEA act as the main governing body for E-waste management, assisted by a variety of other government agencies such as the Department of Import and Export Control, the Sri Lanka Standards Institution, the Consumer Affairs Authority, the Telecommunications Regulatory Commission of Sri Lanka, and the Ministry of Health, Nutrition and Indigenous Medicine [21]. In addition, a number of E-waste processing agencies are also operating in the private sectors in different parts of the country. Therefore, proper interventions should be initiated to promote coordination of these stakeholders, to avoid unnecessary barriers in E-waste management systems.

Unavailability of Organized E-waste Collection Mechanism

In 2017, the CEA has admitted that there is no well-coordinated programme to manage E-waste in Sri Lanka [22]. According to CEA, around 17 licensed E-waste collecting companies are operating in Sri Lanka at present. However, an efficient island-wide E-waste collection mechanism is lacking in Sri Lanka, while the capacity to treat collected E-waste is also limited [23]. A "National Corporate E-Waste Management Programme" was launched by the CEA under the theme of "Ensuring an E-waste free environment" in 2011 with the objectives of establishing a properly functioning island-wide E-waste collection mechanism, organizing drop-off events, and raising awareness among citizens. Even though this programme is still in operation with the involvement of more than 20 partner organizations, the objectives are not being achieved successfully yet [16, 26].

The CEA has also declared a National Electronic Waste Management Week from 5th to 9th October 2020, with the association of the Department of Posts of Sri Lanka under the theme "Sri Lanka is a Breathtaking Country, Electronic Waste Free Sri Lanka" [24]. An Islandwide annual E-waste collection programme was launched during the week and it was expected to receive household E-waste via post offices all over the country. But the programme was affected by the operational weaknesses of the E-waste collection mechanism. Even though the programme was launched as an annual event it was not conducted in 2021. Therefore, lacking a properly functioning E-waste collection system in Sri Lanka has become a key challenge for proper E-waste management.

Limited Financial Resources and Technology

The establishment and maintenance of properly functioning and up-to-date E-waste treatment facilities is costly and requires technical expertise [9]. As a developing country, Sri Lanka is having limited financial resources, and the accessibility to high technology in E-waste treatment is limited. Therefore, limitations in the availability of financial resources have hindered the establishment and operation of E-waste treatment facilities in Sri Lanka.

Recommendations and Way Forward

A properly functioning E-waste management system is characterized by several fundamental activities that are important in handling E-waste. A well-defined

policy-based E-waste management framework is highly essential as a country and CEA must act immediately to make public the finalized E-waste management policy. Further, importing used EEE must be examined thoroughly and moderated with well-established rules and regulations. The available lifespan of used EEE is a significant factor to be considered in controlling the import of second-hand EEE. Therefore, regulations should be enacted on discouraging the imports of low quality and used EEE, while encouraging the imports of equipment that has less harmful elements. Even though the government has restricted importing used computers, certain importers tend to import EEE as "knocked down" goods and assemble those locally [14]. Therefore it is necessary to implement legislation on controlling the imports of used parts of EEE, as well.

Making people aware of the hidden danger in consuming End-of-Life EEE including the impacts on health and environmental effects is vital for proper handling of E-waste. Consumer-touch-points of EEE such as electronic shops can be easily used to educate EEE consumers about E-waste and methods to handle E-waste properly. The authorities can enforce retailers to display figures and flyers, while selling EEE and awaring consumers. Currently, social media is the most effective method to reach the entire general public of the country, and the government and non-government institutes can use social media platforms to effortlessly reach a higher level of awareness in the general public about the proper handling of E-waste and the associated dangers. In addition, consumers must be encouraged not to purchase EEE unnecessarily. Manufacturers of fascinating electronic items such as smartphones, smartwatches, tabs, laptops, etc. highly influence people to upgrade their devices to newer versions rapidly by adding new attractive features. Therefore reducing the user of EEE can be obtained only through a thorough awareness programme on the E-waste crisis.

Currently, the recycling facilities established in the country detach plastic and metallic components from E-waste and sell them to downstream vendors, while printed circuit boards are exported. The government should facilitate E-waste recycling centers to be upgraded to cater to the entire downstream management of E-waste. For this economic tools such as the provision of soft loans and tax subsidies, etc. should be provided for the private stakeholders, while empowering the E-waste management framework through policies. In addition, the government has to fund state level E-waste treatment facilities in the country, with collaborations with other developed countries for technical expertise. Further, the E-waste handling process must be streamlined from door-to-door collection to ending up with fundamental dismantling and metal recovery practices.

In addition, the promotion of institutional coordination among the relevant entities and key entities to establish an effective E-waste management system is also important. Also, well designed training programmes and awareness campaigns have to be organized for different target groups to make them aware of the coming E-waste crisis, their roles, and responsibility to address this issue, while attempting to change their attitudes to participate in proper E-waste management practices to defend Sri Lanka from the "Tsunami of Electronic Waste".

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CHAPTER 02

SUSTAINABLE E-WASTE MANAGEMENT FOR SAFE ENVIRONMENT AND HUMAN WELLBEING: PRIORITIZING POLICY INTERVENTIONS IN SRI LANKA

Sustainable E-waste Management for Safe Environment and Human Wellbeing: Prioritizing Policy Interventions in Sri Lanka

A.K.H. Priyashantha, N. Pratheesh* and P. Pretheeba

Abstract Every year, an enormous amount of e-waste is collected throughout the world. As an emerging economy in the Sri Lankan context, the generation of e-waste is increasing at an alarming rate, although adequate measures have not been taken to minimize this accumulation. Due to the presence of many different toxic components, e-waste is classified as hazardous trash. Toxic compounds mainly include heavy metals such as arsenic, cadmium, copper, iron, lead, lithium, mercury, and other organic chemicals like decabromodiphenyl ethane. These toxic compounds are released into the environment through improper disposal and landfilling, which damages air, soil, and water, eventually affecting human health and causing significant diseases such as multiple organ failure, nervous disorders, and cancer. This chapter sets out to highlight these detrimental effects owing to e-waste and how Sri Lanka could move forward by mitigating the adverse effects. The country is still in need of effective enforcement of the measures implemented. There is also an urgent need to close the loopholes in the existing directives, which are crucial to addressing the e-waste scenario. Raising public awareness and empowering formal e-waste collection and recycling mechanisms are the other two key e-waste management concerns that need to be addressed.

Keywords: E-waste, Existing directives, Toxic compounds, Public awareness, Recycling mechanisms

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Introduction

Along with the rapid development of world science and technology and the growing interest of consumers, global electrical and electronic equipment (EEE) is being updated at a faster iteration speed [1]. The term "EEE" refers to any product with circuits or electrical and electronic components that need to be supplied with electricity or batteries to perform their functions. Today, EEE is becoming more common to dispose of, and such products that are redundant, obsolete, or broken and are disposed of by their users, are called waste electrical and electronic equipment (WEEE) or, more commonly, e-waste [2, 3]. According to the International Telecommunication Union (ITU) and the Basel Convention, e-waste is regarded as waste, including all components, sub-assemblies, and consumables that were part of the EEE at the time the equipment became waste [4]. Figure 1 shows some of the e-waste generated by households.

Figure 1. Household collection of e-waste. Waste EEE or e-waste encompasses a wide range of items used in households and businesses, including laptops, telecommunication equipment, TVs, radios, lamps, cooking and kitchen appliances, and so on (Photo credit: A.K Hasith Priyashantha, Field survey-2021).

Today, e-waste is considered one of the most critical and pressing issues worldwide, though it is frequently overlooked [5]. Ismail & Hanafiah [6]; Li & Achal [7]; and Singh et al. [8] highlighted that the amount of e-waste rises at an alarming rate every year. For instance, since 2014, global e-waste production has increased by 9.2 metric tons (Mt) and in 2019, about 54 Mt of e-waste was generated globally (7.3 kg of waste per capita). With this accelerating rate, 74.7 Mt of e-waste is expected to be generated in 2030. Asia produced the most e-waste in 2019, with 24.9 Mt, followed by the Americas (13.1 Mt), Europe (12 Mt), Africa (2.9 Mt), and Oceania (0.7 Mt) [3]. The main reason for this rapid growth of e-waste is the frequent discarding of personal computers (PCs). The global market for PCs is far from being saturated, and the average lifespan continues to decrease. In 1997, central processing units (CPUs) had a lifespan of 4–6 years, though that dropped to 2 years in 2005 [9]. The situation is similar with many other electrical and electronic devices such as printers, televisions, mobile phones, refrigerators, and air conditioners, whose lifespan is becoming shorter and shorter, thus accelerating the e-waste accumulation [9, 10].

Despite the great production, e-waste is classified as hazardous waste by the Basel Convention. This is due to the presence of harmful substances that harm the environment and can cause life-threatening illnesses to humans. The Basel Convention has been tackling e-waste challenges since 2002, including environmentally sound management; preventing illegal transit to developing countries, and building capacity to better manage e-waste around the world [10]. The Basel Convention was also intended to reduce the movement of waste across countries or other political borders; however, illegal transport could not be stopped entirely. For example, the transboundary e-waste movement is responsible for about 70% of the e-waste generated in China [11]. Today, China has become the world's largest e-waste dumpsite, while in 2019 China produced 10,129 kt (7.2 kg per capita) of e-waste [3]. As a result of the unregulated nature of e-waste, many negative impacts have been observed around the world in recent years. Therefore, more attention needs to be paid to address this mounting issue [11, 12].

As a small island in the Indian Ocean, Sri Lanka is also being accompanied by the free market economy. Because of this fact, Sri Lanka annually imports a large amount of EEE [13]. As a result, Sri Lanka is now recognized as a popular e-waste destination alongside other developing countries such as India, Bangladesh, Pakistan, China, the Philippines, Benin, Ghana, Ivory Coast, Nigeria, and Liberia [14]. To further address the scenario, cell phones first became available in Sri Lanka in the early 1990s, and the country now has the highest cell phone penetration rate among other South Asian countries. In addition, TVs, PCs, refrigerators, and washing machines show the next highest penetration rates, respectively [13]. The continuous expansion of this market availability has led to an accumulation of e-waste and in 2019, about 138 kt (6.3 kg per capita) of e-waste was generated in the country, which is 21 kt (5.6 kg per capita) higher than that produced in 2015 [3]. Figure 2 shows the total amount of EEE put on the market and produced e-waste in the past several years. Though e-waste is accumulating at an alarming rate, the attention given in the country seems to be minimal. There is only a handful of literature available on studying the e-waste scenario in Sri Lanka [13, 15, 16].

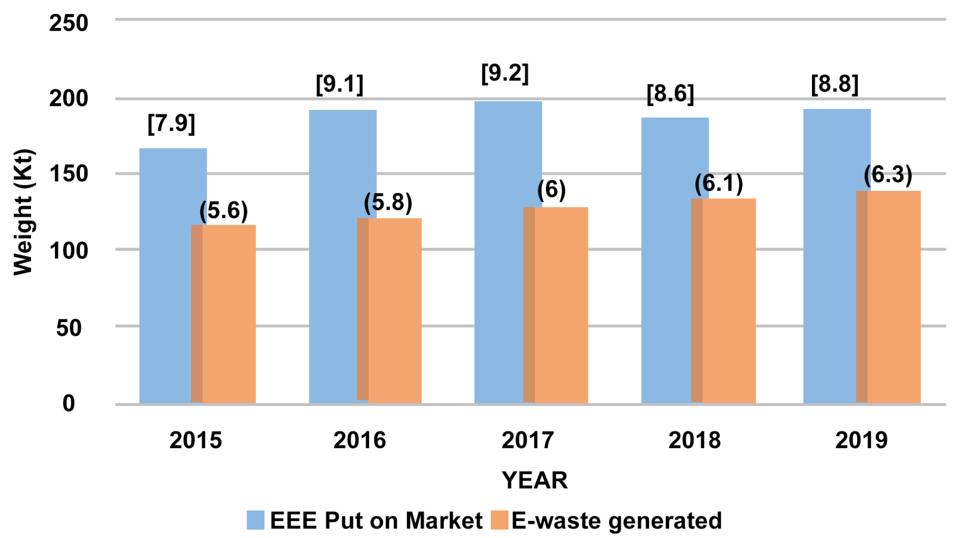

Figure 2. The total amount of electrical and electronic equipment (EEE) put on the market and e-waste generated in Sri Lanka. The values in brackets show the EEE brought into the market in kg per capita, while the values in parenthesis indicate the generated e-waste in kg per capita [17].

In light of these circumstances, this chapter has been written to emphasize the threats posed by e-waste to the environment and people, as well as the present predicament and e-waste management shortcomings in Sri Lanka. It is also anticipated to give recommendations for the island to mitigate the e-waste challenge and for its sustainable management.

Emission and Contamination of Toxic Compounds in E-waste and Their Harmful Effects

First, it is ideal to look at how e-waste becomes harmful. Essentially, e-waste is very complex and many components available in e-waste, such as heavy metals (e.g., arsenic, cadmium, copper, iron, lead, lithium, mercury, gold, silver, and so

on) and organic compounds (e.g., decabromodiphenyl ethane), pose hazards when released into the environment. Nonetheless, such contaminants are not released into the environment until the protective equipment is physically or chemically damaged. Given this fact, many studies have debated the rationale for e-waste disposal, as there is direct evidence of toxic compound release [18–20].

Looking at the Sri Lankan conditions, as shown in Figure 3, it has been found that e-waste threats have occurred due to informal dismantling practices as well as other practices at different levels, such as landfills and burning.

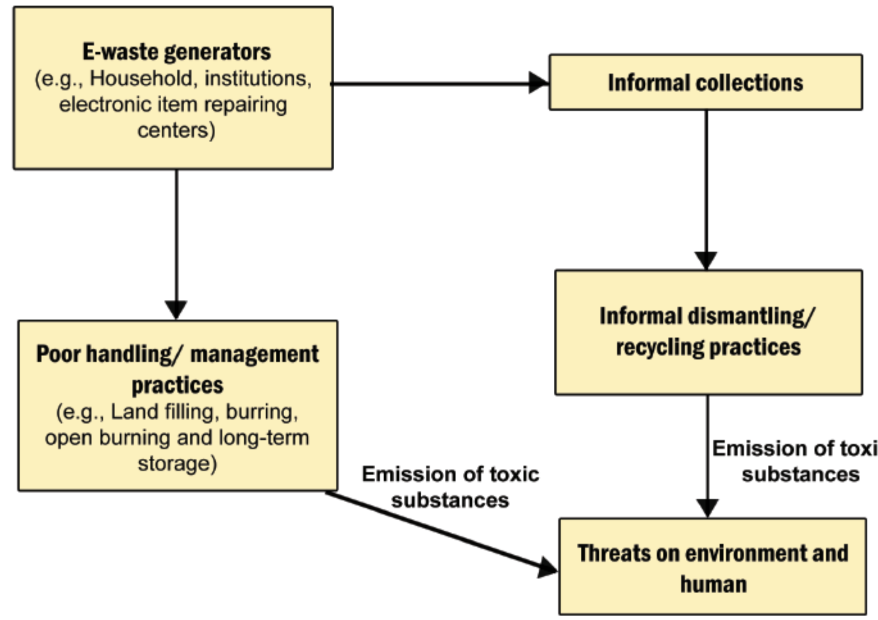

Figure 3. Pathways of environmental pollution and human health impact due to e-waste, in Sri Lanka (Adapted from: [21]).

Hazardous Emissions Due to Informal Dismantling

Available precious metals in e-waste such as gold, silver, aluminum, iron, copper, platinum, and many more can be extracted by recycling and returned to the production cycle. This has resulted in the emergence of new businesses and numerous job opportunities [2]. In 2019, the value of raw materials in worldwide e-waste generated was estimated to be around USD 57 billion [3]. Nevertheless, to recover these materials, mostly in developing countries, primitive recycling techniques such as mechanical shredding, manual dismantling, sorting, and open incineration are used.

However, since these practices pose significant environmental and human health impacts, the economic benefits could be negligible. For instance, to dispose of computer casings and collect metals from electronic chips and other components, plastics are burned, frequently at low temperatures, resulting in the emission of polychlorinated biphenyls (PCBs), polybrominated diphenyl ethers (PBDE), furans, dioxins, and other pollutants. On the other hand, strong acids are used to extract the metals from the circuit boards [22, 23].

The use of rudimentary tools to recover copper and steel from Cathode Ray Tubes (CRT) releases organic compounds such as flame-retardants and formaldehyde [22]. Chemical stripping of e-waste using nitric and hydrochloric acid contaminates soil and includes the change of native soil microbial community structure, soil physicochemical characteristics, carbon cycle, and plant productivity [24, 25]. In a study, Yasar et al. [26] found that a higher concentration of Fe (634.7 $\mu g/m^3$), Al (176.8 $\mu g/m^3$), Pb (135.4 $\mu g/m^3$) and Zn (122.5 $\mu g/m^3$) in the air associated with the informal computer dismantling sites. In addition, they found that heavy metals and trace metals are also more concentrated in the following order, from highest to lowest: Si, Fe, Al, Pb, Zn, Mg, Ca, Cr, K, S, and Ti. Furthermore, Yasar et al. [26] discovered higher concentrations of Fe (829.8 g/m^3), Al (184.5 g/m^3), and Pb (115.6 g/m^3) at wire/cable burning sites, as well as some of the elements in the following order: Si > Fe > Al > Zn > Pb > Mg > Ca > Cr > Ti > K > S. Ha et al. [27]; Tue et al. [28] and Pradhan and Kumar [29] also came up with a similar finding as they evidenced the elevated level of contamination of heavy metals and other pollutants associated with the informal e-waste recycling areas. Adjacent communities are highly susceptible to direct or indirect contact with these pollutants and are subjected to health impacts [23]. In particular, direct contamination from informal handling is a common concern among workers engaged in informal recycling activities. The lack of personal safety precautions and sanitary measurements aggravated the problem. Many of these cases have been documented in developing countries such as Chile, China, Ghana, and other African countries, as well as Thailand, Bangladesh, India, and Pakistan [22, 26, 30, 31]. In Bangladesh, about 120,000 e-waste workers have reported suffering from serious health issues. Moreover, about 50,000 child workers from financially stressed families work in e-waste collection and recycling. Regrettably, 15% of child workers died due to unsafe working conditions and 83% suffered from various long-term illnesses [32]. In Lucknow (India), about 76% of e-waste workers have been found to suffer from respiratory ailments such as breathing difficulties, coughing, choking, and irritations [33].

Hazardous Effects Due to Other Ill Practices

Rather than the informal dismantling/recycling practices, other activities such as landfills, open burning, and dumping also cause threats to the environment, also to humans. In a recent study, the authors found such practices are common among household participants in the Eastern province of Sri Lanka [34]. From this viewpoint, heavy metals like toxic elements present in the e-waste could be broken down in the long-term landfill and could leach into the deeper soil and contaminate the groundwater, which could be the source of several freshwater resources. Direct consumption of such water resources could pose a great threat to humans and animals. Irrigation of crop fields using this water may contaminate the crop fields and ultimately concentrate inside the crop plants. Consumption of such crops could create greater threats to human life due to the bioaccumulation of heavy metals [35–36]. Polák and Drápalová [37] have emphasized the danger of informal dumping, even at the lowest level. For example, they claim that just a single mobile phone battery is enough to pollute 600,000 liters of water through cadmium. Intake of such water or food prepared by using such resources can cause damage to the kidneys, liver, and bones. It also causes diseases, including hypertension, diabetes mellitus, obesity, cancer, and coronary artery disease. In addition, cadmium can cause an acute inflammatory response in the intestines and change the gut microbiome. Not only that, but also, Cd binds with the red blood cells and significantly reduces their activity [38, 39]. Some of the health effects due to the accumulation of heavy metals and other toxic substances are shown in Figure 4.

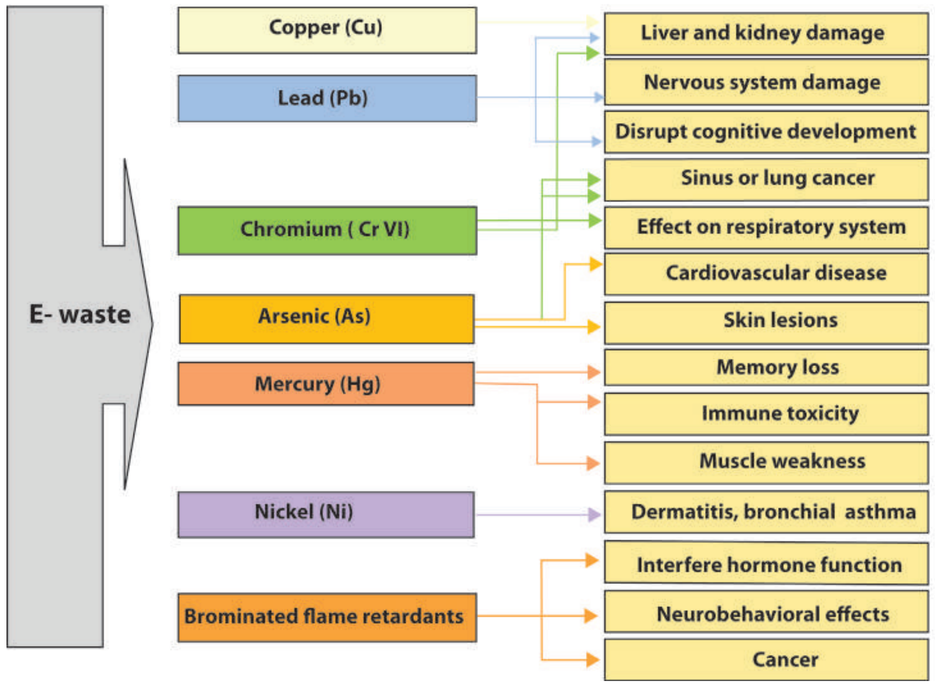

Figure 4. Some of the health implications due to the informal handling of e-waste, which associates with exposure to toxic compounds. Note that, even at low concentrations, the majority of heavy metals are extremely hazardous. Rather than flame retardants, heavy metals such as Pb, Cr, As, Hg, and Ni also show carcinogenicity [13, 36].

E-waste Handling and Management Practices in Sri Lanka

Current Status

No precise data is available for the country, though mobile phones, televisions, batteries, computers, and toners are by far the largest contributors to Sri Lanka's e-waste volume. CFL bulbs are also among those, however, as it continues to be replaced by LED bulbs, particularly with cheap and short-lived products in the future, there is a chance it will become the top-ranked e-waste [34]. Like in other developing countries, the majority of the island's generated e-waste is subjected to informal disposal [34, 40, 41]. For example, in a study, Galappaththi and Suraweera [42] tested the lagoon water collected from Negombo, Sri Lanka and found a considerable accumulation of heavy metals, including mercury. They also concluded that the informal disposal of broken fluorescent lamps could be a cause of such contamination.

The authors have found that burying and burning are the other frequent ill practices among residences, particularly in the Eastern province. Furthermore, the authors have revealed that one of the major reasons for such practices is

the lack of public knowledge about the hazards of e-waste and how to handle it. In addition, poor formal recycling practices aggravated the problem. At the moment, the island has only thirteen formal e-waste collectors and exporters [43], and due to limited facilities and financial resources, all of them collect a limited amount of waste, almost all of which is collected only from the Colombo regain. It is worth noting that the majority of formally collected e-waste in Sri Lanka is subjected to dismantling or preprocessing practices and exported for further processing, where these practices directly lead to minimizing the hazardous impact of e-waste [34].

In addition, not all collected e-waste is supposed to be exported, with items such as printed circuit boards and laptop batteries (Telecommunication battery scrap) being shipped to Japan, Korea, and Europe [43]. This has also been recognized as a positive aspect of e-waste, which has led to generating foreign exchange for the country. However, compared to the negative effects of e-waste, such benefits are negligible. The weak formal collection process has led to strengthening the informal collection and also not caring about the available policies. As a result, unauthorized collection has been observed today as an island-wide practice. Plastic and metal collectors collect waste from almost all the e-waste generation points, including households, the local government solid-waste dumping sites, electronic repair shops, etc. Due to financial incentives, consumers much prefer to sell their waste items to informal collectors. Despite this, particularly urban residents, sometimes dispose their e-waste mixed with common solid waste at the local government's municipal collators [34]. On the other hand, buy-back offers given by the electrical and electronic showrooms gather the obsolete or outmoded items (e.g., televisions, refrigerators, etc.) received from consumers and direct them to the formal e-waste collectors. Furthermore, the tourist hotels, banks, other large companies, and factories hand over their e-waste to the formal collectors as they need to run their businesses as certified companies. As well, governmental departments dispose their waste through formal e-waste collectors. However, in some cases, government institutions also sell e-waste at auctions [44]. It is also common to store or hand over the e-waste to plastic and metal collectors in small-scale business centers. Some of the more frequent informal practices in the country are shown in Figure 5.

Figure 5. Some of the common informal e-waste practices in Sri Lanka. (A). Unsafe electronic equipment repairing and storage practices (B). Roadside disposal of e-waste (C). Plastic and metal collector (D)–(F). Plastic and metal collecting shops located in town areas of Eastern province and waste collected (Photo credit: A.K Hasith Priyashantha, Field survey-2021).

Sustainable E-waste Management
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Management Initiatives

To address this growing issue, the Central Environmental Authority (CEA) has carried out several programs to collect e-waste. In 2010, 47 collection points for old cell phones were set up across the island in cooperation with telecommunications service providers. The following year, CEA launched the National Corporate E-Waste Management Program in collaboration with 14 partner organizations from the private and public sectors. This project aimed to create awareness among the public about e-waste and collect their waste [13]. In 2014, CEA carried out an island-wide e-waste collection week by hand with private sector companies. The e-waste from producers was collected during this program [43]. In the recent past, the local government of Sri Lanka has launched a program to collect e-waste, particularly from households. In addition, several private sectors recently worked together to organize an e-waste collection week to collect household waste, albeit from a limited group. Nevertheless, many of these initiatives led by government and non-governmental organizations were limited to Colombo's surroundings or the big cities and failed to consider/target the rural areas, and ending up with short-term practices.

Management Policies at the National Level

To meet the challenge of e-waste, the Central Environmental Authority (CEA) drafted the National Guideline for the Disposal of Electronic Waste for the first time and published it in a gazette extraordinary dated February 1, 2008. According to the gazette, "No person shall discharge, deposit or emit waste into the environment or carry on any prescribed activity determined by an Order made under Section 23A of the National Environmental Act, No. 47 of 1980 in circumstances which cause or are likely to cause any pollution, except under the authorized license issued by the CEA and following such standards and other criteria as may be specified by the Authority" [45].

The main expectations of this policy are to mitigate the hazardous impacts on the local environment and the public by taking measures against the disposal of e-waste in different places and upholding the social responsibility of all parties concerning the sustainable manufacture and use of electronic products. However, it was not given adequate space to address the import and export practices of e-waste. In this context, the Sri Lanka Standards Institution, on the other hand, develops the criteria that apply to the import and production of electronic and electrical equipment in Sri Lanka, as well as examines whether such products meet the required standards, which helps to strengthen the country's legal implementation on this aspect [20]. However, the expectation of how far it gets the harvest is questionable due to insufficient import-export regulations, which could not entail obstacles to the import of secondhand equipment, primarily used computers, washing machines, televisions, etc., with a short lifespan, making Sri Lanka a dumping site for low-quality and used electrical and electronic devices. Nevertheless, after 2016, much more strengthening of regulations put a barrier to importing some electronic items, including used computers, though importers are clever enough to import the used parts (with no legislative barriers) and assemble them locally, and the same scenario has been continuing [13].

Other than those institutions/agencies, the Telecommunications Regulatory Commission (TRC) of Sri Lanka regulates the importation of mobile phones or devices that are connected to the cellular networks by inserting a SIM card. The TRC has set the requirements and allowed the import of devices that meet the conditions set by the Commission. Also, it facilitated coordination in the handover of the used communication equipment to the CEA recommended collectors, thus further involvement in the formal e-waste collecting mechanism [20].

Required Changes

To address this e-waste aggregation scenario, the following changes or implementations could support effective e-waste management in the country.

1. Fill the gaps in existing policies: Adequate legal implementation is the key factor to address the e-waste scenario. This will help to block the arrival of e-waste into the country and also the internal flow. Some of the identified gaps in current policies are as below.

    The national policy on e-waste management (2008) failed to take into account the conditions that the manufacturer/distributor or agents should carry out the disposal.

    CEA is unable to pursue legal action against generators who improperly dispose of, transport, and store electronic trash.

    The National Environmental Act makes no provision for the producer to enact regulations for the proper management of e-waste. Thus, it is impossible to mandate how the manufacturer should handle formal waste management practices.

    It is also important to update/revisit the implemented policies periodically. It is deemed necessary to require barriers to importing second-hand EEE or parts and low-quality products. Stricken policies may eventually lead to minimizing the informal handling and management of e-waste.

2. Direct e-waste for the recycling process: Another important step should be the establishment of recycling units for e-waste (at least for selected items such as CFL/LED lamps or those that cannot be exported for recycling), as this is seen as one of the best solutions to tackle the e-waste challenge [5]. If such a facility cannot be built in the country, it is always preferable to export them for proper recycling. Providing financial/transport support can strengthen the formal e-waste collectors to extend their collection mechanisms island-wide, including household inhabitants and electronic repair centers. This can further minimize the participation of informal collectors as well as minimize informal dumping.

3. Conducting island-wide long-term e-waste awareness programs (at least at certain time intervals) could be much more effective than running those at regular intervals. In this aspect, TV, radio, newspapers, and other social media may be used to improve the delivery of relevant knowledge. It can also use digital advertising display boards located in cities.

4. Initiates of e-waste-based projects are also a timely and important practice in the country. In India, it has conducted a successful project ''E-Parisaraa'', which was initiated in Bangalore city and later spread to many cities. Through this, it has been made possible to direct the e-waste to the formal processing centers and thereby strengthen the formal collection. India has also made a partnership with the Environmental Protection Agency (EPA), as well as consumer electronics manufacturers, retailers, and service providers, to allow more avenues to donate or recycle e-waste through the ''Plug-in to eCycling'' project [46]. Most importantly, such projects can even be conducted in Sri Lanka as public-private cooperation.

5. Establish e-waste collection bins/drop-off centers in public places. It is also better to indicate (possibly with the local authority) on which days the e-waste is going to be collected at the collection point. This could also encourage the public to dispose of their waste, particularly, larger waste items like electric stoves, washing machines, refrigerators, etc. In addition, it can be facilitated to send small e-waste items such as mobile phones to the collectors via post [16].6.It is also important to mandate the warranty period (towards the customer) for selected EEE. In this regard, the manufacturer or dealer can grant a warranty period, e.g., of at least 24 months (depending on the device type). This may eventually lead to minimizing the huge quantity of e-waste generation.

6. Before issuing the electrical and electronic business license, it is important to confirm the availability of a satisfactory e-waste management mechanism.

7. Assessment of e-waste is another aspect that should be implemented. According to Joon et al. [47], proper assessment needs to be carried out for each type of e-waste and its associated health hazards, which many developing countries still lack. It is also important to quantify the amount of EEE produced locally and exported. Such data needs to be made available for free public access/display to provide awareness for everyone about the status of the e-waste generation.

Conclusions

To conclude, it is crystal clear that Sri Lanka has to develop a robust e-waste management strategy that provides a long-term solution to mitigate the hazardous effect on the environment and the hedonic well-being of locals. Like in many other developing countries, one of the major challenges for Sri Lanka in overcoming this e-waste issue is the lack of enforcement of the existing policies. In addition, there is still a need for revision of the implemented policies to legally bind the e-waste handling and management practices, also to minimize the importation of e-waste and its movement inside the country. Strengthening the legal background alone will not be enough to address the challenge. While giving priority to policies, it is also necessary to attend to other relevant formalities. For example, one of the burning requirements is adequate recycling mechanisms. Other challenges include inactive community engagement, a lack of collaborative work between the government and the private sector or non-governmental/volunteer organizations, insufficient technical skills to handle e-waste, poor infrastructure to store e-waste until direct to recycling, and a lack of financial support for formal collectors to broaden their collections and direct to recycling. In this context, there are only a handful of studies that have been conducted up to date in the country. Thus, researchers also need to take responsibility to support policymakers or other relevant authorities in making their decisions.

Conflict of Interest

Authors have declared that no competing interests exist.

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CHAPTER 03

MARINE ALGAE BASED NUTRACEUTICALS AND FUNCTIONAL FOODS FOR FOOD SAFETY AND NUTRITIONAL SECURITY

Marine Algae Based Nutraceuticals and Functional Foods for Food Safety and Nutritional Security

H.S. Kumarasinghe, T.L. Gunathilaka, P.T. Jayasooriya and K.W. Samarakoon*

Abstract Marine algae have been investigated as a part of the human diet for thousands of years. They have recently been used as raw materials in the production of a variety of seaweed-based foods due to their high nutritional content. Most of the marine algae can be utilized for human consumption, and they are referred to as "edible seaweeds". With the acceleration of the utilization of marine algae as nutraceuticals and functional foods, lots of research were conducted to identify novel bioactive constituents associated with these algae and their functions in advance. For example, algal-derived proteins enriched with unique essential amino acid profiles provide higher protein content than other conventional protein sources. Further, most marine algae contain pigments that can be utilized in functional food industries as they are reported to exhibit significant biological activities. Concerning these facts, the investigation of novel bioactive compounds from marine algae has been progressed during the last decade for application in the nutraceutical and functional food industries. As algal-derived food items are not widely available in the market, increasing awareness of people about the nutritional value and the health benefits of marine algae-derived nutraceuticals and functional foods is important. This chapter provides an overview of the potential utilization of marine algae as a source for developing nutraceuticals and functional foods for human nutrition and wellbeing.

Keywords: Food safety, Functional foods, Marine algae, Nutraceuticals, Nutritional security

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Introduction

Consumers in the new generation have focused their attention on the relationship between a healthy meal, mental, physical wellbeing, and disease prevention in advance [1]. Recently, considerable studies have been aimed at identifying modifiable determinants of chronic diseases and have revealed that diet plays a main role in the progression of several chronic disease conditions, including cancer, diabetes, and cardiovascular diseases [2]. Given that modern consumers are increasingly concerned about food safety and security, quality, and health and wellness issues, there is a growing global interest in novel research and commercialization of nutraceuticals, functional foods, and dietary supplements [1]. Interestingly, both terrestrial and marine ecologies are known for the presence of valuable bio-resources with functional ingredients that may act as a reservoir for natural bioactive compounds. Among those reservoirs, terrestrial environments are supplemented with a vast variety of bio-resources like vegetables, fruits, mushrooms, and cereals, which are directly involved in many biological functions, including disease prevention and nutrition enhancement [3]. Therefore, these food sources have become more popular worldwide based on food safety and nutritional security. When considering marine food reservoirs, consumers in this era focused their attention mainly on marine-based foods as they were enriched with ideal bioactive compounds that are rare among terrestrial food sources [4].

Marine biotechnology, together with marine ecology, represents a unique and dynamic array of marine bio-resources attributed to its immense diversity and serves as a reservoir with untapped prospects for the advancement of the future health sector via the developing nutraceutical and functional food industry [5]. When considering marine bio-resources in advance, marine micro-organisms, sponges, algae (both micro and macro), sea grasses, invertebrates and vertebrates, along with fish species can be taken into account as they can be utilized by humans to obtain lots of health benefits directly at once or after processing [6]. Almost all of these marine bio-resources are known to be highly abundant with valuable biomolecules including proteins, amino acids, vitamins, minerals, lipids, and carbohydrates in different ratios [7]. Therefore, marine biosources act as a potential candidate in the nutraceutical and functional food industries [8]. It is estimated that there are about 0.5 to 10 million marine species embedded in the marine ecosystem, which is characterized by wide biodiversity [9]. Approximately, 70% of the earth's total surface is masked by the marine environment, which acts as the living hub for those unique marine organisms. As a result, it is not surprising that approximately a trillion tonnes of marine food, including crustaceans, algae, and mollusks, have been exploited for human utilization since ancient times [10].

Marine Algae

Among marine organisms, marine algae have been recognized as an under-utilized marine bioresource [11]. The term marine algae or seaweed generally refers to marine macroalgae, which play a significant role as they have some specific biological properties [12]. Marine algae can be classified into three segments as rhodophyta, chlorophyta, and phaeophyta based on their color, which occurs as a result of the availability of photosynthetic pigments [13]. Most of the marine algae are utilized for human consumption and are referred to as "edible seaweed." In addition to that, algae play a vital role in its socio-economic basis by serving as a potential contender in the production of algal-based foods such as jam, wine, cheese, soup, and tea on a commercial basis [9]. Moreover, marine algae are identified as a warehouse for structurally diverse, unique bioactive compounds with ideal nutraceutical and pharmaceutical potential [13]. Scientists have concluded that algal-derived bioactive compounds exhibit various biological functions, including anti-viral, anti-coagulant, anti-bacterial, anti-fungal, anti-inflammatory, anti-cancer, anti-diabetic, antioxidant, anti-allergic, and anti-obesity, etc [14]. Apart from that, several research studies have provided insight into marine algal neuroprotective properties. Many algal varieties have long been utilized in traditional remedies as well as food diets in Eastern countries. More recently, some European countries and America have also practiced adding algal-derived foods to their main meal [15]. Due to these facts, marine algae can be referred to have great potential to be used in the nutraceutical and functional food industries on a large scale. According to literature, the protein content of several marine algal varieties ranges between 25–57% [9]. In addition to that, algal biomass productivity is somewhat higher than that of conventional crops. Therefore, algal biomass production and utilization for nutraceutical and functional food industries will be an inexpensive and feasible option for nutritional recovery to meet the recommended nutritional requirements of humans for a healthy life [7]. Concerning the benefits of algal-derived bioactive compound utilization, there is much algae-based research conducted by both local and foreign countries related to the nutraceutical and functional food industries to prepare bioproducts using its unique biochemicals [15]. Currently, it has been examined and reviewed the potential nutritional values and health benefits of marine algae in advance. This book chapter mainly focuses on the potential of utilizing seaweed as nutraceuticals and functional foods for nutritional security and human wellbeing.

Nutritional Value of Marine Algae

Marine algae are known to possess an excellent nutritional profile. Hence, they can be utilized as an alternative to masking the total mineral, protein, and vitamin requirements of humans [3]. Apart from that, it is found that the presence of total oil percentage within these marine algae is generally low, while their essential fatty acid percentage is much higher than in other plants. To improve the digestibility of proteins and to prepare algal-derived bioactive peptides, enzymatic digestion of the fibers available within these marine algae was found to be attempted [8]. In addition to that, new investigations focus their attention on isolating anti-hypertensive peptides from algae, which are in turn characterized as ACE (Angiotensin Converting Enzyme) inhibitors as they are encountered for ideal health benefits [6] [16].

Polysaccharides Marine algal varieties represent an excellent and unique source of secondary metabolites that play a significant role in defense against pathogens and chronic disease [17]. Among those secondary metabolites, polysaccharides are prominent where they can be found within those algae [18]. Marine algae are mainly composed of polysaccharides which are enriched with fibers that cannot be digested by human intestinal enzymes; higher consumption increases the intake of dietary fiber and lowers the occurrence of some chronic diseases [3]. Besides, they are considered an ideal precursor for dietary fiber as well [19]. These dietary fibers are mainly composed of sulfated polysaccharides, and human digestive enzymes can not digest them directly [8]. At the same time, they are composed of polysaccharides like laminarins and fucoidans, which are responsible for their anti-cancer, anti-diabetic antioxidant, anti-inflammatory, skin-whitening, and antiwrinkle activities [20]. According to recent research, major polysaccharides found in red algae, such as galactans, carrageenan, floridean starch, and xylan, are responsible for their major biological functions [21]. Moreover, these red algae were found to consist of floridean starch composed of glucose units and xylan composed of xylose units [13]. Therefore, from the past decades since the 1940s, algal-derived polysaccharides have been utilized as thickening and gelling agents on a commercial scale for various functional food industries.

Proteins and amino acids Seaweeds are a viable protein source embedded with a unique essential amino acid profile. Nevertheless, protein composition among different algal varieties differs from each other [19]. Algal protein content stands out as being ideal for the rest of other plant species, including rice or wheat. However, the quality and quantity of these algal proteins are inferior only to those of animal-derived proteins. The highest proportion of algal amino acids is analyzed to be composed of aspartic acid and glutamic acids [21]. These investigated algal amino acids naturally occur as free amino acids or their salts and protein constituents. It is found that; glutamate is the main component accountable for its distinctive flavor. Alanine and glycine-like amino acids are also responsible for the unique and distinctive flavors of some specific marine algae [22]. Marine algae enriched with taurine, a non-protein amino acid that can be found most commonly among animals and especially among rhodophyta, are encountered for the excretion of bile acid and cholesterol, which in turn is responsible for the lowering of plasma cholesterol [17]. When compared to their dry weight, most common green algae, such as *Spirulina spp*. and *Chlorella spp*., have 70% protein, while *Ulva spp*. have 30% protein. Some red algae like *P. palmata* also contain high protein content, up to 47% of their total dry weight. It has been revealed that during the summer season, microalgal protein content is decreasing because of the nutrient limitations that occur during that period [22].

Vitamins Algae have been investigated to act as a rich source of vitamins, including vitamin A, B1- thiamine, B2- riboflavin, B12-cobalamin, folic acid, niacin, C, D, E, and pantothenic acid [21]. In some algae, they contain high concentrations of cobalamin, vitamin C, and vitamin E. When compared to other algal species, brown algae represent a relatively high level of α-tocopherol, whilst green algae contain a high content of β-carotene [18]. Anyway, vitamin B1 or thiamine plays a vital role in minimizing diabetic complications, which are in turn advantageous in the nutraceutical industry as well [23].

Minerals and trace elements Sea vegetables, or marine algae, are identified as a rich source of essential minerals and trace elements, including sodium, calcium, phosphorus, iron, selenium, potassium, magnesium, zinc, and iodine [24]. It has been found that the percentage of minerals and trace elements in algae ranges between 8 and 40% of its total dry matter [25]. Marine algae have the ability to absorb surrounding heavy metals such as lead, arsenic, nickel, cadmium, and copper [22]. In addition to that, their heavy metal concentration mainly depends on the quality and composition of the seawater where they live [12].

Lipids and fatty acids The lipid content of marine algae ranged between 1.5% and 4% of their total dry matter. As a result, it is reasonable to conclude that these seaweeds are a minor precursor for fatty acids and are responsible for total energy utilization [26]. Nonetheless, the total fatty acid quality and composition of sea vegetables are much higher than those of other plant species. Mainly, algal-derived lipids comprise non-polar glycerolipids, phospholipids, and glycolipids [15]. Among these algal-derived biomasses, carotenoid pigments are noteworthy as they exhibit significant biological properties that are ideal for nutraceutical and functional food industries [26]. Apart from that, seaweeds are enriched with numerous sterol and fatty acid varieties with unsaponifiable fractions such as tocopherols, terpenoids, and carotenoids. When considering

fatty acids present within these marine algae, omega-3 fatty acids are highly abundant, ranging between 10% to 50% of the total available fatty acid content [27]. However, the percentage of omega-3 fatty acids in algae varies depending on several factors, including seawater temperature and the plant's growth stage or maturity status. Mainly in brown algae, they contain sterols including fucosterol in their lipid membranes, while red algae contain β-sitosterol which are responsible for several health benefits [28]. However, the quality and quantity of lipids present within these algae vary on the basis of growth conditions and the type of algal species [29].

Algal Derived Foods and Functional Foods

Marine seaweeds are an important part of the human diet where the majority of vegetarians utilize them as main courses, additions, and starters. In the European region, algal-derived food items have been very popular since a long time ago [29]. They used algal biomass as a precursor in functional food industries as stabilizing, gelling, and thickening agents [30]. Among them, algal polysaccharides such as agar, alginate, and carrageenan are used as hydrocolloids in the food industry for the production of gels and viscous solutions [31]. From these polysaccharides, agar and carrageenan act as potential candidates for thermos-reversible gel preparation, while alginate can be used to prepare thermally stable gels with the aid of chosen divalent metals [9].

Alginate is one of the major polysaccharides embedded within marine algae, which can be commonly utilized for the production of gels and as a viscosity regulator in the food industry [32]. It improves the physical appearance of milk-derived foods and canned foods by supporting water retention. Thus, it is directly responsible for the enhancement of the physical appearance and the smooth texture of bakery products. It has also been revealed that alginate can be utilized as a stabilizer in the beer industry as well [33].

Other than alginate, agar is another important structural polysaccharide embedded within marine algae. It is comprised of hardly solidifying agarose, and non-solidifying agaropectin [32]. Most commonly, red algae like *G. edulis* are used to prepare agar on a commercial scale, which is then used in the food and nutraceutical industries. It has been shown that approximately 90% of the produced agar is utilized in the food and functional food industry as vegetarian gelatin that is enriched with bulk fiber stock [34]. Agar is used as an essential ingredient in the production of fruit jellies and canned meat. In addition to that, they are added to the stuffed pastries before baking with the expectation of reducing the melting effect inside the oven [33].

Carrageenan is another important polysaccharide derived from marine algae that is very useful in the food industry [30]. Because of the excellent properties of carrageenan, it is very important in the dairy industry as it can bind to the milk proteins well. Hence, it can maintain solid particles in milk in suspension and stabilize them even at micro concentrations [33]. This feature can be applied for the production of crystal solids in dairy ice cream and for the separation of whey from cheese, which gives a smooth texture to those products [35]. Apart from that, carrageenan is widely used in the meat industry due to its specific properties like water retention ability. These features are essential for the production of poultry products, ham, seafood, and hamburgers [21]. In addition to that, carrageenan has the ability to act as aqueous gels, which are very significant in the production of juices, jelly candies, fruit gels, and marmalade [36].

Health Benefits of Algal Derived Foods and Functional Foods

When compared with other plant-based foods, algal-derived foods and functional foods are recognized as ideal sources for many bioactive compounds, including polysaccharides, vitamins, minerals, and trace elements, fatty acids, lipids, proteins, and amino acids [37]. Bioactive compounds present within these algae are responsible for numerous health benefits as they act as potential candidates in both the pharmaceutical and nutraceutical industries [5]. As some research findings revealed, sargachromanol E, which is isolated from the marine algae *Sargassum siliquastrum*, exhibits anti-inflammatory activities in lipopolysaccharide-induced RAW 264.7 cells via the mitogen-activated protein kinase pathway (MAPK). Hence, this identified property is important in responding to infections or injuries [38]. Some edible algal varieties, such as *Ecklonia cava*, were discovered to have a hepatoprotective effect associated with the phlorotannins dieckol on carbon tetrachloride-induced hepatic injuries in ICR mice liver, whereas *Caulerpa racemosa* has anti-inflammatory and antioxidant properties with them [39].

Chnoospora minima and *Nannochloropsis oculata* were found to be excellent sources with high anti-cancer and anti-inflammatory potential via in-vivo and in-vitro studies [40]. *Gracilaria edulis* is also investigated as a good source of numerous biologically active compounds with antioxidant, anti-diabetic, anti-cancer, and hypoglycemic activities [41] [42] [43]. Some brown algae like *C. minima* exhibit excellent anti-diabetic, antioxidant, skin whitening, antiwrinkle, and anti-inflammatory properties [44] [45] [46]. Some evidence revealed that silver nanoparticles derived from *C.minima* are able to fight against human breast cancer cells (MCF-7) by observing their cytotoxicity in vitro [20].

Food Safety and Nutritional Security of Marine Algae-based Nutraceuticals and Functional Foods

When considering the food safety and nutritional security of algae-based nutraceuticals and functional foods, it is not a wonder that there are also some possible safety risks associated with them, including excessive uptake of toxic heavy metals, cyanotoxins, allergenicity, and some certain secondary metabolites including kainoids and prostaglandins [47]. Apart from that, contamination that occurs due to toxic xenobiotics, pathogens, and radioisotopes may also cause severe risks among these algal-derived food items. Under neutral circumstances, proper metal uptake by algae leads to the enhancement of the nutritional quality and quantity of algal-derived foods [48]. Furthermore, consumption of polluted algal-derived food items may be responsible for severe health conditions among people. However, previous studies have revealed that excessive metal uptake can cause severe toxicities among algal foods. Brown algae are believed to have a higher concentration of heavy metals than either red or green algae, though there are some exceptions [49]. Those heavy metals can cause human allergies as well as various mutations when consumed by pregnant mothers. Previous research has shown that algae can absorb heavy metals such as cadmium, copper, cobalt, zinc, and lead using their uptake kinetics [25]. Regardless, some microalgal varieties that are harvested from polluted sites are recognized as a vector for carrying toxic heavy metals into the human diet [1]. However, a few studies have found allergic reactions in algal-based foods, primarily as a result of heavy metal contamination. It is also found that some algal varieties, including *spirulina* are composed of hepatotoxins and neurotoxins produced by cyanobacteria and microcystis species [47]. Hence, consumption of those algal varieties can cause severe allergies among consumers as well. Apart from that, algal-derived protein from *Chlorella* protothecoides was investigated to cause allergic conditions after consumption, which was concluded after testing it on rats [8]. Some rhodophyta are also composed of kainic acid, which has been previously identified as a brain neurotransmitter, where high doses caused numerous diseases in tested rat species.

Policy Intervention

As there is a high probability of contaminating foods with unfavorable additives, chemicals, and toxins, it is a prerequisite to implement awareness programs on the quality and nutrition of foods and to implement possible policy interventions to assure national food security and safety [47]. Therefore, it is necessary to study the nutrient composition and the creation of food composition tables of algal derived foods, the nutrient contents of foods and their functionality, and the development of research and policy studies. To ensure food safety, risk evaluation of agrochemicals or food additives, research on agrochemicals and their impact on human health, survey data on toxicity in food crops, research on methods to reduce toxicity in food, research on foodborne diseases and control measures, and raising public awareness about food poisoning are all necessary. Furthermore, programs for research and development of algae cultivation and processing technologies are still required [50]. Apart from that, the building of open-access facilities for the development and testing of algae cultivation and processing at commercially relevant scales is important. As a government, they can develop tools to create sustainable algae value chains. Research to improve indigenous algal variations to fight invasives, encourage utilization of indigenous species, research on cost-effective farming systems, research on bioherbicides, manufacturing of bio-pesticides employing indigenous knowledge, information campaigns among farmers and agriculture officers, characterization of native species, and research on control measures are all important aspects of eco-friendly agriculture. Furthermore, to maintain food security and safety in postharvest handling and processing, it is necessary to establish a competent marketing system for aquacultural products, develop low-cost postharvest handling methods, and develop unconventional approaches for harvesting and processing [48]. By increasing the transparency of societal and market benefits and costs, we can also increase the demand for algae among people. While developing sustainable fish-catching methods, breeding methods for high demand and endangered species, and developing proper communication channels to increase the profits for farmers, developing sustainable fish-catching methods, excellent breeding methods for high demand and endangered species, and the development of sustainable fish-catching methods are also critical for commercial and small farmer profits. Identification and utilization of economically valuable underutilized and unutilized fish stocks; development of disease-resistant varieties and improved immune systems for important fish diseases; research on the impact of climate change on fisheries; reduction of post-harvest losses at all levels; development of improved breeds and breeding techniques; production of feed raw materials; and value addition to animal products are all important to ensure food safety and security related to marine food in advance [50].

Conclusions

Recent advancements in the nutraceutical and functional food sectors have provided sufficient evidence to prove the statement "seaweed-derived functional ingredients are encountered for lots of benefits related to human health and nutrition". Moreover, direct products and by-products derived from algae such as proteins, vitamins, minerals, polysaccharides, phlorotannins, and pigments can be utilized as functional ingredients in nutraceutical industries. Therefore, marine seaweed-based diets can be potential candidates in the expansion of

human health promotion and well-being by addressing the issues of food and nutritional security.

Conflict of interest

The authors declare no conflict of interest.

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YOUNG SCIENTISTS FORUM

CHAPTER 04

CHILDREN, SALT CONSUMPTION AND RELATED REGULATIONS IN SRI LANKA

Children, Salt Consumption and Related Regulations in Sri Lanka

H.P.E. De Zoysa* and W.C. Prasadani

Abstract Changing lifestyles cause people to consume salty foods more frequently. Salt is the ordinary source of dietary sodium. High salt intake leads to the cause of non-communicable diseases (NCDs). Hence, the World Health Organization (WHO) recommends minimizing salt intake (< 5 g per day). In Sri Lanka, "colour coding for sugar, salt, and fat" regulation was implemented to label foods with the level of salt. Food habits and consumption patterns start in childhood and last throughout life. Since Sri Lankan children are exposed to influencing advertising on food choices and dietary habits, a Nutrient Profile Model (NPM) for Sri Lanka was prepared with suggestions on the marketing of foods and non-alcoholic beverages (FNB) to children. Quantifying sodium in foods in which the sodium content has not been quantified and establishing threshold limits (TL) for food groups without TL is vital in implementing NPM. The TL of certain food groups in NPM does not tally with the sodium level corresponding to the green code of food colour coding, which is healthier and creates contradictory issues when implemented together. Product reformulation with reduced salt is feasible to be in line with the green code and implementing recommendations to manufacturers to reformulate varieties of high, medium, and low salt products or reduce salt equal to the TL provided in the model is critical. Moreover, it is important to precede campaigns to improve the nutrition literacy of the community. In NPM, sodium refers to the salt content of food, whereas in the regulation of colour coding, salt means total salt content in the form of sodium chloride (NaCl) and allows quantifying NaCl by analysing chlorides. Hence, establishing accurate analytical methods to quantify sodium is vital.

Keywords: Colour coding, Nutrient Profile Model, Non-communicable diseases, Sodium Chloride

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Introduction

Rapid urbanization and changing lifestyles have a considerable effect on the consumption of unhealthy foods with a high caloric value that are packed with sugars, saturated fats, trans-fats, and salt. Salt can be considered as the major ordinary source of dietary sodium in the human diet. Other sources of sodium in the human diet include monosodium glutamate (MSG), disodium phosphate, baking soda (sodium bicarbonate), baking powder (sodium bicarbonate) and other compounds that have "sodium" within the name [1]. It was found that people consume high amounts of salt by consuming processed fast foods such as ready-to-serve foods and meals, processed comminuted meat products including bacon, sausages, and ham, various cheese products, salty snacks, instant noodles, etc. [2]. Other than the addition of salt during cooking, people tend to consume a high amount of salt more frequently in large quantities as a result of using dips, sauces, and dressings such as soy sauce, fish sauce, and MSG. In addition to processed food items, sodium is naturally abundant in various sources of foods, including meat, milk, and shellfish [1]. Since there is no Nutrient Profile Model (NPM) available, the nutrition for health and development unit of the regional office for the South-East Asia Region (SEAR) of the World Health Organisation (WHO) implemented a regional NPM. NPM is considered as an impartial methodology to categorize commonly consumed foods that tend to be components of a healthy diet. The major intention of developing NPM for SEAR is to regulate the marketing of foods and non-alcoholic beverages (FNB) to children [2]. This is due to the fact that exposing children to marketing of unhealthy foods that are condensed with sugars, saturated fats, trans-fats, and salt is considered a main reason for developing childhood obesity and non-communicable diseases (NCDs). Furthermore, food marketing involves using a variety of influential strategies to persuade the food attitudes, food preferences, and food consumption patterns of children. There are strong evidences to confirm that being overweight in childhood leads to obesity in adulthood [3]. The dietary habits established in childhood and adolescence also influence eating patterns in later life [4].

Health Impact of Excessive Consumption of Sodium

Excess sodium and salt consumption, according to the American Heart Association, may increase the risk of adverse health conditions such as enlarged heart muscles, headaches, kidney diseases, osteoporosis, stroke, heart failure, high blood pressure, kidney stones, and stomach cancer [5]. There are evidences to confirm that intake of a high amount of salt in children influences blood pressure and may lead to the development of a number of diseases, including elevated blood pressure, osteoporosis, and respiratory illnesses such as asthma, stomach cancer, and obesity [4].

Key Facts About NCDs

According to the WHO fact sheet, in 2019, cardiovascular diseases (CVD) are the main reason for global deaths. It was estimated that CVD caused 17.9 million deaths, which accounted for 32% of all deaths in the world in 2019. It was found that 85% of these deaths occurred as a result of heart attack and stroke. Moreover, it was assumed that more than three-quarters of deaths caused by CVDs were reported from low- and middle-income countries. It is estimated that excess salt/sodium intake is responsible for 4.1 million annual deaths in the world [6].

According to the action plan of WHO to prevent and control NCDs in SEAR, NCDs are the main reason for the deaths in the SEAR. It was estimated that in each year, 7.9 million deaths are caused by NCDs, which accounts for 55% of all deaths in SEAR. Furthermore, in comparison to other regions of the world, NCDs cause deaths at a younger age in SEAR than in other regions of the world. For an example, in SEAR, NCDs caused 34% of deaths among people under the age of 60, while 23% of deaths were caused in the same age group of the people in the rest of the world in 2008. Therefore, it can be considered that CVDs are the main reason for the deaths caused by NCDs in SEAR [7].

WHO Recommendations for Reducing Sodium Consumption

Since consumption of a high amount of salt is associated with NCDs, most countries, along with WHO and other key stakeholders, develop strategies to minimise salt consumption among the population to less than 2 g per day [2]. Additionally, countries that are members of WHO agreed to implement strategies to reduce salt consumption by 30% by 2025 [4].

The Impact of Food Advertising on Children

Although NCDs cause deaths in adulthood, it is believed that risk factors connected to unhealthy diets start during childhood and develop throughout life. Currently, children are exposed to food advertisements, which influence food choices and dietary habits of children significantly. For example, when analysing child-specific programming in Switzerland, it was identified that 47% of food advertisements which were telecasted during children's programmes were about fast foods [8]. In the United States of America, it was observed that advertising for fast food during children's viewing time has increased remarkably. The facts and figures collected from countries including the United Kingdom, the United States of America and Switzerland indicate that food advertising promotes foods dense in sugar, salt and fat [9].
A study by FJ Zimmerman et al. (2010), which focused on the types of content

children view on television along with their body mass index, emphasized a strong correlation between children's obesity and viewing. According to the data gathered, this interconnection is caused by television advertisements for foods high in fat, sugar, and salt [10]. It was found that even in Sri Lanka, food advertisements are mostly broadcast during both family and children's TV schedules. Most of these food advertisements are about obesogenic foods [11].

With the intention of addressing these issues and to prohibit the pervasive impact of marketing, a set of recommendations on the marketing of FNBs to children was put forward by WHO in 2010 at the sixty-third World Health Assembly. It is recommended to implement actions at national level by member countries of WHO while cooperating to establish necessary requirements to minimise the influence of marketing of obsogenic foods.

Nutrient Profile Models

Nutrient profiling is "the science of classifying or ranking foods according to their nutritional composition for reasons related to preventing disease and promoting health." Australia and New Zealand, as well as countries in the European Union such as Ireland, Norway, Sweden, the United Kingdom, and the United States of America, use well-developed NPMs. Some of these countries have incorporated these well-established NPMs into their legislation. The nutrient profile models developed by Denmark, Norway, and the United Kingdom are currently used in Europe to limit the marketing of FNB to children [12, 13]. Globally, nutrient profiling is identified as an unambiguous and reproducible method of evaluating the quality of foods with respect to their impact on health. NPMs are used for various purposes by both the government and industry. For example, NPM is helpful in front-of-pack food labelling and to reformulate food products for food industries, while the government uses NPM to formulate food taxes, instruct food manufacturers to reformulate food products, and to improve nutrition literacy of the community.

The NPM for SEAR was developed with technical contributions from 11 Member States, including Sri Lanka, to regulate the marketing of FNB to children [2].

Health Condition of the Sri Lankan Community

It was found that although people live longer in Sri Lanka, as a result of NCDs, people suffer more years from various diseases and disabilities. For an example, in Sri Lanka at the time of birth, the life expectancy is 74.9 years. But the bitter truth is that the healthy life expectancy of Sri Lankans at birth is only 67.0 years [14]. In addition to that, according to the annual health statistics 2019 released by medical statistics unit of the ministry of health, ischemic heart disease is identified as the most prominent reason for hospital deaths in Sri Lanka. In 2019, 37.2 deaths per 100,000 populations were caused by ischemic heart diseases. Among these deaths that occurred, mortality from CVDs became the main reason for hospital deaths [15].

Health Condition of Children in Sri Lanka

Currently, in Sri Lanka, overweight and obesity have become major health problems among children. For example, in Sri Lanka, there were 6.1% of overweight children and 2.9 % of obese children in 2016 [16]. The highest level of prevalence of overweight was noted among 11-year old children, while the percentage of overweight increased with increasing age, except for 12 year old children [16]. The highest percentage of obesity, which is 4.1%, was reported among 12-year old children [16]. Furthermore, female children showed a higher prevalence of being overweight, which is 6.7 %while 5.4% of males were identified as overweight. When it comes to obesity, male children showed a higher prevalence of obesity, which is 3.4 % compared to females, which is 2.4 % [16]. It was found that the prevalence of obesity increased among children with the increasing level of their mother's education up to an advanced level [16]. When concerned about the provincial distribution of the number of obese children, the highest number of obese children was recorded in Western province, which is 4.9 % and it is the lowest in Uva province, which is 1.7% [16]. The persistence of overweight children varied from 10.9 % in the Western Province to 4.0 % in the Central Province [16].

Current Situation of Food Related Regulations in Sri Lanka

Among NCDs, heart diseases, diabetes, and high cholesterol are on the rise in Sri Lanka. It is identified that high consumption of salt, fat, and sugar are the major contributory dietary factors to the abovementioned health problems in our society. Therefore, the Ministry of Health of Sri Lanka has introduced a new regulation under the Food Act which is called "colour coding (CC) for sugar, salt, and fat", which was effective from 01.06.2019. According to this regulation, solid or semi-solid food that contains greater than 1.25 g/100 g salt will be labelled in red. Solid or semi-solid foods with a salt content of 0.25 to 1.25 g/100 g are labelled in amber, while those with a salt content of less than 0.25 g/100 g are labelled in green.

However, products that contain single ingredients such as drinking water, tea, coffee, etc, primary agricultural products including fish and meat, spices and condiments, curry mixtures and flavouring mixtures, fruits and vegetables, cooking oils, cereals, sugar and salt, fresh milk and infant milk formulae, foods

in which the label displays that it is to be used under medical guidance or on the guidance of a medical practitioner, foods packed in bulk packs where the retail packs comply with these regulations, are exempted from food labelling according to the guidelines given in the new regulation of the CC system.

Although the regulation CC for sugar, salt, and fat is effective from 2019 onwards, according to the findings of Weerasinghe et al, 2019, only a limited number of buyers were aware of the regulation on the system. Moreover, they were not aware of what this regulation stood for or its real meaning. Furthermore, it was found that when purchasing soft drinks, buyers pay attention to brand name and taste, price and quantity, and ingredients, rather than the meaning of the CC system level of fat, salt, and sugar. In addition to that, buyers do not pay attention to the impact on health when using soft drinks [17].

Based on the NPM for SEAR introduced by WHO, which consists of threshold limits (TLs) for sodium, in 2018, the nutrition division of the ministry of health, nutrition and indigenous medicine prepared a NPM for Sri Lanka with the intention of implementing guidelines on the marketing of FNB to children of Sri Lanka to minimise the impact of marketing of foods high in fat, salt, and sugar.

The NPM for Sri Lanka does not classify FNB as healthy or unhealthy, but it creates a platform to regulate and control the marketing of FNB to children. The NPM can be used to empower consumers to make informed food choices and to improve nutrition literacy. But NPM does not prohibit the manufacturing or trading of any food items for consumers.

According to the guidelines given in NPM, fresh and frozen vegetables, fruits and legumes, and juices of fresh fruits and vegetables that do not contain added sugar, food products such as colours, additives, and binders, foods that contain more than 0.5 g of trans-fat per serving, and foods that contain alcohol that contribute to more than 0.5% of total energy are excluded from NPM for Sri Lanka.

To categorise a food product as "acceptable" according to NPM for Sri Lanka, the fat, sugar, and salt content of a food product in its ready-to-eat or drink form, which is calculated using the information provided in the food label, has to be equal or lower than the corresponding TLs specified for the relevant category in NPM. If any of these values obtained for fat, sugar, or salt content of the product is higher than the TLs given in NPM for a particular food category, the product is categorized as "not acceptable" according to NPM.

If the product is able to be consumed as it is without reconstitution prior to consumption, the nutrient composition on the label can be used to compare with the TLs given in NPM to decide the acceptability of a particular food. NPM suggests that foods categorized as' acceptable 'are allowed for marketing to children, while any type of food categorized as' not acceptable ', will not be permitted for advertising and marketing to children. However, NPM allows marketing a food product within a reasonable time period during a celebratory event if that particular food product is considered a traditional item that is associated with that particular celebratory event.

The key limitation of NPM is that for certain food groups, including confectionary, coffee, coffee substitutes, tea, herbal infusions, nut-based beverages, fresh and frozen meat, juices, milk and dairy based drinks, poultry and game products, TLs for sodium content were not provided within NPM, which might cause problems when implementing as a legislation to regulate the marketing of FNB for children.

Level of Sodium in Foods That are Commonly Consumed in Sri Lanka

There is no comprehensive database that contains the sodium content of foods that are commonly consumed in Sri Lanka. In addition to that, limited research has been done to quantify the sodium content of foods that are consumed commonly within the Sri Lankan context, which causes problems when implementing both NPM and the legislation of "CC for sugar, salt, and fat".

When concerned about the findings of Jinadasa et al, 2018, [1], which is on the sodium content of mixtures and bite types, bakery products, meat and fish, milk and milk-based products, pasta, noodles, and papadam, snacks and sweets, sauces and pickles, the sodium content of these foods varies according to the values mentioned in Table 1.

Table 1: Average sodium content of selected food groups

Food group	Number of samples analyzed	Average (±SD) Sodium content (g /100 g)
Mixture and bite type	16	1.355 ±0.224
Bakery product	10	0.511±0.296
Meat and Fish	35	1.395± 0.681
Milk and dairy products	10	0.525 ±0.248
Pasta, noodles and Papadam	19	0.996± 0.942
Snacks and sweets	17	0.822±0.56
Sauce	8	0.939± 0.686
Pickle	2	0.497± 0.292

SD: Standard Deviation

Zoysa et al 2021, [18], quantified the sodium content of food categories according to NPM for SEAR by WHO. Sodium content of confectionary (CON, n=37), cereals (CER, n=10), fine bakery ware (FBW, n=42), bread and ordinary bakery ware (BO, n=30), water based flavoured drink (BEVC, n=8), cereal, grain, tree nut based beverages (BEVE, n=5), frozen dairy based desserts and edible ices (FDD, n=7), curded dairy based desserts (CDD, n=19), composite foods (CPF, n=8), pasta, noodles and like products (PNO, n=4) and sauces, dips and dressing (DRE, n=3) were analysed using flame photometer (Model 420, Sherwood Scientific) after dry-ashing. The range of sodium content (mg/100g ± SD) varies according to Table 2.

Table 2: Range of sodium content of Food groups of SouthEast Asia Region model

Food groups of South East Asia Region model	Number of samples analyzed	Range of Sodium content (mg/100 g)
Confectionary	37	0-0.269 ± 6
Cereals	10	8±1 - 291±10
Fine bakery ware	42	43±1 - 1613±29
Bread and ordinary bakery ware	30	5±0 - 867±37
Water based flavored drink	8	7±0 - 156±3
Cereal, grain, tree nut-based beverages	5	0 -158 ± 15
Frozen dairy-based desserts and edible ices	7	0 - 158±15
Curded dairy-based desserts	19	32±1 - 158±15
Composite foods	8	233±2 - 525±14
Pasta, noodles and like products	4	4±0 - 427±13
Sauces, dips and dressing	3	3±0 - 1442±10

The TLS for sodium in the model were 100, 200, 250, 350, and 300 mg/100g for FDD and CDD, BEVE, FBW, BOB and PNO, CER and CPF, BEVC and DRE, respectively, although CON TLs were not specified. Among tested samples, the percentage to be prohibited from each category according to the TLs was for CER, BEVC and BEVE - 0%, CDD - 16%, FDD - 29%, DRE - 33%, BOB and PNO-50%, FBW-55% and CPF-67% [18].

Prasadani et al 2021 [19], evaluated and quantified commonly consumed food samples which were randomly collected and categorized to groups: confectionary (CON,n=37), cereals (CER, n=10), fine bakery wares (FBW, n=42), bread and ordinary bakery ware (BOB, n=30), curded dairy based desserts (CDD, n=19), composite foods (CPF, n=27), pasta, noodles and like products (PNO, n=4) and sauces, dips and dressing (DRE, n=3). Sodium content was analyzed using a flame photometer (Model 420, Sherwood Scientific) after dry ashing. Based on calculated salt content as NaCl, the percentage of food items that belong to the red, amber, and green logos of CON, CER, FBW, BOB, CDD, CPF, PNO, and DRE are described in Table 3.

Table 3: Percentage of food groups of NPM for SEAR that bear red, amber and green logo.

Food group	**% of food items bear the logo of**		
	Red	**Amber**	**Green**
	>1.25 g / 100 g of salt	**0.25 to 1.25 g / 100 g of salt**	**less than 0.25 g / 100 g of salt**
Confectionary (CON)	0	11	89
Cereals (CER)	0	30	70
Fine bakery wares (FBW)	12	74	14
Bread and ordinary bakery wares (BOB)	17	50	33
Curded dairy-based Desserts (CDD)	0	16	84
Composite foods (CPF)	11	85	4
Pasta, noodles and like products (PNO)	0	50	50
Sauces, dips and dress-ing (DRE)	33	0	67

None of the samples of CON, CER, CDD, and PNO belong to the red logo, whereas 12% of FBW, 17% of BOB, 11% of CPF, and 33% of DRE belong to the red (≥1.25g/100g). Among food groups, 85% of CPF, 74% of FBW, and 50% of BOB and PNO belong to the amber logo (0.25-1.25g/100g), whereas 89% of CON, 70% of CER, 14% of FBW, 33% of BOB, 84% of CDD, 4% of CPF, 50% of PNO, and 67% of DRE belong to the green logo (≤0.25g/100g)[19].

Policy Gaps and Recommendations About Sodium Related Health Issues in Sri Lanka

Findings from recent national studies which were conducted by the Ministry of Health of Sri Lanka revealed that there is a tendency for increasing micronutrient deficiencies within the country even though certain micronutrients are present in excessive amounts among some groups [16]. Since there is no database of foods which contains the composition of nutrients of foods commonly consumed, increasing or decreasing the consumption of certain foods to reduce the consumption of sodium might worsen the scenario.

Iodine is added to edible powdered and crystal salt in Sri Lanka to prevent goitre and other health complications associated with iodine deficiency disorder. According to the legislation which was implemented in 1995 under the FOOD ACT No. 26 of 1980, salt should contain a minimum level of 50 ppm of iodine at factory level and 25 ppm of iodine at consumer level. However, when quantifying the sodium content of a food, both intrinsic sodium and fortified sodium by the addition of edible salt are quantified together. Therefore, it is important to quantify the iodine content of these food groups as reduction of the addition of iodised salt during preparation of foods to be in line with TLs for sodium given in NPM might lead to iodine deficiency.

Due to the lack of complete nutrient labelling in some food items, although people tend to consume them in higher frequency, especially street foods, the NPM cannot be applied to such products to compare TLs given for sodium for regulatory purposes. Therefore, it is important to carry out a comprehensive study to evaluate and quantify sodium in such food items.

For the food groups, confectionery, juices, milk and milk-based drinks, coffee, coffee substitutes, tea, herbal infusions, nut-based beverages, fresh and frozen meat, poultry, and game products, TLs were not provided for sodium in the NPM for Sri Lanka. Therefore, it is important to evaluate sodium in such food items and to compare those values with the TLs given in other models to similar food products to establish TLs for sodium in these food groups.

According to a new regulation implemented under the Food Act, which is called "colour coding for sugar, salt, and fat," in 2019, 1.25 g/100 g salt will be labelled in red. Solid or semi-solid foods with a salt content of 0.25 to 1.25 g/100 g are labelled in amber, while those with a salt content of less than 0.25 g/100 g are labelled in green. In the NPM for Sri Lanka, the TLs given for sodium in cereals, water based flavoured drinks, cheese and analogues, composite foods, processed meat, poultry and game products, processed fish and seafood products, processed fruits and vegetables, sauces, dips and dressings, and seasoning fall in between 0.25 to 1.25 g/100 g of salt in food regulation, colour coding for sugar, salt, and fat. Meanwhile, TLs for sodium given in NPM for Sri Lanka for other food groups fall to less than 0.25 g/100 g of salt level of food regulation, colour coding for sugar, salt, and fat. Therefore, the implementation of food regulation, colour coding for sugar, salt, and fat, and NPM together will create contradictory issues. So, revising TLs for sodium in the NPM to be in line with the green colour of the CC system is vital to prevent occurrences of conflicts. Furthermore, contradictions in the NPM and colour coding systems may cause loopholes when implementing tax-base fiscal policies.

Since the variation in salt content among products of same food group suggests that product reformulation to further reduction of salt content to less than 0.25 g / 100 g is feasible to be in line with the green colour code of food colour coding system which is more health friendly [19], it is vital to implement recommendations to persuade food processors to reformulate food products either to make available high salt, medium salt and low salt food products of a single type or a brand or to reduce the salt content to less than 0.25g / 100g.

According to the findings of Zoysa et al 2021 [18], among tested samples, the percentage to be prohibited from each category according to the threshold limits given in the NPM for SEAR by WHO was for cereals, water based flavoured drinks and cereals, grain, tree nut based beverages -0%, curded dairy based desserts - 16%, frozen dairy based desserts and edible ices - 29%, sauces, dips and dressing - 33%, bread and ordinary bakery ware and pasta, noodles and like products -50%, fine bakery ware -55% and composite foods -67%. Therefore, it is important to implement recommendations in the marketing of food and beverages to children and to make manufacturers aware of the need to reformulate food products based on the TLs for sodium provided in the NPM.

After making necessary revisions to NPM for Sri Lanka, it should be implemented as a legal policy to evaluate, quantify, and reformulate foods available for consumers and especially for children, for a healthier nation. Foods sold in canteens of schools, fast food outlets, and street vendors can be randomly sampled with the aid of public health inspectors and sodium content can be quantified via accredited laboratories and legal actions can be taken based on TLs.

Since it was found that nutrition literacy is low within the community [20], it is important to precede island-wide awareness campaigns by using mass media to aware consumers, including both buyers and end-users, about the limits given in both the Food CC system and NPM to minimise NCDs.

Although the NPM suggests establishing a comprehensive framework to reduce the impact and exposure on children of marketing foods high in saturated fats and trans-fatty acids, free sugars, or salt, allowing for a standard implementation monitoring and evaluation process, it is currently not practiced in Sri Lanka. Therefore, it is extremely important to implement a framework to reduce children's exposure to marketing of obsogenic foods high in saturated fats, trans-fatty acids, free sugars, or salt.

After analysing all the policy gaps, it is recommended to establish an integrated approach which consists of policy changes to reduce salt intake, product reformulation to minimise the salt content of each food item within each food category to restrict or eliminate the availability of foods that contain high

amounts of salt; establish regulations on preventing marketing and advertising of high-salted foods to children, implement public awareness campaigns to improve nutrient literacy among children and adults; and simultaneously implement a food labelling and monitoring system, which will be more effective to minimise the negative health impact of excessive consumption of sodium .

As a part of the monitoring and evaluation process according to NPM for Sri Lanka, it is important to quantify salt or sodium chloride content. Since a negative health impact is created by sodium, it is important to establish analytical methods that quantify sodium to calculate sodium chloride other than the test methods that quantify chloride to calculate sodium chloride. This is because sources of both sodium and chloride available in foods can be other than sodium chloride. Quantification of sodium by using a flame photometer and an atomic absorption spectrophotometer according to Association of Official Analytical Chemists (AOAC) test methods such as AOAC 975.03, AOAC 965.01 etc. can be suggested as accurate and reliable test methods.

In NPM developed by WHO for SEAR, sodium refers to the salt content of the food, and 1 g of sodium is equivalent to about 2.5 g of salt. As demarcated in the regulation of cc for sugar, salt, and fat, salt means total salt contained in food in the form of sodium chloride (NaCl). Therefore, this definition allows quantifying sodium chloride (NaCl) by analysing chlorides that cause erroneous results, which lead to underestimation or overestimation of salt content. Therefore, it is important to correct this definition.

Conclusions

In Sri Lanka, among NCDs, heart diseases, diabetes, and cholesterol are on the rise as a result of consumption of foods that contain higher amounts of salt, fat, and sugar. Currently, among Sri Lankan children, being overweight or obese has become a major health problem. It has been established that a high salt intake in children has an impact on their health and may lead to the development of a variety of diseases such as high blood pressure, osteoporosis, and respiratory illnesses such as asthma, stomach cancer, and obesity, among others.

The Ministry of Health of Sri Lanka has introduced a new regulation under the Food Act which is called "colour coding (CC) for sugar, salt and fat". This was effective from 01.06.2019 to make consumers aware of the level of sugar, salt and fat in foods by labeling them in red, amber and green based on the level of sodium.

Food advertisements influence food choices and dietary habits significantly in children. Risk factors connected to unhealthy diets that lead to suffering from

NCDs during adulthood start in childhood and develop throughout the entire life. Currently, in Sri Lanka, food advertisements are mostly broadcast during both family and children's TV schedules. Most of these food advertisements are about obesogenic foods. Based on WHO NPM for SEAR, NPM was developed for Sri Lanka to implement recommendations on the marketing of FNB to children.

When implementing both CC and NPM, quantifying sodium in foods in which sodium content has not been quantified yet and establishing TLs for food groups, in which TLs were not provided for sodium, is vital. The TLs of certain food groups in NPM do not fall into the level of sodium for green, in the CC system, which is more health-friendly.

Product reformulation to reduce salt content is feasible to be in line with the limit of sodium for the green colour of the CC system. It is essential to implement recommendations to persuade food processors to reformulate food products.

To improve nutrition literacy among the community, including both food producers and end users, it is essential to precede awareness campaigns about health risks associated with the consumption of foods dense in sugar, fats, and salt by using mass media.

To avoid erroneous results, it is critical to recommend accurate analytical test methods for quantifying sodium and calculating sodium chloride. According to the WHO NPM, sodium refers to the salt content of the food, whereas salt in CC refers to total salt contained in food in the form of sodium chloride. Correcting the definition in regulation CC is important to prevent quantifying sodium chloride (NaCl) by analyzing chlorides, which can cause an erroneous estimation of salt content.

Therefore, it can be concluded that addressing these gaps and implementing an integrated approach is important to minimize possible health risk factors associated with the health of children and to have a healthier nation in the future.

Abbreviations

AOAC-Association of Official Analytical Chemists
BEVC-water based flavoured drink
BEVE-tree nut based beverages
BOB-bread and ordinary bakery ware
CC-colour coding
CDD-curded dairy based desserts
CER-cereals
CON-confectionary
CPF-composite foods
DRE-sauces, dips and dressing
FBW-fine bakery ware
FDD-frozen dairy based desserts and edible ices
FNB-Foods and non-alcoholic beverages
FNB-foods and non-alcoholic beverages
MSG-monosodium glutamate
NaCl-sodium chloride
NCD-non communicable diseases
NPM-Nutrient profile model
NSS-non-sugar sweeteners
PNO-pasta, noodles and like products
SEAR-South East Asia region
TL-Threshold limits
WHO-World Health Organisation

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CHAPTER 05

A CONTEMPORARY APPROACH FOR AN UPDATED FOOD SAFETY AND SECURITY STRATEGY FOR SRI LANKA

A Contemporary Approach for an Updated Food Safety and Security Strategy for Sri Lanka

M.D.N.R. Dayananda

Abstract Access to healthy and safe food is a fundamental human right, an elementary human necessity, and a primary determinant of human health, including the main components of food availability, access, utilization, and stability. The rapid globalization of food trade, climate change, increase in the world's population, cost-push inflation, pandemics, and environmental burdens will have consequential but unpredictable effects on food security, resulting in hunger in the short run. On the other hand, food-borne diseases significantly impact livelihoods, health systems, the human economy, trade, and tourism. Hence, integrating food safety strategies into government policies and providing suitable interventions is necessary to improve and enhance the community's nutrition requirements and food security. Stakeholders expect that the government and responsible authorities provide substantial guidance in response to current and emerging food safety challenges and provide appropriate resources at specific levels for improving systems to ensure food safety across the country's entire food and feed chain. Therefore, implementing the broader strategies, including strengthening national food controls, promoting scientific evidence-based risk assessment in establishing and reviewing food control measures, imposing national standards for food contaminants, including heavy metals, pesticide residues, etc., and inspection, implementing an improved national food safety system to promote international food trade, strengthening food monitoring and surveillance programs, encouraging the active engagement of stakeholders in risk assessment and communication, and implementing an integrated agricultural system are suggested to overcome the food safety and security issues in Sri Lanka.

Keywords: Food safety, Food security, Strategies, Food control system

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Food Security and Safety as Public Health and Socioeconomic Priority

Access to safe and healthy food is a primary determinant of human health and a fundamental human right. On the other hand, acquiring food is about self-satisfaction and feeling connected to the community and belonging. Food safety can be explicated as "all people, at all times, having physical and economic access to sufficient, safe, and nutritious food to meet their dietary needs and food preferences for an active and healthy life" [1].

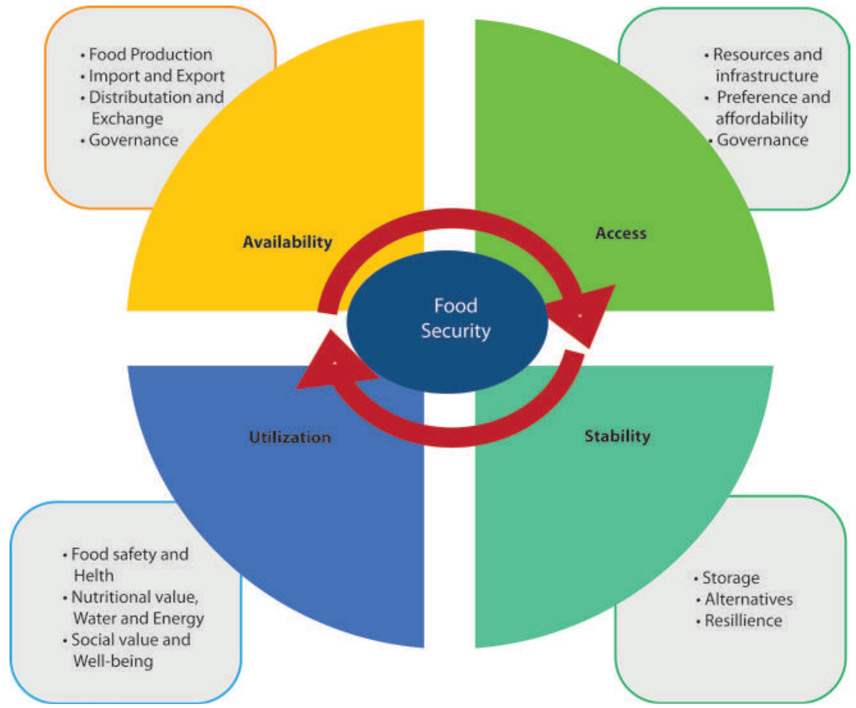

Figure 1: Essentials in food availability, access, stability, and utilization to ensure the food security of a nation.

Food security relies on four main components: food availability, access, utilization, and stability. The availability set out for adequate quantities of food with proper quality supplied via household/state production or imports. Access refers to acquiring a nutritious diet by individuals from adequate resources or infrastructure without any interference from the existing legal, political, economic, and social arrangements of the community they live in. A population, a household, or an individual must have access to all physiological needs, including a secure nutritional diet, clean water, sanitation, and healthcare at all times to reach a better level of nutritional well-being, and those are described under Utilization [1]. Availability, access, and food utilization should be stable and should not collapse due to unexpected stresses such as an economic, pandemic, or climatic crisis. When any of these components is not functioning well or does not meet the requirements mentioned, it leads to food insecurity. Incidents related to insecure food have increased with the rapid food production and trade worldwide [2]. Climate change, global population growth, rising food prices, and environmental pressures will have significant but uncertain effects on food security. Insecure productivity with inadequate hygiene leads to unsafe food, food-borne diseases, and demise. Food-borne diseases significantly impact livelihoods, health systems, the human economy, trade, and tourism [3]. Still, continuity of insecure food production gives rise to malnutrition (especially among children), including exhaustion, nutritional deficits such as micronutrient and vitamin deficiencies, underweightness, and even death in the long run. Frequent consumption of unhealthy foods (fast food, prepacked/canned foods, frozen/dehydrated foods) is driven by food insecurity. For example, meals with high fat and carbohydrates can result in obesity and non-communicable health conditions; diabetes, cardiovascular diseases, hypertension, etc. Chronic malnutrition among the younger generations forces their slow brain development, resulting in poor learning abilities or uncomprehending that will limit their employment capabilities and profit-making opportunities in maturity. However, such wide-ranging exposure has never been assessed worldwide, as food-borne diseases go unnoticed, especially in developing countries like Sri Lanka. Hence, food safety is about ensuring that the food will not harm the consumer during its consumption. It is becoming an essential benchmark in sustainable development goals, which are straightly connected with productivity and livelihood improvement [4].

Foods are produced, managed, delivered, and consumed in ways that could not have been anticipated two decades ago. Therefore, updated strategies and policy arrangements to adapt to global change are urgently needed, including novel techniques that begin with identifying proper land-use patterns, irrigation, food processing/preservation, managing the post-harvest, and food prices and trade along with safety over the coming decades. Therefore, it is all-important to incorporate food safety strategies by providing necessary interventions to improve nutrition status via food security in every community to maintain the good well-being of a country. Thus, the development of an approach with multidimensional and integrative procedures involving stakeholders at each level, including industrial and health sector professionals, policymakers, and most importantly, consumers, is crucial to ensure food safety in a country. These factors call for a fresh global approach to improving food safety to strengthen national food safety systems while strengthening international and national collaboration. While recognizing that food safety is a shared responsibility among multiple stakeholders, countries must show leadership in adopting and

implementing food safety policies to ensure that each stakeholder knows and correctly plays their part.

Food Safety Threats in Sri Lanka

Food Contamination from Pesticide Residues, Heavy Metals, and Artificial Fruit Ripening Chemicals

Agrochemicals, especially pesticides, perform a significant function in present-day intensive agriculture. Therefore, there is an immediate potential health risk associated with the presence of pesticide residues in the agricultural harvest in countries like Sri Lanka. Chronic renal failures, which are prevalent in the North Central province and most dry zone areas of Sri Lanka, are thought to have a well-established link with agrochemical-related certain nephrotoxic heavy metals. Many researchers have reported that chronic kidney disease of unknown etiology (CKDu), which is predominantly found among Sri Lankan farming communities, is associated with dietary exposure to lead and cadmium [5,6]. Most CKDu cases were reported mainly in the irrigated agricultural areas under the river Mahaweli diversion scheme. In another way, cadmium derived from contaminated phosphate fertilizer used mainly in paddy cultivation leached out into the agricultural runoff finds its way into reservoirs where the sinking process happens and contaminates the harvesting parts of crops through bioaccumulation, bringing out considerable cases of CKDu, especially for the residents in those areas with long-term exposure. Moreover, agrochemicals consist of trace amounts of arsenic instead of cadmium, and lead contamination has been reported, which also causes serious health issues, including kidney malfunctions and even cancer [7]. Consequently, overuse of agrochemicals in paddy cultivation and contaminated water resources could multiply the heavy metals and pesticide residue content in agricultural soil. Especially in paddy cultivation, contaminants' transfer from irrigated soil to rice grains is a significant route of exposure to Sri Lankan remote communities that depend on the harvest obtained from their own paddy fields for extended periods.

Sri Lanka has a wide range of agro-climatic zones and the availability and possibility of growing a wide variety of tropical and subtropical fruits and vegetables (raw or processed). Still, progress towards achieving food security is plodding [8]. For example, apart from the fertilizers and pesticide residues, hazardous chemicals are being used to rip fruits and increase the mass and durability of fruits and vegetables, such as calcium carbide, oxytocin, etc. Calcium carbide, a ripening agent, is considered a carcinogenic material and is most commonly used on banana and mango harvests in Sri Lanka. Likewise, a considerable amount of contamination can happen to the fruit and vegetable harvest due to poor methods and practices starting from production until the post-harvest stage.

Mycotoxins in Food

Mycotoxins have the ability to cause mycotoxicosis (diseases and death) in humans, which originate from fungi as their secondary metabolites. Fungal invasion of food items is a well-recognized problem throughout the world, pre- or post-harvesting, food production, storage, and transportation. Moreover, 25% of the world's cereal production is contaminated with mycotoxin [21]. Food contamination by mycotoxins is common in tropical countries like Sri Lanka, which can cause a threatening remark to human health. One of the prominent and commonly found mycotoxins is acutely toxic aflatoxins, which act as immunosuppressive carcinogenic substances. Several *Aspergillus* species, namely *Aspergillus flavus* and *Aspergillus parasiticus*, produce aflatoxins as secondary metabolites, and contamination from them can happen via food chains from the field to yield, affecting the quality and nutritional value of the final product. In the Sri Lankan context, aflatoxin contamination has been reported for rice, maize, copra, peanuts, pulses, and minor food items like spices [10-13]. When considering rice contaminated with aflatoxin, the most common reasons include poor pre-and post-harvest practices, the soaking of rice to manufacture parboiled commercial rice, improper storage facilities, etc. [9]. Even the low contamination levels should be considered because rice is the staple food for Sri Lankans. It can be harmful to one's health because the average Sri Lankan consumes a lot of rice in their lifetime. In addition, aflatoxin in products made by coconut, dairy (milk), and medicinal plants is highly correlated with poor storage conditions and a lack of proper quality control measures [13].

Implications for Sri Lankan Food Security

The ban on importing inorganic agrochemicals, including chemical fertilizers and pesticides, has far-reaching implications for Sri Lankan food security. A considerable reduction in agricultural output can be expected soon, resulting in food inadequacy and an unaccustomed rise in the prices of food items. Without a significant increase in imports, the country will not be able to feed its population, especially at the current rate of exchange. If the food imports are delayed or unable to fulfil the quality concerns, hunger and malnutrition will emerge from the communities because the production and supply of organic agrochemicals cannot meet the demand and low quality. As a result, the decision to prohibit the import and use of chemical fertilizers and other agrochemicals should have been based on more scientific evidence, as hybrid varieties are grown today rely on chemical fertilizers and pesticides to achieve expected high yields. These unintended policy statements seriously threaten food security and pressure farmers and consumers economically and socially. In the middle of a pandemic situation, this severely affects the living and food security of the entire nation.
The suggested alternatives, such as the use of organic fertilizers, were unable to

immediately increase the harvest of important food crops in Sri Lanka, resulting in a significant drop in harvest, forcing the country to import rice. The reduction of export quantities of plantation crops results in less income. Both will hit the economy and living standards of Sri Lankans and directly affect food safety and security in the community. Therefore, the exploration of a solution for toxin-free food and a healthy environment cannot be accomplished by stressing out the ongoing agricultural system, and it should be performed with careful planning, proper scientific experiments, and shreds of evidence.

Current Trends in Food Safety in the Sri Lankan Context

Food-Borne Diseases in Sri Lanka

Food-borne diseases result in unsafe food containing harmful bacteria, viruses, parasites, chemicals, or physical substances that adversely affect public health acutely or chronically. Infants, children at younger ages, the elderly, and people who are immunocompromised are the main vulnerable groups to unsafe food or food-borne diseases [14]. There are more than 200 diseases, ranging from diarrhoea to cancer to permanent disability or death. Food and water-borne diseases are critical issues in food safety assurance in Sri Lanka, with an increasing incidence level.

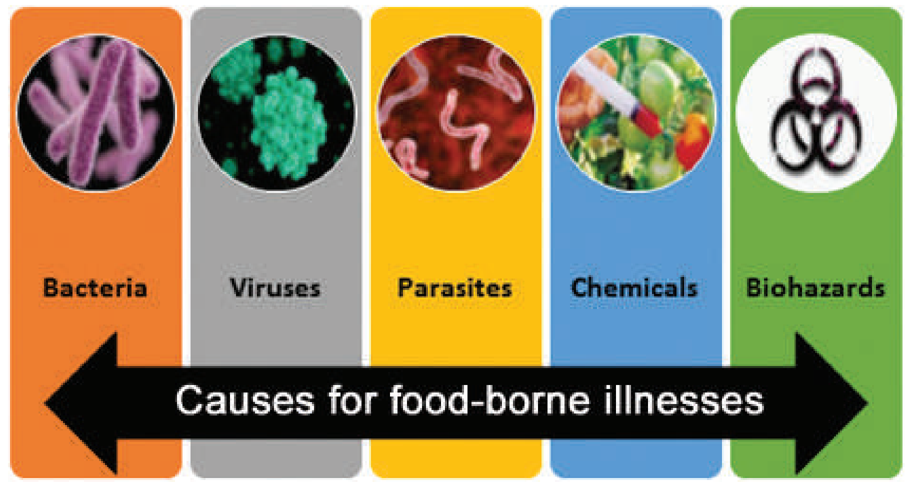

Figure 2: Common causes for occurring food-borne illnesses

Bacterial diarrhoea and hepatitis A, *Salmonella* infections, contamination by *Listeria monocytogenes*, and *Vibrio cholerae* are familiar sources of food-borne disease in Sri Lanka [15]. A country like Sri Lanka, categorized under low- and middle-income countries, is experiencing losses in productivity and trade-related issues, and there are considerable medical costs for treatments associated with the consumption of unsafe food and food-borne illnesses.

The COVID-19 Pandemic and Sri Lanka's Food Security

In the past few decades, Sri Lanka has made noteworthy improvements towards securing the population's food security, but the COVID-19 pandemic has intensified the food insecurity problems at community and family levels. According to the Global Food Security Index (GFSI)-2019 [16], which focused on restrictive and essential preventive measures taken by the world's governments to overcome the COVID-19 distribution, Sri Lanka was ranked 66th among 113 countries considering the dimensions including availability, affordability, quality, and safety of foods within the pandemic [17]. But with the economic crisis, that pressure impacted food supply/production chains, food safety and security, and the living status of people.

The labor-intensive agricultural system in Sri Lanka and other food supply and distribution chain activities slowed down due to the workforce shortage, mobility restrictions, banding of agrichemicals, and economic difficulties of farmers, although the cultivation practices were not terminated during the pandemic in Sri Lanka. Meanwhile, due to disruptions in food distribution channels and market closures, post-harvest losses in perishable products such as fresh fruits, vegetables, and fish increased significantly during the lockdown period. Accordingly, intermediary processes, including manufacturing, processing, packaging, storage, and distribution of food items, were influenced. Those supply-side unsettlings gave rise to an increase in prices and also the quality of meals/food items, making food over-priced for low-income families and threatening their food security.

Strategies for Food Quality and Safety Management in Sri Lanka

Human nutrition and food security can no longer be turned a blind eye to, and any divergence in the flow-chain of safe food might have devastating outcomes. In Sri Lanka, strategies and all the actions on certifying food security and nutrition are generally controlled through the National Agricultural Policy of the Ministry of Agriculture, the National Nutrition Policy of the Ministry of Health, Nutrition and Indigenous Medicine, and several other policy documents and authorities. Those are direct food processes, prices, security, safety, and nutrition, particularly the Food Act, which manipulates the manufacturing, safety, importation, sale, distribution, and inspections of food.

As unsafe food threatens consumer health, produces inefficiencies in animal and plant production systems, and creates trade barriers across the global food web,

it is not always possible to control the drivers of change when strengthening food safety systems in a country [18]. Therefore, it is crucial to build awareness on food safety and security among stakeholders, including producers, consumers, and individuals in the community, to be considered and ideally managed into the system's overall design.

There is a worldwide growing awareness about strengthening national food safety systems to improve the protection of consumers' health, gain trust and confidence in the safety of the food supply, to facilitate food trade. Stakeholders expect that the government and responsible authorities provide substantial guidance in response to current and emerging food safety challenges and provide appropriate resources at specific levels for improving systems to ensure food safety across the country's entire food and feed chain. Therefore, implementing the strategies given here provides a broader pathway to achieving the above target.

i. Strengthening national food controls.
ii. promoting scientific evidence-based risk assessment in the development and evaluation of food control measures
iii. Imposing national standards for food contaminants, including heavy metals, pesticide residues, etc., and inspection.
iv. Implementing an improved national food safety system to promote international food trade.
v. Strengthening food monitoring and surveillance programs
vi. Encouraging the active engagement of stakeholders in risk assessment and communication.
vii. Implementing an integrated agricultural system

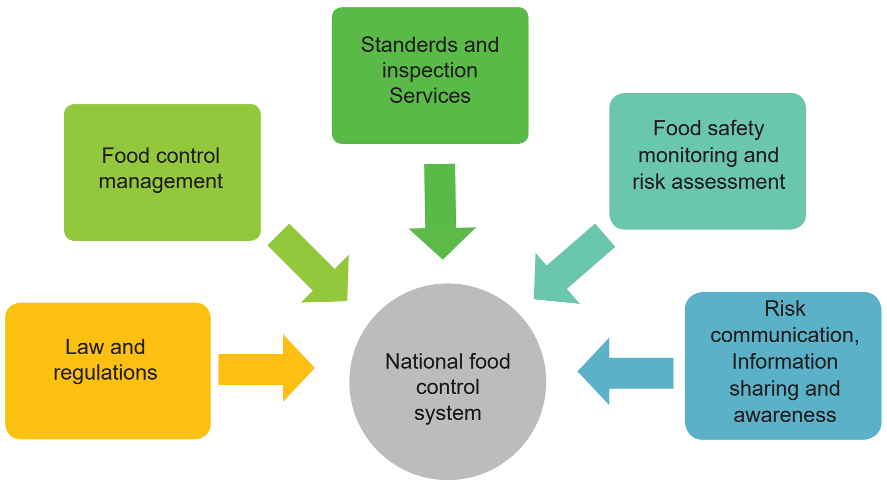

Figure 3: Essential elements in a national food control system to ensure the food security and safety of the country.

Food safety refers to procedures in the preparation, handling, and storage of food in order to prevent foodborne illness and injuries to consumers. In that regard, food safety standards are essential requirements to ensure the hygiene and health of food. Today, food regulations have become very crucial because they point out and emphasize the alterations in food production, supply, and contamination, including factors due to environmental, social, and economic changes. National governments need to pay more attention to capacity-building, awareness-raising, and science-based solutions. Food safety infrastructure at the national level must be not only maintained but reviewed and improved.

A multipronged approach is needed among consumers, government authorities, and industries for the better scientific detection of multistate outbreaks because of emerging hazardous bacterial, viral, and parasitic species, toxins, and antibiotic resistance in food-borne germs severely affect food safety and security nowadays. Therefore, implementing new techniques for quick detection and rapid analysis of food-borne infections to determine the exact cause of an illness holds great potential. However, most of these tests require centralized laboratories, highly skilled technical staff, and a lot of funding, which is not always available. Encouraging the private sector to facilitate these requirements is an essential step to resolve this issue, and they can be easily incorporated into the equipment, packaging systems, and food manufacturing monitoring systems like HACCP [19, 20].

Implementing surveillance and monitoring procedures for foods coupled with

risk assessment, management, and communication with the participation of stakeholders is an essential task. Unregulated long market chains have pressurized rural producers or farmers and the urban poor in the current situation. In addition, climate-related events and pandemic situations hit the supply chains, which result in the socio-economic status of the low incomers. As a result, building physical and institutional capacity reduces the vulnerability of food price fluctuations and provides more consistent access to affordable food. The intensive agricultural production systems of Sri Lanka are the major contributors to the food supply in the country. Implementing an integrated agricultural system is an urgent need instead of banding inorganic agrochemicals. Overuse of synthetic fertilizers and pesticides should be controlled, and organic farming should be encouraged simultaneously. The integrated agricultural system can be achieved through the development of national standards for organic agriculture, maintenance of soil fertility by enhancing the biological cycles, adoption of biological methods to control pests and diseases, implementation of biological and mechanical practices for weed control, promotion of high-quality organic fertilizer production, and incorporation of traditional and indigenous knowledge into modern agriculture.

Conclusions

It is imperative to integrate food safety into government policies and provide necessary interventions to improve nutrition and food security for the community. Therefore, implementing the broader strategies, including strengthening national food controls, promoting scientific evidence-based risk assessment in establishing and reviewing food control measures, imposing national standards for food contaminants, including heavy metals, pesticide residues, etc., and inspection, implementing an improved national food safety system to promote international food trade, strengthening food monitoring and surveillance programs, encouraging the active engagement of stakeholders in risk assessment, proper communication, and implementing an integrated agricultural system are suggested to overcome the food safety and security issues in Sri Lanka.

Conflict of Interests

Authors have declared that no competing interests exist.

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CHAPTER 06

FOOD AUTHENTICATION FOR FOOD SAFETY AND NUTRITIONAL SECURITY IN SRI LANKA

Food Authentication for Food Safety and Nutritional Security in Sri Lanka

K.M.R.U. Gunarathne* and J.M.N. Marikkar

Abstract Safety and nutritional security of food and agricultural products have become a major concern and challenge in Sri Lanka. The increasing demand, coupled with shortages in food supply, leads to food safety issues and nutritional insecurity. As food quality issues like adulteration and other forms of fraudulent practices are rampant in today's world, sound scientific approaches are required to tackle them. Deliberate or in-deliberate addition of foreign materials and removal of value-added food substitutes frequently takes place in the food supply chain. Hence, international and local regulatory control measures are required to be implemented to safeguard the quality and safety of food commodities. In this backdrop, food authentication can play a crucial role to ensure the quality and safely of food produces in compliance with the standard guidelines. Food authentication throughout the food production and supply lines would aid not only to ensure food safety among the general public but also increase the competitiveness of our local products in the international market. Further, establishing comprehensive data bases on nutritional compositions of locally available agro-food products would help to address nutritional insecurity prevailing in the Sri Lankan Society.

Keywords: Authentication, Food adulteration, Food quality, Food safety, Nutritional security

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Introduction

Product quality, particularly in relation to foods, has gained importance over the past several years worldwide. In many countries, food quality control has become an essential part of the supply chain line from farm to table. Almost all foodstuffs in the market pose quality-related problems in various aspects. The quality issue would become more serious if the food product had a high intrinsic commercial value. In this connection, monitoring of food adulteration or contamination of food with undesirable substances has become a crucial task to ensure the quality of food. Thus, certification of product quality has an added value for product marketing within a competitive system.

Consumers around the world have increasingly become cautious about the quality of the food they consume. Speculative reports of food adulteration in the social media pose a growing challenge to the food manufacturing sector. Owing to this, food manufacturers are at times compelled to confirm the authenticity of their finished products or ascertain the source of origin of the ingredients used in the formulations. Determining the authenticity of food and other agricultural produces has been an ever-increasing challenge. This can help to prevent false descriptions or incorrect labelling, substitution of cheaper ingredients, and other adulteration issues. This increased demand for authenticity comes amid various legislative and regulatory pushes that increase the level of regulation imposed on the food supply worldwide.

Food Quality Issues in the Agro-food Sector

Because of the growing public awareness of food quality and safety issues, the authentication of food commodities has become a rapidly advancing field of study. Scientific community, law enforcement authorities, food manufacturing companies, and personnel involved in supply chain management are interested in keeping an update on the developments taking place in this arena. A quick review of the literature reveals how many different analytical approaches have been investigated by researchers all over the world to cross–check the authenticity of various food items. As there are numerous practices of a fraudulent nature taking place, it has become essential to take steps to monitor food quality at different stages of production.

What is Food Adulteration?

Food adulteration is a global concern that adversely impacts the quality and safety of foods. Generally, it refers to the deliberate or inadvertent substitution of inferior foreign materials into food or the removal of value-added food substitutes from the primary food commodity [1]. The practices of adulteration include dilution, unauthorized enhancements, counterfeiting, substitution, concealment, grey marker production, mislabelling, etc. [2]. This process can actually either reduce the nutritional quality or subsequently cause an injurious impact on the consumers or can cause both [3]. An elevated risk of food adulteration can emerge when a country faces a low food supply, leading to an imbalance between the supply and demand. Furthermore, the likelihood of food adulteration would be high in developing countries due to insufficient policies and monitoring mechanisms [4]. This topic is actually contemporary and would be very much relevant to the present economic situation in Sri Lanka in the wake of shortages of commodities in fulfilling the demands of the food sector.

A number of food commodities are known to be victims of either adulteration or mislabelling by the unscrupulous. Milk, butter, honey, olive oil, virgin coconut oil, gee, spices, and tea are some of the common examples of commodities having a high vulnerability to adulteration. Many studies have been carried out in the past to provide insight into potential adulterants in different food commodities. Just a few examples include palm oil in olive oil or rapeseed oil [5], low-grade rice in good quality rice [6], starch, melamine, and water in milk [4-7], invert sugar or jaggery in honey, chicory in coffee powder, brick dust in chili powder, metanil yellow in pulses and turmeric [8], and so on. Over the years, scientific literature has discussed the detection of these adulterants in various food items, emphasizing the need for quality control in the food sector. Some of the most common adulterants that can be found in several food items are shown in Table 1.

Table 1: Some common adulterated foods and the respective adulterants

Food	Adulterant	Target parameters and action	References
Milk	Ammonium sulphate	Preservation action to increase the lactometer reading	[9], [10]
	NaCl	To maintain the density of milk, Increase solid-not-fat	[9], [10]
	Sodium bicarbonate, sodium hydroxide	Act as a neutralizer, suppress the microbial growth, enhance shelf life	[10]
	Starch, sugar, sulfate salts	Increase solid-non-fat	[9]
	Urea	To Increase non-protein nitrogen content	[9]
	Melamine, Dicyandiamide	To Increase protein content	[9], [11]
	Formalin, Benzoic acid, Salicylic acid,Hydrogen peroxide	Preservation action, enhance shelf life	[9]
	Vegetable oil	To Compensate the fat content	[9]
	Detergents	Emulsification and dissolve the oil in water	[9]
Honey	Artificial sweeteners: High fructose corn syrup, sugar, maltose syrup, inverted beet syrup	To adjust the sweetness in low quality honey	[12]
	Foreign diastase and amylases	To falsely indicate the freshness of honey	[13], [14]

Olive oil	Olive pomace oil, rapeseed, soybean oil, corn oil and sunflower oil	To increase the bulk	[15], [16]
Turmaric	Starch, chalk dust, wheat or rice flour dyed with colorants like tartrazine, metanil yellow,lead chromate	To increase the bulk	[17]
Coconut oil	Sunflower oil, soybean oil, corn oil, palm oil, fried coconut oil	To increase the bulk	[18], [19]
Virgin coconut oil	Lard, mustard oil, palm kernel oil, palm oil,paraffin oil, mustard oil, re-refined deep- frying palm oil	To increase the bulk	[20], [21]
Tea	Cashew nut husk	To increase the bulk	[22]
	Starch, caffeine, china clay, sand, chicory, leather flakes, french chalk, iron filings, talcum powder	To conceal the quality defect and falsely make the product more attractive	[23], [24]
	Azo dyes: tartrazine, sunset yellow, carmosine, indigo carmine, brilliant blue	To conceal the damage and inferior quality tea	[23]
Green tea	Sibutramine	To enhance weight loss illicitly.	[24]
	Glutinous rice flour	To Improve the flavour	[25]

Milk is reckoned as one of the foods most frequently subjected to fraud. It downgrades the overall nutritional quality of the milk and can cause numerous human diseases [9-10]. Vegetable protein, whey, milk from other species and water are reckoned as some of the common adulterants found in milk that do not pose serious health issues [9]. Meanwhile, adulterants like sodium bicarbonate, sodium hydroxide, detergents, ammonium sulfate, formalin, urea, melamine, boric acid, salicylic acid, hydrogen peroxide, and benzoic acid are reported to have a drastic negative impact on human health [9-11].

Honey is a sweetening agent that has good nutritional value and health promotion benefits. After olive oil and milk, honey has the highest likelihood of becoming adulterated in the commercial fraudulent process [12]. Adulteration of honey is reported to have different facets and is categorized as both direct and indirect. The addition of sugar syrups after production and the blending of high-priced honey with inferior quality honey are examples of direct adulteration, whereas overfeeding of bees during the main nectar period is an example of indirect adulteration [13-14, 26-27]. Ferreiro-González et al. [12] stated that the addition of inexpensive sweeteners to pure honey is the most commonly practiced adulteration method. Among the different types of sweeteners, high fructose corn syrup is used often due to its low cost as well as its compositional similarities to honey [12]. Honey proteins are reported as an important compound associated with honey properties [13]. The diastase/amylase activity serves as one of the quality parameters of honey that is indicative of the freshness and overheating of honey [14]. Therefore, their loss in activity is indicative of the inferior quality of the honey. In this matter, foreign amylases are being added to honey to mask the quality loss of honey [13].

Spices hold great economic value in both local and export markets. As their trading process goes through a complex supply network, they pose a high risk of vulnerability to adulteration. The increasing demand and high prices of spices appeared to have fueled the temptation to engage in fraudulent practices [17, 28-29]. Turmeric (Curcuma longa) is a famous spice that has been extensively used in traditional cuisine and medicinal applications. In an attempt to increase the bulk of turmeric, dyed materials such as rice flour, starch, wheat flour, and chalk dust, pre-extract rhizomes, low-quality spices, and cheap natural ingredients are commonly added to turmeric powder [17]. In this regard, metanil yellow, tatrazine, and lead chromate are reckoned as some of the most frequently used colorants [17]. Black pepper is reckoned as the "King of spices," which claims its demand for a great economic value among different spices. Cheaper bulking materials such as papaya seeds, non-functional pepper substances like defatted pepper materials, pepper husks, and pinheads are some of the common adulterants in pepper [29-30].

Tea is a globally famous beverage, being consumed abundantly around the world and coming in different types and grades. Some of the high-grown teas are expensive and commanding a high price in the market. Various adulterants, like plant-based materials and inorganic substances, are being added to tea in fraudulent practices. Among those, cashew nut husk is reported to be used more often as a plant-based tea adulterant [22]. Furthermore, starch, caffeine, china clay, sand, chicory, leather flakes, french chalk, iron filings, talcum powder,

are some other potential adulterants of tea [23–31]. Low-grade black tea is often dyed with artificial colorants like azo dyes to cloak its inferior quality or damage [23-32]. Green tea is scarce in production and reputed for its claimed health benefits. Illegal adulterations of tea with sugars and glutinous rice flour [25] and synthetic slimming substances like sibutramine may pose adverse impacts on human health, leading to strokes and heart attacks [24].

Olive oil is well known for its extensive sensory, nutritional, and health characteristics. It is a fundamental ingredient of the reputed Mediterranean dietary pattern [16]. Generally, olive oil comes in different grades as they fall under different quality categories based on their fatty acid composition, degree of acidity, peroxides, spectrophotometric index, and sensory attributes. Amongst, the alkyl esters of fatty acid composition of olive oil are reckoned as an important quality parameter where the quality of the oil would decline when their value is higher than the legislative recommendations [33]. Among the different grades of olive oil, extra virgin olive oil is reckoned as a premium product with a high tendency to be adulterated due to its high commercial value and supply shortage [34]. Adulteration of olive oil could take place in a number of ways where the most primary way of adulteration refers to the partial replacement of the oil with other low-priced commercial oils like low-grade olive oil, pomac oil, rapeseed, soybean, corn, and sunflower oils [15-16].

Coconut oil is frequently used in oil-based culinary practices both in the industry and households. Moreover, it might act as a functional food pertaining to its unique saturated nature that comes with small-to medium-chain fatty acids [18]. Owing to the body of knowledge-based evidence, the commercial value of virgin coconut oil is undergoing rapid growth and is becoming a valuable source of nutrition, similar to olive oil [20-35]. As there is a high demand in the market place for coconut oil, this triggers the profit-motive adulterations by the traders in the oil business. Some common adulterants of coconut oil are palm oil, other low-priced vegetable and seed oils, or fried recycled coconut oil [18-19]. In several Asian countries, coconut oil is reported to be adulterated with palm olein and sold as a "genuine" product [34]. Palm kernel oil, palm oil, paraffin oil, mustard oil, re-refined deep-frying palm oil, and low-cost animal fats can be reckoned as other common adulterants of virgin coconut oil [20-21]. These kinds of fraud and falsification could not only ruin the organoleptic properties of virgin coconut oil but also its health outcomes.

Food safety Policy Gaps in Agro-food Sector

Food authentication exercises would help in many ways to ensure food safety among the general public of a country. Food safety issues are multifarious based on the nature of different food systems. Outbreak of food-borne diseases is a particular concern as the economic costs associated with foodborne diseases can be severe on people, food companies, and a country's reputation. They can cause short-term symptoms, such as nausea, vomiting, and diarrhea (commonly referred to as food poisoning), but can also cause longer-term illnesses, such as cancer, kidney or liver failure, brain and neural disorders. These diseases may be more serious in children, pregnant women, elderly people, and those who have a weakened immune system. The causes are unhygienic practices in food production, harvesting, and preparation. A lack of accurate data on the full extent and cost of foodborne diseases has been a major obstacle to address food safety issues. In order to fill this data gap, research institutions and regulatory authorities could make necessary contributions through specific programs of action.

With the advancement of technology, various food additives are increasingly being used in processed food items wich demand long shelf life. Often times, additives are used as preservatives, colorants, flavour enhancers, stabilizers and taste and texture improvers, etc. Some of these additives might have negative consequences for the health of the consumers, being associated with possible carcinogenic effects [36]. Nevertheless, additives, which are toxic in nature, would not pose any hazard to human health if they are present below certain limits according to regulatory guidelines. Hence, updated national level policies and guidelines are required to implement the regulatory control over the use of these additives in commercial food production. Frequent amendments and revisions are required to be carried out for regulatory control guidelines with the advancement of scientific knowledge.

The perception of consumers regarding the intake of foods containing high levels of chemical additives has changed considerably over the last few decades. Owing to the adverse side effects of some of the chemical preservatives on consumers' health, food suppliers have demanded foods to be microbiologically safe with no chemical preservatives in them [36]. As a result, research on alternative antimicrobial strategies and systems should begin using knowledge of the physiological responses expressed by various microorganisms [37-38].

Process-induced toxicants are becoming big food safety issues in the food manufacturing sector. Acrylamide is one such example of a process-induced contaminant occurring in fried products like French fries. The toxic nature of acrylamide has been well established by now [39]. Frequent monitoring of food supply outlets in Sweden, the UK, and Denmark has led to the detection of acrylamide contaminated foods. As this kind of surveillance is hardly operational in Sri Lanka, the exposure of these contaminants is not known in detail. Food control authorities should therefore make this a national priority by allocating funds for the development of analytical methods for routine cross-check in

major cities.

Food irradiation is the treatment of foods by ionizing radiation in the form of beta, gamma or X-rays [40]. It has been increasingly becoming a means of reducing the microbial load in herbs, spices, potatoes, flour, packed pork and beef, etc. Although this technology provides many benefits to the food industry in terms of shelf-life extension, certain segments of society do not like to eat irradiated foods on the grounds of perceived health risks. Some improvements are therefore necessary to revise the food labelling practices in Sri Lanka for consumers to identify irritated foods easily. Regulatory agencies in Sri Lanka should also develop necessary legal policies to determine ways to identify and label irradiated foods using appropriate terminology.

Need for Comprehensive Food Data-bases

Establishing comprehensive food compositional databases is essential for various food commodities to facilitate their food authentication. This should be done by national level bodies responsible for upholding standards. This kind of initiative would not only help to curb fraud by unscrupulous practices happening in the local trade, but also facilitate the enhancement of the superior quality of local produces in the competitive marketing system. The Department of Agriculture, Sri Lanka recently compiled the proximate composition and mineral composition of various bean varieties locally grown in the country [41]. Likewise, the systematic data compilations for several other food commodities should be encouraged in the future by allocating funds for research, infrastructure facilities, and other resources. This can be further strengthened by efficient information sharing through networking among different government agencies.

Food compositional data bases play a significant role in food authentication and quality assurance. Hence, accuracy and reliability in food compositional databases are of prime importance. Accomplishment of this task should be done through accredited laboratories having validated methods of analysis. These databases should contain information about macronutrients and micronutrients. Macronutrients are required in larger quantities and include carbohydrates, lipids, and proteins. Micronutrients are those that required in smaller quantities and include vitamins and minerals.

In classical authentication, the proximate compositional data of food samples can be used as references for cross- checking the suspected sample to see if its values deviate significantly from the range found in the reference [42]. This approach has been successful in many cases as it is remarkably sensitive to adulterations. When using this method, detecting adulteration becomes more difficult if the composition of the adulterant and the authentic material become too similar. In such cases, alternative strategies proposed by various research groups need to be adopted by regulatory bodies [43]. In this regard, some examples from the oil and fat sectors could shed some light on the issues to get better clarification. Coconut and palm kernel oils are two examples of lauric oils with similar fatty acid profiles. Despite some differences due to the country of origin, the fatty acid compositions of olive oil and canola oil were similar [44]. Likewise, fatty acid profile similarities were noticed in cocoa butter and cocoa butter substitutes [44-45].

Thermal analysis by differential scanning calorimetry (DSC) has been a potentially useful technique in food authentication. In a pioneering effort, Dyzel and Baish [46] demonstrated the use of DSC in the identification of various edible vegetable oils. This study triggered the curiosity among the research community to investigate the use of DSC to establish the standard reference curves of several plant oils [44-45], and animal fats [47-48]. The DSC output, coming in the form of melting and cooling curves, could serve as fingerprint to identify different oils and fats. If any significant deviation is detected in the DSC curve of a particular oil or fat with respect to the standard reference curve, it can be taken as preliminary evidence of adulteration. Food control authorities in a country should encourage the use of this modern authentication technique for quality assurance of locally produced oils, dairy products, spices, and essences.

Nutritional Insecurity

Nutrition insecurity can be defined as the inability to access adequate quantities of nutritious foods required for optimal growth and development. It has been recognized that well-nourished people are healthier, better learners, and more productive in life. Although Sri Lanka performs well in most health indicators, child nutrition among those below 5-years is still a major challenge. Severe vitamin A deficiency is one of the major public health problems in rural Sri Lanka, causing increased susceptibility to infections and permanent damage to both eyesight and development. According to multiple reports, the most vulnerable groups are children younger than five years and women of reproductive age [49].

There has been a close link between nutritional insecurity and food adulteration. There are a host of fruits that are low in supply due to their existence in particular regions of the world. In such cases, adulteration of fruit products by some manufacturers and suppliers is inevitable, as they usually add cheaper substitutes to highly valued fruit products. This practice can affect the nutritional value, sensory attributes, and chemical composition of the authentic products, violating consumer’s rights and expectations. Therefore, monitoring of the

authenticity of food products, including fruit juices, represents a demanding and necessary task to be performed by regulatory agencies.

In general, there has also been a close link between nutritional insecurity and climate risk all around the world. Experts believe that climate change accompanied by extreme weather patterns is a concern for the productivity of all arable crops in Sri Lanka. The nutritional qualities of various foods may be at risk due to factors that affect plant nutrient uptake. This kind of climate risk would lead to nutritional insecurity across many developing countries in Asia and Africa.

Food authentication could lend a helping hand to assess nutritional losses caused by various food processing operations. Generally, the nutritional composition, bioactivities, and functional properties of raw food items are affected by the application of different food processing methods such as freezing, thawing, baking, drying, frying, etc. [50]. Remedial measures to retain essential nutritional attributes of foods may be taken if food authentication is carried out to cross-check the short fall in nutritional quality due to processing.

Conclusions

The rising prevalence of fraudulent practices in the food sector has become a critical concern in terms of food quality and safety. Exercises of profit-motivated and nutritional insecurity related food adulteration with cheap substances and hazardous materials would not only impact on the quality of food but also on consumer health. Thus, regulator bodies have made establishments to control food falsification by making guidelines for different food parameters. Therefore, food authentication is crucial and must be implemented throughout the production process of food and agricultural produces. However, the authentication process could vary based on the type of the adulterant and the commodity type, and interestingly, a number of analytical methods have been developed to accomplish this aspect. Meanwhile, the development of accurate and descriptive nutritional data bases on macro and micronutrients of different food commodities would greatly assist the food authentication process. Therefore, food authentication practices accompanied by generating nutritional databases are essential in order to ensure the overall food quality. However, further and fine-tuned authentication practices are warranted

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Conflicts of Interests

The authors declare that there is no conflict of interest.

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CHAPTER 07

FARMERS' PERSPECTIVE ON FOOD SAFETY AND QUALITY MANAGEMENT OF PEPPER IN SRI LANKA

Farmers' Perspective on Food Safety and Quality Management of Pepper in Sri Lanka

M.M.S.C. Senevirathne* and D.A.M. De Silva

Abstract Pepper is one of the most important export crops in Sri Lanka, which paves a path for foreign exchange earnings for the country. Safety and quality compliance of these traded food commodities have moved higher on the trade agendas, which are critically determined along the value chain. Despite the enormous potential for growth in the international market, the Sri Lankan pepper sector hinders the opportunities due to its low-quality standards and non-compliance. Pepper farmers play a vital role in determining issues of quality and safety compliance. Hence, this study attempts to analyze the perspective of the farmers on the quality and safety compliance of pepper. The chapter has developed on the analysis of data collected from the key pepper growing areas: Kandy, Matale, Kegalle, Rathnapura, and Badulla. Farmers are preventing the adoption of quality standards and compliance primarily due to a lack of coordination among value chain actors; poor literacy on food safety and quality; a lack of infrastructure facilities for post-harvest operations; and the absence of a proper pricing mechanism. It is evident that the crucial needs of implementing timely important policies with the upstream and downstream knowledge filling procedure, implementing an appropriate pricing mechanism for certified pepper, technological upgrades to the post-harvest activities, and timely revisions to the quality standards are appropriate policies to safeguard the pepper industry in Sri Lanka. Therefore, it is concluded that the potential of the pepper industry can be fully utilized through the appropriate strategies and national policies.

Keywords: Farmers, Pepper, Quality Standards, Safety Standards, Value Chain

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Introduction

Pepper (Piper nigrum) belongs to the family Piperaceae and is globally known as the king of spices, which is traded around the world, and it is one of the most popular cuisines in every household and food industry as a spice and flavoring agent. Pepper is also used in the perfume, pharmaceutical, and cosmetic industries. As evidenced in the historical records, pepper originated in South India and it is now cultivated throughout 42 countries [1]. The global demand for pepper is increasing rapidly, and currently, there is a dynamic market for pepper products [2]. The main pepper-producing and trading countries are Vietnam, followed by Indonesia, India, Brazil, Malaysia, and Sri Lanka. The countries listed account for 90% of total global pepper demand [3], and there is fierce competition among them to increase their market share.

Sri Lanka, the spice island, ranked in seventh place among the global suppliers with a 5.7% contribution to the world's pepper demand and fifth place in terms of area under pepper cultivation [4]. Sri Lankan pepper has very special and unique characteristics with an excellent aroma and a high content of volatile oil, oleoresins, and piperine. Therefore, Sri Lanka has immense potential and a comparative advantage in becoming the key player in the pepper industry. According to [5], India is the main destination for Sri Lankan pepper, accounting for 79.97% of total pepper exports from Sri Lanka, followed by Germany (9.50%), the United States (2.54%), Spain (1.06%), the United Arab Emirates (0.85%), and the United Kingdom (0.83%). It is noted that the majority of the Sri Lankan black pepper export destinations are low-end markets, and to a lesser extent, they are exported to high-end markets. Sri Lankan pepper needs to be exported to the high-end markets as the current supply of Sri Lankan pepper to these high-end markets is not substantial. Table 1 shows the pepper production values in Sri Lanka from the year 2014 to the year 2019.

Pepper is cultivated in Low and Mid country Wet and Intermediate agro-climatic zones in Sri Lanka up to an elevation of about 800 m above mean sea level. Pepper cultivation is spread across ten districts in the Central, North Western, Western, Sabaragamuwa, Southern, and Uva provinces, including Kandy and Matale in the Central province; Kurunegala in the North-Western province; Badulla and Monaragala in the Uva province; Kegalle and Rathnapura in the Sabaragamuwa province; Galle, Matara, and a portion of Hambantota in the Southern province [6]. The estimated extent of pepper in Sri Lanka in 2017 by district is shown in Figure 1.

Table 1: Pepper production in Sri Lanka

Year	Cultivated area (Hectares)	Production (Mt)	Export Volume (Mt)	Export Value (Rs. Mn)	Export Price (F.O.B), Rs. per kg.[b]
2014	32,291	18,660	1,162	9,447	1,130.87
2015	32,527	28,177	880	20,215	1,187.25
2016	39,515	18,476	897	11,147	1,329.69
2017	39,284	29,546	918	13,462	977.04
2018	40,244	22,551	817	12,620	927.86
2019 [a]	41,030	22,156	805	9,031	1,083.46

Source: Central Bank Economic and Social Statistics Report (2020)

(a) Provisional
(b) From 2007 onwards categories are reclassified based on National Import Tariff Guide – 2010

Sri Lankan pepper has very special and unique characteristics with an excellent aroma and a high content of volatile oil, oleoresins, and piperine. Therefore, Sri Lanka has immense potential and a comparative advantage in becoming the key player in the pepper industry. However, currently, safety and quality compliance are gaining increasing importance for entering the international markets and can even result in a price premium. The USA and the EU are the most attractive destinations for spices, which are known as high-end markets (Ministry of Development Strategies and International Trade). The stringent quality standards, which are required by the high-end international markets such as the EU and USA, act as a roadblock for the Sri Lankan pepper industry to be fully exploited. Day by day, the safety and quality requirements are becoming more stringent, and consumers' awareness and concerns about high-quality products are also increasing tremendously. Further, it is a well-known fact that food safety and quality standards are given low attention in low-income countries, resulting in a wider range of food safety risks. Unfortunately, as a developing country, Sri Lanka also faces some limitations in maintaining the quality of the production for local consumption as well as meeting the international quality standards for pepper-like spices. Therefore, the comparative advantage in Sri Lankan spices is no longer sufficient to maintain competitiveness in the international market.

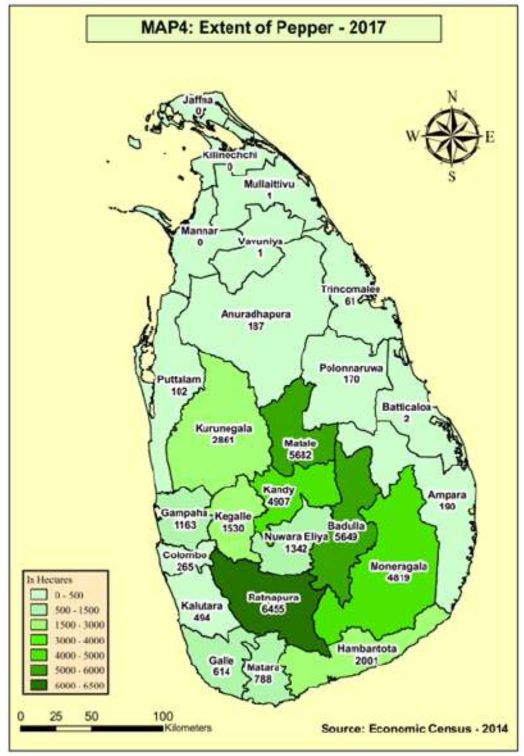

Figure 1. The estimated extent of pepper by District in 2017. Source: EAC Stat Book, 2018

The quality standards are determined and should be adhered to along the value chain. Typically, the Sri Lankan spice value chain is relatively long and complex compared to the value chains of other crops. Meanwhile, comparatively to the other crops, the spice value chain is relatively weak and many problems are yet to be solved [7]. Smallholder farmers dominate the Sri Lankan spice industry, farming over 70% of the country's cultivated land in plots ranging in size from 1/4 to 3 acres [8]. Therefore, farmers play an important role as the starting point of the value chain in maintaining the safety and quality requirements of pepper. Thus, identifying the perspective of safety and quality management in Sri Lankan pepper farmers is a pivot in enhancing quality compliance to meet world standards.

This study takes a closer look mainly at the perspective of the pepper farmers on the quality and safety management of the pepper. Moreover, the study intends to explore the prevailing issues along the value chain related to the quality standards and propose policies that have to be implemented to sustain the pepper industry in Sri Lanka.

The study has been carried out in key pepper growing areas: Kandy, Matale, Kegalle, Rathnapura, and Badulla, and reviewed the previous literature based on industry reports and academic papers. Mixed methods were adapted to collect qualitative and quantitative data, and the primary data was collected through an interviewer-administered structured questionnaire, in-depth interviews with key value chain actors, focus group discussions with the farmers and traders of key pepper growing areas, and the engagement of key stakeholders in a stakeholder meeting.

Moreover, the study [9] is based on the data collected from the farmers based on kandy and matale, and used a questionnaire survey, focus group discussions, and key informant interviews to collect the primary data. This study may be the first to analyze the safety compliance specifically for the pepper farmers in Sri Lanka, where more attention is needed to focus on this area.

Standards and Certifications Apply to Pepper Production, Processing, and Marketing

Sri Lanka Standards for Black Pepper (SLS 105 Part 1: 2008) and White Pepper (SLS 105 Part 2: 2008) are currently in place for pepper and neither of these product standards are currently required for export. The international marketplace, especially in the EU and other high-end destinations, requires companies to comply with good agricultural practices (GAP), system certification, good manufacturing practices (GMP), HACCP (Hazard Analysis and Critical Control Points), and ISO 22000 as the most important requirements. Further, the GAP and GMP schemes for pepper have not been developed yet, and currently, there is no government-mandated quality control mechanism for the export of pepper. According to the results of the study [9], ISO22000 is going to be important to enter the developed markets, but it is not a requirement at the moment given that much of the exports go to India, where Sri Lankan pepper has a market. Moreover, the exporters rely on the specifications set forth by importers, and they frequently request those quality-certifying authorities to certify the pepper. Before export, pepper purchased from growers and/or dealers is dried, cleaned, and graded to ensure quality meets importer specifications. Exporters collaborate closely with their overseas buyers, with whom they have developed a long-term partnership based on mutual understanding.

Organic is another emerging segment and various private agencies and groups, such as SLSI (Sri Lanka Standard Institute), SEPTA (Spice Council and Spices and Allied Product Producers and Traders Association), and the Spice Council, facilitate providing information on standards. However, according to the results of our study, organic and fair trade certifications have been obtained by approximately 10% of the exporters.

The Safety and Quality Requirements of the Local Market

Currently, there are two standards for pepper in Sri Lanka; black pepper (SLS 105 Part 1: 2008) and white pepper (SLS 105 Part 2: 2008). Quality standards approved by the Sri Lanka Standard Institute for pepper are given in the following Table 2.

Table 2: Quality standards approved by the Sri Lanka Standard Institute

	Sp. Grade I	Grade I	FAQ
Moldy berries %	1	1	2
Other extraneous matter % (insects live or dead, stones, sand, plant parts, mammalian fecal matter, etc.)	1	1	2
Light berries %	Max. 4	Max. 4	Max. 10
Moisture %	12	14	14
Appearance	The dark black color with surface grooves	Dark black to brownish-black color with surface grooves	

Source: Department of Export Agriculture (http://www.dea.gov.lk/pepper/)

Safety and Quality Requirements of the International Market

India is the main destination for Sri Lankan pepper, accounting for 79.97% of total pepper exports from Sri Lanka, followed by Germany (9.50%), the United States (2.54%), Spain (1.06%), the United Arab Emirates (0.85%), and the United Kingdom (0.83%) [5]. It is noted that the majority of the Sri Lankan black pepper export destinations are low-end markets and, to a lesser degree, high-end markets. The USA and the EU are the high-end markets where Sri Lankan pepper should be fully exploited, and the current Sri Lankan pepper supply to these high-end markets is not substantial, which should be more penetrated. However, the stringent quality standards, which are required by the high-end international markets such as the EU and USA, act as a barrier for the Sri Lankan pepper industry to be fully exploited. Several food safety organizations, including the US Food and Drug Administration, have established strict guidelines for the safety of spices intended for human consumption. Though Sri Lanka is currently exporting pepper to the top potential countries, the concern is that Sri Lanka is catering to only 0.6% of the total imports by the USA and

2.6% of the total imports of pepper by Germany [6]. The total pepper need in Europe also has to be fulfilled by importing since the pepper is not growing in Europe. The demand for pepper is also increasing rapidly among European consumers. Unfortunately, the Sri Lankan contribution to the EU (excluding the UK) is only 0.27%, with a negative average growth rate of-15.63% [5]. The EU is maintaining the strongest food quality and safety requirements supported by solid legislation with an increasing interest in the traceability of food and quality requirements. The Rapid Alert System for Food and Feed (RASFF) acts as a key support system in detecting the risks in traded food commodities. Compliance with European legal requirements is required for border crossing, and in general, only a small number of developing-country pepper suppliers meet the requirements. Safety and quality compliance are pivotal to entering the EU market and can even result in a price premium. There are some quality parameters such as bulk density, pungency, piperine content, moisture content, dust, and extraneous matter. Mandatory requirements can be listed as follows;

- Food safety: traceability, hygiene, and control as specified in the General Food Law
- Mycotoxins contamination: for pepper, maximum levels of mycotoxins are set for aflatoxin (between 5.0 µg/kg for aflatoxin B1 and 10 µg/kg for the total aflatoxin content of B1, B2, G1, and G2). For ochratoxin, the maximum level is 15 µg/kg;
- Maximum residue levels of pesticides: especially in Vietnam;
- Microbiological contamination: the presence of salmonella
- Food additives and adulteration: containing undeclared, unauthorized, or excessive levels of extraneous materials;
- Maximum levels of polycyclic aromatic hydrocarbons: contamination with PAHs stems from bad drying practices;
- Irradiation: this process is legal, but it is rarely used by consumers.
- Food safety certification: British Retail Consortium (BRC), International Featured Standards (IFS Food), Food Safety System Certification (FSSC 22000), and the Safe Quality Food Program (SQF).
- Corporate Social Responsibility (CSR includes the Supplier Ethical Data Exchange (SEDEX), Ethical Trading Initiative (ETI), or the Business Social Compliance Initiative code of conduct (BSCI).
- Pepper quality requirements are;
  Comply with the Quality Minima Document from the European Spice Association (ESA). The Quality Minima Document is the leading document for the national spice associations in Europe and most key players in the market. It specifies the legal European requirements for unprocessed pepper.

Additional niche market requirements of the EU are;

- Sustainable product certification: Organic, Fairtrade, and Rainforest Alliance;
- Self-verification: Unilever's Sustainable Agricultural Code (SAC) or the Olam Livelihood Charter

(Source: www.trade.etc.europa.eu)

However, these requirements are arbitrary for the final buyers/markets. India is the major buyer of Sri Lankan pepper, followed by Pakistan, which is not very quality-conscious and none of the markets required safety and quality certificates.

Compliance with the Safety and Quality of Pepper

The pepper value chain encompasses the range of products such as green, black, and white pepper and their value-added forms such as extracts, oils, pepper oleoresin, powder, gift packs, and consumer retail packs. The main two value chains of the pepper, like other spices, are organized or formal value chains and informal, traditional, or less organized value chains. A majority (76%) of the pepper producers were small and medium-scale operators, and they were connected with informal value chains. Informal value chains are characterized by shorter, less complex, and more limited support services. On the other hand, the formal or organized value chains were lengthier, complex, and linked with a large number of supportive services. Value chain supporters and enablers were facilitating the pepper flow from farm to table. Safety, quality standards, certification, as well as promotion and innovative practices, have all been used to strengthen formal value chains. However, quality issues in pepper affect the entire industry, from the farmer to the exporter.

Farmers

Pepper is a smallholder crop, which means it can be grown in backyards and home gardens with minimal input. Pepper grown in rural home gardens and as a backyard crop ensures farm families' income security. Results of our study also imply that the majority of producers in the pepper value chain are comprised of small and medium-scale farmers and a few large-scale plantations. The sample that was drawn for the study comprised 42% of < 2-acre category and 34% of the 3-5 acre category. Pepper plantations of 6-10 Ac, 10-20 Ac, and >20 Ac included 24%. The results of the Census of Agriculture (2002) (cited in [9]) also confirmed that the majority of the pepper farmers (93.3%) hold small-scale lands of less than 8.1 hectares.

The majority of smallholders and home gardens were found to rarely use inorganic fertilizer, whereas large-scale plantations used it on a regular basis. Green manure was the main source of nutrient supply and crop care. In contrast, large-scale pepper plantations applied both inorganic and organic fertilizers to their pepper cultivations. Packaging and packing material supplies were limited, and usually farmers and collectors used re-cycled polyethylene bags (poultry feed bags, fertilizer bags, etc.).

Other than cultivating pepper and harvesting, post-harvest activities such as drying and cleaning are also carried out by the farmers. However, the pepper producers in the rural areas, the small-scale farmers, still practice traditional methods for harvesting and threshing, i.e. manual and sun drying. Until recent times, the producers, as a practice, stored their harvest after drying in their households. This stored produce serves as their income for day-to-day living. However, the changing market status with price competition between light berries and blackberries made the farmer's families' lives difficult. Accordingly, the traditional way of storing is abandoned, and households turn to strategies like selling their products as green berries or leasing the entire crop at a mature stage. Concerning the drying, most of the small-scale drying equipment was developed by the farmers themselves, using the locally available raw materials and firewood as an energy source. In contrast, large-scale pepper producers tend to use electric threshing and drying equipment. Results of the study [6] also confirmed that the farmers tend to collect the berries and dry them in their backyards or on cement slabs, and then take them to the dealers, where the farmers get paid based on the quality of the peppers. The farmers in this case get a higher price for their products since they can add value to them by employing drying.

Figure 2: Pepper Farmer

Figure 3: Manual Sieve

Figure 4: Drying Yard

Organic Pepper Farmers

The organic pepper export market showed a positive increasing trend where the main organic pepper importers were India and China, and the flow diverted into Australia. Bio-Foods Co. ltd., and PODI (People's Organization for Development Initiative), like private sector initiatives, manage organic farmer clusters in main pepper growing areas where farmers receive secure demand for their harvest and good income, whilst exporters receive regular pepper supplies with hazard-free guaranteed quality. Compared to conventional methods of supply chain management, organic farming is closely knitted to the farmer community by way of organized societies and continuous contact with a pricing mechanism for graded products. Furthermore, the system constantly directs the producer to increase production. The organic pepper initiatives of the DEA are also working closely with the farmers in key pepper growing areas in Kandy, Matale, and Badulla districts.

Factors Affecting the Safety and Quality Compliance of Pepper

Typically, the Sri Lankan spice value chain is relatively long and complex compared to the value chains of other crops. Meanwhile, comparatively to the other crops, the spice value chain is relatively weak and many problems are yet to be solved [7].

SMEs with informal chains were rarely connected to the end-consumer or export markets. Therefore, one of the prominent issues in the pepper value chain is, there is less coordination between the exporters and the farmers as the exporters prefer to purchase pepper from the collectors as they could purchase large quantities from collectors other than the farmers. Therefore, the exporters have little or no direct involvement in cultivation. On the other hand, farmers also tend to sell their products to collectors or traders, as the farmers receive in-kind or cash advances from them.

Aside from coordination flaws, the lack of awareness of the farmers and the other intermediates on the quality standards is another main concern. Unfortunately, there is no motivation to bridge the information/knowledge gap between the upstream and the downstream of the pepper value chain. However, there was a concern about the role of extension officers in providing the intended services to the upstream actors. The main focus of extension officers is to promote and expand production by increasing the extent of cultivation and increasing the productivity per unit of land area. However, it is clear that efforts to promote food safety and quality-based best practices (GAP, GMP, HACCP) along the value chain are hampered by a lack of technical know-how and skills, as well as a lack of knowledge of the most recent developments in the global/local pepper value chain. This could be attributed to the poor food safety and quality consciousness of the largest export market, India. This result is supported by the results of the [9]. The results [6] also confirmed that the farmers were unaware of the international requirements of the buyers. Hence, the intermediaries do not demand products from rural areas that comply with standards, best practices, and certifications.

According to the results, none of the farmers was familiar with the pepper standards or the pepper production process's requirements. Though DEA has developed and published the pepper grades (GR 1, GR 2, GR 3, G 4, and pinheads), only a few farmers abide by the guidelines and grade their harvest before selling it. The common practice was to bulk supply and receive a general price. The results of the study emphasize that culture and ethics play a crucial role in producing clean, hygienic, and quality products free from foreign matters. Farmers strongly believe that producing food ingredients needs special care and attention at every step. Unfortunately, the traditions change with the generations and profit-oriented motives deny the ethics of farming.

Moreover, considering the farmer's commitment levels to safety, quality standards, and certification, it is noted that farmers were positively committed to GMP and organic certifications while others, like HACCP, Vidatha certificate, and fair trade, were not given much consideration. However, from the study by ADB (2017), it is evident that the pepper industry in Sri Lanka is characterized by a lack of GAP, GMP, and other standards and quality criteria in production and processing

It is noted that only 10% of pepper farms are currently certified as organic (EU organic/USDA organic/Control Union). The study [9] also confirmed that

the few exporters have also obtained organic and fair-trade certifications. Notwithstanding, organic pepper initiatives of the DEA are working closely with the farmers in key pepper-growing areas in Kandy, Matale, and Badulla districts. The organic pepper movement is organized by several successful farmer societies and, currently, they are working towards certifying the farmlands. However, a limited number of farmer societies or groups received training on safety and quality standards and certification, organic pepper production, processing techniques, incentive schemes, etc.

The pepper's peak harvesting season is from November to January, when 70% of the total harvest can be collected [6]. It is identified that the farmers are most likely to harvest the pepper at a premature stage (when pepper is harvested at a premature stage, it is known as "light barriers") due to the fear of crop theft. The fear of theft was identified as one of the most important social issues among the pepper farmers as well as the village-level collectors. The results of [6], [9] also supported the fact that the farmers are most likely to harvest the pepper at a premature stage due to the fear of crop theft and the need for speedy cash. Other reasons for pre-mature harvesting include the anticipation of a better subsequent crop; following neighbors' behavior; the location of cultivation being far away from the residence; easy disposal; overestimation of the crop by leasees, and anticipation of drought/diseases [9].

According to the results of the study, the lack of infrastructure facilities for post-harvest operations (harvesting, threshing, blanching, drying, storage, and transport) has adversely affected the quality of pepper supplied by SMEs. A majority of the smallholders were not capable of investing in or maintaining their threshing and drying facilities/equipment due to inadequate knowledge of best practices, limited access to machinery, and, more importantly, financial constraints. A rental arrangement for threshing equipment was observed in the field. Therefore, the pepper producers in the rural areas still practice traditional methods for harvesting and threshing, such as manual and sun-drying. Producers used to store their harvest after it had dried in their homes until recently. This stored product is their source of income for day-to-day expenses. However, the farmer families' livelihoods were made tough by the changing market status and price competition between light and blackberries. As a result, traditional storage methods have been abandoned, and households have resorted to options such as selling their product as green berries or leasing the entire crop at maturity.

Further, the pepper value chain did not benefit from certified products and rarely did intermediaries pay premium prices for certified and quality products. The common view and the tragedy is that whether the product is certified or not, the same price remains. Very few farmers received higher margins compared to others who were covered under organic/or other certifications. There was no proper mechanism to determine the price of the product, and it was a decision forced on farmers by the trader network. Farmers cannot make any decisions on pricing as they are always price takers because they are small in number and often take an individualistic approach. If they clustered together, they could meet their demand, but it has yet to happen. Low-profit margins and non-attractive prices act as demotivating factors for farmers to move away from obtaining certified products..

Currently, there is no government-mandated quality control mechanism for exports. Moreover, according to the results of the study by the Institute of Policy Studies in Sri Lanka and the Department of National Planning (2017), exporters' view is that ISO22000 is going to be important to enter the developed markets, but it is not a requirement at the moment given that much of the exports go to India, where Sri Lankan pepper has a market. The delays in the Sri Lankan Standards Institution's review process negatively affect the quality of supplies as well as the trade performance of the industry. Further, the testing capabilities of local laboratories are also inadequate to meet the emerging stringent requirements of international markets [9]. Further, there are no agreements between exporters and their suppliers, but there is an agreement signed by the supplier to comply with the standard requirements in the case of exporters who have received certifications such as ISO22000 or organic [9].

Pests and diseases are other barriers to maintaining the quality standards of pepper in Sri Lanka. Quick wilt, slow wilt, pepper yellow mosaic virus, and pepper blight are the common diseases of pepper found in Sri Lanka [4]. In the meantime, pepper has also been reported as a spice frequently contaminated with mycotoxins, aflatoxins, and ochratoxins [10].

The processors/traders have sound knowledge of detecting good and poor-quality pepper at the farm gate. Unfortunately, their knowledge, exposure, and experience in safety, quality standards, and certification were very poor. The quality parameters emphasized by the collectors include appearance, maturity, bulk density, low moisture content, and the number of extraneous materials (soil, dust, stones, stalks, etc.). Adverse climatic conditions make the trading operations irregular, and the farmers affected by low price offers are forced to sell immature/green berries due to the non-availability of machinery/equipment for processing, drying, and storing.

The Role of Institutions in Quality and Safety Management

The Department of Export Agriculture (DEA) is the apex national body responsible for the development and promotion of pepper and all spices and

related products in Sri Lanka. They are mandated by an act of parliament in Sri Lanka with an established network to link all stakeholders in the spice product VC. The extension officers of DEA were entrusted to play a vital role in building the capacity of the upstream value chain actors. However, there is a doubt about whether the extension service is superior to disseminating the knowledge to the VC actors.

The Sri Lanka Standard Institute (SLSI) is playing an integral role in formulating national standards under the Food Act and disseminating information on standards, technical regulations, and standards-related activities to the community at the national level. The laboratory facilities are also provided by the SLSI. The Spice Council is another apex body that works on enhancing the competitiveness of the spice industry with the collaboration of the stakeholders. Further, it acts as a forum for the producers, exporters, processors, dealers, and others involved in spices and allied products to promote high standards of business. SGS is a global company that undertakes inspection, verification, testing, and certification of products. The Industrial Technology Institute is also providing testing facilities as a government body. Moreover, Sri Lankan universities are also working towards enhancing food and safety compliance by producing expertise in the food industry and conducting research related to food safety and quality. It is also identified that the institutional mechanisms are operated in isolation and scattered with overlapping of functions and mandates.

Recommendations

To improve the quality standards of pepper, collective measures should be taken by all the stakeholders and the government. To meet the requirements of the quality standards, the study identified the need to improve the existing knowledge of the farmers on quality standards. Therefore, the efficiency of the extension service should be further improved, and it should be more focused on giving knowledge to the farmers on proper agricultural practices that should be followed by them (harvest at the right time, follow correct harvesting methods, threshing, drying, and storage recommended by DEA). Moreover, effective farmer training/educational programs should be more focused on changing their attitudes towards adopting good agricultural practices. These knowledge transfer, skills, and attitude change programs can be coupled with an incentive scheme, which is essential to enhance the compliance/adoption of food safety best practices and quality standards applicable to international trade. It is a severe tragedy that young people are not attracted to farming activities because of their perceived low social status. To overcome this challenge, the training/education programs have to be properly designed to attract them to farming activities with the proper attitudes towards quality and safety compliance.

Moreover, strong market linkages should be facilitated locally and internationally. Meanwhile, exporters should be encouraged to backward integrate for direct purchases from farmers in order to maintain consistent quality across the value chain. An upstream and downstream knowledge filling procedure with transparency of the pepper value chain should be helped to disseminate the end buyers' requirements to every value chain actor. An ICT-based traceability system can be developed to strengthen the safety and quality compliance to harmonize the activities along the value chain..

The theft issue is identified as another major challenge confronted by the farmers, resulting in pre-mature harvesting. Therefore, it is urgently required to study the current status of legal enforcement and effectiveness to identify the gaps and challenges to maintaining farming lands and safeguarding crops.

More technological upgrades should be introduced to the farmers and intermediates to do the post-harvest activities on the pepper. A huge opportunity is available in the pepper growing area of manufacturing machinery and tools, which are currently considered an expensive investment by the pepper farmers. The researchers have to be especially encouraged to develop economically appropriate threshers, separators, and dryers. Soft loan schemes can be introduced for product innovation and development in line with HACCP/GMP/GAP as a motive for farmers to adopt safety and quality compliance.

Moreover, because there are a large number of SMEs in the pepper value chain, it is more appropriate to build up central collecting/processing/storage centers in the industry through shared service facilities in rural producing areas. Establishing producer clusters in the main pepper growing areas (Matale, Kandy, Rathnapura, and Badulla districts) and establishing the pepper farmer societies will facilitate the process.

Most importantly, the government of Sri Lanka should take immediate action to implement a quality-based pricing mechanism for giving a premium price to the farmers based on the quality standards. Further, quality price incentives could also be introduced to the industry, which will act as an incentive for the farmers to maintain quality compliance. A harvesting calendar for the competitors can be developed and arrangements be made to release the stocks during the offseason of competitors as a strategy to obtain high prices for the farmers.

According to the study findings, GAP and GMP schemes for pepper have not been developed yet, and it is important to pay special attention to develop

these timely schemes. Further, Sri Lanka Standards for Black Pepper (SLS 105 Part 1: 2008) and White Pepper (SLS 105 Part 2: 2008) need immediate revision. In general, standards need to be revised every 5 years, and since prolonged delays in the Sri Lankan Standards Institution's review process negatively affect the quality of supplies as well as the trade performance of the industry, such delays should be avoided.

Summary

This study was aimed at analyzing the farmers' perspective on food safety and quality management of pepper in Sri Lanka. It is identified that though the Sri Lankan pepper has unique characteristics with high potential to become the market leader, the pepper industry in Sri Lanka faces several threats and issues related to quality and safety compliance. The main causes of quality deterioration in the pepper value chain are a lack of coordination, a lack of farmer awareness of quality standards, a lack of infrastructure facilities for post-harvest operations, malpractices such as premature harvesting, profit motives, pest and disease, and the absence of a proper pricing mechanism for quality products. Therefore, the study suggests some precautions to be taken in order to maintain the quality requirements of pepper. Accordingly, the study suggests implementing knowledge sharing and training programs on the safety and quality of pepper production through superior extension service, along with the upstream and downstream knowledge filling procedures of the pepper value chain. Moreover, more technological upgrades should be introduced to the farmers to do the post-harvest activities on the pepper. The study suggests the legal enforcement and effectiveness of identifying the gaps and challenges to maintaining farming lands and safeguarding the crops. It also suggests the need to revise the quality standards every 5 years and prolong them.

Conflict of Interest

Authors have declared that no competing interests exist.

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CHAPTER 08

SMART CROP PROTECTION IN ORGANIC AGRICULTURE AND POLICY RECOMMENDATIONS FOR THE SRI LANKAN CONTEXT

SMART Crop Protection in Organic Agriculture and Policy Recommendations for the Sri Lankan Context

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Abstract Sri Lanka's agriculture has a 2500-year-old history. Agriculture is the backbone of the country's Gross Domestic Product (GDP). To meet the rapidly growing population, healthy fruit and vegetable production needs to be increased by several folds. The scope of the present government is to transform the entire farming of Sri Lanka towards organic due to the suspicion that the overuse of synthetic agrochemicals has caused a deleterious impact on human and environmental health. Furthermore, recent agricultural policy directives discourage the use of imported agro inputs in the national agricultural production system and promote organic agriculture, which relies on ecological processes, biodiversity, and cycles adapted to local conditions rather than the use of inputs with negative effects to sustain the health of soils, ecosystems, and people. Anyhow, pest and disease attacks are probably high in organic agriculture; therefore, attaining the expected yield through organic agriculture cannot be met until we bridge the tradition with technology in crop protection. A smooth technology-based transition of crop protection techniques prescribed for organic agriculture through publically acceptable policy changes to strengthen food security is timely. This chapter focuses on new technological approaches such as rapid development of resistant varieties through molecular breeding and biotechnological approaches, RNAi technology for induced disease resistance, genetic improvement of biological control agents, mass production of technology-assisted immune boosters; nano-formulation of pesticides; and how to utilize the modern ICT and Nano-based pest and disease surveillance and exclusion systems to control pest and disease in organic agriculture, as well as applicable policy changes needed to keep up with the existing bottleneck in pest and disease management in organic agriculture. Therefore, the information presented in the chapter would be a guide for young scientists and policymakers to take the organic agriculture of the country a step forward.

Keywords: Crop protection, Genome editing, Green technology, Organic agriculture, Resistant breeding

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An Introduction to Organic Agriculture in Sri Lanka

Agriculture plays an important role in providing livelihood to nearly 38% of the employees in the agriculture sector, who are mainly farm labourers, increasing the level of national income and export revenue, generating new employment opportunities, and indirectly enhancing the nutrition and health of the nation. In Sri Lanka, agriculture's contribution to GDP steadily declined from 33.53 % in 1960 to 8.36 % in 2020. As a result, there is a need to increase healthy fruit and vegetable production by several folds in order to meet the food needs of the growing national population, increase per capita income, and expand the country's exports and tourism industry. Since 1960, the green revolution has boosted crop production several-fold. Therefore, today's agriculture has produced enough food for the global population, but it has not given access to everyone everywhere to sufficient, safe, and nutritious food. Moreover, the present Sri Lankan government's amendments to agricultural policy change intend to scale-up organic approaches which can contribute to ensuring sustainable and resilient agricultural and food systems today and into the future: assuring food security, environmental sustenance, resilience to climate change, women's empowerment, and increased peasants' control over agri-food systems. In Asia, the tremendous contribution of small-scale agriculture and agroecological-based production systems to food security has been realized in the midst of scenarios of climate change and economic and energy crises in the last decade. But the question for economists is whether organic farming will be able to feed the entire world population, which is expected to reach 9.7 billion by 2050 [1, 2]. Therefore, we are at a critical point to decide and adopt the most efficient cutting-edge green technologies to boost food production organically. Nationwide technological adaptation and policy transformation are really an urgent task to uplift organic agriculture to the next level.

In agriculture, biotic stresses are major obstacles, with pests and diseases causing 20–40% of crop production to be lost from the field to consumption [2]. This loss is proportionately greater when modern high-yielding germplasms are grown organically. Therefore, it is the prime task of Green Revolution 2.0 to mitigate crop loss from pest diseases. Plant scientists work tirelessly to improve existing crops and develop new varieties that are pest and disease resistant as well as climate-smart for sustainable agriculture [3]. The proposed book chapter addresses how smart technological approaches need to be followed to cope with the pest and disease problem, and applicable national agricultural policy changes need to be adopted to modernize the organic agriculture of the country to get out of the dilemma.

Sri Lankan Agriculture has 2500 years of its own history. Our ancestors, followed sustainable and organic agricultural practices to exemplify the

interconnectedness of nature and human life. Lesson learned from the experiences of conservative tactics in controlling pests and diseases, inherited from generation to generation was helped to protect the crops from biotic stresses without harming the environment. Conventional approaches like tillage operations using a variety of tools, biodynamic farming, crop diversification, conservation and augmentation of natural control factors, on-time harvesting, variety of designed wooden storage devices, regular monitoring of pest in their fields, cultivation of repellent plants, application of inert materials, application of medicinal, underutilized plant extracts, cow urine, *panchgavya*, and fermented microbial products, scaring tools to keep away the pest. application of organic amendments and green manures were mainly concentrated and intensively applied to manage the soil borne pathogens and plant nematodes. or prevent the crops from soil-borne plant pathogens in an intelligent manner [4-9]. These all approaches were technique-based, and the principles behind every tactic were scientifically well understood and explained through various research scientists' efforts. All these all tactics were very successful because of the following reasons [10].

1. Crops were cultivated organically.
2. The crop varieties used were naturally selected germplasm carrying diverse resistant genes.
3. Less selection pressure on the pest or pathogen due to the use of diversified tools in crop protection.
4. Favorable environment for natural control factors to work effectively to do their role in the crop production system.
5. Fertile soil with highly disease suppressive secondary metabolites of beneficial microbes to control soil-borne pathogen growth and proliferation.

Traditional approaches were not technologically oriented, so food production was insufficient to feed the rapidly growing population. The world population was on the brink of mass famine in the early 1950s. When technology advances, the green revolution opened a new era in agriculture. From 1960 onwards, a tremendous transformation in traditional agriculture, especially in rice cultivation, started in Sri Lanka with the invention of dwarf, short age, and high yielding varieties through the green revolution. Green revolution principles were used to increase food production by orders of magnitude. Therefore, the above-explained strengths were not sufficient to prevent the economic losses. Introduced high-yielding varieties were highly fertilizer responsive and improved primarily in yield, productivity, height (short or dwarf), and age (short term varieties), with a narrow gene pool as a result of selection. Moreover, mono-intensive agriculture was mainly focused on. Therefore, the system becomes favorable for pests and diseases. Farmers did not have any choice other than to use synthetic pesticides and other inorganic inputs. Overexploitation of green revolution technologies has led to soil degradation, depletion of natural resources, and enormous environmental costs. The lesson learned from the negative impact of over-application of synthetic chemicals and fertilizers over the last century, as well as forceful and appealing canvassing on the importance of eco-friendly farming by nature lovers, is gradually changing the mindset of rural peasants toward organic farming [1].

Why Technological Approaches are Needed

For the following reasons, managing the pests and diseases in commercial organic cultivation is becoming more difficult now than ever using traditional approaches.

1. Rapid transition to organic agriculture in the absence of a sufficient supply of high-quality organic inputs and the adoption of green technologies.
2. The aggressive nature of pests and pathogens does not respond rapidly and effectively (anti-feeding and repellent) to phyto-chemicals compared to synthetic pesticides.
3. Natural resistance and virulence are natural in pests and pathogens' responses to phytochemicals due to the adaptation and selection pressure induced frequent mutation that happens in inorganic agriculture.
4. Natural enemies' (predators, parasitoids, and entomo-pathogens) population has declined tremendously or in endangered state. Few kinds of natural enemies have been wiped-out (extinct) from the ecosystem. Some natural enemies have even lost their biocontrol behavior, and likewise, antagonistic microorganisms may sometimes express their pathogenic strain behaviors [11, 12]. These behavioral changes are major catastrophes in organic crop production [13].

Therefore, the identification and implementation of publically affordable, cost-effective, and sustainable modern technologies are needed to transform the traditional organic agricultural system of the country towards organic smart agriculture (OSA).

Current Trends of Pest management in Organic Agricuture

The rapid discovery and evolution of modern approaches such as next-generation sequencing, bioinformatics, genome editing, information and communication systems (ICTs), and Artificial Intelligence (AI) has ushered in a new era for comprehensive understanding of host and pest/pathogen genomics and phenomics in order to develop innovative pest and disease surveillance, forecasting, and management options in OSA (Figure 1).

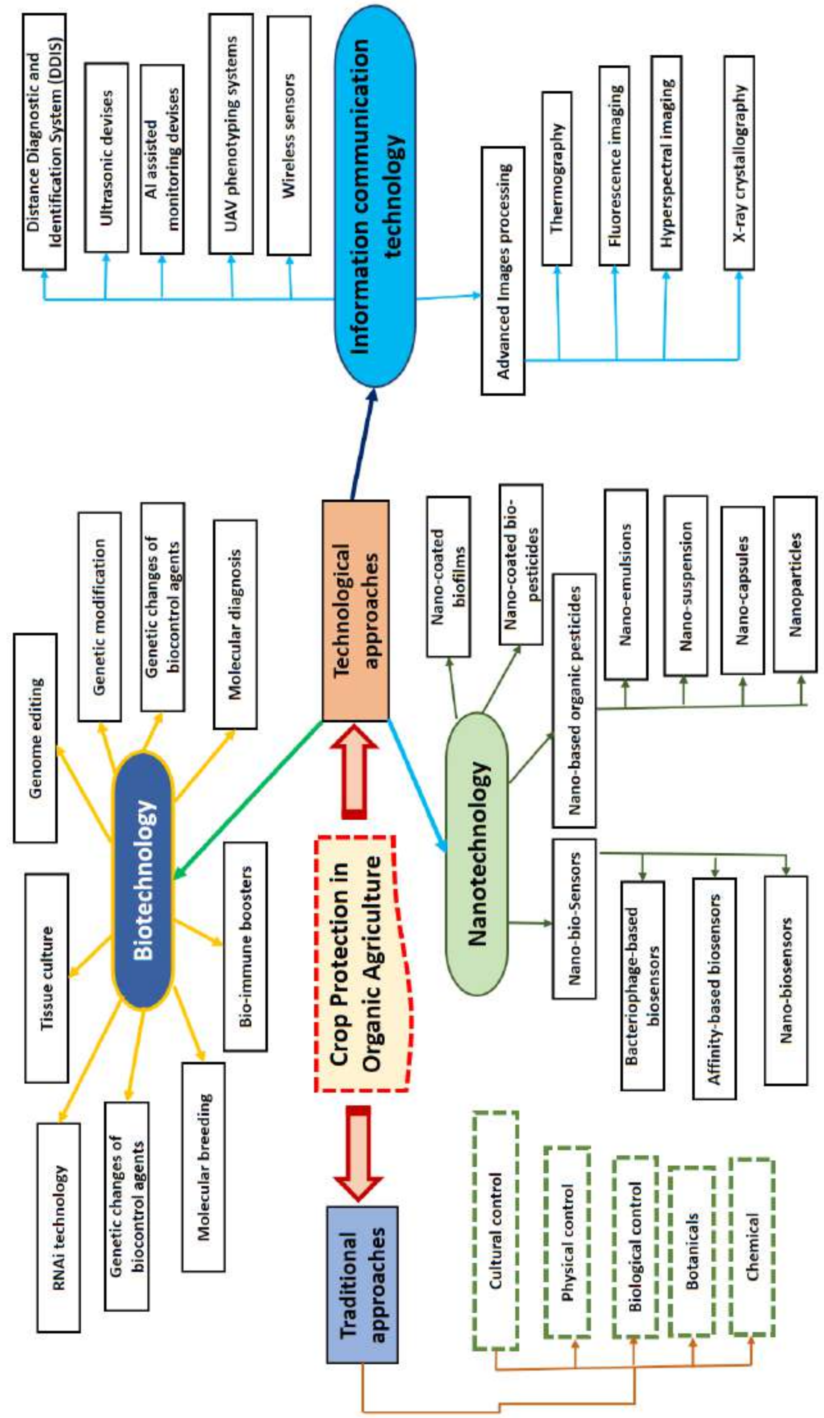

Figure 1: Technological approaches of crop protection in organic agriculture

Fast Production of Resistant Cultivars in the Genomics Era

In organic agriculture, obtaining a high crop yield is not always achievable unless modern technologies are applied to stack the gene(s) governing yield, absorbing higher nutrients and genes responsible for biotic and abiotic stress resistance [14-17]. To enhance the potential traits associated with the resistance to biotic and abiotic stresses in crops, labor-intensive and time-consuming traditional plant breeding is still being practiced in Sri Lanka. Therefore, we cannot meet the expected food demand in the short term through organic agriculture [15]. The majority of the crop varieties cultivated on a commercial scale in Sri Lanka are green revolution invented modern germplasms which are highly susceptible to pests and diseases. For example, traditional rice varieties like "*Moddaikkaruppan*", "*Pachhaipperumal*" are highly resistant to blast diseases, but commercial scale cultivation of these traditional varieties is being practiced only in a few pockets of Sri Lanka due to low yield. To achieve the expected food production through pure organic agriculture in a short time, modern biotechnological and molecular approaches such as marker-assisted genetic selection, mutagenic breeding, whole-genome sequence-based approaches, functional genomic tools, and targetted genome editing technology using programmable nucleases, clustered regularly interspaced short palindromic repeats (CRISPR), and CRISPR-associated (Cas) proteins are smart genomic approaches to improve the contributed Therefore, molecular tagging of resistance genes presents in the local cultivars and marker-assisted backcrossing into modern molecular could be a fast approach to minimize the unwanted pets or disease management and environmental cost in OSA in Sri Lanka.

Genome Editing Approach to Target Gene Transfer

The genome-editing approach is a recently emerged technology to engineer crops as per the needs of human beings. At the beginning of the 21st century, the transgenic approach was intensively applied for the improvement of crops towards biotic resistance by incorporating pest resistance genes such as natural and synthetic Cry genes, protease inhibitors, trypsin inhibitors, and cystatin genes, as well as chitinase, glucanase, osmotin, defensin, and pathogenesis-related genes against plant pathogens [18]. Therefore, genetically engineered (GE) crops have been considered as a tool for IPM because they reduce consumption of pesticides in many folds [farmers reduced pesticide spraying by 776 million kilograms, or 8.6 percent, between 1996-2018] and provide tolerance to herbicides (e.g., glyphosate, glufosinate-ammonium, dicamba, or 2-4 D) [19]. Due to public reluctance [anti-GMO groups] to use GE crops for consumption because of the foreign genes present in the GE crops, genome editing approaches have been transformed from transgenic to cisgenic

approaches where the foreign genes come from a sexually compatible donor organism, therefore, follows natural breeding principles. Cisgeneic techniques allow stacking of cloned resistance genes onto the susceptible cultivars very precisely without linkage drag [20]. The cisgenic approach made resistant varieties of many economically important horticultural crops, such as late blight resistant potatoes and disease resistant grapes, available, resulting in a significant reduction in pesticide input for plant protection measures as well as yield loss in organic agriculture. Moreover, with the availability of precise genome editing tools like CRISPR/Cas9, improving various biotic stress resistance traits in important horticultural crops like tomato, brinjal, citrus, grape, and potato, etc. are the most economically feasible and environmentally sustainable approaches to implement in developing nations like Sri Lanka. Moreover, pathogen effector proteins can be used to identify resistance resources and to inform cultivar deployment [21]. Several recently published comprehensive review articles summarize the current success stories around the globe [18, 22]. So far, no genome-edited crops have been allowed to cultivate in Sri Lanka due to policy restrictions. For example, *Bt* cotton and *Bt* maize have been cultivated in many other countries, like the US, India, China, etc. Through these genome edited crops, these countries have reduced pesticide use by half.

RNAi Technology for Induced Disease Resistance

RNA interference (RNAi) is a natural mechanism that is increasingly being applied in the field of plant sciences towards integrated pest management in sustainable agriculture as an eco-friendly strategy throughout the globe to secure current and future food production [23]. In this technology, small interface RNAs (siRNAs) are used to target the mRNAs to neutralize, therefore, switch on or off or modify the gene expression of the host as well as pests or pathogens.

Moreover, suppression of virulence genes present in pests and pathogens could be another option to protect the plants effectively.

RNAi is used in two ways to silence the gene expression.

1. Host-induced gene silencing (HIGS) is a sequence-specific regulatory mechanism for the silencing of gene expression triggered by long double-stranded (dsRNA) or hairpin-structured RNAs. Targeted gene expression in plants as well as in target pest and pathogen genes can both be silenced within plants. Hence, this is considered a GMO approach.

2. Spray-induced gene silencing (SIGS): Topical applications of pathogen or pest-specific dsRNA or sRNA target virulence-related genes in pests or pathogens with high RNA uptake efficiency.

SIGS is considered a non-GMO and innovative crop protection strategy alternative to HIGS [24]. Next-generation sequencing (NGS) platforms generate genome, exome, transcriptome, and translatome data, which allows the design of pathogen or pest-specific dsRNAs for SIGS, and minimizes the risk of off-target or non-target gene silencing effects in non-target organisms [23, 24].
Using RNAi technology, several pest and diseases have been successfully managed in an eco-friendly way, therefore, this technology is considered as one of the best strategies to control pests and diseases in OAS in Sri Lanka. So far there is no record of publication of the application of RNAi technology in pest and disease control in Sri Lanka. But all around the world, the economically important pests and diseases that have been successfully managed through this technology are systematically reviewed by several researchers. For example, *Sclerotinia sclerotiorum* and *Botrytis cinerea* in *Brassica napus*, Brown plant hoppers in rice, and aphid in many crops have been successfully controlled using RNAi technology [2, 25].

Improved Biological Control

Various biological control agents are being reported around the world to be utilized as potential biocontrol agents to manage pests and pathogens in sustainable ways. But the major drawbacks of the reported biocontrol agents are incompatibility with many pesticides, inconsistency in controlling pests and diseases, low multiplication rate under field conditions, highly sensitive to environmental conditions, and pollution [26]. Due to the advancement of technology, there is plenty of emerging technology available to improve those biological control agents [27]. These technologies help to improve their predatory behavior, pathogenic behavior, parasitic behavior, and antagonistic behaviors against plant pathogens and pests.

Biological control agents can be improved through the genetic modification of the organisms by chemical/ physical modification, hybridization, or molecular genetics [28]. These modifications may lead to enhancing the production of antibiotics, enhancing the antagonistic ability or requiring activities against pathogens based on the targeted pathogen. Through this method, not only develop superior quality biocontrol agents but can also delete or suppress the undesirable genes that inhibit the efficacy of biocontrol agents by encoding the particular gene sequences [29]. For example, *Pseudomonas fluorescens* strains F113 and CHA0, as well as *P. putida* WCS358, have been genetically modified to produce more antibiotics, 4-diacetylphloroglucinol (PHL), and pyoluteorin (PLT) [30]. Moreover, the antagonistic potential of *Trichoderma* sp was increased by the protoplast fusion of two mutants of *T. viride* and *T. harzianum* [31].

Precise application of biocontrol is another approach to improve the efficacy of the biocontrol agent used. Much research has proved that the conventional approach, augmentative release, and conservation approaches are very effective. Moreover, Hokkanen, et al. [32] used bees as transporters for communities of microbes around them. It has led some scientists to wonder if bees can be recruited to deliver beneficial fungi that protect plants, reducing the need for pesticides in OSA.

Bio-Immune Boosters

Bio-immune boosters are microbial compounds or secondary metabolites when applied to the seed, plant surface, or soil, colonize the plant surfaces and rhizosphere, controlling phytopathogenic agents by inducing the defense mechanism of the plants. Currently, bio-immune boosters like lipopolysaccharides (LPS), lipopeptide iturins, proteinase inhibitors (PI), peptaibols, glucosinolates, non-protein amino acids, alkaloids, plant phenolics, terpenes, sesquiterpenoids and sterols, salicylic acid, and jasmonic acid have been isolated from pathogens and plants and are commercially available to persuade the plant immunity before infection by pathogens and pests [33]. The mechanism behind the immune booster is to interfere with host-pathogen signaling pathways and trigger the host defense genes to switch on [34].

Moreover, a variety of microbial pesticides, effective microorganisms (EM), and biofertilizers made through different scientific approaches are being used in organic agriculture as consortia to protect plants from harmful pathogens and promote immunity, growth, and yield in a wide variety of mechanisms such as the production of antibiotics, siderophores, HCN, production of hydrolytic enzymes, acquired and induced systemic resistance [8].

Nano-based Organic Pesticides

Nanotechnology is the science that uses small size particles in the range of 1-100 nm which vary in shape. Modernized agriculture has been using nanotechnology for plant protection in different ways. For example, nanoparticles as a carrier in the pesticide delivery system and green synthesized metallic nanoparticles as biopesticides instead of synthetic pesticides. There are at least four different nano-formulation types of nano-bio-pesticides: nano-emulsions, nano-suspension, nano-capsules, and nanoparticles [35].

Green synthesizing of nanoparticles is a one-step process where the metallic ion is reduced by the plant extract or secondary metabolites of the microorganisms. In this process, the green component like plant extract or secondary metabolites of microorganisms acts as an oxidizing agent and capping agent. Due to the size reduction, the surface area of the particle will increase, therefore, the efficacy is increased many-folds compared to the direct application of plant extracts or secondary metabolites of microorganisms [36]. In nano-bio-pesticides, nano-carriers are being used to encapsulate the active ingredients as a smart system to deliver pesticides precisely to the target at the required quantity. The major advantage of nano-encapsulation is to prevent the loss of pesticides to the environment and less use of pesticides via reducing the cost of pesticides [12]. A variety of materials such as silver, copper, gold, zinc, magnesium, clay, polymers, micelles, dendrimers, liposomes, hybrid and compact polymeric nanoparticles, etc. are being used in different scenarios based on their availability and cost [37]. Ditta [38] developed clay nanotubes as pesticide carriers for better contact of the active ingredients with the plant at a lower cost. Liu, *et al.* [39] designed porous hollow nanoparticles that are also being used for the controlled delivery of water-soluble pesticides for slow release.

The Nano-approach is one of the organic friendly advanced technologies that needs to be incorporated into organic agriculture to protect crops from pests and diseases. Recent success stories have demonstrated that nano-coated botanicals are highly effective at controlling a variety of pests and diseases [37, 40-43]. Therefore, in Sri Lanka, diversified potential medicinal herbs and underutilized plants showing antifungal, antibacterial, anthelmintic, anti-feeding, anti-oviposition, and pesticidal properties, are available. Formulation and application of nano-plant pesticides would be cheaper and eco-friendlier alternatives to synthetic pesticides in organic agriculture.

Modern ICT and Nano-based Pest and Disease Surveillance and Exclusion

Pest and diseases are conventionally being identified visually by human raters, and non-conventionally by polymerase chain reaction (PCR), fluorescence in situ hybridization, enzyme-linked immunosorbent assay (ELISA), immunofluorescence, flow cytometry, and indirect methods like diversified biosensors thermography, fluorescence imaging, hyperspectral techniques, and gas chromatography, etc [44]. In smart agriculture, with the assistance of ICT and artificial intelligence (AI), several nano-based biosensors are in the process of development in pest and disease diagnosis, and surveillance systems that could help farmers to detect volatiles, chemical residues in crops, pathogens, and environmental changes in advance and take early decisions cheaply, efficiently, and rapidly. They are equipping farmers.

The agriculture modernization projects are running all around the developed and developing nations to incorporate feasible and applicable smart agriculture technologies. Among the identified technologies, wireless sensors, automatic

crop protection systems, smart ultrasonic insect repellent devices, and Artificial Intelligence (AI) guided image processing techniques are currently being used intensively in pest and disease monitoring, detection, diagnosis, and management with the assistance of computer vision and precise image processing software. The principle behind the image analysis technique is to distinguish the objects from the plant-based background, thereby ensuring accurate feature information is used to make decisions by anybody in an in-ground scenario just using a smartphone with a quality camera and internet [45]. In Sri Lanka, pest and disease detection using image processing is currently in practice at a very minimal level [46]. Therefore, relevant authorities should take initiatives for the further development and implementation of high throughput AI guided phenotyping surveillance systems at the farmer's level to prevent unwanted pesticide use [47, 48].

Policy Gaps to Adopt Modern Technology in Organic Agriculture

Sri Lankan agriculture mainly focuses on eliminating poverty and hunger by 2030 and meeting the sustainable development goals. The current national agricultural policy (NAP) 2007 aims to: 1) increase domestic agricultural production to ensure food and nutrition security for the nation; 2) improve agricultural productivity and ensure sustainable growth; 3) maximize benefits and minimize negative effects of globalization on domestic and export agriculture; and 4) adopt productive farming systems and improved agro-technologies to reduce unit costs of production and increase profits; 5) Adoption of technologies in farming that are environmentally friendly and harmless to health; 6) Promote agro-based industries and increase employment opportunities; 7) Enhance the income and the living standard of farmers (NAP, 2007) [49].

Even though the national agricultural policy allows adopting improved technologies, the expected smart technologies were not implemented in the field of plant protection. Moreover, there is no approved organic agriculture policy in Sri Lanka; however, SLCARP took initiatives to formulate a national policy on organic agriculture and identified productivity improvement through sustainable land improvement, making available quality organic inputs at an affordable price, quality aspects of organic foods, post-harvesting, processing and value addition, certification, marketing, and trade promotion, and developing the scientific basis for indigenous organic measures as thematic research priority areas need to be focused on to uplift organic agriculture to the next level (https://www.slcarp.lk /organic agriculture/).

The recently imposed sudden import ban of synthetic chemicals into Sri Lanka by the government of Sri Lanka has created a major controversy among the farmers and agricultural community with the government, even though, many farmers welcomed organic agriculture, due to the unavailability of the required quantity and superior quality of alternate inputs. As a result, existing policy gaps had to be filled by incorporating the following applicable strategies into the new policy when it was developed.

1. Modern biotechnological approaches are now popular throughout the world and are available at affordable costs to developing countries like Sri Lanka. Therefore, focus on the improvement of traditional cultivars quickly using safe modern biotechnological tools such as detection of cost-effective molecular markers, marker-assisted backcrossing, gene stacking, and targeted genome editing approaches.
2. Focus on the mass scale production of traditionally used bio-pesticieds using new technology as well as the development of nano-formulated bio-pesticides: Nano-technology opened a state-of-the-art technology to develop nano-bio-pesticides to increase the efficacy of plant-based extracts.
3. Production of supper compost: The government should take the initiative to establish a commercial scale supper compost production unit in every district for the continuous supply of bio-fortified compost to minimize the soil borne disease attacks and enrich the beneficial microbes in the soil.
4. Extension activities: Conduct extension training among the farming communities to provide knowledge about cutting edge plant protection technologies available and their handling and operating technologies.
5. Focus on target oriented technology development: The government should take initiatives to sign MOUs with countries that are leading in the application of green technologies massively in agriculture to train local agricultural professionals to develop target-oriented technologies needed for the countries with collaboration.
6. Research and development with high-tech institutes: The government should take initiatives through agriculture modernization projects to fund the advanced research and innovation of smart technologies for plant protection.
7. Strategic and systematic plans and supportive government schemes are required to adopt smart farming technologies and endorse their implementation.
8. Support and incentives: Adequate incentives and technical support should be provided by the government to farmers for adopting smart farming technologies. Tax incentives should be provided for the importation and

local manufacturing of drones and other equipment to be used in smart agriculture practices.

9. Development of bio-safety protocols: The government should develop and implement biosafety protocols for research on RNAi research and GMOs regulations and restrictive PPP risk assessment methods. If this happens, there is likely to be a disincentive to investment in R&D on agricultural applications of RNAi-based technology in Sri Lanka.
10. Empower youth and women in agriculture with support for mechanization, access to modern technologies, and productivity-based incentive systems.

Conclusions and Future Prospects

Sri Lankan agriculture is shifting towards organic agriculture. Currently, Sri Lanka is facing big challenges due to the unavailability of quality and required quantity of organic inputs and pest and disease problems to achieve the expected yield from organic agriculture. To keep up with the existing pest and disease problem, affordable technologies such as rapid development of resistant varieties through biotechnological approaches; application of RNAi technology for induced pest and disease resistance; genetic improvement of biological control agents; mass production of technology-assisted immune boosters; nano-formulation of pesticides; and application of modern ICT tools in pest monitoring and surveillance are urgently needed. Sri Lankan agricultural policy is not stable and changes are being made unexpectedly and suddenly. Therefore, proposed policy gaps have to be rectified wherever possible while revising the agriculture policy of the country. In the present and future, the identification and implementation of the state-of-art technology and forthcoming technologies in plant protection with a publically acceptable restructured firm and stable policy guide would be the best strategy to increase the productivity of organic agriculture. Focus on technology SMART sustainable organic agriculture is necessary to eliminate poverty and ensure the food security of the country to meet the sustainable development goal by 2030.

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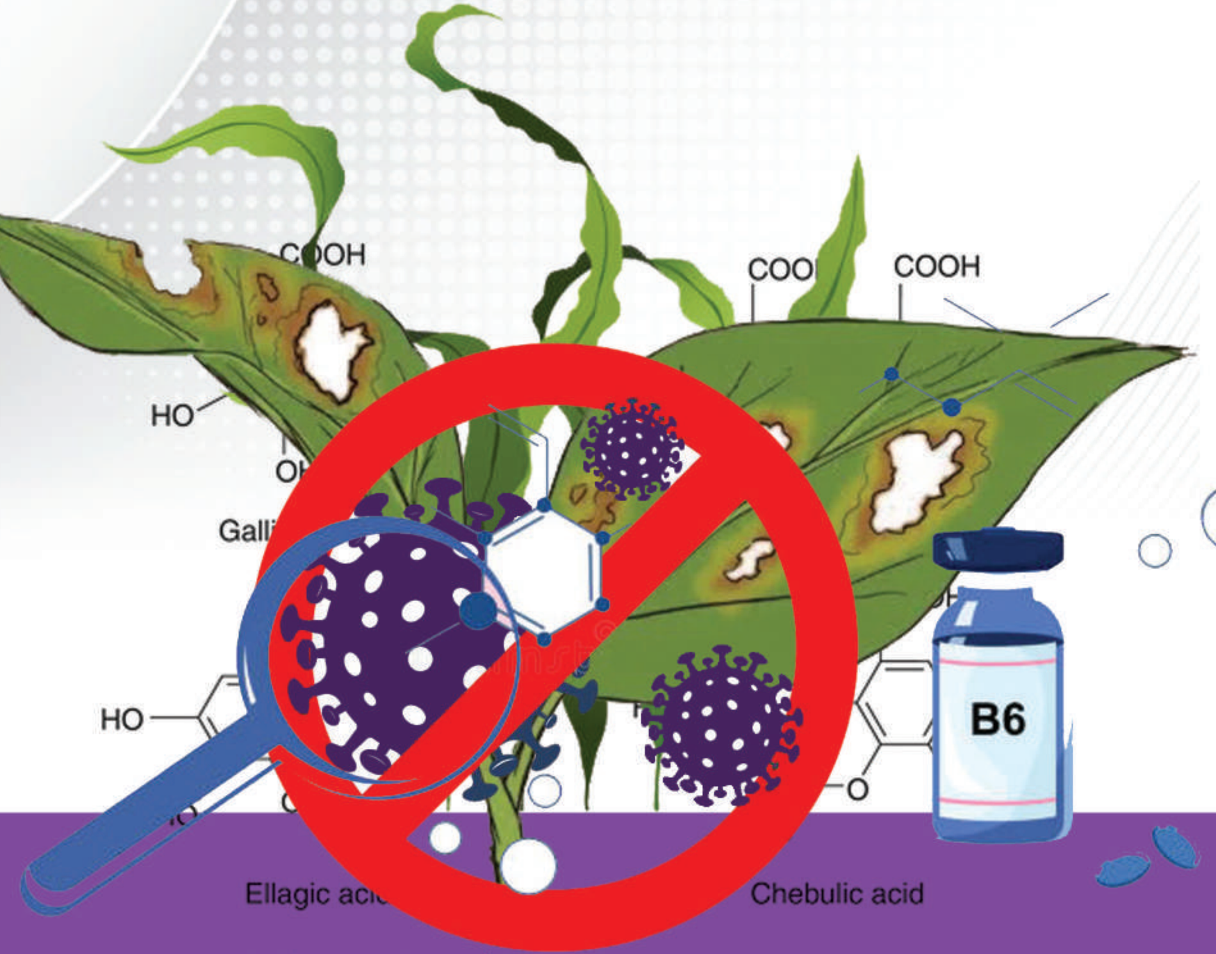
CHAPTER 09



POTENTIALS OF SEAWEED EXTRACTS IN MANAGING PHYTOPATHOGENS

Potentials of Seaweed Extracts in Managing Phytopathogens

N. Vathshalyan*, G. Hariharan and B. Karunarathna

Abstract Growing concern about environmental safety and the global desire for chemical residue-free food has sparked an interest in plant disease control. At present, tapping seaweed as a potential biopesticide to manage pests and diseases is getting increasingly popular. It offers plants immunity, thereby indirectly reducing the invasion of pathogens. The chapter reviews the economic value of seaweed in organic agriculture, its antimicrobial components, and its potential for phytopathogen management. It also analyzes the present policy gaps and limits in Sri Lanka's organic agriculture, as well as potential solutions using seaweed. Seaweed is recognized as an exceptional marine bio-resource as it contains various bioactive components such as carbohydrates, polysaccharides, sulfated polysaccharides, carotenoids, bioflavonoids, amino acids, and polyunsaturated fatty acids which have antiviral, fungicidal, nematocidal, and bactericidal properties. Antifungal and antiviral effects are achieved by inhibiting mycelial growth and microsclerotia formation in fungal pathogens and particle aggregation in viral pathogens, respectively. Also, it triggers systemic acquired resistance (SAR) or induced systemic resistance (ISR) in infected plants via induced activities of defense-related enzymes and upregulates the defense marker genes. However, the antimicrobial efficacy of seaweed extracts varies with the extraction methods and solvents used to recover the bioactive components, seaweed species, season, and location where it is cultivated. Moreover, the policies on organic agriculture in Sri Lanka emphasize the minimal use of synthetic pesticides. But, utilizing plant and marine resources to manufacture biopesticides is given less importance. Therefore, it could be recommended to initiate a public-private partnership (PPP) in seaweed farming in Sri Lanka, thereby ensuring the production of biopesticides, organic fertilizers, and other value-added products.

Keywords: Antimicrobial activity, Bioactive components, Biopesticides, Plant diseases, Seaweeds

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Introduction

Crop diseases are obstacles when cultivating a crop globally for both small and commercial levels. It causes the range of yield losses to ultimate crop death. Phytopathogens are one of the ruling factors for plant growth and development. Predominantly, fungi, bacteria, viruses, nematodes, viroids, and phytoplasmas disturb the plant's growth by altering it either locally or systematically. The severity of the crop's damage may be determined by the degree of defense mechanism the crop has against the pathogen and the pathogen's virulence level, and the environment.

Globally, direct yield losses to pathogens range between 20 and 30% for primary food and cash crops, and this value is shared with animal pests [1],[2]. It is believed that plant diseases cost the global economy about 220 million annually. Crop loss due to plant diseases leads to hunger. This is especially true in developing countries, where access to disease control methods is restricted, and major crops lose 30-50% annually [3].

Maintaining crops with a disease-free state or keeping a crop with minimal damage due to diseases is necessary to attain higher food production worldwide. Managing crop diseases is mainly based on agrochemicals, creating environmentally detrimental effects. The negative impacts are contaminating water bodies [4], altering agricultural soil [5], its microbial diversity [6], polluting non-target organisms [7], declining pollinators [8], etc.

Current agricultural practices incorporate new tactics to reduce the negative environmental impact of pesticides in managing diseases. As a result, some active ingredients in pesticides have been banned for agricultural usage. It demands the development of alternative control measures that are environmentally friendly and efficient. In this context, sustainable plant protection provides farmers with tools to produce safe and high-quality food while reducing climate impact, maintaining a pollution-free environment, and ensuring high-quality groundwater.

Seaweed-based crop protectants provide a sustainable alternative to enhance plant immunity to pathogens [9]. The growing biostimulant era, especially over the last decade, is exemplified by a booming use of various seaweed-based extracts [10]. Seaweed extracts promote plant health by affecting plant physiology and metabolism and affecting rhizosphere microbial communities, thereby indirectly reducing the invasion of pathogens into plants [11].

The chapter discusses the economic importance of seaweed in organic agriculture, the antimicrobial components of seaweed extracts, and the potential

of seaweed extracts in managing phytopathogens. Also, it identifies the policy gaps and constraints in Sri Lanka's organic crop protection. Finally, possible recommendations towards sound policymaking to manage phytopathogens using seaweed are proposed.

Economic Importance of Seaweed in Organic Agriculture

Plant diseases and pests have an influence on plant availability and safety for human and livestock use, as well as agricultural yield and quality, as agriculture struggles to sustain the world's rapidly rising population [12]. Diseases and pests can cause worldwide production losses of up to 30% of critical staple crops, with estimated global economic implications of hundreds of billions of dollars [13]. Plant fitness is therefore critical for human health since it is a primary driver of food security and safety, a source of livelihood in plant-based agriculture, a source of pharmaceuticals, and a component of healthy environments [14].

Organic farming has become increasingly popular in recent decades among the consumers due to result of potential human health risks associated with the overuse of agrochemicals and environmental deterioration. As a result of this growing awareness, organic substances are receiving greater attention these days [15]. In organic farming, pest and disease control is mostly dependent on maintaining soil fertility through balanced crop rotations that include nitrogen-fixing crops, cover crops, intercrops, manure and compost additions, and reduced soil tillage [16]. Organic crop protection relies on environmental management rather than direct disease control, allowing plants to survive possible threats [17]. Synthetic fertilizers will be phased out in favor of organic amendments and manure, resulting in a microbially driven system and changes in micronutrient supply. This can have a significant influence on plant resistance and the pathogen-beneficial microbial balance of the soil [18].

Because of the rising popularity of organic farming and the detrimental impacts of agrochemicals in crop protection, the seaweed business is rapidly developing as an income-generating sector across the world. Seaweeds naturally boost plant immunity, allowing plants to withstand drought, disease, and frost; their high fiber content acts as a soil conditioner and aids moisture retention; and their mineral content functions as a fertilizer and trace nutrient source. Using seaweed also improves plant resistance to pests and diseases, as well as plant growth, yield, and quality [19]. Seaweed-based bioproducts are gaining prominence in crop production and protection systems due to their specific bioactive components and effects. They contain phytostimulant properties that boost plant growth and yield characteristics in several important crop species [20]. It also contains important minerals that plants require, and seaweed contains growth-stimulating hormones that stimulate growth as evidenced by plant growth and crop yield [21,22,23], develop tolerance to environmental stress [24], increase nutrient uptake from soil [25], enhance antioxidant properties [26], and protect against phytopathogenic fungi [27].

Antimicrobial Components of Seaweed Extracts

Seaweeds are considered an exceptional marine bio-resource with numerous bioactive components that help combat plant diseases. The broad spectrum of antiviral, bactericidal, fungicidal, and nematocidal activities are chiefly due to the bioactive molecules, viz. carbohydrates, polysaccharides, sulfated polysaccharides, carotenoids, bioflavonoids, amino acids, and polyunsaturated fatty acids [28]. Furthermore, structural (especially cell wall) and storage components in brown, green, and red seaweed that is similar to alginates, carrageenans, fucans, laminarin, and ulvans could elicit diverse responses from plants against pathogenic infestations [29]. The antimicrobial potential of seaweed extracts are heavily reliant on the extraction process and the types of solvents employed to maximize the recovery of various bioactive compounds. The chemical constituents of the extract, as well as its efficacy, may be affected by seaweed species, season, and raw seaweed harvest site [30, 31].

Table 1. Antimicrobial components of some seaweeds in plant disease management

Antifungal activity					
Seaweeds	**Pathogen**	**Host plant**	**Disease**	**Identified components**	**References**
Sargasam vulgare	*Phythium aphanindermatum*	Potato	Phythium leak	Phenolic acids Flavoids	[32]
Gracilariopsis persica	*Aspergillus niger Botrytis cinerea,* *Penicillium expansum Pyricularia oryzae*	Fruits and vegetables Rice	Black mold Grey mold Blue mold Rice Blast	Rosmarinic acid, quercetin, palmitic acid, oleic acid,	[33]
Caulerpa racemosa, Caulerpa racemosa var. *lamourouxii*	*Ganoderma boninense*	Oil palm	Basal stem rot	Phytol, l-(+)-ascorbic acid, 2,6-dihexadecanoate	[34]
Kappaphycus alvarezii	*Colletotrichum gloeosporioides*	Chilli	Anthracnose	κ-carrageenan	[35]
Ulva armoricana	*Erysiphe polygoni, E. necator* *Sphareotheca fuliginea*	Common bean grapevine cucumber	Powdery mildew	ulvans	[36]
Antibacterial activity					
Seaweeds	***Pathogen***	**Host plant**	**Disease**	**Identified components**	**References**
Sargassam wightii	*Xanthomonas oryzae pv. oryzae*	Rice	Bacterial blight	sulphoglycerolipid 1-0-palmitoyl-3-0(6′-sulpho-α-quinovopyranosyl)-glycerol	[37]

Padina gymnospora	*Ralstonia solanacearum* *Pectobacterium carotovora*	Egg plant	Wilt Soft rot	Palmitic acid	[38]
Antiviral activity					
Seaweeds	***Pathogen***	**Host plant**	**Disease**	**Identified components**	**References**
Hypnea musciformis	*Tobacco mosaic virus*	Tobacco	Mosaic disease	sulphated polysaccharide 4, κ-carrageenan	[39]

Researchers have discovered a myriad of new antibacterial components in addition to the ones listed above. For example, Fiallos et al. [40] used water extracts of seaweeds namely, *Agardhiella subulata*, *Bryothamnion triquetrum*, *Codium isthmocladum*, *Dictyota dichotoma*, and *Halymenia floresii*, experimented on *Fusarium oxysporum*, *Colletotrichum gloeosporiodes* and *Psedocercospora fijiensis* and revealed the antifungal activity of *H. floresii* against *P. fijiensis* due to sulfated polysachcharide i.e. carrageenan. The recent contribution of El-Sheekh et al. [41] used chromatography-mass spectrometry and infrared spectroscopy techniques to identify iron-monocarbonyl, cyclononasiloxane and other functional groups, viz. amine, ether, as the anti-fungal molecules in *Ulva fasciata* and *Enteromorpha flexuosa* seaweed extracts that inhibit mycelial growth and microsclerotia formation in *F. solani* and *M. phaseolina* pathogens. Machado et al., [42] investigated organic extracts of *Ochtodes secundiramea* and *Laurencia dendroidea* and found that the seaweeds had potent inhibitory effects on the fungal pathogens *C. gloeosporioides* and *C. musae*, which cause anthracnose disease in papaya and banana, respectively. Antifungal components such as halogenated monoterpenes and diterpenes in *O. secundiramea* and *L. dendroidea*, as well as quercetin in *P. capillacea*, have also been discovered. Furthermore, seaweeds have been found to have antiviral activities against viral plant pathogens. Pardee et al. [43] discovered that methanolic extracts of *Fucus gardneri*, *Alaria marginata*, *Ralfia* sp., *Codium fragile*, *Fragilaria oceanica*, and *Eeregia menziesii* had and inhibitory effect of 80 % against Potato Virus X (PVX) and that alginates in *F. gardneri* caused viral particle aggregation during infection.

Potentials of Seaweed Extracts in Managing Phytopathogens

Seaweeds are generally applied as biofertilizers, bio-stimulators, and soil amendments in the integrated nutrient and plant disease management approaches and have shown potential in plant growth, yield promotion, and disease prevention. A plethora of research findings have confirmed the beneficial effects of seaweeds that are either applied in powdered forms or extracts that are amended with soil or as a foliar spray to control bacterial, fungal, viral, and nematode phytopathogens [44]. The management of different phytopathogens using extracts from diverse seaweed species is given below in Table 2.

Table 2: Promising effects of seaweed extracts on various phytopathogens

Pathogen	Disease	Host plant	Seaweed	Remarks	Reference
Rhizoctonia solani	Sheath blight	Rice	*Gelidium pusillum*	Seed and prophylactic spray applications of 20% *G. pusillum* decreased disease incidence of 82, 80 and 86% at 30, 50 and 70 days after transplanting, respectively.	[45]
Erysiphe pisi	Powdery mildew	Pea	*Ascophyllum nodosum*	Commercial *A. nodosum* extract and chitosan application inhibited pathogen development and reduced disease severity to 35%, increased plant defense related enzymes and modulated defense signaling pathways.	[46]
Verticillium dahliae	Verticillium wilt of olive	Olive	*Ulva lactuca*	In an *in-vitro* assay, the Ulvan polysaccharides of 2g/L reduced disease severity and final incidences to 39.9% and 28.9%, respectively and inhibited mycelial growth of *V. dahlia.*	[47]
Macrophomina phaseolina *Fusarium solani*	Charcoal rot Wilt	Cucumber	*Ulva fasciata,* *Enteromorpha flexuosa*	The tested seaweeds extracts inhibited the mycelial growth of *F. solani* and did not affect the growth of *M. phaseolina* but affected the microsclerotia formation.	[41]
Podosphaera aphanis	Powdery mildew	Strawberry	*Ascophyllum nodosum*	In a greenhouse experiment, foliar spray of 0.2% of *A. nodosum* showed 75% of reduction in spore germination and in field conditions the applications exhibited 37.2% reduction in disease incidence.	[48]
Pseudocercospora griseola	Angular leaf spot	Bean	*Ulva fasciata*	Control of disease is associated with the interaction between the bean genotype and the environment.	[40]
Fusarium solani *Fusarium sambucinum*	Fusaium Dry Rot	Potato	*Sargassum vulgare*	Aqueous or methanolic extracts of *S. vulgare* inhibited *F. solani* and *F. sambucinum* mycellial growth 30.4 and 39.4%, leision diameter and rot penitration 66.7 and 67.5 % respectively	[49]
Agrobacterium tumefaciens *Verticillium dahliae*	Crown gall disease Verticillium wilt	Tomato	*Cystoseira myrophylloides* *Laminaria digitate* *Fucus spiralis*	In an *in-vitro* and greenhouse tests, spray applications of methanolic extracts of the seaweeds resulted significant inhibition of growth and aqueous extracts of *C. myrophylloides and F. spiralis* reduced crown gall diseases.	[50]
Plasmodiophora brassicae	Clubroot	Broccoli	*Durvillaea potatorum* *Ascophyllum nodosum*	Commercial seaweed extracts prepared from *D. potatorum* and *A.* inhibited primary and secondary infections by 55 and 84%, correspondingly	[51]
Colletotrichum gloeosporioides *Fusarium oxysporum* *Pseudocercospora fijiensis*	Anthracnose Fusarium wilt Black Sigatoka leaf streak	Tropical Fruits Banana	*Agardhiella subulata* *Bryothamnion triquetrum* *Codium isthmocladum* *Dictyota dichotoma* *Halymenia floresii*	In *in-vitro* assays, the application of aqueous crude extracts of *H. floresii* inhibited conidial germination of *P. fijiensis*	[52]
Plum pox virus	Sharka disease	*Nicotiana benthamiana*	*Asparagopsis taxiformis* *Caulepra cylindracea*	Soaking *N. benthamiana* seeds in 1.5% aqueous extracts of *C. cylindracea* decreased the disease severity	[53]
Meloidogyne javanica		Soybean	*Ascophyllum nodosum*	Soil drenching and foliar applications of aqueous extracts of A. nodosum resulted 65% reduction in nematode density.	[54]

Potentials of Seaweed Extracts in ....

Seaweed extracts, both organic and crude, as well as commercial formulations, have shown promising effects on a variety of plant diseases and activated plant defense systems. Jiménez *et al.* [55] discovered that aqueous and ethanol extracts of *Gracillaria chilensis* prevented the growth of the soil-borne pathogen *Phytophthora cinnamomi,* which causes dieback disease in nursery plants, in an *in-vitro* and *in-vivo* experiment. To manage *Alternaria solani* in tomato plants, *Hernández-Herrera et al.* [56] used polysaccharide supplemented seaweed extracts from *Ulva lactuca, Caulerpa sertularoides, Padina gymnospora, and Sargassum liebmannii.* After treatment with the studied seaweed extracts, necrotic lesions in *A. solani* were decreased, and *U. lactuca* elevated the expression of SWR, defense, signal pathway, and protease-associated genes. Foliar applications of 0.5% commercial *Ascopphyllum nodosum* against foliar disease-causing bacterial pathogen *Xanthomonas campestris pv. vesicatoria* and fugal agent *Alternaria solani* in tomato and sweet pepper plants resulted in a 60% reduction in disease levels in greenhouse and field experiments. Further, the extract induced activities of the defense-related enzymes, namely, chitinase, peroxiadase, phenylalanine ammonia lyase, polyphenol oxidase, β-1,3-glucanase and total phenolic compounds. Interestingly, upregulation of defense marker genes *PinII* and *ETR1* was also observed and thus indicating the involvement of salicylic acid (SA), jasmonic acid (JA) and ethylene (ET) which can trigger systemic acquired resistance (SAR) or induced systemic resistance (ISR) in infected plants [57].

Integrated plant disease management is considered a potential source to promote sustainable agriculture. Seaweed also has been incorporated in the concept. For example, to treat green mold disease caused by *Penicillium digitatum* in orange fruits, a combination of extracts from seaweed *A. nodosum*, plants i.e. alfalfa, and sugarcane, as well as the chemical fungicide Imazalil (at a lower dose), was utilized. The integrated strategy decreased the incidence and severity of the disease, induced the expression of defense-related genes, reduced the residual concentration of synthetic fungicide in orange fruit peel, and was conceived as environmentally friendly [58]. This finding indicates seaweed extract as an appropriate source for integration.

Seaweed extracts were shown to be highly effective against viral plant pathogens. El-Sawy et al. [59] tested 0.2% of *Ascophyllum nodosum* extract mixed with 2-nitromethyl phenol and zinc nanoparticles against cucumber mosaic virus (CMV) and found it to be effective to control the pathogen. The disease severity and incidence were dramatically decreased in eggplants treated with the seaweed extract, and the CMV symptoms were completely suppressed in greenhouse conditions. In another study [55], the extracts of *Durvillaea antartica* reduced the damage caused by tobacco mosaic virus (TMV) in tobacco plants.

Controlling plant-parasitic nematodes (PPN) has relied heavily on synthetic chemicals that are toxic to humans and the environment. Managing PPN using biopesticides is a viable and equitable option in sustainable agriculture [60]. The application of seaweed extracts might be an alternate approach that has been used for decades and has shown to reduce PPN infections significantly [61]. The root-knot-nematode (RRN) *Meloidogyne incognita* is a devastating parasite in agriculturally important crops. Ghareeb et al. [62] evaluated the nematicidal activity of methanol extracts of *Corallina mediterranea*, *C. officinalis* and *U. fasciata* against *M. incognita*. The laboratory and greenhouse experiments exhibited a reduction in the number of galls, egg mass/ plant and the number of juvenile 2 (J2) of the RRN infecting tomato plants. The treated plants with seaweed extracts showed higher activities of plant immunity related enzymes peroxidase and polyphenol oxidase, indicating induction of plant defense against *M. incognita* infestation.

Sargassum sp., a brown seaweed widespread in Sri Lanka's coastal areas, has the potential to be employed as a biopesticide in agriculture to control PPN. For instance, soil amendments of *S. tenerrimum*, *S. swartzii*, and *S. wightii* exhibited strong nematicidal action against J2 of *M. javanica* which causes infestations in okra [63]. In addition, the application of *Sargassum* sp. [64], *Ulva* sp. [65], and *A. nodosum* [66] in the management of *Meloidogyne* sp. exhibited favorable results.

Identifying Policy Gaps and Constraints in Organic Crop Protection Sector: In Sri Lankan Context.

Agriculture is the spine of Sri Lanka's economy. However, Sri Lanka's agriculture sector endures lower productivity, leads to food uncertainty and poverty due to many reasons, namely climate change, pests and disease problems, abiotic stresses, and land degradation due to the non-discriminate use of synthetic fertilizers and agrochemicals to the crop farming. The Government of Sri Lanka launched its Vision 2025, underscoring priority reforms concerning agriculture and sustainable development to help the country become more prosperous [67].

One of the reforms emphasizes that government encourages nutritious farming practices. They introduce a national policy on food quality and the permitted fertilizer levels in this context. This ensures the adequate availability of organic produces in the market [67]. Sri Lanka National Agricultural Policy highlighted the minimal use of synthetic pesticides through promoting biopesticides and integrated pest management (Ministry of Agriculture Development and Agrarian Services, n.d). It also emphasizes promoting the production and use of environmentally friendly biopesticides with public and private sector participation.

Further, thrust areas identified by the government of Sri Lanka on organic agriculture also made a point of the biological control of pests and diseases [68]. Agriculture modernization projects encourage farmers to move away from pesticide dependent pest control practices and promote the use of botanical pesticides and biological controls.

Though few policies and policy initiatives spotlighted the necessity of environmentally friendly biopesticides, those are very broad in coverage, and the particular focus is given to insect pests. Most government programmes pinpoint the significance of organic crop fertilizers and insect pest management strategies among the farmers. The introduction of "Green life" organic fertilizer certified as 100% organic-based by the Ministry of Agriculture is one example of the government initiative towards the organic fertilizer recommendations. However, less priority is given by the government, policymakers and relevant stakeholders to emphasize the development and commercialization of botanicals and biopesticides with zero pollutants to control plant pathogens, specifically. Instead, these biopesticides and botanicals are considered in insect pest control measures. Also, less priority is given to utilizing the plant and marine resources to prepare the botanicals for disease management.

Farmers use indigenous knowledge to prepare botanicals from locally available plants, namely neem, garlic, onion, ginger, tobacco, papaya, holy basil etc. However, they do not know much about the effectiveness of the extraction protocols they followed to get the botanicals. It leads them not to get the maximum results when they apply for upsurge pest damage in their field. Hence, farmers prefer to use chemical pesticides to control particular situations. Primarily, growers rely on synthetic fungicides, nematicides, and bactericides to control plant pathogens.

There is insufficient coordination between policy and plant protection measures at the field level. Hence, there is a lot of overlap, and the performance isn't outstanding. Significant knowledge and capacity gaps exist island-wide, resulting in a divergence between policy direction at the national level and action in the field. It elucidated some light on the present situation and the challenges facing the crop protection sector, which needs policy, strategy, and program changes.

Recommendation Towards Sound Policymaking to Manage the Phytopathogens by Seaweed.

Sri Lanka's food demand continues to increase. On the other hand, crop diseases are a significant challenge in crop farming. Seaweed-based biopesticides must be a viable alternative to control plant pathogens since they have microbial

and bioactive components that improve plant immunity and control plant pathogens. In Sri Lanka, few seaweed-based liquid extracts are available in the market, primarily used as organic fertilizer.

The studies conducted island wide in tomato [69], maize [70], chilli [71], Amaranthus [72], Cowpea [74], Long bean [75] showed that the seaweed extracts could use as a nutrient source to improve plant growth and development. However, no much field level-specific studies have been done on seaweed antimicrobial activities against phytopathogens. But, experiments from other countries confirm the bio pesticidal properties of seaweed. The chapter thoroughly discussed some of the components and their antimicrobial potential against phyto pathogens.

Sri Lanka has a coastline of around 1700 kilometers, which is home to a diverse array of seaweeds [76]. Several researchers have identified around 320 species from various families, particularly along the northern, western, and southern coasts [76]. In Sri Lanka, the brown seaweeds of the genus Sargassum are the most numerous. They grow on rocks and other filthy surfaces, but they easily break off and wash ashore during heavy monsoons [77]. Crop protection may be improved if these resources were used as biopesticides in sustainable farming. On that line, the suggestions below propose to strengthen plant disease control by addressing policy gaps and limits through the use of seaweed.

Seaweed cultivation is currently being done on a micro level [78]. Small-scale seaweed growing is a low-tech, low-input method that has been employed for decades in several Asia countries. However, it is still in its early phases in Sri Lanka. Although, the island has various sheltered bays, lagoons, and estuaries that may be utilized, the country has yet to undertake large-scale projects to establish seaweed production [77]. Furthermore, because the large-scale seaweed business requires significant money, government and private partnership (PPP) is required to move the seaweed cultivation down the coast.

In this context, a policy should initiate the PPP in seaweed farming in Sri Lanka may ensure the continuous supply of raw materials. It facilitates the production of biopesticides, organic fertilizers, and other value-added products in the pharmaceutical and food sector. It also boosts the blue economy of the country. The seaweeds also take decisive measures to conserve coastlines by reducing wave energy and ocean acidification.

Some of the constraints to developing a solid seaweed industry in Sri Lanka include a lack of awareness and knowledge, a lack of technology dissemination, a lack of seed stocks, individual attitudes and a lack of drive among fishing communities, environmental variations, and the short, seasonal lifecycles of certain seaweed species [78]. The fisheries and aquatic resource development sectors may undertake training programs to produce farmers skilled in seaweed cultivation to address these obstacles. Furthermore, the government should take the first measures to support seaweed-based small businesses by establishing adequate funding and technological know-how. Again, private sector investment is required to grow the seaweed business in Sri Lanka.

The research initiatives should explore the available seaweed species in Sri Lanka since this is largely unknown. Also, funding should direct to research and development programmes for bioactive components profiling and investigating the antimicrobial ability of abundant seaweeds. Then the knowledge that comes from the research activities should communicate with the private sectors via PPP, thereby promoting the development of seaweed-based biopesticides to control plant pathogens. Again, support from the government is crucial to ensure the market for the farming inputs produced. Initiative steps to form a collaboration of agrochemical manufacture companies, fisheries and aquatic resource development board, and the department of agriculture would facilitate the continuous production and supply of seaweed-based organic fertilizers and biopesticides.

Moreover, The Ministry of Agriculture would emphasize field demonstrations through the establishment of farmer field schools (FFS) [78]. Because it is a realistic technique to persuade farmers to use biopesticides. FSSs can genuinely demonstrate to farmers the successful disease control that can be expected by using seaweed extracts as well as user-friendly techniques. This will help to change farmers' perspectives and educate them about the initiatives, motivating them to implement them as well.

Special consideration needs to be given to environmentally friendly disease management techniques with seaweed biopesticides, and they should be amended with the country's organic agriculture policy. The policy should have the space for the registration and commercialization of those products.

Conclusions

Crop diseases are an impediment to crop cultivation globally. Pathogens cause direct yield losses of 20–30% in key food and cash crops. Crop disease management is primarily dependent on agrochemicals, which have negative environmental consequences. Hence, crop protectants derived from seaweed offer a sustainable way to boost plant immunity to diseases. Seaweeds are regarded as an extraordinary marine bio-resource since they contain several bioactive components that aid in the combat of plant diseases. The antimicrobial efficacy of seaweed extracts is highly dependent on the extraction procedure

and the solvents employed to enhance the recovery of different bioactive components. Researchers say seaweed has been shown to have a plethora of novel antimicrobial components. Antifungal components such as halogenated monoterpenes and diterpenes have also been identified. It is also effective against viral plant pathogens and root-knot nematodes. Some of the most investigated seaweeds belong to *Sargassum* spp., *Kappaphycus* spp., *Ulva* spp., and *Ascophyllum* spp.

Sri Lanka's National Agricultural Policy highlighted the minimal use of synthetic pesticides by promoting biopesticides and botanicals. However, most government programs propose the significance of organic crop fertilizers and insect pest management strategies. Less priority is given to emphasizing the development and commercialization of botanicals and biopesticides. To ensure a continuous supply of raw materials, a policy should be put in place to initiate PPP in seaweed farming in Sri Lanka. Furthermore, an initiative to form a collaboration between agrochemical manufacturing companies, fisheries, and aquatic resource development boards would facilitate organic fertilizers and biopesticide production.

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CHAPTER 10

ADVANCES AND INNOVATIONS IN SUSTAINABLE MANAGEMENT OF MAIZE STORAGE PESTS TO SUPPLY SAFE FOOD AND FEED

Advances and Innovations in Sustainable Management of Maize Storage Pests to Supply Safe Food and Feed

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Abstract Maize is one of the most important cereal crops in Sri Lanka and the world. With the increase of the world population, demand for maize keeps on increasing, which is accelerated by the increasing demand for poultry feed, for which maize is the main energy source. The loss of grain in quantity and the deterioration of quality by storage pests remain a main concern. The preservation of maize during storage needs to be done sustainably. Considering the drawbacks of the traditional storage methods, farmers shifted to chemical pesticides to preserve stored grain. The public awareness of environmental safety, toxicity to humans and animals, and the increasing demand for pesticide-free food have created pressure on the research community to develop alternative measures for the management of stored products insect pests. The research findings indicate that the resistant traits in maize can be improved by identifying the resistance against storage pests in local varieties and through hybridization. The progress in the research, development, and application of biopesticides shows the potential for the use of local resources to produce biopesticides for managing the stored products pests. The alternative storage pest management strategies are considered simple, economical, effective, and environmentally friendly. It is recommended to formulate policies to invest more in IPM research, development, and implementation, which also include development and cultivation of resistant maize varieties and development and application of biopesticides against storage pests to ensure a sustainable and safe supply of maize grain for food and feed.

Keywords: Food security, Grain storage, Postharvest losses, Insect pests

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Magnitude of the Problem

Maize (*Zea mays* (L.)) is a major cereal crop due to its various uses as a food, feed, and raw material for industries [1]. Maize is the most widely used grain in the diets of intensive poultry production in the world [2]. The demand for maize in the developing world will be increased by two-folds by 2050 [2]. Consuming maize is one of the most important ways for the human body to acquire nutrients that are necessary for its normal functioning [3]. On the other hand, maize is considered to have a relatively high nutritional value for poultry, where the contribution of maize is around 65% of the metabolizable energy and 20% of the protein requirements in a broiler starter diet [4].

Maize is the second major cereal crop in terms of the extent of cultivation and productivity in Sri Lanka. As shown by Premarathne and Samarasinghe [5], the major user of maize in Sri Lanka is the feed manufacturers. Maize grain is also used for "Thriposha", which is a processed food for feeding mothers and infants. Part of the harvested green corn is directly used for human consumption, while another portion of the local production is used in the feed industry. According to [5], the gap between local supply and demand for maize has been widening since 2014, mainly due to higher demand for poultry feed formulation that paved the way for maize imports [6].The storage of maize grain to be used during the off-cultivation season is a common practice. According to Kumari et al. [7], 3.3%–33.6% of maize is stored after harvesting in the Anuradhapura district. The storage statistics of Sri Lankan maize have been hard to estimate. However, estimates suggest that 44,000MT of maize grain may be stored annually from local production. Kumari et al. [7] stated that the percentage of loss during storage was 5%-13%. According to Wasala et al. [8], insect infestation accounts for 4–6% of grain losses in tropical countries such as Sri Lanka during warehouse storage. In the Sub-Saharan Africa region, maize weevils (*Sitophilus zeamais*), larger grain borer (*Prostephanus truncatus* (Horn)), moths, and red rust flour beetle (*Tribolium castaneum* (Herbst)) are the major insect pests [9]. These pests can incur 100% grain loss within months if they are not controlled.

According to Manandhar et al. [10] and Otieno and Alwenge [9], the use of chemical pesticides, such as phosphine, actellic super, shumba dust, and super grain dust to manage maize storage is common in developing countries. The authors' preliminary observations found that actellic compounds are mainly used to control maize storage pests indiscriminately. The use of chemical pesticides in protecting food and food products is found to have a deleterious effect on human health [11]. A study on rabbit feed formulated with maize contaminated with higher concentrations of actellic dust resulted in toxicity symptoms and sometimes death in growing rabbits (Omoyakhi et al., [12].

The usage of chemical pesticides to manage storage pests is a common practice and the subsequent multi-faceted effects have been documented elsewhere [13], [14]. The extensive use of chemical insecticides for the management of stored pests has become a global issue due to the environmental hazards associated with the development of resistance to the chemicals, bioaccumulation in the food chains, broad-spectrum of actions on non-target organisms, and the exorbitant cost of the chemicals [15].

The public's understanding of environmental safety, toxicity to humans, and the increasing demand for pesticide-free food have compelled the world research community to focus on the development of alternative mechanisms like the use of resistant maize varieties and biopesticides against the storage pests. Therefore, it is necessary to look for an eco-friendly solution to manage the store products pests which is non-toxic to non-target organisms and easily biodegradable and could be produced from locally available raw materials while minimizing the use of synthetic pesticides to sustain the supply of safe food and feed.

Insect Pests Associated with Maize Grain

The insects that cause damage to the maize in storage, affecting the quantity and quality, have already been identified by several research studies. Insects that affect healthy grains like maize and inflict losses on grains are referred to as primary pests. Secondary pests, on the other hand, are those that target already damaged grains and inflict more harm [16]. Table 1 summarizes the insect pests that damage the maize grains.

Due to their feeding activities, insects increase the temperature of the product, resulting in "hot patches' that can reach up to 57 °C [23]. These patches cause a concentration of dampness within the product, promoting grain degradation and more fungal growth. The influence of quality can be significantly damaged by a secondary infection from a variety of fungal species. Fungal contamination causes changes in color, taste, and odor, as well as a decrease in nutritional value, an increase in free fatty acids, and a decrease in germination capacity [4]. Mycotoxins are metabolites generated by this fungus that can cause a variety of health issues. Aflatoxin produced by *Aspergillus* spp. has particular concern over its significant carcinogenic qualities, which has restricted global trade [23].

Table 1: Common maize storage pests

Common name	Scientific name	Type of pest	Reference
Maize weevil	*Sitophilus zeamais*	Primary Pest	[17], [18]
Granary weevil	*Sitophilus granarius* (L.)	Primary Pest	[17], [19]
Rice weevil	*Sitophilus oryzae* (L.)	Primary Pest	[20], [18]
Red rust flour beetle	*Tribolium castaneum* (Herbst)	Primary Pest, Secondary Pest	[17], [18]
Confused flour beetle	*Tribolium confusum* (Jacquelin du Val)	Primary Pest, Secondary Pest	[20], [17]
Lesser grain borer	*Rhyzopertha dominica* (Fabricius)	Primary Pest	[20], [19]
Larger grain borer	*Prostephanus truncates* (Horn)	Primary Pest	[21], [17]
Saw toothed grain beetle	*Oryzaephilus surinamensis* (L.)	Secondary Pest	[21], [22]
Yellow mealworm beetle	*Tenebrio molitor* (L.)	Secondary Pest	[21], [17]
Flat grain beetle	*Cryptolestes pusillus* (Schonherr)	Secondary Pest	[18], [17]
Rusty grain beetle	*Cryptolestes ferrugineus*	Secondary Pest	[17], [20]
Merchant grain beetle	*Oryzaephilus mercator* (Fauvel)	Secondary Pest	[17]
Square-necked flour beetle	*Cathartus quadricollis*	Secondary Pest	[17]
Indian meal moth	*Plodia interpunctella* (Hubner)	Secondary Pest	[18], [22]
Rice moth	*Corcyra cephalonica* (Stainton)		[18]
Maize grain moth	*Sitotroga cerealella* (Olivier)	Primary Pest	[17], [18]
Tropical warehouse moth/ Almond moth	*Ephestia cautella* (Walker)	Secondary Pest	[17], [18], [20]

Further, because of contamination with dead insects, waste materials, frass, and dust due to insect activity, the grain loses its economic value and earns a poor grade [25]. A pest infestation can also increase the amount of fatty acids in the grain and leave large amounts of uric acid, which causes grain rancidity [6]. Contamination of the embryo of seeds by Eurotium fungus can result in a 50–100% diminution in germination, lower levels of amino acids in the grain, and loss of the unique grain odour and flavour [24]. The natural odour of grain

bulk is changed into a musty or mouldy odour in extensively infected grain bulk. Several *Aspergillus* and *Penicillium* species are linked to mycotoxins (orchratoxin A in maize) that can cause serious health problems in humans and animals [24]. Consumer demand for safe and hygienic food free of pests and chemical residues has increased over the years. Even though exporting countries strive to keep their grain consignments 'insect-free', sometimes, as a result of phytosanitary measures failing, when live insects are spotted at importing terminals, the entire shipment of grain may be rejected, or a demurrage fee, as well as disinfestation fees, may be imposed [23].

The intake of contaminated feed by animals is the most common route for pesticide/insecticide contamination of animal origin food [27]. Hamid et al. [28] reported that, chlorinated pesticide residues were observed in the body tissues and eggs of chickens i.e., Bifenthrin and difenoconazole were found in egg samples. Because of the lipophilic nature of the organochlorine pesticides, they congregate in fatty tissues and bioaccumulate throughout the food chain [29]. As a result, these chemicals are present in larger amounts in fatty foods, and organochlorine pesticide exposure can also occur through low-level food contamination. Eggs have a high fat content and will acquire long-lasting organic contaminants such as polychlorinated biphenyls (PCBs), dioxins, and pesticides [28]. As shown by [30], the Endosulfan pesticide caused lower egg-hatchability and sterility in hens. The following insecticides are frequently used in maize storage to eliminate pest damage by local farmers.

Actellic Super (Pirimiphos methyl)

Actellic super is a frequently used insecticide in Sri Lanka to prevent storage pests during the storage of maize grains by the local farmers [31]. The active component in Actellic super dust is O-2-diethylamino-6-methylpyrimidin-4-yl-O, O-methyl phosphorothioate, also known as pirimiphos-methyl [12]. Actellic super is a broad-spectrum organophosphorous non-cumulative insecticide and acaricide with the mode of action of contact and fumigant [12]. After exposure for 14 days, pirimiphos-methyl causes an elevated level of death to immature larvae of around 60% in maize storage [32]. Likewise, pirimiphos-methyl controlled four psocid (Psocoptera) species on maize by 100% [33]. Another study based on pirimiphos-methyl was found to be successful in controlling twelve populations of *Sitophilus granarius* [34]. The average residues of pirimiphos-methyl found in the food products were frequently in the range of 40 -60% of the nominal dose [12].Mahugija et al. [35], found that pirimiphos methyl was detected at different levels in kidney, liver, and muscle samples of the chickens in Tanzania. A study conducted in Egypt also revealed that pirimiphos methyl was found in chicken samples [36]. Pirimiphosmethyl is a relatively cheaper pesticide that is extensively used to preserve food from pests across the globe, notably in the African region. Pirimiphos-methyl is a non-cumulative insecticide that causes the hydrolysis of body choline esters, including acetylcholine, at cholinergic synapses [37]. Inhibiting aforesaid enzymes will result in both nicotinic and muscarinic actions in the body, such as muscular contraction and secretion in numerous glands.

Storage Methods Used to Store Maize Grains

Storage methods are mainly divided into traditional, conventional, and modern, which are further subdivided based on either construction techniques or both construction techniques and principles used (Figure 1). Traditional grain storage management practices have losses ranging from 20% to 50% [38]. Traditional grain storage buildings are offered to farmers in order to conserve and propagate them for future use. Apart from being environment-friendly, these structures are cheaper, and locally accessible, preserve the stored grains and do not pose any health risks [39]. However, farmers moved away from traditional and conventional methods and began using synthetic chemical preservatives due to the inefficiency of traditional and conventional methods [40]. It was found that the initial investment and the related technology are the main obstacles in adopting modern storage methods by smallholder farmers in developing countries [41].

Development of Resistant Maize Varieties

Several research studies conclude that the development of resistant maize varieties against grain stored product pests is possible and can be encouraged for field and commercial cultivation. Table 2 summarizes resistant maize varieties identified or developed against stored product pests and corresponding recommendations by various research studies in various regions of the world. According to Zunjare et al. [49], the developed resistant varieties would be a sustainable and economically viable solution to post-harvest loss of grains during storage.

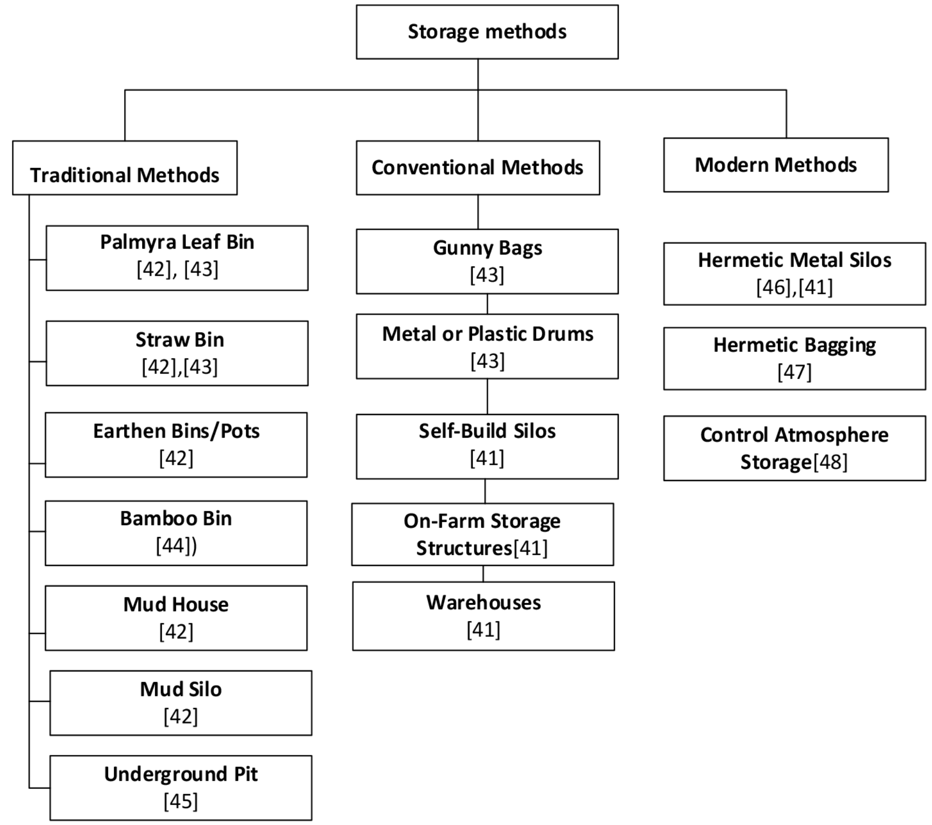

Figure 1: Traditional, conventional and modern methods used to store maize grain

Table 2: Resistant varieties identified against maize storage pest

Resistant varieties and recommendations	Target pest	Reference
2000SYNEE-WSTRand TZBRELD3C5. Can be used singly or best in an integrated pest management process.	*Sitophilus zeamais* (maize weevil)	[50]
ZM421 and ZM521 highly tolerant maize varieties. Need to breed ZM521 and ZM421 maize varieties in breeding programs for weevil resistance.	*Sitophilus zeamais* (maize weevil)	[51]
2000SYNEE-WSTR and TZBRELD3C5. Can be used to control grain damage in maize storage.	*Sitophilus zeamais* (maize weevil)	[52]
The variety SR52 under the laboratory CTH and the stock room ATH conditions is considered as resistant. Resistance to can be developed to minimize the grain loss.	*Sitophilus zeamais* (maize weevil)	[53]
BHQP-542' can be used in storage management	*Sitophilus zeamais* (maize weevil)	[54]
Pertiwi 3 are resistant ones. Bisi 19, Bisma, Bisi 18, Pioneer 21 and Pioneer 29 are moderately resistant in Indonesia. Can be used to reduce grain losses during storage.	*Sitophilus zeamais* (maize weevil)	[55]
Early-Thaï, DMR-ES and Tzee-Yellow Can be used to reduce the maize postharvest losses.	*Prostephanus truncatus* (Horn) (larger grain Borer)	[56]
BHQP-542 is the resistant maize variety. Promoted for stored pest management in eco-friendly manner for small scale farmers in the tropics.	*Sitophilus zeamais* (maize weevil)	[57]
Transgenic avidin maize, Avidin when present in maize at levels of ≥100 ppm toxic to and prevents development of insects which cause damage to grains during storage.	*Sitophilus zeamais* (maize weevil) and many other species of stored-product pests	[58]

The term "insect resistance" refers to "the relative amount of heritable qualities possessed by a plant or its materials (for example, its seeds) that influence the ultimate degree of damage done by insects." [59]. For stored grains, resistance represents the ability of a certain crop variety to produce grains that maintain better quality than commonly cultivated varieties following long storage under similar insect populations" [60].

The host plant resistance (HPR) is found in the seeds that are readily available to farmers for cultivation. After seeding them, farmers do not require more effort in order to manage post-harvest pests of maize. HPR to post-harvest insects is an inherent characteristic that has been demonstrated as antibiosis, antixenosis, and tolerance [61]. Antibiosis is the negative impact of the host-plant on the biology of the insects and their progeny (survival, development, and reproduction). Antixenosis is when the plant and the seed are not desirable as a host and the pests and post-harvest pests look for other hosts. Tolerance refers to a situation where the plant is able to withstand or recover from stem borer damage [62].

Nwosu [63] concluded that the variation in resistance levels of the elite maize varieties is a measure of the intrinsic ability to resist *S. zeamais* attack. The antibiosis effect of the resistant elite maize varieties significantly affects the survival and development of *S. zeamais*. The combined effect of antixenosis (non-preference) and antibiosis due to the presence of a higher level of crude fiber in grain, phenolic acid, and trypsin inhibitor is responsible for resistance to *S. zeamais* infestation. On the other hand, higher levels of protein, starch, and minerals cause the elite varieties to become susceptible. Further, Nwosu [63] suggested that the testing of protein, starch, and minerals are needed for impairment for a maize breeding program which will help against the infestation by *S. zeamais* in stored maize. However, it is important that this does not lead to substantial nutritional losses in the amount required by human beings and livestock.

Lopez-Castillo et al. [20] demonstrated that the understanding of resistance mechanisms is the basis for the development of new effective and resistant varieties for a sustainable measure for developing countries. The mechanisms of resistance (anatomical, biochemical, and genetic) and underlying factors for each resistance type and their implications for different storage pests are comprehensively investigated and documented.

Nwosu [63] indicates that the integration of the resistant chemical properties into other maize varieties is necessary to increase their resistance to *S. zeamais*. Several studies indicate that physical properties have been shown to be a basis for resistance to the attack of *S. zeamais* and some other insect pests of stored maize [64]. The existing literature clearly indicates that resistant traits in maize can be improved by identifying the resistance against storage pests in existing local varieties and through hybridization. The development of resistance varieties is considered the easiest, most economical, effective, and environmentally friendly way of managing insect pests on stored grains. Further, there is no specific technology that can be used by the farming community and they need to invest only in seeds. It is also important to note that the method can be easily incorporated with IPM since it is highly compatible with other pest management methods in grain storage.

Use of Biopesticides for Maize Grain

Researchers found the various aspect of stored grain pest management techniques including design of storage structure with different capabilities for manipulation of the environment, application of chemical and biopesticides, mechanical and traditional pest control methods and factors to prevent the infestation in the stored grains. Plant essential oils and their components with fumigant actions are used as biopesticides since the use of plant sources with the benefit over traditional fumigants in regards to low mammalian noxiousness, rapid decaying, and readily available in the local environment. Several plant species have been recognized with fumigant properties to control insects of stored grain during the last four decades (Table 3) . It has been evident that most of the plant extracts can control the feeding and breeding of stored grain insects or even kill them swiftly to chemical fumigants [65]. For example Sharma [66] found that neem-based products with recommended concentrations protected maize against *S. oryzae*, *S. cerealella*, *R. dominica*, and *T. castaneum* over five months. Neem has also been demonstrated to be effective against maize storage insects in several investigations [67].

Table 3: Plant parts used for insecticidal activities against storage insects of maize

Scientific name	Common name	Plant part used	Target pests	Reference
Acorus calamus (L.)	Sweet Flag	Rhizome	*Sitophilus oryzae, Tribolium castaneum*	[68]
Anethum graveolens (L.)	Dill	Seed	*T. castaneum*	[69]
Annona squamosa (L.)	Bullock's Heart	Leaf and stem	*S. oryzae*	[70]
Artemisia annua (L.)	Mugwort	Stem and leaf	*T. castaneum*	[71]
A.capillaris	Chinese wormwood	Stem and leaf	*Sitophilus zeamais*	[72]
Carum carvi (L.)	Caraway	Fruit	*S. zeamais, T. castaneum*	[73]
Eucalyptus globulus	Blue Gum	Leaf	*S. oryzae, T. castaneum*	[74]
Hyptis spicigera	Black Sesame	Whole plant	*S. zeamais*	[75]
Lavandula angustifolia	Lavender	Whole plant	*S. oryzae, R. dominica, T. castaneum*	[76]
Momordica charantia (L.)	Bitter Gourd	Leaf and seed	*S. oryzae, T. castaneum*	[77]
Cinnamomum aromaticum	Cassia	Bark	*T. castaneum, S. zeamais*	[78]
Psidium guajava (L.)	Guava	Leaf	*S. oryzae*	[79]
Mentha citrate	Peppermint	Aerial part	*T. castaneum, C. maculatus*	[80]
Z. officinale	Ginger	Rhizome	*T. castaneum*	[81]
Convolvulus arvensis (L.)	Bind weed	leaves	*R. dominica, S. oryzae*	[82]
Colocasia esculenta var. esculenta (L.)	Cocoyam	Rhizome	*S. oryzae, T. castaneum, C. chinensis*	[83]
Pimenta racemosa	Bay rum tree	leaves	*S. zeamais*	[81]
Lantana camara (L.)	Shrub verbena	Leaves	*S. oryzae, T. castaneum, R. dominica*	[84]
Tagetes filifolia	Irish lase	Aerial parts	*T. castaneum*	[85]
Vitex negundo (L.)	Nirgundi	Leaf	*S. oryzae*	[86]
Eucalyptus spp.	Gum tree	leaf	*S. oryzae*	[82]

The subject of biopesticides has developed excellent application prospects during the last ten years, with numerous social and economic benefits. Biopesticide research and use have progressed to the point where hazardous pesticides are being replaced in the market, resulting in a decrease in chemical pesticide manufacturing by 2% each year in recent years [87]. Application of biopesticides is considered an eco-friendly method to reduce the effect of pests on stored products while also reducing the hazards to the environment and also humans and animals. At present, improving the quality of stored products is a challenge due to the storage pest attack. It is necessary to improve quality and quantity while improving the range of commodities, keeping quality with scientific-technical advancements in line with the demand of the country. Further, the preservation quality and quantity would ensure better nutrition for a mass of the population who suffer from malnutrition.

Conclusions

This chapter evaluated the literature on challenges caused by insect pests in storage of maize, storage methods used, chemical pesticides used to manage storage pests, research and developments on resistant maize varieties which produce grains that are less susceptible to storage pest damage; and advances made on biopesticide applications. The purpose was to explore the progress in innovations and developments in storing and supplying maize grain sustainably that are safe for human consumption and animal feed formulation. A significant portion of maize grain loss by insect pests takes place during the storage, which is, however, dependent on the environmental conditions, micro-climatic conditions of the storage, maize variety, nutrient composition of the grain and the methods used to manage the pests. The traditional methods used to store maize grains are ineffective in controlling the storage pests. Certain conventional and modern methods used are not affordable for small-holder farmers. Though chemical pesticides significantly reduce grain loss, environmental threats, chemical resistance development, the availability of harmful residual effects in food, a broad spectrum of actions on non-focal organisms, and the high cost of the chemicals are major concerns. Mazie variety identification and hibrydization in different parts of the world indicate the high potential for the development of resistant varieties to produce less susceptible grain to maize storage pest attack. The progress made with regard to biopesticide application indicates the potential for local innovations through research and development using local resources.

Advances and Innovations in
Sustainable....

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CHAPTER 11

CURRENT STATUS OF NATIONAL BIOSAFETY REGULATORY SYSTEMS IN SOUTH ASIA

The Current Status of National Biosafety Regulatory Systems in South Asia

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Abstract Biotechnology has revolutionized the way of life on earth. The Modern biotechnology approaches have been instrumental in developing genetically modified organisms (GMOs) that are now frequently being used in most of the major industries, particularly in food and agriculture. It is evident that these GMOs have increased the production and productivity and brought in many positive incentives in many industries. Since these genetic modifications involve the transfer of genetic material between widely unrelated organisms, despite the benefits, concerns have risen over the use of GMOs with respect to environmental safety, human and animal health, and several other social, ethical, and cultural aspects. Among which, food safety and the impact of GMOs on biodiversity are two key areas of concern. Given the concerns, ensuring the safe use of GMOs has become one of the major global discussions of the past few decades. Since its first attempt in the early 1970s, ensuring biosafety of GMOs has evolved and strengthened with the addition of numerous regulatory instruments, with the Cartagena Protocol on Biosafety acting as the main legally binding global protocol on ensuring biosafety. The national biosafety regulatory frameworks vary across countries depending on the extent of utilization of GMOs and related products and the extent of biotechnology research conducted. Developing and practicing biosafety regulations has become a timely need as it ensures the sustainable utilization of genetic resources. This chapter summarizes the current status and prospects of the national biosafety regulatory systems of the countries in the South Asian region. Furthermore, the chapter discusses the main challenges and the way forward in implementing and improving national biosafety regulatory systems.

Keywords: Biodiversity, Biotechnology, Genetically Modified Organisms, National Biosafety Framework, South Asia

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Biotechnology and Biosafety

The continual population growth and changes in the way of living due to rising per capita income have shifted the industries and the world's economy into a new dimension. With limited resources available, maintaining continuous supply to cater to the ever-growing demands has become a pressing challenge in most of the major industries, particularly in food and agriculture. Modern biotechnology approaches (i.e. development of transgenic organisms *via* genetic engineering, gene editing) are now being frequently used as promising approaches to meet the gap between demand and supply. Two decades after revealing the structure and function of the DNA molecule in the 1970s, recombinant DNA technology has emerged as an efficient way of bringing together genetic material from multiple origins [1]. Since then, scientists have used this technique for the modification of plants, animals, and microorganisms through precise manipulation of their genetic structures to make them more efficient and productive in commercial ventures. Genetic modifications *via* recombinant DNA technology produce new genetic combinations that are beyond the scope of conventional selection and breeding techniques. Such modified organisms are known as transgenic, Living Modified Organisms (LMOs) or more popularly, Genetically Modified Organisms (GMOs).

GMOs are being successfully used in enhancing crop production while minimizing the use of agrochemicals, cost-effective food or drug production, improving nutrient composition and quality of food, and sustainable resource utilization [2]. Production of synthetic human insulin is one of the early achievements of genetic engineering. In the field of agriculture, a tomato called FLAVR SAVR™, which was modified for prolonged shelf life, was released as the first genetically modified product. The release of Bt cotton, which was genetically modified to produce an insecticide, and Roundup-ready soybean, which was modified to be resistant to glyphosate (a broad-spectrum herbicide), brought many advantages back to the industry, including increased production and minimized use of agrochemicals [3]. However, despite its potential, the use of GMOs and related products, especially in agriculture and food production, has been immensely debated over the last two decades given the anticipated risks to biodiversity and human health.

Concerns have risen about the environmental safety (e.g. impact on non-target organisms and biodiversity), human and animal health (e.g. buildup of antibiotic resistance, unexpected allergies and production of toxins, nutritional changes), social, ethical, and cultural impacts [4], [5] based on the fact that the development of GMOs involves gene transfer between widely unrelated organisms. Furthermore, potential trade monopolies and agricultural crop ownership, international trade, and movement across regional and country

boundaries have emerged as socioeconomic concerns associated with GMOs [6]. More importantly, the concern about food safety and the impact of GMOs on the environment have captured the attention of the world since both have direct and indirect effects on human and animal health. The lack of solid evidence concerning the safety of GM food and the possibility of unintentional gene transfer into the agro-ecosystems *via* pollen or seeds of GM crops has made the public more vigilant about the safety of GM food. Use of GM technologies in modern crop improvement has been raised as one of the reasons for genetic erosion in agro-ecosystems. The introduction of crops with highly specific characteristics and mass cultivation of those has reduced the abundance of local varieties in farmer's fields, leading to reduced genetic diversity. Given the concerns, various instruments on biosafety regulations related to modern biotechnology have been developed and implemented at both the national and international levels to ensure the safety of humans and the ecosystem.

International Instruments of Biosafety

Discussions on the need for biosafety measures in handling recombinant DNA technology and related products started in the early 1970s. A set of guidelines developed by the Recombinant Advisory Committee of the United States National Institutes of Health in 1974 is considered the first attempt made to ensure biosafety related to biotechnology. The said guidelines were produced to ensure the safety and ethical issues related to research involving recombinant or synthetic nucleic acids and molecules [7]. Taking after the United States, several other countries with strong biotechnology industries have included biosafety regulations and risk-assessment systems into their national legislation and have also entered into international agreements regarding biosafety issues, particularly related to transboundary movement of GMOs and related products.

The Convention on Biological Diversity

The Convention on Biological Diversity (CBD) was opened for signature at the United Nations Conference on Environment and Development (the Rio "Earth Summit"; 5 June 1992) and entered into force on December 29, 1993, with 168 signatories. The CBD has three main objectives; the conservation of biological diversity, the sustainable use of its components; and the fair and equitable sharing of the benefits arising from the use of genetic resources. The Convention on Biological Diversity addresses the issue of biosafety and emphasizes the need to ensure human and environmental health from the anticipated risks of the products coming from modern biotechnology. On the other hand, CBD recognizes the potential of modern biotechnology to improve human health and well-being and sustainable resource use. While referring to both the potential and issues of modern biotechnology, the overall objective of the CBD is to reduce the threats to biological diversity [8]–[10].

The Cartagena Protocol on Biosafety

In 2003, as a supplementary agreement to the CBD, the Cartagena Protocol on Biosafety (hereinafter referred to as the Protocol) entered into force. The protocol addresses the safe transfer, handling, and use of LMOs with possible adverse effects on biodiversity and human health. It specifically focuses on transboundary movements of LMOs to be used as food, feed, or for processing and for direct introduction into the environment [11]. The Protocol comprises 40 articles, which describe the requirements and legal aspects of the safe transfer, handling, and use of LMOs. As of January 2022, 173 parties have ratified or acceded to the Protocol (https://bch.cbd.int/protocol/parties/) indicating their willingness to accept imported commodities that include LMOs. Parties communicate their decision on LMO importation and related matters to the international community through a mechanism known as the “Biosafety Clearing House (BCH),” which is used to exchange information and experience with LMOs [12].

Apart from the Protocol, many other international instruments (Box 1) are directly or indirectly relevant to different aspects of biosafety. The Organization for Economic Cooperation and Development, the International Plant Protection Convention, the World Trade Organization-Agreement on Application of Sanitary and Phytosanitary Measures and the Codex Alimentarius Guidelines on Foods Derived from Genetically Engineered Plants are some of these agreements.

Biosafety Regulations in South Asian Countries

The biosafety regulatory systems vary across countries. National mandates on biosafety regulations depend on the extent of utilization of GMOs and related products and the extent of biotechnology research conducted. Some countries developed entirely new biosafety regulatory systems, while others amended the existing regulatory systems to address the rising biosafety concerns. At present, three of the eight countries that belong to the South Asian Association of Regional Cooperation (SAARC) are producing biotech crops [13]. GM cotton (Bt cotton-pest resistant) is widely cultivated in India [14] and Pakistan, while GM Brinjal (Bt-Brinjal - pest resistant) is grown in Bangladesh [15]. Recently, the Bangladesh government has cleared the way for the commercial cultivation of golden rice, GM rice with high levels of beta-carotene [16]. Further, biotechnology research is conducted in all the SAARC countries except Bhutan. However, all eight countries are parties to the Protocol and have already established or are in the

Box-1: International Instruments of Biosafety

The International Plant Protection Convention (IPPC)-1952: develops international standards on phytosanitary measures against pests of plants and plant products including GMOs.

The Organization for Economic Cooperation and Development (OECD)-1961: involves in harmonization of international regulations, standards and policies.

The Codex Alimentarius Commission (CAC)-1972: involves in developing international standards including those for food safety and food labeling.

The World Trade Organization (WTO)-1995: addresses the issues related to procedures of risk analysis of plant and animal pests and diseases, and food safety under the WTO Agreement on Application of Sanitary and Phytosanitary Measures.

process of establishing National Biosafety Frameworks (NBFs) to comply with the obligations under the Protocol.

The Global Environment Facility (GEF) of the United Nations Environment Programme (UNEP-GEF) has been operational since 2002 to assist countries to comply with the Protocol when modeling their NBFs [13], [14]. As defined by the UNEP-GEF, a national biosafety framework is,
“a combination of policy, legal, administrative, and technical instruments that are developed to ensure an adequate level of protection in the field of the safe transfer, handling, and use of living modified organisms resulting from modern biotechnology that may have adverse effects on the conservation and sustainable use of biological diversity, taking into account risks to human health” [19].

A NBF consists of five key components (Box 2) that address policy, regulation, legislation, and administration, as well as public awareness [19].

Box 2 - The Key Components of a National Biosafety Framework

(a) A National Biosafety Policy: A stand-alone policy on biosafety or part of policies on biotechnology, agricultural production, food production and/ or food safety, biosecurity and/or quarantine, biodiversity conservation, environmental protection, science and technology or sustainable development

(b) A Regulatory Regime: that comprises legislations, laws, acts, regulation, decrees, or guidelines, etc.

(c) An Administrative System: that includes the competent authorities responsible for receiving and handling requests for permits, systems/ procedures for handling notifications and requests for permits, risk assessment, decision-making and meeting obligations under the BCH and national participation in the BCH

(d) Mechanisms for public awareness, education and participation: includes public access to information on GMOs, public involvement in the decision-making process for GMOs and awareness and education on GMOs

(e) Systems for follow up: includes monitoring for environmental effects and effects on human, animal or plant life or health, enforcement to ensure compliance, offences and penalties.

The following section summarizes the current status of NBFs in each South Asian country and how other policy, legislative, and administrative efforts contribute to ensure biosafety in each country.

Afghanistan Afghanistan became a party to the Protocol in 2013. However, over the past years, only a few steps have been taken by the local authorities to comply with the Protocol. Afghanistan is in the process of developing a NBF. The National Environmental Protection Agency's international relations division and natural inheritance protection department have been designated as National Focal Points (NFP), but a National Competent Authority (NCA) for the protocol has yet to be identified. According to the third national report on the implementation of the Protocol, some regulations and legal instruments such as the National Food Safety Act, Transboundary Trade Act, Environmental Law, and procedure for protection and utilization of wild plants are in place in compliance with the Protocol [20].

Bangladesh Even at the time Bangladesh became a signatory to the Protocol (2000), some regulatory measures on biosafety were included in the national

legislature (i.e., Bangladesh Biosafety Guidelines: 1999). After ratification of the Protocol in 2004, existing biosafety regulations were reviewed to see how far the existing ones were adequate to comply with the Protocol. In order to fulfill the protocols' obligations, the NBF of Bangladesh was developed in 2007 and it acted as the foundation for the administrative and regulating system to safeguard human health and the environment from the use of GMOs. The NBF contained six chapters explaining the relationship of the NBF with the Protocol; the outline of the administrative system to deal with GMOs in safe transfer, handling, and utilization; existing legislation on biosafety; the outline of the proposed regulatory regime; the status of biotechnology and biosafety in the country; and future prospects of strengthening national biotechnological research and development capacity and the public participation in the decision-making process on GMO related issues. The NBF of Bangladesh is administered through various ministries and the associated departments. The Ministry of Environment and Forest functions as the (NFP) as well as the NCA to the Protocol. National Committee on Biosafety, Biosafety Core Committee, Institutional Biosafety Committees and Field Level Biosafety Committees etc. are responsible for ensuring Biosafety at the respective administrative levels [21-23].

Apart from the NBF, many other acts, rules, and guidelines were enforced to strengthen the biosafety regulations. The Biosafety Guidelines of Bangladesh were formulated by the Ministry of Science and Technology in 1999 (revised during 2004-2006 considering the obligations towards the Protocol) with the objective of ensuring the safe use of LMOs in lab experiments and field trials, transboundary movement, transit, and handling [22]. The Guidelines are applicable to all research and development activities in modern biotechnology conducted in Bangladesh. The Bangladesh Biosafety Rules (2012) regulate the approval process for genetically engineered (GE) products. It emphasizes the mandatory approval of GE products to be imported or sold domestically within Bangladesh. The Bangladesh Standardization and Testing Institute is in charge of determining the safety of foods derived from GE plants. The Guidelines for the Environmental Risk Assessment of Genetically Engineered Plants (2016) enable the planning and conducting of environmental risk assessments before the open release of a GE plant in Bangladesh. The Users' Guide to the Biosafety Regulatory Process on Genetically Engineered Plants in Bangladesh (2017) serves as an informational resource for interested parties to understand the regulatory processes associated with biosafety in the country [22].

Bhutan With the intention of protecting biodiversity and promoting organic agriculture, Bhutan has been adopting a precautionary policy regarding GMOs. Since GMOs are currently banned from domestic use, research and development related to modern biotechnology are not practiced in Bhutan. Under the Biosafety Act (2015), the cultivation, import and distribution of GE crops are currently prohibited in Bhutan, and any form of environmental release of viable

GMOs is strictly prohibited. However, GE food and feed, which are in non-viable forms, are allowed into the country only after a safety assessment by the Biosafety Technical Working Group and the approval of the National Biosafety Board of Bhutan. With the funding and assistance received from UNEP-GEF, Bhutan developed the NBF in 2006. The Bhutan Agriculture and Food Regulatory Authority was designated as the NCA to the Protocol. The National Biosafety Board acts as the highest administrative body for biosafety in Bhutan. It has the power to exercise the jurisdiction and discharge the mandates conferred or imposed by the country's Biosafety Act [24].

India The National Biotechnology Board's Biotechnology Safety Guidelines (1983) are regarded as India's first biosafety initiative. After several changes in the administrative structure, at present the responsibility of environmental protection and biodiversity conservation concerning GMOs, the commercial release of GMOs and their transboundary movement is shared between the Department of Biotechnology under the Ministry of Science and Technology and the Ministry of Environment and Forests of India. The Environmental Protection Act (EPA;1986) acts as the foundation of the biosafety regulatory framework in India with rules related to manufacture, utilization, import, export, and storage of hazardous microorganisms/GMOs or cells; large-scale commercialization of GM crops; and post-approval monitoring of violations and non-compliance with biosafety guidelines. The five competent authorities (Institutional Biosafety Committees, Review Committee on Genetic Manipulation, Genetic Engineering Appraisal Committee, State Biotechnology Coordination Committee, and District Level Committee) are identified by the EPA collaboratively strengthening the biosafety system of India.

The EPA has introduced and implemented a three-tier system of approval for GMOs and related products. In this system, the initial assessment is done at the institutional level by the Institutional Biosafety Committees and the proposals are recommended to the Review Committee on Genetic Manipulation. Approval is granted upon the evaluation of the proposals by the Genetic Engineering Appraisal Committee [25]. As per the requirements of the Protocol, with support from the GEF-World Bank capacity building project, India established its BCH in 2006. The NBF of India is successfully implemented *via* GEF-India. The Ministry of Environment and Forests is designated as the NCA in order to administer the functions mandated by the Protocol [26].

Maldives Maldives ratified the Protocol in 2003. To effectively implement the protocol, the Ministry of Environment, Energy and Water of the Maldives initiated a project to develop a NBF with funding from the UNEP-GEF. The National Biosafety Commission acts as the NCA and the Environment Research Centre, Ministry of Environment, Energy and Water, serves as the NFP to the

Protocol. The NBF was developed after consulting relevant stakeholders, and it provided the needed framework for regulating products resulting from modern biotechnology for their safe use. The National Biosafety Commission acts as the NCA under the Protocol. The Maldives' NBF is based on the precautionary principle and advanced informed agreement [27], [28].

A Biosafety Bill has been formulated in 2021 and is currently at the review stage. This bill addresses the ways of developing, handling, transport, utilization, and transboundary movement of LMOs with minimum risks to biodiversity and human health. Although the current Biosafety Bill prohibits the contained use of LMOs in the country, there will be changes to this policy when the bill gets enacted. This Bill contains the procedures for the transit of LMOs. It proposes the collaborative function of the Maldives Customs Service and the NCA to ensure the safe handling and transport of LMOs in transit. To date, there has been no formal record of the use of LMOs in food, feed, or processing industries in the Maldives. However, during the stakeholder consultation programs, it was evident that, there is a high possibility of using LMOs in food, feed, or processed products even though it is not formally recorded. Hence, formal record-keeping of LMOs and related products has been made mandatory through this Bill [28]. The Environmental Protection and Preservation Act (1993), the Law on Plant Protection (1993), the Maldives Customs Act (2011), the Import and Export Law (2011), the National Standard for Labeling Packaged Foods (2016), the National Food Safety Policy (2017), the Fisheries Act (2019), the Good Agricultural Practices Certification Scheme (2020), and the Consumer Protection Act (2021) are other legal instruments that indirectly apply to Maldives biosafety [27].

Nepal As a party to CBD, Nepal became a signatory to the Protocol in 2001 and has initiated regulation of biosafety concerning GMOs and related products. Currently, the two main mechanisms which are responsible for biosafety regulation in Nepal are the Biosafety Guidelines (2004) and the National Biosafety Framework (2006). The Biosafety Guidelines focus on regulating laboratory and GMO safety, and these guidelines explain the processes of releasing GMOs and related products to the environment. The NBF of Nepal was implemented in 2006 and it involves the authorization of the concerned agencies for biosafety regulatory measures and to avoid potential risks of GMOs.

The framework addresses the development, production, contained use, field-testing, introduction into the environment, and transboundary movement of GMOs. Further, the NBF covers the existing and potential use of GMOs in improving human health, agricultural productivity, the food and feed industry, and waste management. It also deals with the flow of information, risk assessment in laboratory and field-testing, and socio-economic and ethical issues concerning GMOs. The Ministry of Forest and Soil Conservation acts as the NFP of the Protocol and the BCH. In addition to the NCA, the government of Nepal has formed six sectoral competent authorities for effective monitoring and regulation of GM products. These sectoral competent authorities perform risk assessments on proposals related to GMOs and submit comments to the NCA. Further, the government of Nepal has formed a National Biosafety Committee, which is in charge of drafting policies, guidelines, and legislation. The committee is responsible for establishing cooperation with national and international bodies on biosafety, formulating standards and procedures for risk assessment and labeling of GMOs, and issuing final decisions on all proposals on GMOs and related products [29].

Pakistan Pakistan became a signatory to the Protocol in 2001 and ratified the same in 2009. To meet the obligations of the Protocol, the National Biosafety Centre (2006) was established in the Pakistan Environmental Protection Agency (Pak-EPA). The biosafety system of Pakistan was built upon two biosafety instruments; the Pakistan Biosafety Rules (2005) and the Biosafety Guidelines (2005). Pakistan Biosafety Rules were devised under the Pakistan Environmental Protection Act and notified by Pak-EPA. These rules are administered through three governing bodies, which include the National Biosafety Committee (NBC), Technical Advisory Committee (TAC), and Institutional Biosafety Committee (IBCs) [30]. The National Biosafety Centre provides secretariat support to these three biosafety committees. The goal of the NBC is to establish national policies on biosafety, authorize commercial release and trade of crops/products generated from biotechnology, ensure regulatory compliance, and act as a source of information for product developers and the general public. The role of the TAC is the provision of technical information needed by the NBC and the IBCs are responsible for routine research activities within their institutions, such as monitoring of ongoing research projects, inspecting laboratory facilities, coordinating with the NBC to provide guidance and training to researchers, etc. The central regulatory mandate of the Pakistan Biosafety Rules is that any commercial activity, contained use, and deliberate release into the environment of LMOs or related products requires a license issued by the NBC.

The National Biosafety Guidelines (2005) by the Pak-EPA were prepared after consulting stakeholders representing multiple disciplines, including academia, research and development, industry, and non-governmental organizations (NGOs). The goal of the guidelines is to provide guidance for conducting laboratory and field research and commercial release of GMOs. The guidelines also provide information for requesting liquescence for GMO related activities and provide a clear understanding of the roles played by the three authorities (NBC, TAC, and IBCs) responsible for the regulation of biosafety in Pakistan [31]. Even after several years of ratification of the Protocol, Pakistan has not yet established a national BCH. It has become a key consideration in the current

biosafety regulatory framework, and recently, the NBC has prepared a project proposal for the establishment of BCH at the National Biosafety Centre [32].

Sri Lanka Sri Lanka signed the Protocol in 2000 and ratified it in 2004. In compliance with the Protocol, the National Policy on Biosafety was formulated by the Ministry of Mahaweli Development and Environment (MoMDE) and approved by the Cabinet of Ministers of Sri Lanka in 2005. Under the National Policy on Biosafety, the NBF was formed with the support of UNEP-GEF. The NBF of Sri Lanka is based on a precautionary approach. It has two main objectives: one is to provide an overview of the current situation in the country related to biosafety (i.e. policies, legislation, administrative systems, etc.) and the other is to identify what is lacking to complete the NBF (the required legislation, filling the gaps in the administrative or enforcement systems, etc.). The Ministry of Environment acts as the NFP and six NCAs (Central Environmental Authority, Department of Health Services, Department of Animal Production and Health, Department of Fisheries and Aquatic Resources, Department of Agriculture, and Department of Wildlife Conservation) are identified.

A national coordinating committee (NCC) has been established under the NBF. The NCC consists of representatives from all the biosafety related stakeholders, including the MoMDE, Ministry of Agriculture, the Ministry of Animal Production and Health, Department of Wildlife Conservation, Department of Agriculture, etc. In 2014, the Biosafety Act of Sri Lanka was drafted by the MoMDE under the NBF and it is yet to be enacted. The act consists of regulations for the utilization, research, commercial production, and imports and exports of GMOs/LMOs and related products. Further, the detailed procedures for approval, monitoring, and enforcement of penalties for violations related to GMOs /LMOs will be included in the Act. A National Biosafety Project themed "Implementation of the National Biosafety Framework in accordance with the Cartagena Protocol on Biosafety" has been implemented by the MoMDE with funding support received from GEF and technical support from the Food and Agriculture Organization (FAO) of the United Nations. The Sri Lanka BCH website has been established under this project and it acts as a repository of information pertaining to all the aspects of biosafety in the country. Based on the Biosafety Act, biosafety regulations are being developed under the NBF. Biosafety regulations address all the research and development activities concerning GMOs/LMOs within every domestic research facility, including government research institutes, universities, international organizations, private companies, etc. The regulations also address field testing, transboundary movement, handling, and use of all GMOs/LMOs [33], [34].

South Asia Biosafety Program

The South Asia Biosafety Program (SABP) was commenced in 2005 to assist the governments of South Asian countries in strengthening institutional governance, risk assessment, and research and development in biosafety. The main objective of the SABP program is to facilitate the implementation of transparent, efficient, and responsive regulatory frameworks for the products of modern biotechnology in South Asia. The SABP is primarily focused on Bangladesh and India, where a huge amount of modern biotechnology research and development activities take place. The SABP has initiated many activities that promote biosafety in South Asian countries. SABP provides assistance in regulating document development (i.e. Standard Operating Procedures, Guidelines for Environmental Risk Assessment of GE Plants, User's Guide to Biosafety Regulatory Process for GE Plants, etc.). It facilitates training and workshops for researchers and biosafety policy-makers, organizing conferences where researchers, policy-makers, and concerned parties of the region can meet and share experiences (i.e., The annual South Asia Biosafety Conference and providing biosafety research grants). The SABP has initiated collaborations with several other organizations, such as the SAARC Agriculture Centre and the International Life Sciences Institute Research Foundation. With the objective of promoting biosafety harmonization among the South Asian countries, the "Regional Expert Consultation Meeting on the Progress and Prospects of Agricultural Biotechnology and Biosafety in South Asia" was held in Dhaka, Bangladesh in June 2019 [33], [35].

Challenges of Ensuring Implementation of National Biosafety Framework and Way Forward

The SAARC member countries are facing several challenges and issues when developing and implementing their NBFs and biosafety related policies, guidelines, and administrative systems. Insufficient capacity for enforcement, lack of trained human resources at all levels of implementation, lack of funding, the need for improved national and regional collaborations, and a lack of communication with stakeholders are some of the challenges faced by the countries in the region. Capacity to carry out research, policy making, regulation, field trials, and monitoring releases of GMOs into the environment has to be enhanced at the local and regional level. The Protocol itself provides only a loose framework for capacity building efforts. Article 22 of the protocol states that the *"Parties shall cooperate in the development and/or strengthening of human resources and institutional capacities in biosafety*" and refers to existing international, regional, and national institutions, as well as non-governmental organizations (NGOs), as vehicles for capacity building related to biosafety issues. The challenge for the South Asian countries is to establish mechanisms for enhancing capacity for implementing policy and administrative setups that have been started over

the last few years in compliance with the protocol. International organizations, including the GEF, United Nations agencies, bilateral donor agencies, regional networks, and other NGOs, have come together to offer support in funding and building technical, scientific, and regulatory capacity needed for effective development and implementation of NBFs.

The process of developing and implementing NBFs requires a large number of trained scientific and regulatory experts (i.e., scientists, lawyers, administrators, policy-makers, customs officers etc.). With international assistance on knowledge sharing and training, the existing shortage of trained human resources can be resolved. Another significant challenge in the development and implementation of a national biosafety system is the lack of communication between regulatory bodies and the stakeholders, in particular the general public. Effective communication could be promoted by improving the transparency of the NBFs, providing more opportunities for the public to provide input and feedback (i.e., opening regulatory meetings to stakeholders, particularly the public and including public representatives in NBCs) at all stages of the NBF development and implementation.

The collective efforts of the South Asian member countries in setting regional standards in biotechnology and biosafety are of great importance. Harmonizing biotechnology and biosafety regulations in South Asia through the support and consultation of SAARC and other organizations could be promoted in order to help the developing countries meet the regional biosafety standards. In addition, organizing conferences and regional dialogues; encouraging member countries to maintain biosafety related web portals to facilitate information exchange; experience and knowledge sharing; and developing effective mechanisms to create public awareness on biosafety issues can be recommended as ways to overcome the challenges in developing and implementing NBFs in the South Asian region.

Summary

With growing concerns about GMO biosafety and in accordance with the Cartagena Protocol on Biosafety, countries in the South Asian region have stepped in to develop NBFs to ensure the safe use and handling of GMOs and related products. All the eight SAARC countries are parties to the Cartagena Protocol and have already established or are in the process of establishing NBFs to comply with the obligations under the Protocol. However, the process of establishing and implementing NBFs is carried out under numerous challenges given the economic and social constraints faced by most countries. With the

support extended by international organizations, regional networks, and other NGOs, countries are progressing along the path of formulating NBFs and setting regional standards on the biosafety of GMOs.

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