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A Review of Usage, Challenges, and Sustainable Innovations of Plastic Packaging in Sri Lanka

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Abstract: This study evaluates the issues in plastic packaging in Sri Lanka through its usage and environmental and health challenges. The target of this paper is integrating the knowledge about single-use plastics, evaluating the current waste management practices, and finding sustainable packaging. This review proposes actionable strategies for transitioning towards a sustainable circular economy and packaging solutions. Published academic literatures, official government reports, and local case studies on plastic in Sri Lanka were reviewed to pinpoint critical deficiencies in waste management infrastructure and policy enforcement and innovations in bio-plastics and biodegradable materials. Every day, around 400 metric tons of plastics are produced in Sri Lanka, in which 11-20% of are recycled due to lack of infrastructure and consumer behaviours. Single-use plastics (SUP) are dominant in food packaging, contributing to marine and land pollution and health issues in populations from micro-plastics. Sustainable alternatives for plastic face hurdles like scalability and high cost. The high-impact measures such as, improved waste segregation, implementing Extended Producer Responsibility (EPR) schemes, investing in research for local bio-plastic production and launching education campaigns for public are crucial for reducing environmental burdens and creating a sustainable, circular packaging future.

Index Terms: Bio-plastics, Packaging industry, Plastic pollution, Sustainable plastics

1 Introduction

Plastic packaging has completely transformed the contemporary packaging sector due to its unparalleled advantages. These essential materials to international trade are derived from synthetic polymers such as polystyrene (PS), polyethene (PE), polypropylene (PP), and polyamides [1]. From everyday meal papers to commercial beverage bottles, plastic packaging is prominent in Sri Lanka. It reflects a worldwide consumption pattern but also pose a serious local environmental problem. Packaging accounts for over 30% of all plastic usage worldwide, making it a major consumer. Sri Lanka mirrors this pattern, where the country's environmental burden has been greatly increased by the rise in Single-Use-Plastics (SUP). It is driven by fast urbanization and shifting consumer lifestyles.

Although plastics are strong, they do not biodegrade. This is where the main problem arises with end-of-life management. According to global data, only 5% of SUPs are effectively recycled into new items. This becomes severe in Sri Lanka, where 400 metric tons of plastic are produced daily, yet only 11-20% of it is recycled. This is due to poor consumer segregation, inadequate infrastructure, and logistical challenges [2].

In environment, impacts of plastics are significant. Those are alive in ecosystems before the breakdown of it into micro-plastics and nano-plastics and seep into everywhere. It affects country's economy and tourism by affecting the coastal areas and makes them into vulnerable condition. Moreover, the chemicals related to plastics endanger the human health through a serious number of illnesses.

The Sri Lankan government has established the critical challenges to reduce plastic usage for packaging by 30% and marine pollution by 80% within 2030. Yet, it underscores a large difference between legislation and real-world applications. Sustainable alternatives, especially bioplastics, produced from renewable resources provide a viable route to reduce the impact of plastics. This technology is important for long-term sustainability despite its current status due to high cost and constraints. This paper target to synthesize the current knowledge on plastic packaging in Sri Lanka, especially, usage, challenges on health and environment, and potentiality to shift towards sustainable alternatives. Moreover, it discusses the urgent need of systemic change and adoption of new circular economy to save the precious health and environment of Sri Lanka.

2 Plastics in Food Packaging

2.1 Types and Properties of Plastics

The plastic can be classified into two main categories as thermoplastics and thermosets, according to their behaviour at temperatures [1]. While heating, the polymer chains present in thermoplastics allow them to be reshaped and recycled. This behaviour of thermoplastics makes them suitable for moulding and extrusion, whereas in thermosets, the cross-linked polymer chains become harder and heat-resistant while heating, thus thermosets cannot be reshaped but can be decomposed or burnt [3]. Thermoplastics can be further classified into seven categories according to its Resin Identification Code (RIC) system [4]. Table 1 describes the thermoplastics' characteristics. Even though RIC 7 is included in thermoplastic, some types of it, such as PLA and polycarbonate, show thermoset characteristics at higher temperatures.

Table 1: Categories and characteristics of thermoplastics

RIC	Type	Uses in the food industry	Properties	Recyclability
1	PET (Polyethylene Terephthalate)	Bottles Food trays packaging for snacks	Rigid Transparent Gas-impermeable	High
2	HDPE (High-Density Polyethylene)	Juice bottles Grocery bags Containers (fatty foods, condiments)	Strong Rigid Resistant to chemicals and moisture	High
3	PVC (Polyvinylchloride)	Cling wrap Containers (non-fatty foods)	Rigid Flexible Resistance to chemicals and weather	Low
4	LDPE (Low-Density Polyethylene)	Plastic bags Squeezing bottles Lid for bottles	Soft Flexible Tough	Low
5	PP (Polypropylene)	Reusable food storage containers Tubs and caps of bottles Food containers for the microwave	Heat resistant Tough Fatigue-resistant	Medium

6	PS (Polystyrene)	Disposable containers	Lightweight Rigid or foamed Brittle Less durable	Very low
7	Other	Reusable water bottles (Polycarbonate) Biodegradable cups (PLA)	Rigid to biodegradable	Very low

There is a lot of food packaging trash in the environment. Most food packaging plastics end up in waste streams soon after purchase, particularly in single-use packaging applications [5]. This is due to a rise in on-the-go food and beverage consumption. The problem of limited bin availability in some areas might lead to greater littering. A large portion of the plastic used in food packaging ends up in landfills, where only a few can be recycled. Only 14% of single-use plastic packaging is collected for recycling, and only 5% of that is successfully recycled into new plastic globally [5]. Packaging accounted for approximately half of the global plastic trash created in 2015. This percentage has remained high, with food packaging accounting for more than a third of the global packaging market.

Plastics are utilized in food packaging because they have a wide range of visual and performance capabilities that are derived from the intrinsic characteristics of the individual plastic material, as well as how it is processed and used [6]. Plastics are resistant to many sorts of compounds – they are not highly reactive with the inorganic chemicals such as acids, alkalis and organic solvents – making them excellent for food packing [6]. Plastics do not allow microorganisms to flourish. Some plastics may absorb some food elements, such as oils and fats [7]. Hence, it is critical to do rigorous testing on all food applications for absorption and migration. Plastics are permeable to gases such as oxygen, carbon dioxide and nitrogen, as well as water vapour and organic solvents [6]. The rate of permeation is determined by types, thickness and surface area, method of processing, concentration or partial pressure of the permanent molecule, and storage temperature [8].

2.2 Drivers of Usage

Plastics are chosen for specific technical uses, taking into consideration exceptionalities in packing, distribution and storage and product use, as well as for marketing purposes, which might include environmental perception issues **[6]**. As described by **[9], [10]**, containers, component containers, and flexible packaging are all made of plastic. Plastic packaging is the second most widely used type of packaging by weight and the first in terms of value, accounting for more than half of all goods, including rigid plastic containers such as bottles, jars, pots, tubes and trays; flexible plastic films in the form of bags, sachets and pouches; plastics combined with paperboard in liquid packaging cartons; plastic lids and cap; pouring and dispensing devices, plastic bands to provide external tamper evidence; plastic films used in cling, stretch and shrink wrapping; and films used as labels for bottles and jars **[10]**.

To broaden the variety of qualities that can be accomplished, plastics are employed as coatings and in laminations with other materials such as regenerated cellulose film, aluminium foil, paper and paperboard **[10]**. Plastics can be used to improve seal strength, initial tack and low-temperature flexibility in adhesives **[11]**. Depending on the type of packaging, plastics can be coloured, printed, ornamented or labelled in a variety of ways. Alternatively, some plastics are glass clear, while others have varying degrees of transparency and might have glossy or matte surfaces.

Plastics are also used to store and distribute food in bulk in the form of drums, intermediate bulk containers, crates, fresh produce trays and plastic sacks **[12]**. Plastics are used in food packaging for a variety of reasons: they protect food from spoilage by offering effective barriers, are integrated with food processing technology, are relatively light in weight, which reduces transportation cost, are not prone to breakage, which ensures the product safety during handling, do not result in splintering if damaged, and are available in a wide range of shapes, structures, and designs, allowing for maximum market appeal and utility **[13], [14]**.

Chemical components like plasticizers, nanoparticles, and monomers from packaging are well known to migrate into meals, but researchers and regulators are paying closer attention to how much migration occurs and what the possible health impacts are **[15], [16]**. However, little research has been done to investigate the long-term negative effects of these exposures on human health.

3 Impacts of Plastic Packaging

The plastics widely impact the human and the living environment in multiple ways as discussed below.

3.1 Detrimental Effects on Environment

The non-degradable nature of plastics leads to the accumulation of them in diverse ecosystems like water, soil, and air as an acute pollutant. The breakdown of plastics when exposed to sunlight into smaller fragments, called micro-plastics, which are less than 5mm, and nano-plastics, which are hardly visible under a powerful microscope [17].

The plastics found in soils collapse the soil structure and the presence of soil microorganisms through biogeochemical processes [18]. The plastic residues can contaminate the groundwater, alter the porosity of the soil, suppress the enzymatic activity, and reduce crop yields by impeding the growth and germination of plants [19]. The plastic particles can uptake and transport a variety of toxins, including heavy metals and organic pollutants [20]. The improper segregation of plastic waste from households limits the composting facilities, as it declines the soil health and agricultural productivity of this country. While micro-plastics affect the physiology of the plants, the nano-plastics are taken up and distributed within plant tissues [21]. As the plants are the primary producers of a food chain, the toxins can easily enter the other elements which depend on the plants. During flooding periods, the blockage of drainage canals occurs due to the plastics. At that time, these places are the breeding sites for mosquitoes to spread diseases like dengue [22]. In the terrestrial environment, the impact of plastics can be observable. The fauna and flora in the wildlife environment are affected by plastics and increase their mortality.

The marine environment, which is a habitat for countless species, is affected by plastics. As a result, 267 species are in an endangered condition [23]. These toxic plastic particles can be taken up through their feeding, impair their growth and development, and move through the food web to other animals. As well, in other aquatic environments, the commercially valuable species like mussels and oysters are under threat due to the toxins from plastics affecting their physiology [24]. Research identified that the shrimp varieties from Sri Lanka consist of micro-plastics [25]. As Sri Lanka is an island surrounded by sea, the people of Sri Lanka depend on seafood as a major protein source; humans also ingest a part of micro-plastics through seafood and salt consumption (Ranatunga et al., 2021). The coastal erosion and coral reef depletion affect the tourism of Sri Lanka as well. In 2021, the M/V X-Press Pearl ship caught fire and subsequently sank in the coastal region of Sri Lanka, releasing a large amount of HDPE and LDPE resin pellets [28]. The PAH (polyaromatic hydrocarbon) levels of burnt and unburnt plastics were 10^5 ng/g and 10^2-10^4 ng/g, respectively [29].

The plastic production depends on the breakdown of fossil fuels and the release of hydrocarbons and volatile organic compounds. Those emit the plastic monomers, which contribute to the smog in the air [30]. Apart from it, the plastic wastes are incinerated or burnt in an open environment, which emits hazardous pollutants such as dioxins and heavy metals (cadmium, lead) in the ash, diminishing the air quality and agricultural productivity [31]. The hazardous incineration of clinical plastic in hospitals [32] and the open burning of plastic waste at the domestic level were identified during the COVID-19 pandemic period.

3.2 Detrimental Effects on Human Health

Plastic pollution, which comes in a variety of sizes, especially micro- and nano-plastics, has an impact on even the tiniest species on the planet, such as plankton. When small creatures get poisoned as a result of ingesting plastic, it affects the bigger animals that depend on them for food through the food chain and web [33]. This led to the contamination of whole animals ingested with plastics. Human health is affected by micro-plastics and nano-plastics through ingestion and inhalation processes as they are transported by soil, water, and air [34]. The hazardous substances and chemicals present in plastic affect the human organ systems.

The reproductive system is affected by plastic chemicals and induces abnormal conditions in the foetus and early puberty in females and reduces the quality of the sperm in males [35], [36]. The digestive tract is disturbed, and a collapse in micro-biome occurs, which leads to diabetes, insulin resistance, and obesity [36]. Some chemicals present in plastics categorized as carcinogenic agents, damage the DNA and alter the genetic flow [37]. The people who are involved in plastic production industries are exposed to lung disease as they have high levels of plastic inhalation [38]. As well, those plastics affect the immune system and nervous system through inflammation and neurological disorders [39]. Hence, the women, children, and elders are the vulnerable population who are susceptible to these detrimental health effects due to their critical body conditions.

4 Plastic Waste Management in Sri Lanka

In the food industry, plastic packaging is used to increase the shelf life of goods. However, it increases the waste accumulation around the world. As mentioned by [40], the United States, Brazil, and China are the top suppliers of plastic packaging. Approximately one-fifth of total plastic production is used for food packaging each year [41]. Most of them are single-use plastics that have high versatility and can be easily discarded after use in nature. In some countries, the plastic usage is restricted, and the waste is exported to undeveloped or underdeveloped countries. For instance, China was the major importer and the producer of plastics in the world. Then the ban was imposed in 2017 against the accumulation of foreign plastic waste, and by 2030 it is going to displace 111 million tons of plastics [42].

4.1 Current Waste Management Practice

In Sri Lanka, the majority of plastic packaging waste is in single-use plastics (SUP). According to the Plastic Mismanagement Waste Index (MWI), 97 countries are categorized as “Very High MWI” out of 200 countries. Sri Lanka is in the 34th position in the very high category with an MWI of 89.2% [43]. Annual plastic waste generation is nearly 1.6 million metric tons. According to annual central bank estimates, Sri Lanka generates Rs.2.8 billion in foreign currency from plastic imports and exports. Sri Lanka currently has 232 enterprises engaged in plastic processing for both domestic and foreign markets [44].

Every year, Sri Lanka imports approximately 260000 MT of main plastic raw materials and intermediate products. Meanwhile, Sri Lanka exports over 28000 MT per year, while our domestic processing sector has a capacity of nearly 120000 MT per year, with an annual average growth rate of around 10% [45]. Each day, Sri Lanka produces approximately 400 MT of plastic and polythene [46]. There are 15 million lunch sheets and 20 million shopping bags in this total [44]. Even though the central environment authority has registered approximately 170 plastics/polythene collectors and recyclers, plastic and polythene recycling are not occurring at a satisfactory level [44], [47]. Now Sri Lanka has been ranked as one of the world's top five plastic polluters [44], [48].

The plastic waste is managed through collection and recycling processes. The collection phase is completed in two ways, including formal collection and informal collection [49]. Formal collection of garbage is done by the local authorities like the municipal council, urban council, and Predeshiya Sabha. The informal collection is done by informal collectors, who are collecting plastic bottles. The mechanical recycling of collected waste is conducted after the collection. PET, HDPE, and PP are the major which undergoes into the recycling [49]. The remaining plastic varieties go with landfilling and incineration.

Open dumping is the most popular technique of solid waste disposal. Because plastics are non-biodegradable, they accumulate near the wetlands, coastline, rivers and other streams, which become the dumping grounds for the plastic and other combined trash [44]. The remaining plastics are burnt at home or disposed of in the oceans via a stream and other waterways. In Sri Lanka, a survey was conducted by ocean conservation guidelines, which determined that the amount of marine litter collected within Sri Lanka's coastal zone in 2017 was 10.38 kg per km.

Open burning is commonly done at the household level, particularly in situations where official waste collection services are poor. This uncontrolled burning of waste is harmful since it emits a variety of harmful air pollutants such as dioxins, furans, cadmium, and lead straight into the atmosphere [50]. These pollutants are recognized endocrine disruptors and human carcinogens. Open burning has become more common during the COVID-19 pandemic, when waste collection services were negatively affected [51], [52].

4.2 National Action Plans and Bans

In Sri Lanka, as part of the National Action Plan on Plastic Waste Management (2021-2030), the ban on particular types of Single Use Plastic (SUP) and some packaging materials has been implemented. This process encourages the country to use biodegradable or alternative plastics to prevent the pollution of the surrounding environment, especially the marine. It emphasizes the preventive approach based on the Reduce, Reuse, and Recycle 3R system. It also gradually decreases the usage of SUP by 2021 and achieves an 80% reduction in the production and consumption of SUP by 2025 [45].

Even though the regulatory actions are conducted to reduce the nine plastic products in 2023, they are circulating due to their higher demand and lack of awareness. A study conducted in the Anuradhapura district of Sri Lanka shows that nearly 50% of retailer shops sell the banned products. With requirements for reusable/recyclable packaging by 2027 and at least 25% post-consumer recycled (PCR) content in non-food grade packaging by 2030, a 30% reduction in the total amount of plastics used in packaging is the goal [45].

According to the National Environmental Act of 1980 as well as the national regulations on plastic manufacturing, there are some bans imposed on plastic packaging. Those are;

Order No. 2034/34 (2017) – Polythene food wrappers (lunch sheets in HDPE, LDPE, and PP)

Order No. 2034/35 (2017) – HDPE polythene bags (commonly referred to as "sili-sili bags")

Order No. 2034/38 (2017) –Expanded PS of food containers (lunch boxes, plates, cups, and spoons)

The prohibition is made on the manufacture and trade of this raw material within the country.

5 Sustainable Alternative to Plastics Packaging

Finding cost-effective ways to produce packaging materials is an issue. Food packaging has been influenced by major changes in food distribution, including the globalization of the food supply, consumer demand for fresher, and a need for safer and higher-quality foods, in addition to the above-mentioned environmental problems. Consumers are asking that food packaging materials be more natural, disposable, and perhaps biodegradable as well as recyclable due to these and other problems [53], [54]. New and unique food-grade packaging materials or technologies have been created to address the rising demand for recyclable or natural packaging materials, as well as customer expectations for safer and higher-quality meals [55]. Bio-based polymers, bio-plastics, and biopolymer packaging goods manufactured from agricultural or marine raw resources are examples of these packaging materials [56]. Starch, cellulose, chitosan/chitin, and lipids are examples of bio-related packaging materials [57]. Biopolymers or bio-based food packaging materials having biodegradable characteristics include edible films, gels, and coatings, are made from renewable resources, which can be used in the food industry [55]. Plastics have become a target of environmental criticism because of their inability to biodegrade. Counties all over the world are quickly embracing the concept of environmentally conscious materials (eco-materials) [58], [59]. Biodegradable polymers are being considered as a waste-management option for the environment [60]. They are a loosely defined family of polymers that are designed to degrade through the action of living organisms and provide a potential alternative to traditional non-biodegradable polymers in situations where recycling is impractical or not cost-effective. The two main reasons for interest in biodegradable materials are the growing waste problem, which has resulted in a general shortage of landfill availability, and the need for environmentally responsible resource use, as well as the CO_2 neutrality aspect [61].

New technologies developed by major corporations are reviving interest in biodegradable plastics. Biodegradables are expected to grow at a nearly 20% annual rate [59], [62]. Until now, the adoption of such plastics has been limited to very small niches due to performance limitations and high costs [63]. The real challenge is to find applications that consume large enough quantities of these materials to lead to reductions, allowing biodegradable polymers to compete economically in the market [64], [65].

The challenge in replacing conventional plastics with biodegradable materials is to design materials that are structurally and functionally stable during storage and use while also being susceptible to microbial and environmental degradation upon disposal with no negative environmental impact [66]. Designing appropriate biodegradable materials will necessitate a thorough understanding of the factors influencing material properties and performance, as well as biodegradability, to make appropriate trade-offs [67]. To ensure that biodegradable materials can perform their intended functions, their performance must be maintained during processing, storage, and use [68]. Blending biodegradable polymers lowers the overall cost of the materials and allows for the modification of both properties and degradation rates; however, a blend, especially one containing a non-biodegradable polymer, can reduce or even prevent the degradation of the biodegradable component [58]. Prices for biodegradable materials can only be reduced through mass production, and that is only possible through constant production [59]. Because of the serious environmental threat, the entire world will take a serious look at the use of biodegradable polymers soon.

6 Future Directions and Recommendations

A comprehensive and well-coordinated approach involving infrastructure, technology, policy, and societal changes is needed to address the growing plastic packaging problem in Sri Lanka. It is important to expand the list of banned single-use plastics and impose penalties for non-compliances. The government should establish Extended Producer Responsibility (EPR), making manufacturers as the responsible for post-consumer goods. As well, it is important to create standards for biodegradation and composting to guarantee the integrity of substitute material. Sri Lanka should invest in research and development, which produce biodegradable packaging materials using agricultural wastes and make them in affordable prices with high productivity. Enhancing waste management infrastructure is crucial for effective management of recycle of challenging polymers. The testing and certification laboratories need to be established to ensure the bio-plastics are long-lasting and non-toxic. The collection systems should be normalized to oversee the waste segregation and collection for municipal council, urban council, and Predheshiya Sabha. Digital waste tracking systems must be integrated to observe plastic flows from manufacturer to disposal and make data-driven decisions. Public awareness and behavioural changes should be made regarding the plastic pollution in media and schools. Moreover, the subsidies and incentives could be provided to consumers, who use sustainable packaging. These all systems must be supported through monitoring and evaluation systems with performance indicators and environmental audits.

7 Conclusion

In Sri Lanka, the over usage of single-use plastics (SUP) has emerged crisis in health and marine and terrestrial environment. Apart from its essentiality, the pollution is observed in concerning levels, due to its persistence and improper disposal. The contaminants and chemical components present in plastics deteriorate the soil and water quality, which threaten the agriculture and biodiversity of this country. Though, regulatory initiatives and prohibitions on particular plastic products are made, low public awareness and persistence of prohibited products limit progress. This could be induced through strong policy execution, modern waste collection and recycling infrastructures, and systemic behavioural change among citizens. Apart from it, sustainable substitutes for plastics, made from renewable resources provide solution by reduce reliance on fossil fuels and minimize environmental collapse. However, the market affordability and high output are challenging producers and consumers. Hence, the research and development for environment friendly innovations using bio-plastics can accelerate the production. Sri Lanka is at a turning point, where the change to sustainable packaging material is a socioeconomic and environmental mandate and requirement. This can ensure a cleaner healthier future by adopting the tenets of circular economy, improving regulation, and encouraging public behavioural attributes through visionary leadership and organized action.

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