Life cycle assessment of single-use biodegradable bags produced from corn-derived biopolymer

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ABSTRACT- Single-use biodegradable bags have been recently introduced as an environmental-benign alternative to conventional plastics while addressing a prevailing global issue. Natural corn starch is often used as the key raw material due to the availability in large scale worldwide. Despite the view of the general public over biodegradable alternatives, existing studies regarding the life cycle emissions provide a result opposed to it as polythene is possible to recycle once or more. This study follows the cradle-to-gate life cycle approach focusing on the evaluation of environment emissions/eight impact potentials using the ReCiPe world (H) V1.12 impact assessment method in the SimaPro Life Cycle Assessment software while analysing the degradation pattern of each type with the aid of Scanning Electron Microscope. Key findings from this study quantify the current levels of environmental impacts that support future decision making for environmentally-benign innovative product from a possible alternative source.

Key words: Single-use biodegradable bags; Impact assessment; Degradation behaviour

INTRODUCTION

Polythene or polyethylene, a polymer which is mainly derived from petroleum by-products is a lightweight, relatively cheap, and flexible material which is more suitable for hygienic applications like fresh and frozen food packaging. Since the late 1950s, polythene production has been increased from 2 million tonnes to 381 million tonnes by 2015 (Ritchie & Roser, 2018). Packaging is the dominant sectorial use of plastics globally accounting for 42 percent (146 million tonnes) in 2016 (Giacovelli, 2018). One of the widely used major products made out of polythene is single-use polythene bags. It is estimated that nearly five trillion plastic bags are consumed worldwide each year.

At the end of the consumption stage of single-use polythene bags, 79% settles in landfills, dumps or in the environment, whereas about 12% has been incinerated and only 9% of the nine billion metric tonnes of polythene produced has been recycled (Giacovelli, 2018). It is estimated that, if current consumption and waste management practices continue as it is, then by 2050, there will be around 12 billion metric tonnes of polythene litter in landfills and the environment (Ritchie and Roser, 2018). Policy interventions to reduce single-use plastic bags have been implemented at national and subnational levels.

Due to the light weight and balloon-shaped design of plastic bags, they are easily blown in the air, eventually ending up on land and in the ocean. Sri Lanka has been identified as one of the top sea polluters discarding 1.6 million metric tonnes of plastics to the sea (Jambeck et al., 2015). Due to that, plastic bags have many adverse effects on land and the ocean. It is evident that the toxic chemicals and dyes added during the manufacturing process transfer into the animals' tissues. When plastic breaks down into micro-plastic particles, it becomes even more difficult to detect and remove from the open oceans, and finally ended up in human organs through food chains.

It is clear that bio-based bags are designed in a manner which cannot be recycled. Hence, it is obvious that overall environmental impacts through the entire life cycle of recycled plastics are rather less than that of single-use biodegradable bags. Thus, it is highly required to perform a comprehensive analysis of the overall production process of biodegradable bags and a standard comparative analysis with environmental perspective using an established technique used worldwide.

METHODOLOGY

Experimental procedure to investigate the degradation behaviour

Step 1: Four identical specimen sets were prepared by taking a single-use bio-based (PLA) and conventional polythene samples with equal dimensions from each type. (15 cm x 8cm)

Step 2: One set was directly exposed to sunlight and other climate conditions by keeping on the ground.

Step 3: Other three sets were buried under ½ feet depth from almost 100% flat ground level.

Step 4: Photographic observation was carried out after three weeks, one month, 2, 3, and 4 months respectively to identify physical changes.

Step 5: After 4 months' time from the initiation of the experiment, surface of each test specimen will be observed through the Scanning Electron Microscope (SEM). Hence, the degradation behaviour of each type of grocery bag under each test condition could be experimentally predicted.

Life cycle assessment

Applied methodology to conduct the comprehensive and comparative analysis for this study is LCA (Life Cycle Assessment) under ISO 14040/44 framework which consists of four consecutive steps (Edwards and Parker, 2012).

Goal & scope definition: This study relies on a cradle-to-gate system boundary concerning the three main life cycle stages, such as corn cultivation, production, and transportation with a main goal of evaluating the total environmental impacts of single-use bio-degradable bags made of corn-derived biopolymer (PLA), followed by a comparative analysis with the impacts from HDPE consumer bags. The functional unit (FU) was set as 1 MT of bags for all the inventory calculations.

Inventory analysis: Necessary data were collected for mass and energy flows, including resource utilizations and waste emissions within the system boundary in order to evaluate environmental impacts in this step. Most common techniques used for data collection were, primary data from previous studies carried out for global context and referring LCA inventory databases (Sima Pro Software – Eco invent).

Impact assesment- Climate change, Terrestrial acidification, Photochemical oxidant formation, Human toxicity, Eco-toxicity (Terrestrial eco-toxicity, Marine eco-toxicity), Marine eutrophication, Particulate matter formation were considered as the environment impacts to be assessed under the life cycle impact assessment using the ReCiPe world (H) V1.12 impact assessment method in the SimaPro Life Cycle Assessment software.

RESULTS AND DISCUSSION

Visual observation of samples (after 4 months)


Figure 1. HDPE sample buried


Figure 2. HDPE sample placed on soil


Figure 3. Bio-based sample buried


Figure 4. Bio-based sample placed on soil

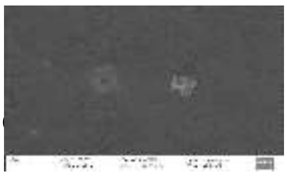
Figure 5. HDPE sample *buried*

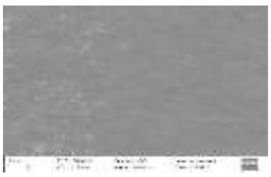
Figure *6.* HDPE sample placed on soil

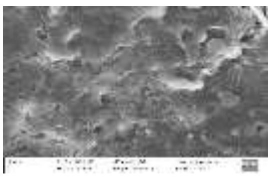
Figure *7.* B*io*-based sample buried


Figure *8.* Bio-based sample placed on the soil

From the visual observations and SEM images, it is clearly visible that bio-based samples are more susceptible to degradtion than HDPE samples. PLA consists with more active ester functional group which is more active than C-C bonds and C-H bonds. Hence, PLA is more likely to degrade faster than HDPE.

Impact Assessment results

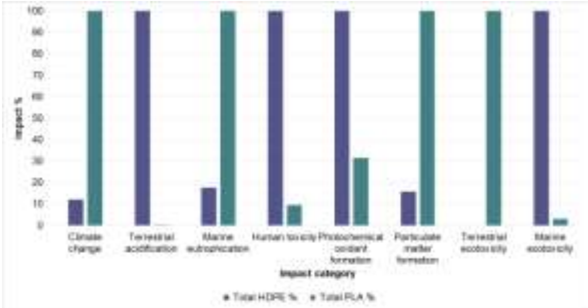

Figure 9. Comparison of relative contribution to each environmental impact by HDPE and PLA derived bags

According to the environmental impact results shown in Figure 9, the single-use PLA bags production life cycle contributes only around 1% to terrestrial acidification, 3% to marine ecotoxicity, 10% to human toxicity, and 30% to photochemical oxidation, in comparison to the respective environmental impacts from the single-use HDPE bags production life cycle. Thus, single-use PLA bags production would have environmental-genign aspects, comparatively. However, the single-use PLA bags life cycle is relatively responsible for approximately 90% of climate change, 80% of marine eutrophication, 85% of particulate matter fromation, and 100% terrestial ecotoxicity than the corresponding environmental impact contributions by the HDPE bag production life cycle.

CONCLUSION

According to the key results, although biodegradable bags made of corn-derived biopolymer could not be identified as the most environmentally benign alternative to reduce the environmental impacts due to conventional plastics, some of increased toxicity impacts of single-use HDPE bags indicate a positive decision regarding degradable bio-based bags. In conclusion, key findings from this study could be utilized to further investigate alternative sources with reduced overall environmental impacts, such as waste biomass or a by-product from a bio-based process, including analysis of end-of-life scenarios.

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